II. SPECIES ACCOUNTS

Section II contains accounts of all species covered in this recovery plan, presented in taxonomic order following the American Ornithologists' Union checklist (1998). These accounts are not meant to be a complete reference, but rather to summarize sufficient relevant information about each species in order to understand the prescribed recovery strategy and the prioritization of recovery actions. All of the Hawaiian forest birds face the same set of threats, but the relative importance of those threats varies among species depending on their life history, current distribution and status, and habitat requirements. The priority placed on each component of the recovery strategy therefore varies among species. The species accounts build on and refine the overall recovery strategy discussed in the Introduction (Section I), and justify the recovery criteria presented in Section III as well as the recovery actions and priorities presented in the Recovery Actions Narrative (Section IV). Each account also includes a summary of previous and ongoing conservation efforts, including Federal and State regulations, land acquisition, research, and management directed at or relevant to the recovery of the species. All of the accounts follow the same format and contain the following section headings: description and taxonomy; life history; habitat description; historical and current range and status; reasons for decline and current threats; conservation efforts; and recovery strategy. Longer accounts for better-studied species contain additional subheadings to help locate information. When available, maps showing the historical and current distribution of the species and recovery areas appear in the accounts (Figures 6 through 21).

Recovery plans are prepared following a determination that a species merits listing as endangered or threatened under the Endangered Species Act (Act). The Act is not meant to serve as a primary mechanism for species conservation, but the protections afforded by the Act are intended to arrest the immediate decline of the listed species and provide opportunities for partnerships and funding that will enable its recovery. The Federal listing of a species as endangered or threatened is included in this plan as a conservation effort, but it should be recognized that the ultimate goal of our recovery program is to effectively address the threats to listed species and restore their populations to the point that their long-term viability in their natural ecosystems is assured and the protections of the Act are no longer needed.

1. O`ahu `Elepaio, *Chasiempis sandwichensis ibidis*

DESCRIPTION AND TAXONOMY

Adult male O`ahu `elepaio. Photo © Eric VanderWerf.

Description. The O`ahu `elepaio is a small (12.5 grams [0.4 ounce] average weight, 15 centimeters [5.9 inches] total body length) monarch flycatcher endemic to the island of O`ahu (VanderWerf 1998a). It is dark brown above and white below, with light brown streaks on the breast. The tail is long (6.5 centimeters [2.6 inches]) and often held cocked up at an angle. Adults have conspicuous white wingbars, a white rump, and white tips on the tail feathers that are often displayed. The throat is white with black markings in both sexes, but males tend to have more black than females, especially on the chin. The lores (area between the eye and bill) are white and the auricular (ear patch) is often blackish. Juveniles and subadults are rufous above and on the breast, with a white belly and rusty wingbars. `Elepaio have a 2-year delay in plumage maturation, acquiring the distinctive white markings of adults when they are 3 years old (VanderWerf 2001b). The bill is medium-length, straight, and black, with the base of the lower mandible bluish-gray in adults and yellow in juveniles. The legs and feet are dark gray. The iris is dark brown. Males average approximately 10 percent larger than females in wing length, tarsus length, and weight, but bill length does not differ between the sexes (VanderWerf 1998a). Geographic plumage variation has been described in the Hawai`i subspecies (Pratt 1980), and coloration of the O`ahu subspecies also varies among different parts of the island; birds in drier, leeward areas are paler and grayer on the back, while birds from wet, windward forests are darker and more reddish-brown (E. VanderWerf, unpubl. data).

The primary song, given almost exclusively by males, is a shrill, whistled “el-e-pai-o,” with an accent on the third syllable, from which the Hawaiian name is derived. The female often answers the male song with a loud two-note call. Both sexes also give a variety of scolding calls and chatter, and a soft "chup" contact call given by pairs while foraging. The song varies among different parts of the island, and response varies to playbacks of different local dialects (E. VanderWerf, unpubl. data).

Identification. Identification of adult `elepaio is relatively easy. White-rumped shama (*Copsychus malabaricus*) and red-vented and red-whiskered bulbuls (*Pycnonotus cafer* and *P. jocosus*) have white rumps and white-tipped tails like adult `elepaio, but are much larger and lack white wingbars. Juvenile `elepaio can be confused with juvenile `apapane (*Himatione sanguinea*), which are similar in size and overall color and may also cock the tail up, but `apapane have a curved black bill and lack the contrasting wingbars and tail tips of the `elepaio.

Taxonomy. The `elepaio comprises a monotypic genus of the monarch flycatcher family (Monarchidae) that is endemic to the Hawaiian Archipelago (American Ornithologists' Union 1998). The closest relatives of `elepaio are other monarch flycatchers from eastern and central Polynesia (Filardi and Moyle 2005). Three subspecies of `elepaio are recognized, each endemic to a single island: the Hawai`i `elepaio (*C. s. sandwichensis*); the O`ahu `elepaio (*C. s. ibidis*); and the Kaua`i `elepaio (*C. s. sclateri*). The taxonomy used here follows Pratt *et al.* (1987) and Pyle (2002), in which all forms are regarded as subspecies, but the form on each island originally was described as a separate species. The O`ahu form was known as *C. s. gayi* (Wilson 1891b) until Olson (1989) pointed out that the epithet *ibidis* (Stejneger 1887) has priority. Only the O`ahu subspecies is listed as endangered; the Kaua`i and Hawai`i subspecies are still relatively common. Throughout the remainder of this account, `elepaio refers to the listed O`ahu subspecies unless otherwise noted.

LIFE HISTORY

Demography and Reproduction. `Elepaio are non-migratory and defend all-purpose territories year-round (Conant 1977, VanderWerf 1998a). The average territory size was 2.0 hectares (4.9 acres) in forest composed of alien plant species in Mānoa Valley (Conant 1977) and ranged from 1.2 to 1.8 hectares (3.1 to 4.5 acres) in three valleys in southeastern O`ahu, depending on forest structure (VanderWerf and Smith 2002). Annual survival is high, 81 percent in the absence of predation by alien mammals, but survival of females is heavily impacted by predation from alien rats (VanderWerf and Smith 2002; see Current

Threats below). `Elepaio are socially monogamous and have high mate and site fidelity; in the absence of predation by alien mammals, 97 percent of males and 95 percent of females remain on the same territory between years, and almost all pairs remain together between years (VanderWerf and Smith 2002). Young birds are subordinate and act as floaters while they attempt to acquire a territory and a mate.


O`ahu `elepaio nest. Photo © Eric VanderWerf.

The nesting season usually extends from February to May, but active nests have been found from January to July (VanderWerf 1998a). The nest is a finely-woven, free standing cup made of rootlets, bark strips, leaf skeletons, lichens, and spider silk, and is placed in a fork or on top of a branch (Conant 1977, VanderWerf 1998a). Nests have been found in a variety of plants, including 7 native species and 15 introduced species (E. VanderWerf, unpubl. data). Both sexes participate in all aspects of reproduction, but the female plays a slightly larger role in nest building and the male provides more food for the nestlings (VanderWerf 1998a). Although both sexes incubate and brood, only the female develops a brood patch and only the female incubates at night. Clutch size is usually two, sometimes one or three, and eggs hatch after 18 days (Conant 1977, VanderWerf 1998a). The nestling period averages 16 days, and fledglings are fed by their parents for more than a month after leaving the nest, remaining on the natal territory for up to 9 months at the start of the next breeding season (VanderWerf 1998a). Fecundity is low; even if nest predators are controlled the mean number of fledglings per pair is 0.70 per year (VanderWerf and Smith 2002; see Current Threats below). O`ahu `elepaio will re-nest once or twice after failure, but they rarely attempt to re-nest if the first nest is successful. Other than introduced predators, the most common cause of nest failure is storms with heavy rain and strong winds (VanderWerf 1998a).

Annual Variation and Population Fluctuation. Survival and reproduction of O`ahu `elepaio vary considerably among years (VanderWerf and Smith 2002; E. VanderWerf, unpubl. data), probably in association with climatic factors that affect populations of nest predators and disease-carrying mosquitoes. These annual variations are unpredictable in nature and are not cyclic, but the average interval of occurrence of both rodent irruptions and disease episodes is approximately 5 years. Demographic monitoring from 1995 to 2006 revealed that there were two years (1996 and 2004) with high disease prevalence and two years (1999 and 2004) with high rodent abundance (VanderWerf *et al.* in press; E. VanderWerf, unpubl data). Conditions that increase the severity of these two threats do not necessarily coincide, and `elepaio populations therefore can be expected to fluctuate over time in a complex pattern.

Diet and Foraging. The foraging behavior and diet of `elepaio are extremely varied. In a study on Hawai`i Island, VanderWerf (1993, 1994) found that `elepaio foraged at all heights on all available plant species, and that they caught insects from a variety of substrates, including the ground and fallen logs (2 percent), trunks (5 percent), branches (24 percent), twigs (38 percent), foliage (20 percent), and in the air (11 percent). `Elepaio are versatile and agile in pursuit of prey, using a diversity of foraging behaviors that is among the highest recorded for any bird, including perch-gleaning (48 percent), several forms of flight-gleaning (30 percent), hanging (11 percent), aerial flycatching (7 percent), and active pursuit (4 percent) (VanderWerf 1994). The diet consists of a wide range of arthropods, particularly insects and spiders, and includes nonnative taxa such as fruit flies (Tephritidae; VanderWerf 1998a). Large prey such as moths and caterpillars are beaten against a branch before being eaten.

HABITAT DESCRIPTION

O`ahu `elepaio are adaptable and occur in a variety of forest types composed of both native and introduced species (Conant 1977; VanderWerf 1993, 1994, 1998a). Plant species composition in `elepaio habitat varies considerably depending on location and elevation, but some of the most common native plants in areas where `elepaio occur are alahe`e (*Psydrax odorata*), pāpala kēpau (*Pisonia umbellifera*), lama (*Diospyros sandwicensis*), hame (*Antidesma platyphyllum*), māmaki (*Pipturus albidus*), kaulu (*Sapindus oahuensis*), and `āla`a (*Pouteria sandwicensis*), and some of the most common introduced plants are strawberry guava (*Psidium cattleianum*), common guava (*Psidium guajava*), kukui (*Aleurites moluccana*), mango (*Mangifera indica*), and Christmas berry (*Schinus terebinthifolius*) (VanderWerf *et al.* 1997, VanderWerf 1998a). Nest site selection by O`ahu `elepaio is non-specialized; nests have been found in 7 native and 15 introduced plant species (E. VanderWerf, unpubl. data). Shallenberger and Vaughn (1978) found the highest relative abundance of `elepaio in forest dominated by introduced guava (*Psidium* spp.) and kukui (*Aleurites moluccana*) trees, but they were also found in the following forest types (in order of decreasing abundance): mixed native-exotic; tall exotic; koa (*Acacia koa*) dominant; mixed koa-`ōhi`a (*Metrosideros polymorpha*); low exotic; `ōhi`a dominant; and `ōhi`a scrub. They currently are not found in very wet, stunted forest on windswept summits or in very dry scrubland.

Unlike many Hawaiian forest birds, `elepaio have adapted well to disturbed forest composed of introduced plants (Conant 1977, VanderWerf 1998a). VanderWerf *et al.* (1997) found that: 1) forest structure was more important to `elepaio than plant species composition, 2) most `elepaio occurred in areas with a continuous forest canopy and a dense understory, and 3) population density was roughly twice as high in tall riparian vegetation in valleys than in scrubby vegetation on ridges. Fifty-five percent of the `elepaio's current range is dominated by introduced plants, and 45 percent is dominated by native plants (VanderWerf *et al.* 2001). This does not imply that `elepaio prefer introduced plant species, but simply reflects a preference by `elepaio for riparian vegetation in valleys and the high degree of habitat disturbance and abundance of alien plants in these riparian areas (VanderWerf *et al.* 1997). Of the 45 percent dominated by native plants, 23 percent is categorized as wet forest, 17 percent as mesic forest, and 5 percent as dry forest, shrubland, and cliffs (Hawai`i Heritage Program 1991).

HISTORICAL AND CURRENT RANGE AND STATUS

Historical Range and Status. Before humans arrived, forest covered about 127,000 hectares (313,690 acres) on O`ahu (Hawai`i Heritage Program 1991), and it is likely that `elepaio formerly inhabited much of that area (Figure 6). Reports by early naturalists indicate that `elepaio were once widespread and abundant on O`ahu. Bryan (1905) called the O`ahu `elepaio "the most abundant Hawaiian species on the mountainside all the way from the sea to well up into the higher elevations." Perkins (1903) remarked on its "universal distribution..., from the lowest bounds to the uppermost edge of continuous forest." Seale (1900) stated the `elepaio was "the commonest native land bird to be found on the

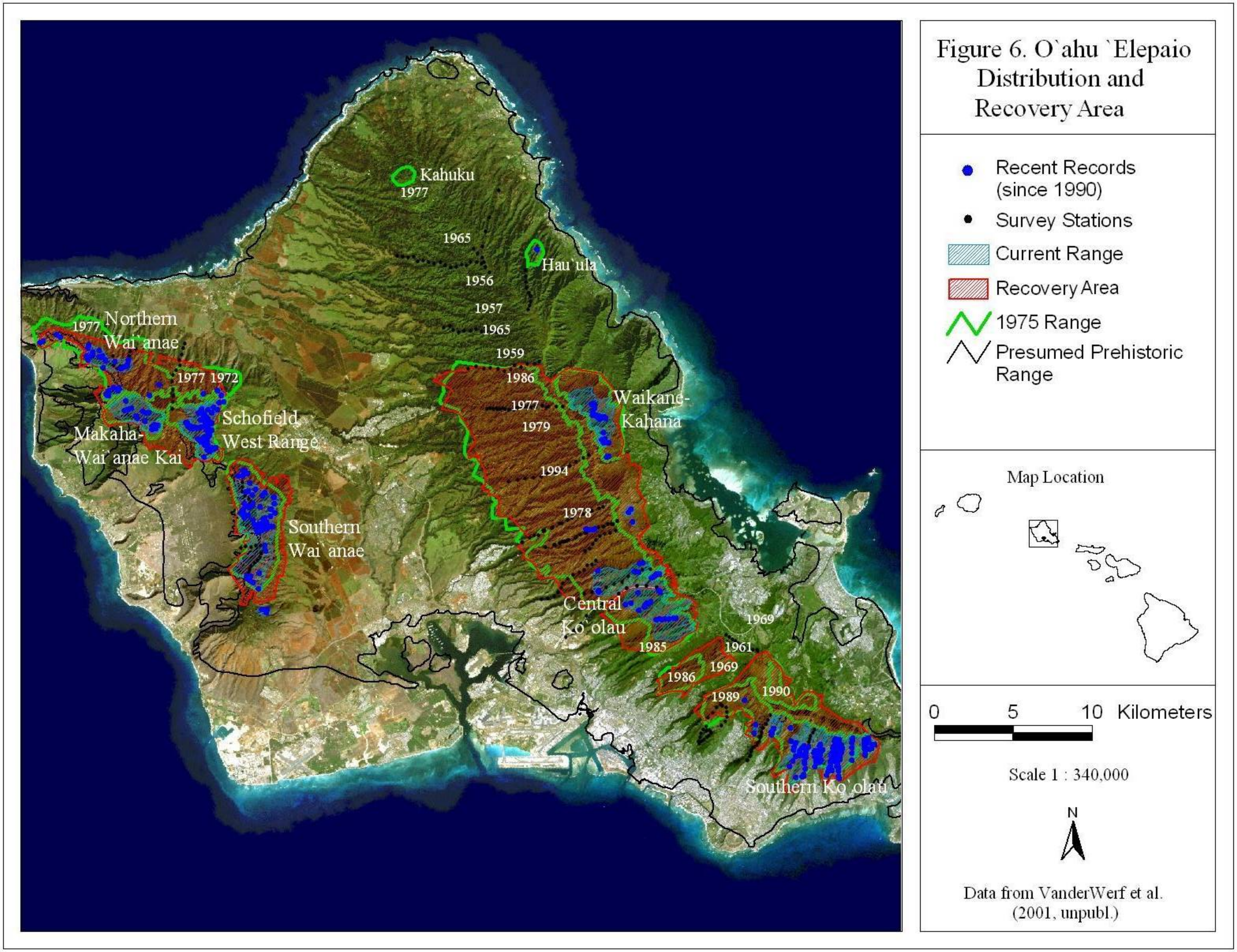


Figure 6. O`ahu `Elepaio Distribution and Recovery Area

island," while MacCaughey (1919) described it as "the most abundant representative of the native woodland avifauna" and "abundant in all parts of its range." The historical range of the O`ahu `elepaio thus apparently included most forested parts of the island, and it was formerly abundant.

Despite its adaptability, the O`ahu `elepaio has declined seriously since humans arrived, and it has disappeared from many areas where it was formerly common (Shallenberger 1977, Shallenberger and Vaughn 1978, Williams 1987, VanderWerf *et al.* 1997). Based on the dates when `elepaio were last observed in various locations (Figure 6), the decline of `elepaio began in three areas, the northern Ko`olau Mountains, the northern slope of Mt. Ka`ala in the northern Wai`anae Range, and near Konahuanui in the south-central Ko`olau Mountains. Perhaps not coincidentally, these are also the three areas with the highest rainfall on O`ahu, suggesting mosquito-borne diseases may have played an important role in the decline.

Current Range and Status. The total geographic area of all current populations is approximately 5,451 hectares (13,464 acres) (Table 4; VanderWerf *et al.* 2001). The O`ahu `elepaio thus currently occupies only about 4 percent of its presumed prehistoric range, and has declined by roughly 96 percent since humans arrived in Hawai`i 1,600 years ago (Kirch 1982). In 1975, `elepaio inhabited approximately 20,900 hectares (51,623 acres) on O`ahu, almost four times the area of the current range (VanderWerf *et al.* 2001). The range of the `elepaio has thus declined by roughly 75 percent in the last 25 years (Figure 6).

The total current population of O`ahu `elepaio is approximately 1,980 birds that are distributed in 6 relatively large populations and several small population remnants (Table 4 and Figure 6; VanderWerf *et al.* 2001). The only previous population estimate (200 to 500 birds; Ellis *et al.* 1992) was not accurate because little information was available when the estimate was made. The number of birds is divided almost evenly between the Wai`anae Mountains in the west and the Ko`olau Mountains in the east, with three relatively large populations in each mountain range. Although the central Ko`olau population covers the largest area (Table 4), `elepaio are sparsely distributed in much of this region and the number of birds is smaller than in more dense populations. Several tiny population remnants consisting entirely of males remain in both the Wai`anae

Table 4. Estimated size and area of O`ahu `elepaio populations. Data from VanderWerf *et al.* (2001).

Population	Total population size	Breeding population size	Area (hectares)
**<u>Wai`anae Mountains</u>** A. Southern Wai`anae (Honouliuli Preserve, Lualualei Naval Magazine)	458	418	1,170
B. Schofield Barracks West Range	340	310	538
C. Mākaha, Wai`anae Kai Valleys	123	112	459
D. Pahole, Kahanahāiki	18	4	256
E. Schofield Barracks South Range	6	0	20
F. Mākua Valley	7	2	49
G. Ka`ala Natural Area Reserve	3	0	21
H. Makaleha Gulch	2	0	7
I. Kuaokalā	3	2	14
J. Kaluakauila Gulch	1	0	6
**<u>Ko`olau Mountains</u>** K. Southern Ko`olau (Pia, Wailupe, Kapakahi, Kuli`ou`ou, Wai`alae Nui)	475	434	1,063
L. Waikāne, Kahana Valleys	265	242	523
M. Central Ko`olau (Moanalua, north and south Hālawa, `Aiea, Kalauao)	226	206	1,396
N. Pālolo Valley	46	42	78
O. Waihe`e Valley	5	4	32
P. Mānoa Valley	2	0	19
Q. Hau`ula	1	0	4
R. Waianu Valley	1	0	8
TOTAL	1,982	1,774	5,663

and Ko`olau mountains, but since there is no chance of reproduction without females and population rescue by immigration is unlikely, these relicts likely will disappear in a few years as the last adult birds die.

The breeding population is about 1,770 birds, lower than the total population, due to a male-biased sex-ratio; only 84 percent of territorial males have mates in large populations (n = 147; E. VanderWerf, unpubl. data), and many small, declining populations contain mostly males (breeding population = 0 in Table 4). The genetically effective population size probably is further reduced by the geographic isolation of populations (Grant and Grant 1992). Adults have high site fidelity and natal dispersal distances usually are less than a kilometer (0.62 mile) (VanderWerf 1998a), but most `elepaio populations on O`ahu are separated by many kilometers of unsuitable urban or agricultural habitat. There may be infrequent dispersal among populations within each mountain range, but it is unlikely that `elepaio cross the extensive pineapple fields that separate the Wai`anae and Ko`olau Mountains. The current distribution superficially appears to constitute a metapopulation (Hanski and Gilpin 1997), but this would be true only if dispersal occurred among populations. There have been no observations of banded `elepaio moving among populations (E. VanderWerf, unpubl. data), though this would be difficult to detect. Investigation of the genetic population structure has begun (Burgess 2005), but requires additional analysis.

REASONS FOR DECLINE AND CURRENT THREATS

Habitat Loss and Degradation. Much of the historical decline of the O`ahu `elepaio can be attributed to habitat loss, especially at low elevations. Fifty-six percent of the original prehistoric range has been developed for urban or agricultural use, and no `elepaio remain in these developed areas (VanderWerf *et al.* 2001). Habitat loss thus has been a major cause of decline, but `elepaio are adaptable, and moderate habitat alteration in the form of gradual replacement of native forest with alien forest has not limited their distribution (VanderWerf *et al.* 1997). Moreover, several areas of O`ahu that recently supported large `elepaio populations and still contain suitable native forest habitat are unoccupied, demonstrating that habitat loss is not the only threat. `Elepaio were observed regularly into the 1970s or early 1980s at Poamoho, Schofield-Waikāne, Mānana, and other areas (Figure 6; Shallenberger 1977, Shallenberger and Vaughn 1978), but they have since disappeared from all of these areas even though the forest is still largely intact (VanderWerf *et al.* 2001).

Predation and Disease. Recent declines in O`ahu `elepaio populations are due to a combination of low adult survival and low reproductive success. The two main causes of reduced survival and reproduction on O`ahu are nest predation by alien black rats (*Rattus rattus*) and diseases, particularly avian pox (*Poxvirus avium*), which is carried by the introduced southern house mosquito (*Culex quinquefasciatus*).

O`ahu `elepaio foot with active pox lesion. Photo © Eric VanderWerf.

In a 10-year study of mosquito-borne diseases from 1995 to 2005, VanderWerf *et al*. (in press) found that each year 20 ± 4 percent of O`ahu `elepaio had active lesions likely caused by pox, and an additional 16 ± 4 percent had deformities and missing toes indicative of healed pox lesions. The prevalence* of avian malaria (*Plasmodium relictum*) was 87 percent over all years combined. Pox prevalence varied among years, and was associated with annual rainfall, presumably due to greater abundance of mosquito breeding sites in wet years. Rainfall amounts at least as high as those associated with pox epizootics in 1996 and 2004 have occurred in 13 years since 1947, or once every 4.5 years (VanderWerf *et al*. in press). The severity of infection varied considerably among birds, and infections involving three or more toes, the feet, or the head were less common in birds with healed lesions than in those with active lesions, suggesting that such infections resulted in mortality more often. Annual survival of `elepaio with active avian pox lesions (65 percent) was lower than annual survival of `elepaio with no pox symptoms (80 percent; E. VanderWerf, unpubl. data). Pairs in which at least one bird had active pox produced fewer fledglings than healthy pairs or those in which at least one bird had healed pox (E. VanderWerf, unpubl. data). Many birds with active pox lesions did not even attempt to nest, and infected birds were sometimes deserted by their mate. Avian malaria is known to be a serious threat to many Hawaiian forest birds (Warner 1968, van Riper *et al.* 1986, Atkinson *et al.* 1995), but its effect on `elepaio has not been quantified.

Black rats are the main predator on O`ahu `elepaio nests, though feral cats (*Felis catus*) may also occasionally prey on adults and nests. An experiment in which automatic cameras were wired to artificial nests containing quail eggs showed that a black rat was the predator in all 10 predation events documented (VanderWerf 2001c). All predation events occurred at night, and most occurred

* "Prevalence" refers to the percent of a population that is affected at a given time

on the first night nests were placed in the field, indicating predation pressure was very high. Control of rats with snap traps and diphacinone bait stations from 1996 to 2000 resulted in an increase in reproduction from 0.33 to 0.70 fledglings per pair (112 percent) and an increase in annual survival of adult female `elepaio from 0.50 to 0.83 (66 percent; VanderWerf and Smith 2002). Both sexes of `elepaio incubate the eggs and brood the nestlings, but only the female incubates at night, making them more vulnerable to predation by nocturnal predators such as rats (VanderWerf 1998a).

The relative threat posed by disease and nest predation can be determined by calculating the rate of population growth, or lambda (λ), under different conditions (calculated as $\lambda = P_A + P_J B$, where P_A is annual adult survival, P_J is juvenile survival, and B is mean number of fledglings per pair per year; Pulliam 1988, VanderWerf and Smith 2002). Without any management lambda was 0.76 ± 0.12, indicating a rapid 24 percent decline per year. At this rate of decline, less than 10 percent of the population would remain in 9 years. With rat removal lambda was 1.00 ± 0.05, indicating a stable population. If disease could be eliminated somehow and all birds survived at the rate of healthy individuals, but rats were not removed, lambda would be approximately 0.83 (E. VanderWerf, unpubl. data), indicating that the population would still be declining at a rate of 17 percent a year. If disease could be eliminated and rats were removed, lambda might be as high as 1.04, which would allow the population to double in 19 years. These calculations suggest that the removal of rats alone may prevent further decline of O`ahu `elepaio, but may not be enough to allow rapid recovery of `elepaio populations.

Other Natural and Manmade Factors. The remaining `elepaio populations are small and isolated, comprising 6 core populations that contain between 100 and 500 birds each, and several small remnant populations, most of which contain fewer than 10 birds and few or no breeding pairs (Table 4). Even if the threats responsible for their decline were controlled, the existing populations would still be threatened with extinction because their small sizes and restricted distributions make them vulnerable to a variety of natural processes, including reduced reproductive vigor caused by inbreeding depression, loss of genetic variability and evolutionary potential over time due to random genetic drift, stochastic fluctuations in population size and sex ratio, and natural disasters such as hurricanes and fires (Lande 1988, International Union for the Conservation of Nature 2000).

O`ahu `elepaio also are threatened by human actions, such as the potential introduction of the brown treesnake (*Boiga irregularis*) from the Mariana Islands, which has devastated the avifauna on Guam (Savidge 1987). A study of the effects of noise from military training showed that O`ahu `elepaio at U.S. Army Schofield Barracks are not affected by noise from military training (VanderWerf *et al*. 2000). However, fires ignited by military training activities are a serious long-term threat to `elepaio and have reduced the amount of suitable habitat for the species, including areas designated as critical habitat for the O`ahu `elepaio at Schofield Barracks and Mākua Military Reservation (USFWS 2003c). Firebreak roads exist to help prevent the spread of fires into mesic forest occupied by `elepaio, but fires regularly start beyond the firebreaks, and each fire removes additional habitat, which is replaced by nonnative fire-adapted plants that are not used by `elepaio, such as swamp mahogany (*Eucalyptus robusta*) and bottlebrush (*Melaleuca quinquenervia*). If this pattern is allowed to continue, there eventually will be no mesic forest left at Schofield Barracks and Makua Valley, and those populations will be lost.

CONSERVATION EFFORTS

The O`ahu `elepaio was federally listed as endangered on April 18, 2000 (U.S. Fish and Wildlife Service 2000b), and thus receives regulatory protection under the Federal Endangered Species Act. Species listed under the Federal Endangered Species Act are automatically added to the State of Hawai`i list of endangered species, and are thus also protected by State regulations. Critical habitat for the O`ahu `elepaio was designated on December 10, 2001 (U.S. Fish and Wildlife Service 2001). The recently established O`ahu Forest National Wildlife Refuge protects a large area of suitable forest habitat in the north-central Ko`olau Mountains (U.S. Fish and Wildlife Service 2000a). This area currently supports few or no `elepaio, but it is suitable for management of threats and reintroduction.

Conservation efforts for the O`ahu `elepaio thus far have included surveys to determine current distribution and abundance (VanderWerf *et al.* 1997, 2001), demographic monitoring to assess population status and identify threats

(VanderWerf 1999), removal of introduced predators (VanderWerf and Smith 2002), and investigation of disease (VanderWerf *et al*. in press). Surveys have been conducted over most of O`ahu, and have shown the distribution to be highly fragmented and the total population to be fewer than 2,000 birds (see Current Range and Status, above). Long-term demographic studies have shown that the two most important current threats are nest predation by black rats and introduced mosquito-borne diseases (see Predation and Disease, above). Rat control is a promising conservation technique for increasing both reproductive success and survival of adult females. Ground-based rat control using snap traps and diphacinone bait stations has been conducted in the Honolulu Watershed Forest Reserve by the Hawai`i State Division of Forestry and Wildlife since 1997, at Schofield Barracks West Range and Mākua Military Reservation by the U.S. Army Environmental Division since 1998, at Honouliuli Preserve by The Nature Conservancy of Hawai`i since 2000, in Lualualei Naval Magazine by the U.S. Navy and U.S. Department of Agriculture, Wildlife Services from 2002 to 2004, in Mākaha Valley by the City and County of Honolulu Board of Water Supply and the U.S. Army since 2004, and in and Moanalua Valley by the U.S. Army since 2005. Blood samples have been collected from over 150 `elepaio for use in disease screening, determination of genetic population structure, and to assist in identification of potentially disease-resistant populations or individuals.

RECOVERY STRATEGY

There are several important components to the recovery strategy for the O`ahu `elepaio, including the identification of recovery areas and protection of remaining forest from development and fire; control of alien nest predators, especially rats; research on disease resistance and transmission; public information and outreach; and possibly captive propagation.

The O`ahu `elepaio currently has a highly fragmented distribution, with 6 relatively large populations of at least 100 birds, a few smaller populations of 10 to 50 birds, and several very small population remnants containing only a few single males (Table 4). Recovery efforts should focus on protecting and managing the six large "core" populations first. These core populations are distributed throughout most of the original historical range, have the greatest chance of long-term persistence because their larger sizes make them less susceptible to stochastic events, probably have lost less genetic diversity than smaller populations, and are most likely to be recovered *in situ* through habitat management. All core populations should be conserved to preserve as much genetic, morphological, and behavioral (vocal) variation as possible. Smaller populations should be addressed next if there are sufficient resources or interested parties, followed by very small populations. If management actions are effective, the core populations eventually may serve as sources of dispersing individuals that can help support smaller populations or even recolonize areas where `elepaio have disappeared.

Habitat Protection. Protection of remaining forest habitat on O`ahu is fundamental to the survival and recovery of the `elepaio. Although `elepaio are adaptable, they are forest birds and require some form of forest in which to forage and nest. Suitable habitat for recovery of O`ahu `elepaio includes wet, mesic, and dry forest consisting of native and/or introduced plant species, but higher population density can be expected in closed canopy riparian forest with a continuous canopy and dense understory (VanderWerf *et al.* 1997, 2001).

The remaining O`ahu `elepaio populations are small and fragmented; even if the threats responsible for their decline were controlled, the existing populations would still be threatened with extinction because their small sizes and restricted distributions make them vulnerable to stochastic fluctuations and catastrophes such as hurricanes and fires. `Elepaio are highly territorial; each pair defends an area of a certain size, depending on the forest type and structure, resulting in a maximum population density or carrying capacity (VanderWerf 2003). Consequently, the currently occupied areas are too small to support `elepaio populations large enough to be considered safe from extinction. Complete recovery will require restoration of `elepaio in areas where they do not occur at present, through translocation, captive propagation and release, or natural dispersal. Identified recovery areas therefore include areas that are currently not occupied by `elepaio, but that still contain suitable forest.

The O`ahu `elepaio evolved in an environment with large areas of continuous forest habitat covering much of the island, and their dispersal behavior is not adapted to a fragmented landscape. `Elepaio are sedentary; adults have high fidelity to their territory and juveniles rarely disperse more than 1 kilometer (0.62 mile) in search of a territory (VanderWerf 1998a). Because the areas currently occupied by `elepaio are separated by many kilometers and `elepaio are unlikely to disperse long distances, the existing populations are probably isolated from one another (VanderWerf *et al.* 2001). Maintaining or restoring links among populations by providing habitat for dispersal would increase the overall effective population size, thereby helping to alleviate the threats associated with small population size. In particular, the enlargement of small subpopulations by expansion onto adjacent lands not only would increase the chances of their long-term survival, but also would improve connectivity among populations by enhancing their value as "stepping stones" within the entire distribution. Recovery areas therefore include areas that may not be used by `elepaio for nesting, but that provide dispersal corridors among populations and suitable forest areas.

Based on the estimated density of `elepaio in currently occupied areas, the recovery areas identified in Table 5 can be expected to support approximately 10,000 `elepaio (see also Figure 6; VanderWerf *et al.* 2001).

Table 5. Recovery areas and potential O`ahu `elepaio populations.

Recovery area	Area in hectares (acres)	Current `elepaio density in area (birds/hectare)	Potential `elepaio population
Northern Wai`anae	4,454 (11,005)	0.45	2,004
Southern Wai`anae	2,422 (5,985)	0.39	945
Central Ko`olau	14,801 (36,573)	0.33	4,884
Kalihi-Kapālama	804 (1,987)	0.39	314
Southern Ko`olau	4,180 (10,329)	0.45	1,881
All Areas	26,661 (65,879)	0.37	10,028

Predator Control. Control of alien predators, especially rats, has been shown to be an effective method of increasing reproductive success and survival of female `elepaio (VanderWerf and Smith 2002). Rodent control programs should be continued and expanded by whatever methods are available. Ground-based methods of rodent control using snap traps and diphacinone bait stations have been effective on a small scale, but are labor intensive. Recovery of the O`ahu `elepaio likely will require large-scale rat control, which can be achieved more efficiently through aerial broadcast methods. Registration of aerial broadcast of diphacinone or other rodenticides with the U.S. Environmental Protection Agency and Hawai`i Department of Agriculture Pesticides Branch should be actively pursued and supported. Aerial broadcast of rodenticides may be feasible only in areas where secondary poisoning to non-target species such as feral pigs and indirect exposure to the human food chain can be avoided. Public education about predator control and coordination of toxicant use among agencies will therefore be important parts of the recovery strategy.

Disease Research. No areas of O`ahu are of sufficient elevation to be free from disease-carrying mosquitoes, and all populations of O`ahu `elepaio appear to be affected by disease (VanderWerf *et al*. in press). Reducing mosquito numbers by removing breeding sites or treating them with larvicides would be extremely difficult due to the abundance of breeding sites (C. Atkinson and D. LaPointe, pers. comm.). The best long-term method of reducing the threat from disease may be to investigate disease resistance or tolerance and its genetic basis. If disease-resistant or tolerant birds can be identified, translocation or captive propagation and release of these birds might help populations recover more quickly and perhaps obviate the need to control mosquitoes. Controlling rodents also may lessen the threat from disease by providing birds that have greater natural immunity a greater chance of reproducing, thereby increasing the proportion of resistant birds more quickly (VanderWerf and Smith 2002). The potential evolutionary acceleration of disease resistance through rodent control was demonstrated quantitatively by Kilpatrick (2006), and appears promising.

Population Surveys and Monitoring. To determine whether the overall recovery strategy is effective and whether the recovery criteria have been met, it will be necessary to conduct rangewide population surveys and monitor demography of populations. Standard survey routes should be established to determine distribution and measure population density. Surveys should be conducted at least once every 5 years to address whether the recovery criteria have been met, and annually if possible to more closely examine population trends and assess efficacy of management actions. Demographic monitoring will require mist-netting, banding, and resighting of birds to measure survival rate, nest searching to measure reproductive success, and data analysis.

Setting a goal of demographic persistence highlights the need for monitoring and helps ensure that threats have been adequately managed and population increases are not transient. Research to date indicates that survival and reproduction of `elepaio populations on O`ahu fluctuate from year to year, in association with epizootics of disease and variation in predator (rodent) populations (VanderWerf and Smith 2002, VanderWerf *et al*. in press). Epizootics of disease and irruptions in rodent populations appear to occur approximately once every 5 years (see Life History: Annual Variation), so the third recovery criterion for the O`ahu `elepaio, stable or increasing populations over a period of 15 years for downlisting and 30 years for delisting, likely would encompass either three (downlisting) or six (delisting) population cycles. If populations are stable in the long-term despite periodic episodes of increased disease and predation, then the species can be considered recovered.

Captive Propagation. Captive propagation and release of O`ahu `elepaio are not necessary for recovery at this time because the number of O`ahu `elepaio remaining in the wild is relatively large and recovery can be achieved more cost-effectively through habitat management. Moreover, the threats that caused the decline of `elepaio have not been corrected in most areas, and no suitable release sites are currently available. Captive propagation and/or rear and release of O`ahu `elepaio may become necessary in the future if habitat management alone proves insufficient to allow recovery, and would be especially valuable if genetically disease-resistant birds can be identified for use as breeding stock. Attempts at captive propagation of `elepaio should consider using birds known to have recovered from pox or identified as genetically resistant. In anticipation of the possible need to implement a captive propagation program for the recovery of this species in the future, surrogate efforts have begun at the Keauhou Bird Conservation Center with the Hawai`i subspecies of the `elepaio. Techniques have been developed for the collection and transfer of eggs, artificial incubation and hand-rearing of chicks, as well as long-term maintenance of birds in captivity (The Peregrine Fund 1995, 1996, 1997, 1998, 1999; Zoological Society of San Diego 2004). Captive management has yet to produce a successful captive breeding or a release of `elepaio from captive-bred animals.

2. Kāma`o, *Myadestes myadestinus*

DESCRIPTION AND TAXONOMY

The kāma`o, also known as the large Kaua`i thrush, is endemic to the island of Kaua`i and is a member of the thrush family (Turdidae). Early descriptions of the kāma`o were made by Stejneger in 1887 from specimens provided to the Smithsonian Institution by Valdemar Knudsen in the 1880s (Munro 1944). Originally described as *Phaeornis obscura myadestina*, Pratt (1982) offered convincing evidence that *Phaeornis* should be merged with the American solitaire genus *Myadestes*, and that some Hawaiian taxa formerly treated as subspecies are sufficiently distinct to merit full species status.

The kāma`o is a medium-sized (20 centimeters [7.9 inches] in length) solitaire, gray-brown above, tinged with olive especially on the back, and light gray below with a whitish belly and undertail coverts. The legs are dark gray-brown and relatively short, but the ventral surface of the toes is pale yellow. The eyes are dark and the bill is black. The kāma`o lacks the white eye-ring and pinkish legs of the smaller puaiohi (small Kaua`i thrush). Immature birds have a spotted appearance. The song is sweet and melodic, sometimes lavish and flute-like, and is often given just before dawn and after dusk. A scolding or hissing "police whistle" alarm note has also been described.

LIFE HISTORY

Little is known of the life history of the kāma`o, but presumably it is similar in many respects to the more common and closely related `ōma`o or Hawai`i thrush (*Myadestes obscurus*). The periods of greatest singing occur in the winter (January to March). Nesting likely occurs in the spring (April to July). The nest has not been described, but may be a cavity or low platform as with the `ōma`o. The eggs are grayish-white with irregular reddish-brown splotches, and the clutch size is one or two. The diet of the kāma`o is reported to consist of fruits and berries, particularly the bracts of the `ie`ie vine (*Freycinetia arborea*), as well as insects and snails (Munro 1944). The kāma`o was often described for its habit of rising on the wing into the air, singing a few vigorous notes and then suddenly dropping down into the underbrush. Early in the morning it sings an elaborate song from treetops. The kāma`o seems to spend less time on the ground than does the smaller puaiohi.

HABITAT DESCRIPTION

In the past half century, the kāma`o has not been seen below 1,100 meters (3,500 feet) elevation. In recent years, kāma`o have been seen most frequently where a healthy open forest canopy existed, primarily of `ōhi`a (*Metrosideros polymorpha*) and `ōlapa (*Cheirodendron* spp.). A diverse understory, lush with epiphytes, tree ferns, mosses, and a variety of native fruit-producing plants, such as `ie`ie, `ōhā wai (*Clermontia* spp.), and `ōhelo (*Vaccinium* spp.), are probably associated with good kāma`o habitat. The `ie`ie vines favored by kāma`o still exist in some areas of the island, but not in the higher elevations to which the birds may be currently restricted. `Ie`ie does not thrive above 1,500 meters (5,000 feet) elevation (Wagner *et al.* 1999). The fact that the kāma`o once existed near sea level, but is now restricted to high elevation native forest without its most preferred food plant, suggests that it may be surviving in marginal habitat.

HISTORICAL AND CURRENT RANGE AND STATUS

In 1881, the kāma`o was considered extremely common in the moist forests near sea level on northern Kaua`i as well as in the upland interior mountain forests. It was still considered common on the outer forest edges in 1899, but by 1928 it became difficult to find in the lower forests. In 1941, it was still considered common in the upland interior forested plateau of the Alaka`i Wilderness Preserve (Munro 1944). The kāma`o became noticeably rare by the mid 1960s. At this time it remained only in the uppermost regions of the Alaka`i in very sparse numbers. From 1968 to 1973, Sincock (1982) found the kāma`o near the southern edge of the Alaka`i Wilderness Preserve, although one isolated occurrence was reported in the upper elevations of Kōke`e State Park (Figure 7). In the summer of 1985, two kāma`o were seen during an intensive 2-week survey of the Alaka`i (Hawai`i Department of Land and Natural Resources, unpubl. data). This followed the moderately severe Hurricane Iwa that occurred in November 1982. The last confirmed observation of the kāma`o was made during the February 1989 Kaua`i forest bird survey (Hawai`i Department of Land and

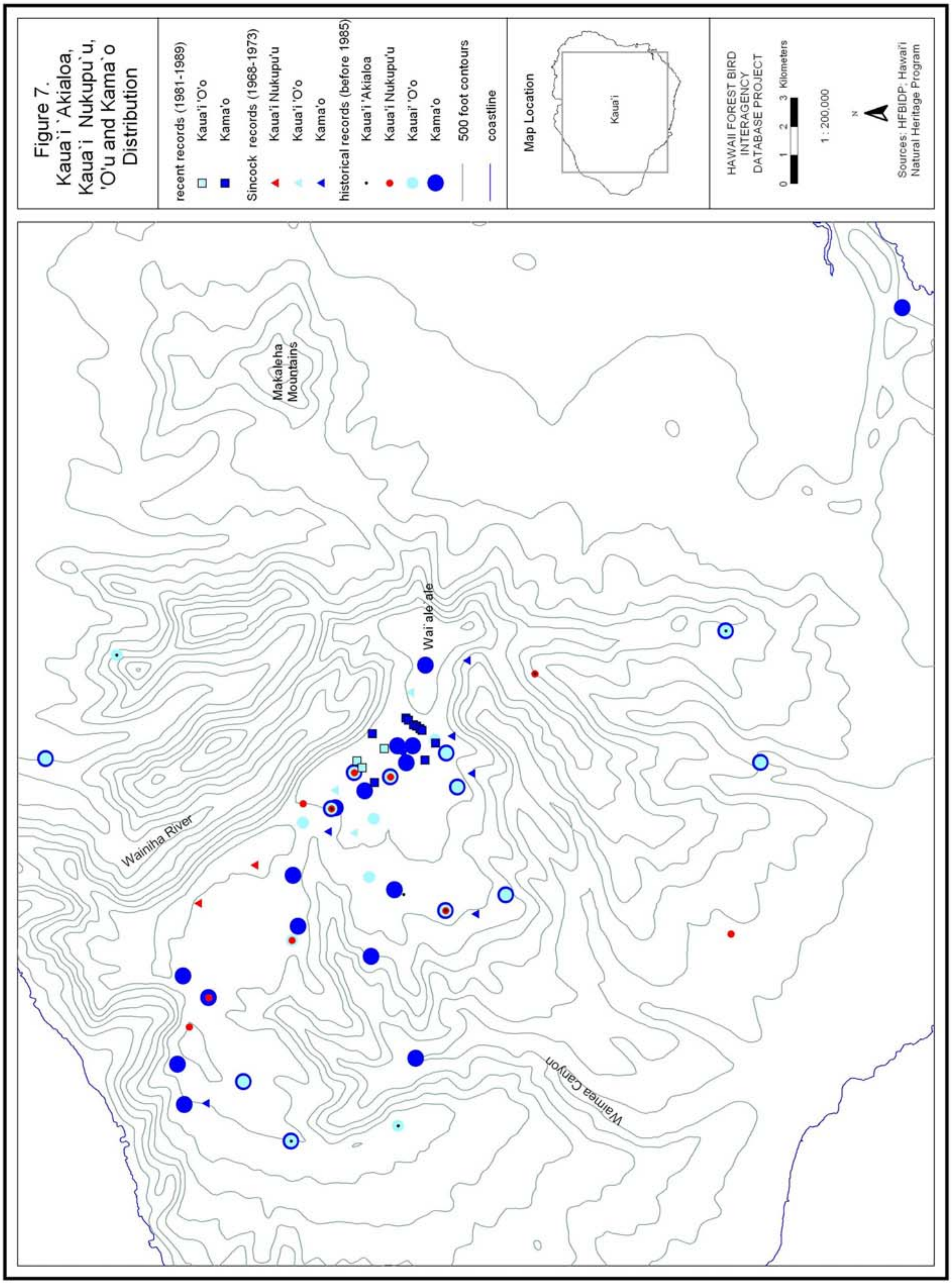


Figure 7.
Kaua`i `Akialoa, Kaua`i Nukupu`u, 'O'u and Kama`o Distribution
recent records (1981-1989)
Kaua'i 'O'o
Kama'o
Sincock records (1968-1973)
Kaua'i Nukupu'u
Kaua'i 'O'o
Kama'o
historical records (before 1985)
Kaua'i 'Akialoa
Kaua'i Nukupu'u
Kauai' 'O'o
Kama'o
500 foot contours
coastline
Map Location
Kaua'i
HAWAII FOREST BIRD INTERAGENCY DATABASE PROJECT
0 1 2 3 Kilometers
1 : 200,000
N
Sources: HFBIDP; Hawai'i Natural Heritage Program
Makaleha Mountains
Wainiha River
Wai`ale`ale
Waimea Canyon

Natural Resources, unpubl. data). In September 1992 hurricane Iniki severely damaged Kaua`i's forests. No sightings of kāma`o were made during a brief post-hurricane survey made in February 1993 (Telfer 1993; Hawai`i Department of Land and Natural Resources, unpubl. data), nor in more intensive surveys conducted in February and March 1994, March 2000, and March 2005 (Hawai`i Department of Land and Natural Resources, unpubl. data; Foster *et al.* 2004).

The fact that the kāma`o has not been seen since 1989 indicates this species is on the brink of extinction. It should be noted, however, that its congener, the puaiohi or small Kaua`i thrush, went many years without being seen, but is now known to number 300 to 400 individuals. Periodic unconfirmed sightings of the kāma`o have been reported since 1989, the most recent in 1995, suggesting the species could still survive. In view of the kāma`o's original widespread distribution to near sea level and the apparent negative impact of avian diseases and the destruction of its lowland habitat, it is unlikely that it will ever be restored to its historical range, but recovery of a population in the upper Alaka`i plateau is remotely possible, should any individuals persist. Additional targeted searches are needed to confirm the status of the species.

REASONS FOR DECLINE AND CURRENT THREATS

Avian disease is by far the most significant factor suspected to limit the kāma`o. Early ornithologists noted the difficulties these birds had with "lumps on their feet and sometimes at the corners of the mouth," which likely were avian pox lesions, transmitted by mosquitoes or other vectors. The fact that some good quality native forest with abundant fruit-bearing plants exists below their current range demonstrates that habitat destruction cannot account for the extirpation of the species in the lowlands and that factors other than habitat quality are limiting the population. The proliferation of introduced fruits, such as blackberry (*Rubus argutus*), banana passionflower (*Passiflora mollissima*), guava (*Psidium cattleianum*), and thimbleberry (*Rubus rosaefolius*) into the mid-elevations, may have been an attractive food source that enticed kāma`o into lower elevations where they were exposed to avian diseases such as pox and avian malaria.

If kāma`o are cavity or low platform nesters, as Hawaiian solitaires generally are, predators such as rats (*Rattus* spp.) may severely limit their nesting success and would explain why some of the smaller arboreally nesting species that nest higher off the ground have had a greater degree of nesting success. Feral cats (*Felis catus*) are occasionally found in high elevation rain forest habitat, and young solitaires foraging on the ground are probably one of the easier prey species for these predators.

Several introduced birds, including the Japanese white-eye (*Zosterops japonicus*), melodious laughing-thrush (*Garrulax canorus*), white-rumped shama (*Copsychus malabaricus*), and the recently established Japanese bush-warbler (*Cettia diphone*) share the same habitat with the kāma`o and may compete with the kāma`o for food and nest sites to some degree. The establishment of other potentially detrimental birds on Kaua`i, such as the red-vented bulbul (*Pycnonotus cafer*) found on some of the other Hawaiian Islands, remains a persistent threat.

Habitat degradation resulting from the invasion of pernicious alien weeds has drastically changed the forest structure and integrity. Two hurricanes in 1982 and 1992 severely disrupted portions of high quality native forest, and have made space for the germination and expansion of noxious weeds such as yellow ginger (*Hedychium flavescens*), daisy fleabane (*Erigeron karvinskianus*), glorybush (*Tibouchina urvilleana*), Japanese honeysuckle (*Lonicera japonica*), and others (see Table 10, page 4-50).

Feral pigs, and goats to a lesser degree, have had a long-term damaging effect upon native forests in the remaining kāma`o range by consuming and damaging understory vegetation, creating openings on the forest floor for weeds, and transporting weed seeds into the forest. Soil erosion and disruption of seedling regeneration of native plants is one of many forest management problems in kāma`o range.

Perhaps less obvious, but potentially detrimental to the health of the remaining kāma`o habitat, are introductions of new alien invertebrates to the forest ecosystem. Although kāma`o are primarily frugivorous, insects and spiders are likely to be an important component of the diet, especially for nestlings. Introductions of predatory and parasitic invertebrates that compete with native species for food pose a continuing threat throughout the islands. Introduced predatory insects also may reduce or eliminate specialized native insects that are necessary for pollination of certain food plants. Many of the food plants used by kāma`o could be negatively affected by herbivorous alien insects, such as the two-spotted leafhopper (*Sophonia rufofascia*), which may reduce their range, fruit set, and eventual survival. Introduced snails that prey on indigenous snails could also reduce food resources of the kāma`o. On the other hand, the detrimental effects of some of these new insects and molluscs could be somewhat offset if they are utilized as direct prey items by the kāma`o.

Finally, the remaining kāma`o population, if indeed it exists, is likely to be extremely small and genetically impoverished, increasing the risks of demographic instability and inbreeding depression.

CONSERVATION EFFORTS

So little is known about the kāma`o and its limiting factors that few species-specific conservation actions have been attempted. Efforts have centered on protecting the integrity of the remaining native forest habitat in the Alaka`i Wilderness Preserve where these and other endangered forest birds have survived during the past half century. The Forest Reserve Act of 1903 was an important action that protected watersheds in Hawai`i. It was later strengthened and re-titled "Hawai`i Department of Land and Natural Resources Title 13, Chapter 104, Rules Regulating Activities Within Forest Reserves," which protects native forest habitats from certain degrading factors caused by human activities. The Hawai`i Department of Land and Natural Resources established the 4,022 hectare (9,938 acre) Alaka`i Wilderness Preserve in 1964 (Administrative Rule No. 1, Chapter 3), recognizing the value of the pristine forest of that area and the need to control potential degrading factors.

The kāma`o was federally listed as endangered on October 13, 1970 (U.S. Fish and Wildlife Service 1970), and it became protected under the State of Hawai`i endangered species law on March 22, 1982.

Surveys and Monitoring. Regular surveys of Kaua`i forest bird populations and habitat conditions in the Alaka`i Wilderness Preserve have been conducted on established transects since the late 1960s. John L. Sincock, Research Biologist with the U.S. Fish and Wildlife Service, Kaua`i Field Station, conducted intensive status and distribution surveys of Kaua`i's forest birds from 1968 to 1973 (Sincock 1982). Large-scale, multi-agency surveys were conducted on established transects in 1981, 1985, 1989, 1994, 2000, and 2005 (Hawai`i Department of Land and Natural Resources, unpubl. data).

Control of Feral Ungulates. The Hawai`i Department of Land and Natural Resources has maintained liberal public hunting seasons to minimize forest damage caused by feral pigs and goats within the Alaka`i Wilderness Preserve for several decades. Unfortunately, public hunting succeeds only in the more accessible areas of the preserve, and ungulate populations in more remote areas remain quite high. Very limited aerial reconnaissance and shooting of feral goats and pigs has been attempted in the most remote regions, but has not been economically effective.

Public Information and Awareness. Materials featuring Kaua`i's endangered forest birds, as well as those found on other islands, have been published and provided to schools to assist in the effort to inform the public and gain support for conservation of endangered species. Privately funded filmmakers including the British Broadcasting Company and National Geographic Society have produced documentaries that inform the public of the plight of endangered forest birds. Several articles have appeared in popular nature magazines and local newspapers to increase public awareness of issues related to the conservation of Hawaiian forest birds, including those on Kaua`i.

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

3. Oloma`o, *Myadestes lanaiensis rutha*

DESCRIPTION AND TAXONOMY

The oloma`o or Moloka`i thrush is a medium-sized (21 centimeters [8.3 inches] in length) solitaire with olive-brown upper parts, grayish white under parts, and a buffy patch at the base of the primaries. The bill and legs are dark. Juveniles exhibit the same scalloped plumage as other young native thrushes. Differences between the sexes and between adults and young have not been studied in detail, nor has molt, but may be similar to those of the closely related `ōma`o (*M. obscurus*) on Hawai`i Island. In that species, males are larger than females on average, and birds in first basic plumage usually retain juvenile scalloping in the wing coverts (Fancy *et al.* 1994). `Ōma`o molt from June through November (Ralph and Fancy 1994b).

The oloma`o is a member of the thrush family (Turdidae) and was historically found on the islands of Lāna`i and Moloka`i, although its former range may have included O`ahu and Maui as well. Recent changes in the taxonomy of the Hawaiian thrushes have done away with the endemic genus *Phaeornis* and instead placed them with the New World solitaires, *Myadestes*, to which they are similar in appearance and song (Pratt 1982, American Ornithologists' Union 1985). The two subspecies, *M. l. lanaiensis* of Lāna`i (now extinct) and *M. l. rutha* of Moloka`i (more grayish below), cannot be safely distinguished by coloration or measurements (Pratt 1982). With the wing measuring 95 millimeters (3.7 inches) and the tail 80 millimeters (3.1 inches), the oloma`o is slightly smaller and has a proportionately longer tail than the `ōma`o. Whether the `amaui (*M. woahensis*) of O`ahu and subfossil remains of solitaires from Maui may actually be oloma`o is one of the remaining questions regarding the systematics of the Hawaiian solitaires (Pratt 1982, James and Olson 1991).

LIFE HISTORY

The breeding biology of the oloma`o is largely unknown but may be similar to that of the closely-related `ōma`o. Three nests attributed to oloma`o were 8 to 9 meters (26 to 30 feet) up in `ōhi`a (*Metrosideros polymorpha*; two nests) and kōlea (*Myrsine* spp.; one nest) trees; one of the nests was found in May, and the dates of the other two were not recorded (Perkins 1903, Bryan

1908). In the `ōma`o, modal clutch size is two, both young usually fledge, and parents tend their fledglings for about 6 weeks (van Riper and Scott 1979, Wakelee *et al.* 1999). Successful `ōma`o parents can raise two broods per season. Immature birds are not known to provide care at subsequent nestings by their parents.

Oloma`o consume a variety of small fruits that they swallow whole and insects are taken at all levels in the forest (Rothschild 1893 to 1900, Perkins 1903, Bryan 1908). The diet of the `ōma`o is essentially the same, and these foods are also fed to nestlings (Perkins 1903, van Riper and Scott 1979, Wakelee *et al.* 1999).

Much like the related `ōma`o, oloma`o live solitarily or in pairs and seldom leave their small home range (Bryan 1908, Ralph and Fancy 1994b). They do not make long flights over the canopy, but rise above the trees during song flights (Bryan 1908). Like other Hawaiian solitaires, they often tremble their wings when perched (Rothschild 1893 to 1900, Perkins 1903, Bryan 1908).

Oloma`o are easily detected by song or calls. Oloma`o usually sing from treetops, but because of the song's ventriloquial quality, the singer is often difficult to locate (Bryan 1908). The song is beautiful, thrush-like, "of a jerky nature" (Rothschild 1893 to 1900), and similar to that of the `ōma`o (Bryan 1908). Described as voluble singers during the day, oloma`o also sing at night in good weather (Perkins 1903, Bryan 1908). Munro (1960) claimed that the Lāna`i bird was "no singer at all." Calls were reported as "a clear call-note" (Rothschild 1893 to 1900), and a questioning cat-like call (Rothschild 1893 to 1900, Bryan 1908), both notes similar to those of `ōma`o.

HABITAT DESCRIPTION

Oloma`o prefer closed forest; if in open forest, they stay close to cover (Bryan 1908). Originally they were ubiquitous throughout wet and dry forests on Moloka`i and Lāna`i, in the lowlands as well as at the highest elevations (Rothschild 1893 to 1900, Perkins 1903). The most recent records have all been from dense rainforest above 1,000 meters (3,300 feet) elevation adjacent to the steep pali (cliff) of Pelekunu (Scott *et al.* 1986).

HISTORICAL AND CURRENT RANGE AND STATUS

The historical range of the oloma`o encompassed the mountains of East Moloka`i and Lāna`i (Figure 8). Bryan reported that oloma`o were most abundant at Hālawa, Moloka`i, where closed forest provided prime habitat (Rothschild 1893 to 1900, Bryan 1908). Past distribution may have included O`ahu (if the `amaui is considered the same species; James and Olson 1991) and Maui, where ample fossils of Hawaiian solitaires have been found (James and Olson 1991) and where, at `Īao Valley, a native informant claimed solitaires to be abundant in the 1860s (Perkins 1903).

The only detections of oloma`o since Bryan's trip in 1907 have been on Moloka`i, including: (1) two birds vividly described in 1963 at Pu`u Haha on Ka`āpahu ridge at 1,100 meters (3,600 feet; Pekelo 1963); (2) two sightings in 1975 one-half mile east (*sic*; west?) of Pu`u O Waha`ulu at 1,360 meters (4,460 feet; Scott *et al.* 1977); (3) five to six detections at various locations near the rim of Pelekunu and on Oloku`i during the Hawai`i Forest Bird Survey in 1979 and 1980 (Figure 8); and (4) a fleeting glimpse in 1988 on Kapapamoa ridge somewhat above 1,220 meters (4,000 feet) (A. Engilis, Ducks Unlimited, pers. comm.). At least three of the detections by the Hawai`i Forest Bird Surveys were questionable and were perhaps Japanese bush-warblers (*Cettia diphone*), a species that had just recently colonized Moloka`i. Scott *et al.* (1986) estimated a population of 19 ± 38 birds. Surveys in 1988, 1995, and 2004 turned up no oloma`o (Reynolds and Snetsinger 2001; Hawai`i Department of Land and Natural Resources, unpubl. data). Currently, there are no known oloma`o populations, and whether the species remains extant is unknown. Survey efforts for this species have been relatively low, due in part to the difficulty of accessing some of its best remaining habitat. An unconfirmed sighting in 2005 provided some hope that the species may still survive (G. Hughes, *in litt*. 2005). Additional searches are needed to ascertain the current status of the oloma`o with greater confidence, particularly of the Oloku`i Plateau.

REASONS FOR DECLINE AND CURRENT THREATS

Reasons for decline and current threats presumably are the same as for other forest birds in Hawai`i. The Lāna`i population of oloma`o died out from 1923 to 1931 when Lāna`i City was built, and "the people brought bird disease

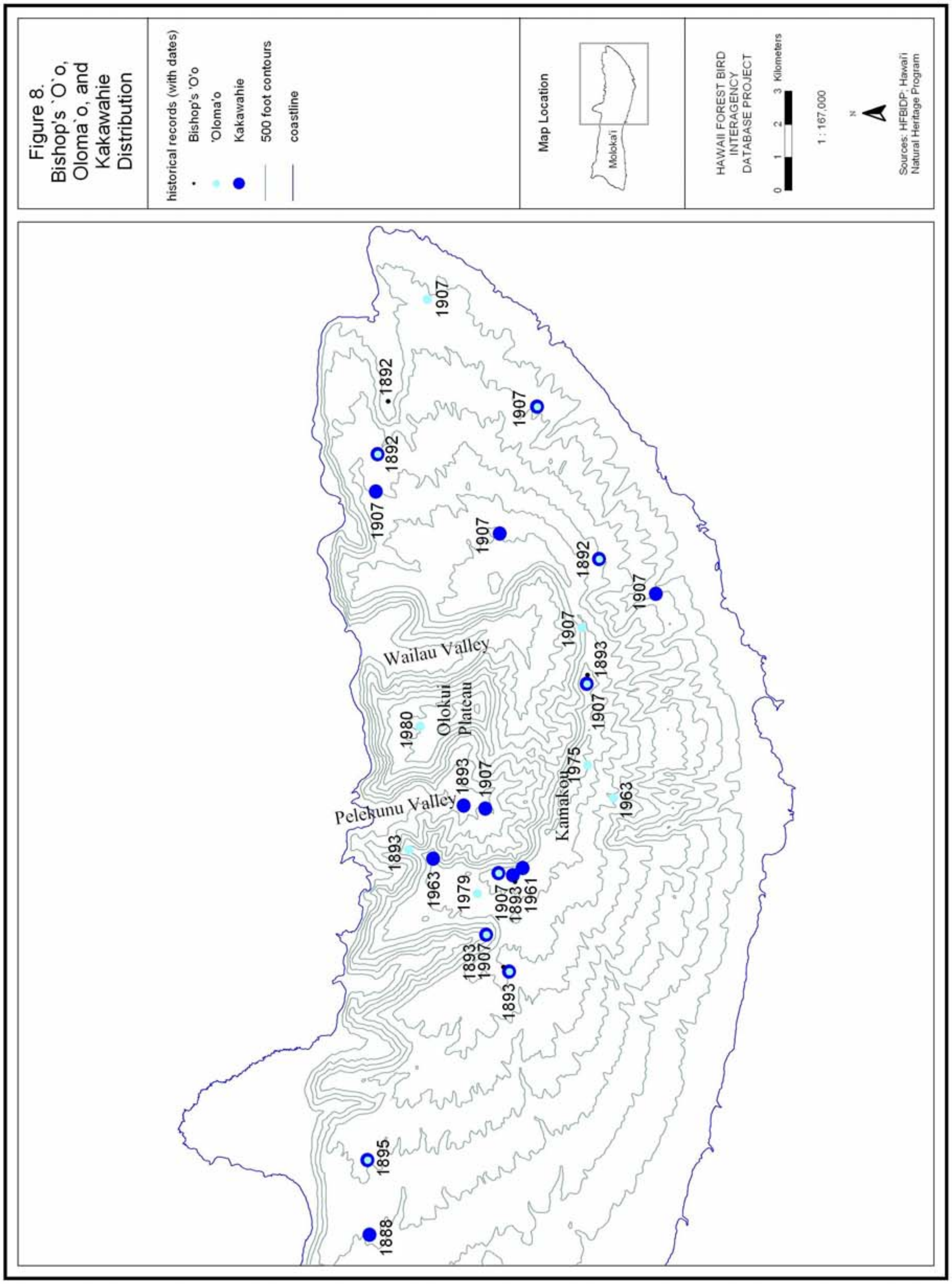


Figure 8. Bishop's `O`o, Oloma`o, and Kakawahie Distribution

with their poultry and these, evidently carried by mosquitoes, were fatal to the native bird population" (Munro 1960). Extensive habitat exists on O`ahu, Moloka`i, and Maui, but only on Maui could a solitaire population be established at elevations mostly above the reach of mosquitoes.

CONSERVATION EFFORTS

The oloma`o was federally listed as an endangered species on October 13, 1970 (U.S. Fish and Wildlife Service 1970), and was included in the Maui-Moloka`i Forest Bird Recovery Plan (U.S. Fish and Wildlife Service 1984a). Past conservation efforts have included the above-mentioned surveys, plus periodic surveys by the State of Hawai`i, and habitat protection. Habitat protection on Moloka`i includes ungulate and weed control on the Pu`u Ali`i Natural Area Reserve by the State of Hawai`i Department of Land and Natural Resources, and on the Kamakou Preserve by The Nature Conservancy of Hawai`i. Forest on the privately owned Lāna`i Hale, the highest point on Lāna`i, suffers from browsing by axis deer (*Axis axis*), for which hunting regulations change from year to year. For habitat protection on Maui, refer to the po`ouli species account.

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

4. Puaiohi, *Myadestes palmeri*

DESCRIPTION AND TAXONOMY

Adult puaiohi. Photo © Jack Jeffrey.

The puaiohi or small Kaua`i thrush is a medium-sized (16.5 to 17.8 centimeters [6.5 to 7.0 inches] long; 37.0 to 43.0 gram [1.3 to 1.5 ounce]) solitaire, drab olive brown above, and medium gray below on the throat, belly and undertail coverts. The legs are pink and relatively long and the tail is relatively short. The eyes are dark with a prominent white eye-ring. The bill is dark gray and narrower than that of the kāma`o. Immatures have an off-white breast with prominent brown scalloping, and light-buffy spotting on the brown back. The simple reedy song usually consists of a preparatory whistle and a prolonged trill, followed by several sharp descending notes. It also commonly uses a scolding or hissing "sherrr" alarm note. Other calls are described in detail in Snetsinger *et al.* (1999).

Early descriptions of the puaiohi were made by Rothschild based on skins obtained by Henry Palmer in 1891, in the mountains of Kaua`i at Halemanu (Berger 1972). Originally described as *Phaeornis palmeri*, Pratt (1982) offered convincing evidence that *Phaeornis* should be merged with the New World solitaire genus *Myadestes*, and that some Hawaiian thrushes formerly treated as subspecies are sufficiently distinct to merit full species status (Scott *et al.* 1986). The puaiohi is in the thrush family, Turdidae.

LIFE HISTORY

Puaiohi nest in cavities or on ledges, usually on vegetated overhanging rock faces, where the nest may be concealed by mosses and ferns (Kepler and Kepler 1983, Ashman *et al.* 1984, Snetsinger *et al.* 1999), or more rarely, in secondary cavities formed in trees (Snetsinger *et al.* 1999). Captive-bred and released birds nested more often in trees than did wild birds, although whether this is an effect of nest-site availability, inexperience, or sampling bias is unknown (Tweed *et al.* 2006). The great majority of available ecological information on wild breeding puaiohi comes from a 3-year study in the Upper Mōhihi drainage of the Alaka`i Wilderness Preserve (Snetsinger *et al*. 2005) During this study, 96 active nests were found, compared to only 4 reported previously for this species. The remainder of this section is drawn from that report unless otherwise indicated.

Puaiohi sing occasionally throughout the year, but with increased frequency immediately before and during the breeding season, with a peak from April to May. The frequency of song of an individual bird is dependent on its stage in the nesting cycle. A socially monogamous mating system is believed to predominate, but verifying this is impeded by the fact that few color-banded adults have been observed nesting. One instance of polygyny was recorded in 1999, when a captive-bred male paired and nested with two captive-bred females simultaneously (Tweed *et al.* 2006). Nesting begins as early as March, peaks from April to June, and continues with decreasing frequency through mid-September. Nest building requires 1 to 7 days, followed by a latent period of 8 to 10 days before the first egg is laid. The female alone builds the nest, and incubates and broods the young. Clutch size is almost always two, although Tweed *et al.* (2006) observed one- and three-egg clutches (one of each type) in captive-bred released females. Eggs are grayish-green to pale greenish-blue with irregular reddish-brown splotches (Berger 1972). Eggs hatch after 13 to 15 days. The male and female both provision the chicks, with the female acting as the primary provider while chicks are still in the nest. After fledging, the male assumes primary responsibility for feeding chicks while the female frequently initiates a subsequent nesting attempt. Occasionally (8 percent of nests), second-year and hatch-year birds assist in nest defense and feeding of nestlings and fledglings, although the relationship of helpers to the breeding adults is unknown. Recently fledged young are highly sedentary for 2 to 4 days after fledging, remaining within 2 meters (6 feet) of the ground, where they may be particularly vulnerable to predation by introduced mammalian predators.

Females readily and quickly re-nest after success or failure of a nesting attempt. This propensity to re-nest, combined with long breeding seasons (3 to 4.5 months) and high rates of nest success, led to remarkably high productivity in 1996 and 1997: an average of 2.8 and 4.9 fledglings per pair, respectively. In 1998, when El Niño Southern Oscillation drought struck the islands, the breeding season lasted only 1.7 months and nest success decreased, leading to production of only 0.4 fledglings per pair per year. The decrease in nesting success appeared to be due to elevated rat predation on nests and nesting females, although additional data are needed to confirm this trend. Whether the observed increase was due to a change in behavior of the rats or the birds, or to a population increase of rats after two favorable years, is unknown. Regardless, based on this limited evidence, it appears that puaiohi are vulnerable to severe drought and to rat predation.

Adult and juvenile survival and dispersal are poorly known because of the difficulty of marking and following sufficient numbers of birds over successive years. At least 73 percent of marked adults, and 25 percent of juveniles (first-year birds) survived until the April of the next breeding season. Dispersal distances of young may generally be short, a fact that has important implications for the rate of natural recolonization of recovering habitat. Of 31 nestlings banded in 1997, 5 established breeding territories 140 to 540 meters (460 to 1,772 feet) from their natal territory, 2 others were seen within 50 meters (164 feet) of the nest they hatched from, and 2 more were observed as floaters. If these short dispersal distances are representative, and keeping in mind the observations of helper behavior by second-year birds on their natal territories, one interpretation is that it is difficult for young puaiohi to establish breeding territories in high-quality sites, hence they may enhance their fitness either by helping their parents rear siblings, or by inheriting their parents' high-quality territories or nest sites.

The diet of the puaiohi includes fleshy native fruits, insects, snails, and other invertebrates (Wilson and Evans 1890 to 1899, Rothschild 1893 to 1900, Perkins 1903, Richardson and Bowles 1964, Snetsinger *et al.* 1999). During the non-breeding season, foraging attempts were 82 percent fruits and 18 percent insects or other invertebrates. While rearing nestlings, the proportion of foraging maneuvers directed at insects increased to 57 percent. A total of 75 percent of foraging attempts occurred in terminal fruit or leaf clusters in lower to midcanopy, 16 percent in upper canopy, 8 percent on main branches or trunks in midcanopy, and 1 percent on the ground. `Ōlapa (*Cheirodendron trigynum*) fruit is known to be an important food of this bird (Richardson and Bowles 1964, Scott *et al.* 1986). Other important fruits include lapalapa (*C. platyphyllum*), `ōhi`a ha (*Syzygium sandwicensis*), kanawao (*Broussaisia arguta*), `ōhelo (*Vaccinium* spp.), pa`iniu (*Astelia* spp.), thimbleberry (*Rubus rosifolius*), pūkiawe (*Styphelia* tameiameiae), kāwa`u (*Ilex anomala*), and pilo (*Coprosma* spp.). In its earlier history, the puaiohi was reported by Perkins (1903) to be a bird of the underbrush and to be largely insectivorous, feeding on beetles, spiders and caterpillars, especially a beetle found on koa (*Acacia koa*) trees, which currently do not occur within the existing puaiohi range. Caterpillars and seeds were identified in the stomachs of type specimens (Perkins 1903).

HABITAT DESCRIPTION


Puaiohi nesting habitat. Photo by Tom Savre.

Puaiohi are permanent residents of stream valleys and associated ridges of the Alaka`i Wilderness Preserve and adjacent forest. Historically occupied habitat was mesic (1,000 to 2,000 millimeters [39 to 79 inches] rainfall a year) to extremely wet (2,500 to 13,000 millimeters [98 to 512 inches] rainfall a year,) montane forest, with deeply dissected terrain containing steep-walled ravines above 1,000 meters (3,300 feet) (Perkins 1903, Scott *et al.* 1986). Its mesic forest habitat is dominated by koa and `ōhi`a (*Metrosideros polymorpha*), while the wet forest is dominated by `ōhi`a, with subdominant `ōhi`a ha and several species of `ōlapa (*Cheirodendron*). Formerly occupied mesic forest is now dominated largely by introduced plant species, including fire tree (*Myrica faya*), glory-bush (*Tibouchina urvilleana*), kahili ginger (*Hedychium gardnerianum*), silk oak (*Grevillea robusta*), strawberry guava (*Psidium cattleianum*), and black wattle (*Acacia mearnsii*). Puaiohi are now confined to wet montane forest, with greater than 6,000 millimeters (236 inches) rainfall a year, at 1,050 to 1,300 meters (3,450 to 4,250 feet) (Scott *et al.* 1986, Snetsinger *et al.* 1999), and are associated with `ōlapa fruit (Scott *et al.* 1986) and `ōhi`a ha (Snetsinger *et al.* 1999).

Although a strong flier, the puaiohi seems to have specific habitat requirements that keep it within areas that provide a year-round food supply and nesting habitat (Wilson and Evans 1890 to 1899, Perkins 1903, Snetsinger *et al.* 1999). Prime nesting sites are found on rock faces along small streams that drain the Alaka`i Wilderness Preserve to the south and west. Species density is currently low in some apparently suitable habitat, but the cause of this pattern is unknown. In recent years this included tracts directly east of Kōke`e State Park that were chosen for experimental release of captive bred birds in 1999, 2000, and 2001, and that now harbor an experimental population of fewer than 10 captive and wild birds.

HISTORICAL AND CURRENT RANGE AND STATUS

Even in the late 1800s, the puaiohi was considered exceedingly rare (Perkins 1903). It has been found in extremely limited numbers during the past half century. Sincock *et al.* (1984) estimated the population at 176 ± 192 for the period 1968 to 1973, and Scott *et al.* (1986) estimated that there were only about 97 ± 129 puaiohi within their 25 square kilometer (9.7 square mile) study area in the heart of the Alaka`i.

Based on more recent field surveys, the total current population of puaiohi is estimated to consist of 300 to 500 individuals (T. Savre, Kaua`i Forest Bird Recovery Project, pers. comm.), in stream valleys and on associated ridges above 1,050 meters (3,450 feet) elevation on the southern and central plateau of the Alaka`i Wilderness Preserve (Figure 9). Although this most recent estimate is slightly higher than previous estimates, it is unlikely that the population has actually increased since previous population estimates were made. The recent surveys have focused on puaiohi and have employed methods designed specifically for puaiohi, so the apparently higher population estimate is likely due to improved survey methods and greater effort. The breeding population is restricted to an area less than 25 square kilometers (9.7 square miles) in size, and more than half of the breeding population occurs within only 10 square kilometers (3.9 square miles). The highest densities of puaiohi occur in three adjacent drainages: the Upper Mōhihi, Upper Waiakoali and the northeastern upper Kawaikōī (the "core" or "Mōhihi/Waiakoali" population). In the Mōhihi, where the intensive study of breeding biology took place, adult puaiohi can be found at a density of approximately 6.3 pairs per kilometer (0.62 mile) of primary stream bottom, plus an undetermined number of floaters (Snetsinger *et al.* 2005). Helpers at the nest, in some cases known to be previously fledged young of the resident pair, were observed at 8 percent of 87 nests by Snetsinger *et al.* (2005). In the Mōhihi area, puaiohi density declines with elevation to about 1,050 meters

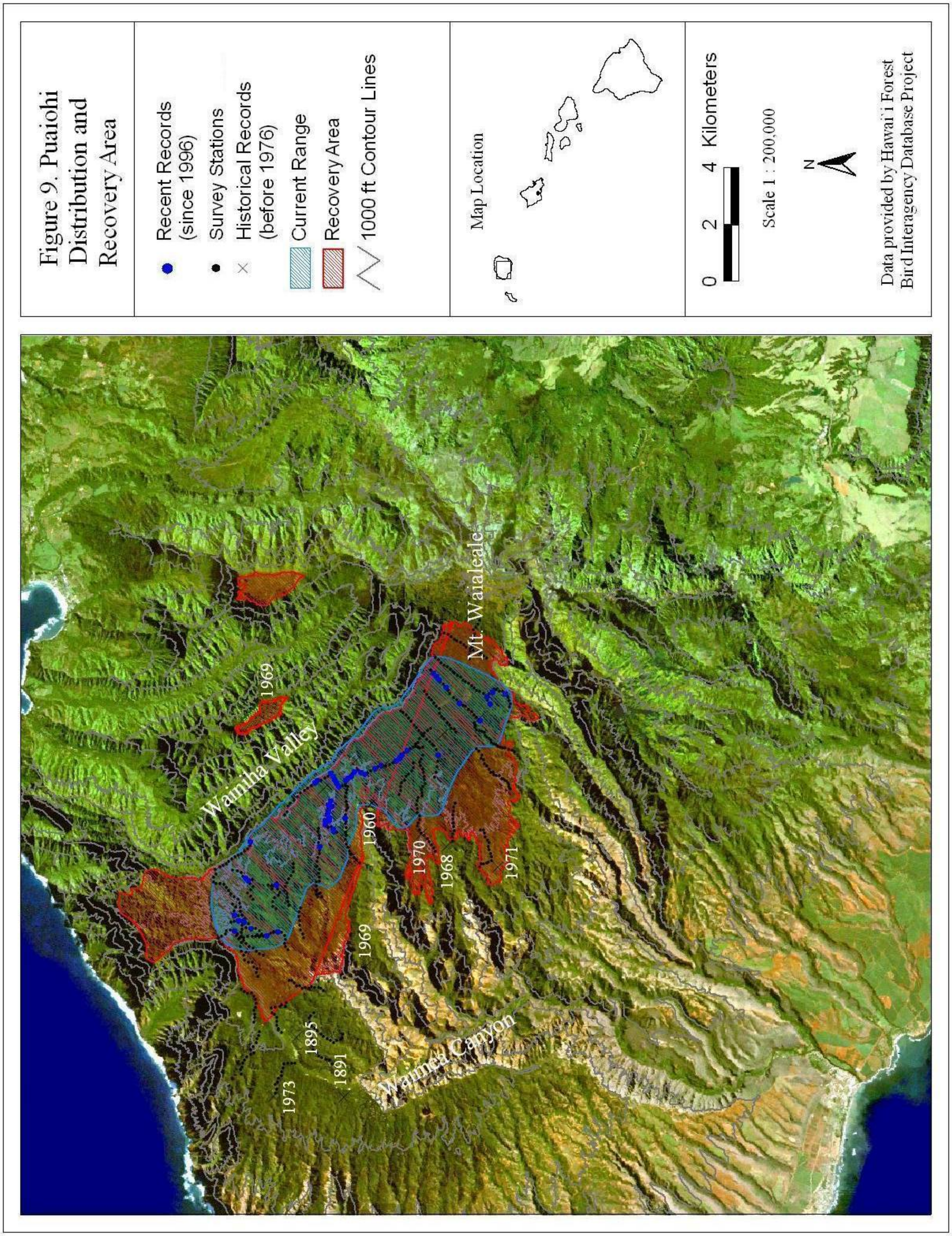


Figure 9. Puaiohi Distribution and Recovery Area

(3,450 feet), a pattern that may be applicable to other areas. The Mōhihi is contiguous with a relatively large area of habitat that probably supports medium to low densities along the Wai`alae Trail to the south and the forest reserve boundary to the north (T. Snetsinger, U.S. Geological Survey, unpubl. data).

The upper reaches of the Halehaha and Halepā`ākai drainages contain a medium-density population that probably continues in lower densities downstream, although the distributional limits of this population are unknown (the "Halehaha/ Halepā`ākai" population). Two small, low-density populations were detected during State forest bird surveys in 1994, on private lands along the Halekua and Waiau streams at the southern edge of the species' range. Neither population was detected during surveys in March 2000 (T. Telfer, Hawai`i Department of Land and Natural Resources, pers. comm.). As of 2006, several additional streams have been surveyed for puaiohi, bringing the total surveyed area to more than 70 percent of the species' current range, but these data have not yet been completely analyzed. These surveys include seven tributaries of the Koaie stream (low to medium puaiohi density), two upper branches of Waialae stream (low puaiohi density), and areas along the cliff edge above Wainiha valley (low to medium puaiohi density) (Hawai`i Division of Forestry and Wildlife and U.S. Geological Survey, unpublished data). Lā`au Ridge, where an incidental observation of puaiohi was made in 1969 (Sincock 1982), has rarely been visited in recent decades; crews did not detect any puaiohi there in March 2000, but a more thorough search is warranted.

The northwestern upper Kawaikōī drainage, near the intersection of the Alaka`i Swamp and Pihea Trails, harbored only two birds prior to the first release of captive-bred birds in connection with a captive propagation and reintroduction program in January 1999 (Kuehler *et al.* 2000).

REASONS FOR DECLINE AND CURRENT THREATS

Disease. Early ornithologists did not note difficulties with lumps on the feet and bills of puaiohi as they did with the kāma`o (evidence of avian pox, *Poxvirus avium*). However, avian diseases, including both pox and malaria (*Plasmodium relictum*), almost certainly limit puaiohi from the lower reaches of stream drainages with suitable nesting cliffs. Mist-netting of forest birds from 1994 to 1997 at three locations, Pihea/Alaka`i Swamp Trail, Koaie Stream**,** and

Sincock's Bog, documented 2 to 5 percent of individuals of all bird species with active malaria infections and up to 12 percent with malarial antibodies (C. Atkinson, U.S. Geological Survey, unpubl. data). Malarial infection rates were highest in the west, at Pihea, and lowest in Sincock's Bog. Mosquitoes are present to the highest elevations on Kaua`i (D. LaPointe, pers. comm.). Two fatalities of native birds near puaiohi habitat are attributed to malaria, indicating that active malaria transmission occurs in the area. The first, a Kaua`i `amakihi, occurred in the fall of 1999 in Kōke`e State Park, and the second, an `apapane, was found in late spring of 2006, just east of Koke`e State Park along the Pihea trail (C. Atkinson, pers. comm.).

As of 2006, only six wild puaiohi have been tested for disease. Of these, none had active infections, but one had antibodies to malaria, suggesting that at least some puaiohi may be able to survive malarial infection (Atkinson *et al.* 2001). However, it is impossible to tell from these data whether survival rates of infected puaiohi are high or low; low infection rates could reflect either low transmission rates or high mortality of infected birds. Because puaiohi are endangered, challenge experiments have not been used to determine survivorship of infected birds.

Predation from introduced mammals. Predators such as rats (*Rattus* spp.) may be a serious limiting factor on puaiohi nesting success and survival of breeding females (females are more vulnerable than males since they attend the nest at night when rats are active). Although their habit of nesting on steep cliff faces may provide some protection from nest predation, 48 percent of wild nest failures and 1 adult female's death were attributed to rats (Snetsinger *et al.* 2005), at least 4 of 9 failed nests built by captive-bred puaiohi were depredated by rats, and 2 nesting captive-bred females were killed by rats (Tweed *et al.* 2006). The tendency of young puaiohi to remain close to the ground for several days after fledging probably makes them particularly vulnerable to predation by feral cats.

Competition from introduced birds. Several introduced birds, including the Japanese white-eye (*Zosterops japonicus*), melodious laughing-thrush (*Garrulax canorus*), and white-rumped shama (*Copsychus malabaricus*) share the same habitat with the puaiohi to some degree and may compete with the puaiohi for food. These and other alien bird species, including the recently established Japanese bush-warbler (*Cettia diphone*), also may serve as reservoirs of disease.

The establishment of other potentially detrimental birds on Kaua`i, such as the red-vented bulbul (*Pycnonotus cafer*) found on some of the other Hawaiian Islands, remains a persistent threat.

Habitat degradation. Feral pigs, and goats to a lesser degree, have had a long-term damaging effect upon native forests in the remaining puaiohi range, opening space for weeds and transporting weed seeds into the forest. As the range of introduced black-tailed deer (*Odocoileus hemionus*) expands, it is expected that they too will degrade native forest. The negative impacts of feral ungulates on forested ecosystems in Hawai`i have been reviewed elsewhere (Cabin *et al.* 2000). Soil erosion and disruption of seedling regeneration of beneficial plants is one of many forest management problems within puaiohi range. Habitat degradation resulting from the invasion of many nonnative weeds has drastically changed the forest structure and integrity. Two hurricanes in 1982 and 1992 severely disturbed areas of native forest and made space for the germination and expansion of alien plants.

Perhaps less obvious, but potentially detrimental to the health of remaining puaiohi habitat, are additions of new exotic invertebrates to the forest ecosystem. Introduced species may affect the birds' food supply directly, as for example by the parasitoid wasps introduced as biocontrol agents, which are known to prey heavily on caterpillars in the Alaka`i (Henneman and Memmott 2001). Introduced snails that prey on indigenous snails could also reduce food resources of the puaiohi. Puaiohi may also be negatively affected indirectly by introduced insects that reduce fruit supplies. Newly introduced insects, such as the two-spotted leaf hopper (*Sophonia rufofascia*), are causing serious damage to many native and nonnative plants. Other introduced predatory insects may reduce or eliminate specialized native insects that are necessary for pollination of certain food plants. On the other hand, the detrimental effects of some introduced insects could be offset if they are eaten by puaiohi.

All of Kaua`i's endangered forest birds are so few in number that lack of genetic diversity poses potential problems. Some of these birds are highly specialized and are ill-adapted for rapid changes in their environment. The puaiohi, with a population size of 300 to 500 birds in a number of widely separated subpopulations, falls below the minimum effective population size of

500 individuals recommended for long-term maintenance of genetic diversity (Soulé 1987).

CONSERVATION EFFORTS

The puaiohi is the only one of the six endangered forest birds on Kaua`i that exists in sufficient numbers to allow research and species-specific management actions to take place. Beginning in 1995, the conservation community initiated a program to study and develop management techniques for this species. Actions taken towards conservation of the puaiohi include legal protection, ecological studies, reintroduction of captive-bred individuals, periodic surveys and inventories, control of feral ungulates, small mammal control, and information and education.

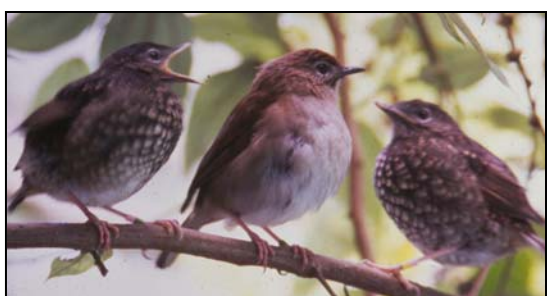
Legal Protection. The Forest Reserve Act of 1903 was an important action that protected watersheds in Hawai`i. It was later strengthened and re-titled "Hawai`i Department of Land and Natural Resources Title 13, Chapter 104, Rules Regulating Activities Within Forest Reserves," which protects native forest habitats from certain degrading factors caused by human activities. The Hawai`i Department of Land and Natural Resources established the 4,022 hectare (9,938 acre) Alaka`i Wilderness Preserve in 1964 (Administrative Rule No. 1, Chapter 3), recognizing the value of the pristine forest of that area and the need to control potential degrading factors.

The puaiohi was federally listed as endangered on March 11, 1967 (U.S. Fish and Wildlife Service, 1967), and it was included in the Kaua`i Forest Birds Recovery Plan (U.S. Fish and Wildlife Service 1983b). By virtue of being on the Federal endangered species list, it also became protected under the State of Hawai`i endangered species law on March 22, 1982.

Ecological Studies. An intensive field study of the ecology and behavior of the puaiohi was initiated in 1995, with the cooperation of the Biological Resources Discipline, U.S. Geological Survey (then the National Biological Service), the Hawai`i Division of Forestry and Wildlife, The Peregrine Fund, the U.S. Fish and Wildlife Service, and Kamehameha Schools. A team of biologists was tasked with locating and learning more about the life history of the puaiohi. Over 200 active nests and old nests were located, and the breeding biology, nesting success, survival, dispersal, and behavior of the species were studied. The results of that research have been presented in quarterly and annual reports to cooperators, in a Birds of North America account (Snetsinger *et al.* 1999), and in several publications recently published, planned, or in preparation (e.g., Snetsinger *et al.* 2005). The biological and ecological data collected during that study forms the foundation on which to make decisions regarding future management of the species (Woodworth 2000).

Dr. Carter Atkinson of the Biological Resources Discipline, U.S. Geological Survey, initiated forest bird disease studies on several of the main Hawaiian islands, including Kaua`i, focusing primarily on blood-borne diseases within the range of endangered Hawaiian forest birds. This research is aimed at understanding the significance of disease and confirming the long-held theory that diseases brought to Hawai`i by introduced exotic birds, and the establishment of alien vectors of disease such as mosquitoes, have had a major role in the decline and extinction of native birds in Hawai`i. As a consequence of this research, one peer-reviewed article relating directly to the puaiohi has been published as of 2006 (Atkinson *et al.* 2001). Although it is a formidable task, hope exists for finding ways of mitigating the disease problem of rare native forest birds.

Captive Propagation and Reintroduction. Beginning in 1995, the U.S. Fish and Wildlife Service, The Peregrine Fund, U.S. Geological Survey, and the Hawai`i Division of Forestry and Wildlife began developing and testing rear-and-release and translocation techniques with the closely-related `ōma`o (*Myadestes obscurus*) as a surrogate for the endangered puaiohi. The research showed that rearing Hawaiian solitaires in captivity and releasing them to the wild using soft-release techniques was highly successful (Kuehler *et al.* 2000). Furthermore, captive-reared yearling birds had greater site fidelity than translocated adult birds (Fancy *et al.* 2001).



Captive adult puaiohi with two fledglings. Photo © Jack Jeffrey.

A captive breeding program for puaiohi was established at The Keauhou Bird Conservation Center on Hawai`i and at the Maui Bird Conservation Center.

The program began in 1996, when five eggs were hatched in captivity from eggs collected from the wild. An additional 10 birds from wild eggs were added to the captive breeding program in 1997 (The Peregrine Fund 1996, 1997).

Maintaining a large captive-breeding program encompassing 90 percent of the original genetic variation of the wild population, although ideal, may not be necessary for puaiohi. A small captive flock may be sufficient for several reasons: (1) a wild reproducing population still exists (~200 females), (2) the newly-established population of puaiohi is not genetically isolated, dispersal distances of captive-reared released birds are long enough to link subpopulations, and pairings between captive-bred and wild birds have been observed, and (3) additional founder stock can be collected from the wild in the future, if necessary, to augment the genetic diversity in captivity. If genetic diversity of the captive flock drops below 90 percent, and funding, prioritization of facility use, and concurrence is reached by the Captive Propagation Partnership, the captive population may be augmented with wild-collected eggs.

The release of captive-bred birds into the wild was begun in 1999, when The Peregrine Fund released 8 females and 6 males into the Kawaikōī drainage, western Alaka`i, and monitored them using radio telemetry for 30 days. One-hundred percent of the birds survived the first 30 days post-release, and appeared to be adept at foraging in the wild (Kuehler *et al.* 2000). Follow-up monitoring by the U.S. Geological Survey demonstrated that all 14 birds survived at least 9.5 weeks after release, and 7 established breeding territories in the Kawaikōī, while the rest dispersed to other drainages (Tweed *et al.* 2003). Both captive-captive and captive-wild pairings were documented (Tweed *et al.* 2006).

On February 1, 2000, an additional 5 birds (4 females, 1 male) were released by The Peregrine Fund/Zoological Society of San Diego and an additional cohort of 15 birds was released in spring 2001 by the Zoological Society of San Diego. The overall release strategy for the first 3 consecutive years of releases (1999 to 2001) is considered highly successful, with 31 of 34 released birds surviving to 30 days after release and released animals breeding in the wild with nesting success comparable to that of wild birds (Zoological Society of San Diego 2001, Tweed *et al.* 2006). However, the Kawaikōī population appears not to have grown appreciably since the last release in 2001, based on limited surveys in 2003 of at least 5 birds in the general release area (T. Savre, pers. comm.).

A second release site for puaiohi was established in the Halehaha/Halepā`ākai stream drainage in good quality puaiohi habitat, and releases have been conducted there for 5 years. As of 2006, a total of 79 puaiohi (43 females, 36 males) have been released at this site by the Zoological Society of San Diego, including 8 birds in 2002, 18 birds in 2003, 17 birds in 2004, 17 birds in 2005, and 19 birds in 2006. This site differs from the Kawaikōī drainage in that the forest is considerably less degraded, and also that wild puaiohi exist there at medium densities.

For releases conducted from 1999 to 2002, 36 of 42 (85.7 percent) released birds survived to 30 days post-release, and survival during the subsequent 40 to 50 days ranged from 67 percent in 1999 to 71 percent in 2001 and 83 percent in 2002. However, only 20 to 43 percent of released birds established breeding territories in the target drainage each year, and the majority of released birds dispersed several kilometers away, often in the direction of high-density populations (Tweed *et al.* 1999, Monahan *et al.* 2001, Pratt *et al.* 2002). Of puaiohi released between 2003 and 2005, most released birds did not breed in the release drainage: no more than four puaiohi (in 2003) established breeding territories in the Halehaha/Halepā`ākai drainages. The maximum known dispersal distances of birds released between 2003 and 2006 averaged 3.0 to 3.8 kilometers (1.8 to 2.3 miles) (P. Roberts, Kaua`i Forest Bird Recovery Project, pers. comm.).

Periodic Surveys and Inventories. Regular surveys and inventories of Kaua`i forest bird populations and habitat conditions within the Alaka`i Wilderness Preserve have been conducted on established transects since the late 1960s. John L. Sincock, research biologist with the U.S. Fish and Wildlife Service, Kaua`i Field Station, conducted intensive status and distribution surveys of Kaua`i forest birds between 1968 and 1973 (Sincock 1982). Large-scale multi-agency surveys were conducted on established transects in 1981, 1985, 1989, 1994, 2000, and 2005 (Hawai`i Department of Land and Natural Resources, unpubl. data).

The Hawai`i Rare Bird Search Team made an intensive systematic effort to locate any surviving endangered Kaua`i forest bird populations in the mid-1990s (Reynolds and Snetsinger 2001). They were successful in locating puaiohi (55 to 70 individuals), providing the impetus for subsequent field studies, but no other endangered birds were recorded during the search (Reynolds and Snetsinger 2001). From 2002 to 2005, the Hawai`i Department of Land and Natural Resources, Division of Forestry and Wildlife, has conducted systematic surveys for puaiohi in all suitable habitat to better understand species distribution and total population, and this formed the basis for an improved population estimate, presented here.

Control of Feral Ungulates. The Hawai`i Department of Land and Natural Resources has maintained liberal public hunting seasons to minimize forest damage caused by feral pigs and goats within the Alaka`i Wilderness Preserve for several decades. Unfortunately, public hunting occurs only in the more accessible areas of the preserve, and ungulate populations in some remote areas remain quite high. Limited aerial reconnaissance and aerial shooting of feral goats and pigs has been attempted in the most remote regions, but has not been economically effective. Long-term protection of the Alaka`i from feral ungulates will require creativity, commitment, political savvy, improved public relations, and significant financial support.

Small Mammal Control. Rat control using registered rodenticides and snap traps might increase nesting success in some areas. Reduced rat predation of nests in the Mōhihi drainage where rats were actively trapped supports this idea, although overall nest success was high (Snetsinger *et al.* 2005). Logistical obstacles to rodent control may be especially great in the Alaka`i, given the difficulty of maintaining bait stations without disturbing native plants in the steep terrain, and the challenges of placing bait near the vertical rock faces on which puaiohi nest.

Information and Education. Materials featuring Kaua`i's endangered forest birds, as well as those found on other islands, have been published and provided to schools to assist in the effort to inform the public and gain support for funding to conserve endangered species. Privately funded filmmakers, including The British Broadcasting Company and National Geographic Society, have filmed and publicized the plight of endangered forest birds. Several articles have appeared in popular nature magazines and local newspapers to tell the story of the endangered Hawaiian forest birds, including those on Kaua`i. Audubon magazine featured the puaiohi recovery effort in its February 1999 issue. Staff directly involved with the puaiohi recovery project have made presentations at public fairs on Kaua`i as well as at scientific conferences.

RECOVERY STRATEGY

Habitat Protection. Prospects for recovery of the puaiohi lie in maintaining and restoring forest habitat by developing, testing, and applying broad-scale habitat restoration measures, including: control of feral ungulates through a combination of hunting, fencing, snaring, and possibly development of lethal non-toxicant devices for use in areas inaccessible to hunters, or in areas closed to hunters; controlling the encroachment of noxious weed plants and insects through tested bio-control, and where feasible, mechanical and chemical measures; and continuing enforcement of State and Federal laws that protect against destructive human activities and development.

Predator Control. A need exists to develop, test, register, and apply toxicants for control of introduced rodents and feral cats in remote forested habitat. The prevention of additional introductions of exotic plants, insects, mammals (especially the small Indian mongoose *Herpestes auropunctatus*, currently a resident on other Hawaiian islands), and alien birds that may act as predators on, or competitors with, native birds is necessary.

Captive Propagation and Reintroduction Programs. Augmentation of natural dispersal and recolonization of recovering habitat through reintroduction of captive-bred puaiohi in selected areas is desirable. Such reintroductions increase the range of the species and increase the probability that the species will survive future catastrophes such as hurricanes or disease outbreaks.

Population Surveys and Monitoring. Continued monitoring of the status of forest bird populations and their habitats to measure the effectiveness of management actions is necessary.

Research and Identification of Limiting Factors. Demographic research to obtain better information on survival, reproduction, and recruitment rates is needed to better understand how to best manage the species, and to help determine whether the release of captive-bred birds provides a significant long-term benefit. Evaluating the relative importance of disease, predators, food, and habitat change in restricting the puaiohi's range and population growth would benefit the development of long-term strategies for conserving the species. The current limited range size renders the species extremely vulnerable to hurricanes, new diseases, and other catastrophic habitat changes. Increasing the range and/or total population size would mitigate these risks.

Other. Continued public information sharing is needed to help generate support for the Kaua`i Forest Bird Project and for habitat management.

5. Kaua`i `Ō`ō, *Moho braccatus*

DESCRIPTION AND TAXONOMY

One of few photographs of the Kaua`i `ō`ō. Photo © Rob Shallenberger.

The Kaua`i `ō`ō or `ō`ō `ā`ā is one of four known Hawaiian species of the genus *Moho* and one of five known Hawaiian bird species within the honeyeater family, Meliphagidae (Sykes *et al.* 2000). It is 19.5 centimeters (7.7 inches) long, shorter-tailed, and somewhat smaller than the `ō`ō species on the other islands, hence the "`ā`ā," meaning dwarf `ō`ō. It is glossy black on the head, wings, and tail; smoky brown on the lower back, rump and abdomen; and rufous-brown on the upper tail coverts. It has a prominent white patch at the bend of the wing. The throat feathers are black with a subterminal bar of white, giving a barred or scaled effect. The thigh feathers are golden yellow in adults, but black in immatures. The iris is dull yellow. The bill and feet are black, and the soles of the feet pale yellow (Berger 1972).

The song consists of loud whistles that have been described as flute-like, hollow, echoing, and haunting. A call note was described as a distinct "took-took" (Munro 1944). Nesting birds are reported to use a "beep beep" call (Scott *et al.* 1986).

LIFE HISTORY

Much of what is known about the life history of the Kaua`i `ō`ō was learned by John L. Sincock who spent many months between 1967 and 1978 searching for and studying Kaua`i's rare birds (Sincock 1982). Its last known habitat was dense native `ōhi`a (*Metrosideros polymorpha*) forest in the deep stream valleys of the central Alaka`i Wilderness Preserve. The only known nests were located in cavities of large dead `ōhi`a snags. One nest was described as being 12 meters (40 feet) above the ground in a dead `ōhi`a tree (Berger 1972). There is little information on the extent of the nesting season, but two nestlings were reported in a single nest in June 1971, and two other nests were monitored in late May and early June (Sincock 1982).

The diet is reported to be insects, spiders, millipedes, moths, crickets, snails, \`ōlapa (*Cheirodendron*) fruits, and nectar from \`ōhi\`a, lobelia, and other flowering plants (Richardson and Bowles 1964; Sincock 1982). Early ornithologists reported that \`ō\`ō fed heavily on the flower bracts of \`ie\`ie (*Freycinetia arborea*), which was abundant in formerly occupied low elevation forest habitat, but is not found in the upper elevation forests that were last occupied.

HISTORICAL AND CURRENT RANGE AND STATUS

The Kaua\`i \`ō\`ō was reportedly very common from near sea level to the high interior forests of Kaua\`i up to the end of the 19th century, but after only 3 decades it was thought to be close to extinction (Figure 7, page 2-21; Munro 1944). Except for inconclusive reports of possible vocalizations, it went without observation until rediscovered by Donagho (1941) and again by Richardson and Bowles (1961). Sincock located and described the first nest in a tree cavity in 1971, and followed subsequent nests in 1972 and 1973. Upon rediscovery during the late 1960s, the Kaua\`i \`ō\`ō population was estimated at only 36 birds (Sincock 1982). Only a single pair was found during an intensive survey made in 1981 (Scott *et al.* 1986). Two hurricanes that struck Kaua\`i in 1982 and 1992 caused much forest damage and possibly eliminated the remnant population. The last plausible record of a Kaua\`i \`ō\`ō was a vocal response to a recorded vocalization played by a field biologist on April 28, 1987, in the locality of Halehaha/Halepā\`ākai Stream (J. Krakowski, Hawai\`i Department of Land and Natural Resources, pers. comm.). It is likely that the Kaua\`i \`ō\`ō is now extinct; no subsequent sightings or vocalizations have been documented despite extensive forest bird surveys in 1989, 1994, 2000, and 2005, and a rare bird search conducted in 1996 (Reynolds and Snetsinger 2001). The vocalizations of this species are loud and distinctive, and are unlikely to be overlooked.

REASONS FOR DECLINE AND CURRENT THREATS

As with several other endangered Kaua\`i forest birds, the Kaua\`i \`ō\`ō was once considered a very common species in the lowlands as well as in upland forests. The rather sudden decline in numbers noted during the first two decades of the 20th century (Munro 1944) points to a limiting factor that had an acute impact on the species. Unfortunately, the Kaua\`i \`ō\`ō is now so rare, or possibly extinct, that identification of threats and reasons for its decline is difficult, if not impossible. Habitat destruction by agricultural development obviously reduced their lowland range, but does not explain the sudden decline noted in the interior uplands as well. After the turn of the century, a large number of alien birds were introduced as many of the native lowland birds disappeared. Some of these alien species may have harbored foreign diseases or parasites for which the `ō`ō had little or no immunity. The mosquito vector of blood-borne diseases was already well established, and could have brought about a rapid decimation of a highly susceptible endemic bird. The fact that *Moho* on other islands suffered a similar fate during approximately the same period suggests disease as a major limiting factor, coupled with the fact that the last `ō`ō were found only at higher mosquito-free elevations. It is possible that the remote high elevation forests of Kaua`i where the `ō`ō persisted was marginal habitat that may have lacked suitable cavities for nest sites.

The use of large old-growth snags for nesting and the paucity of any large-timbered forests after the turn of the century may have limited the `ō`ō's ability to find suitable nest sites, particularly after two hurricanes struck Kaua`i in 1982 and 1992. Cavity nests may also be more susceptible to foraging rats known to be numerous in Hawai`i's forests. Polynesian rats (*Rattus exulans*) are presumed to have become established in the islands with the arrival of the first Polynesian settlers (Tomich 1969). The black rat (*Rattus rattus*) evidently established itself in Hawai`i after the advent of the European explorers in the late 1700s. The demise of many of Hawai`i's forest birds seemed coincident with the arrivals of various new alien fauna, yet the Kaua`i `ō`ō decline was apparently quite sudden, suggesting a particular susceptibility to a single potent limiting factor. Other impacts on their habitat, such as forest damage by feral pigs, goats, and the spread of invasive plants, likely had a supplemental negative impact on the species.

CONSERVATION EFFORTS

The Kaua`i `ō`ō was federally listed as endangered on March 11, 1967 (U.S. Fish and Wildlife Service 1967), became protected under the State of Hawai`i endangered species law on March 22, 1982, and was included in the Kaua`i Forest Birds Recovery Plan (U.S. Fish and Wildlife Service 1983b). The Forest Reserve Act of 1903 was an important action that protected watersheds in Hawai`i. Later strengthened and re-titled, "Hawai`i Department of Land and Natural Resources Title 13, Chapter 104, Rules Regulating Activities Within

Forest Reserves," it protects native forest habitats from certain degrading factors caused by human activities. The Hawai`i Department of Land and Natural Resources established the 4,022 hectare (9,938 acre) Alaka`i Wilderness Preserve in 1964 (Administrative Rule No. 1, Chapter 3), recognizing the value of the pristine forest of that area and the need to control potential degrading factors.

A multi-agency research project aimed at the recovery of the critically endangered puaiohi was initiated in 1995 (see puaiohi account). Information about other endangered Kaua`i forest birds has been gained incidentally, but unfortunately no Kaua`i `ō`ō have been observed during this project. Other research by U.S. Geological Survey personnel is examining the threat from alien diseases and alien vectors of disease, such as mosquitoes, on native forest birds on Kaua`i (C. Atkinson, U.S. Geological Survey, unpubl. data). The Hawai`i Rare Bird Search Team made an intensive systematic effort to locate any surviving endangered forest birds on Kaua`i, but no `ō`ō were recorded during the search (Reynolds and Snetsinger 2001).

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

6. \`Ō\`ū, *Psittirostra psittacea*

DESCRIPTION AND TAXONOMY


One of few photographs of the \`ō\`ū. Photo © Rob Shallenberger.

The \`ō\`ū is a heavy-bodied Hawaiian honeycreeper (family Fringillidae, subfamily Drepanidinae) approximately 15.5 to 17.5 centimeters (7 inches) in total length. The upper parts are dark olive-green, and the under parts are a lighter olive-green grading to whitish on the undertail coverts. The wings and tail are a darker brownish olive. \`Ō\`ū are sexually dichromatic, males having a bright yellow head that contrasts sharply with the back and breast, and females having an olive-green head similar in color to the back. Juveniles are similar to the female in color but somewhat darker. In both sexes the bill is pale pink to straw-colored, with a hooked, parrot-like upper mandible. The legs are pinkish (Munro 1960, Berger 1981, Pratt *et al.* 1987). Males are slightly larger than females.

The \`ō\`ū is a member of the thick-billed Hawaiian honeycreeper tribe (Psittirostrini) and was described by J. G. Gmelin in 1789 from a specimen collected in 1779 (Bryan and Greenway 1944). \`Ō\`ū were found historically on the islands of Hawai\`i, Maui, Moloka\`i, Lāna\`i, O\`ahu, and Kaua\`i, with no known geographic variation (Amadon 1950).

LIFE HISTORY

Although common early in the 20th century throughout most of its range, little has been reported on the life history of the \`ō\`ū (see Snetsinger *et al.* 1998 for a summary of available life history information). Nesting of the \`ō\`ū has never been described and little is known of its breeding habits. Females collected from late March to mid-May had enlarged ovaries, and large numbers of fledglings were noted in June by Perkins, suggesting a peak in nesting during April and May (Rothschild 1893 to 1900, Perkins 1903, Banko 1986).

Collectors in the late 1800s noted that \`ō\`ū fed mainly on the large inflorescences of *Freycinetia arborea* or \`ie\`ie, were fond of the yellow fruits of arboreal *Clermontia* species, and took fruits from many other native trees

(Henshaw 1902, Perkins 1903). Perkins (1903) noted them feeding exclusively on caterpillars (Geometridae), feeding them to young during the summer months in the Ka`ū/Kīlauea area of the Big Island. `Ō`ụ are also known to feed on young koa (*Acacia koa*) leaves, nectar, and on alien fruits such as guava, mountain apple, banana, peach, and mulberry (Henshaw 1902, Perkins 1903, Munro 1960, Scott *et al.* 1986).

Perkins (1903) reported that `ō`ū followed fruit ripening along elevational gradients in the Kona area. He observed them moving from the "wet belt" to the high, dry forests when `ie`ie fruits were scarce and occasionally moving down slope to feed on alien fruits. The `ō`ū is a strong flier and at times was observed flying in small flocks high over the forest canopy to feeding sites (Perkins 1893, Berger 1981).

HABITAT DESCRIPTION

Historically `ō`ū were known from a wide range of forests extending from sea level to alpine areas, but dense `ōhi`a (*Metrosideros polymorpha*) forest with `ie`ie was considered to be preferred habitat (Perkins 1903, Bryan 1908). Although wide elevational movements from the upland māmane (*Sophora chrysophylla*) forests to lowland forests to feed on guava and kukui were observed seasonally in the past (Perkins 1903), recent sightings on Kaua`i (Engilis and Pratt 1989) and Hawai`i (U.S. Fish and Wildlife Service, unpubl. data) show `ō`ū to be confined to mid-elevation (900 to 1,500 meters [3,000 to 5,000 feet]) mesic and wet `ōhi`a forests with 1,200 to more than 2,500 millimeters (47 to 98 inches) annual rainfall. In this area the canopy is dominated by `ōhi`a 10 to 25 meters (33 to 82 feet) high, with a subcanopy of `ie`ie, hāpu`u tree fern (*Cibotium* spp.), `ōlapa *(Cheirodendron* spp.), kāwa`u (*Ilex anomala*), kōlea (*Myrsine* spp.), and pilo (*Coprosma* spp.). These elevations are well within the "mosquito zone" where most native forest birds have been extirpated by mosquito-borne avian malaria and avian pox (Scott *et al.* 1986).

HISTORICAL AND CURRENT RANGE AND STATUS

Historically, `ō`ū habitat extended from lowland dry and mesic forests to montane mesic and wet forests on all of the major Hawaiian Islands (Figure 10;

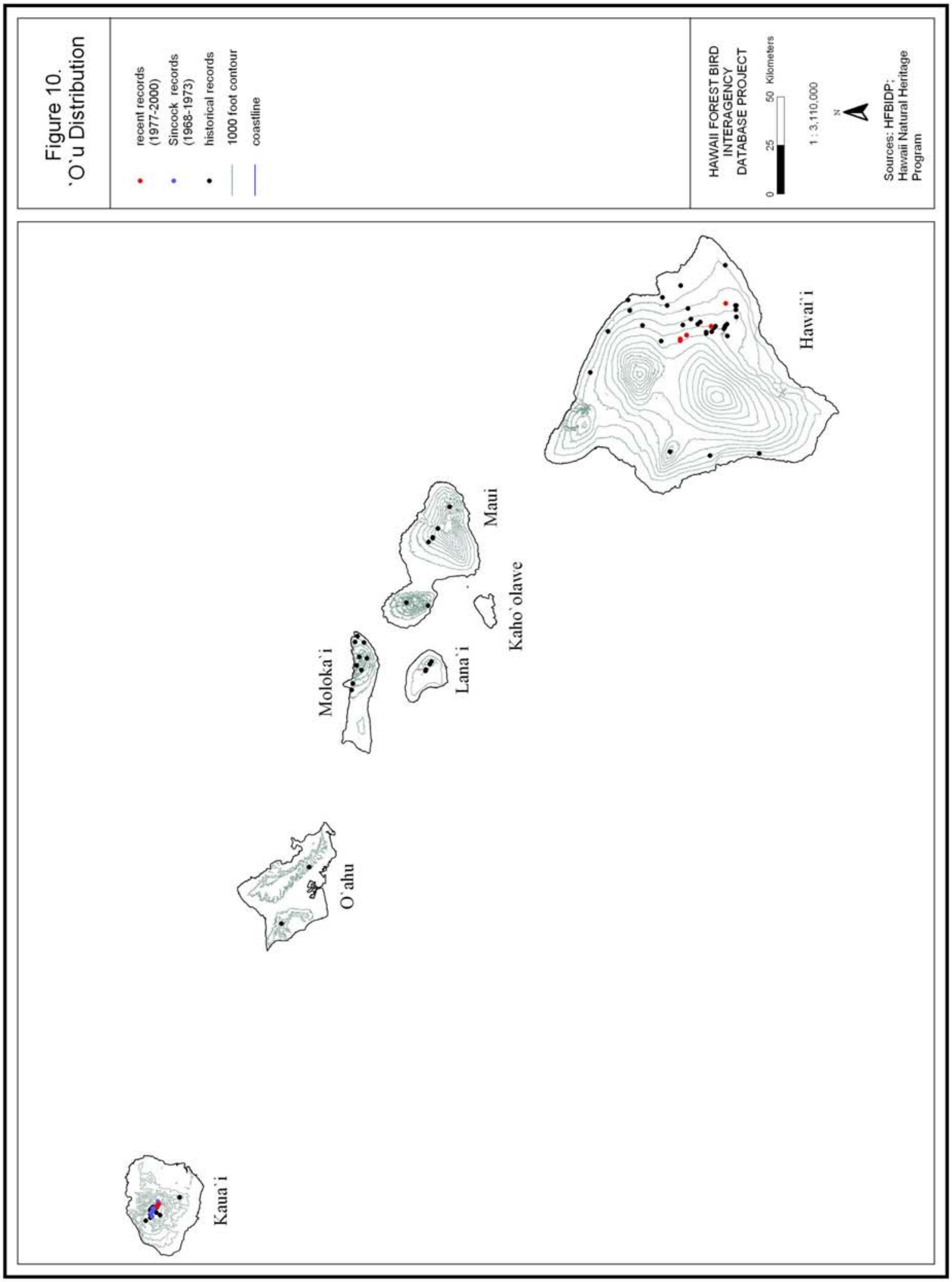


Figure 10.
`O`u Distribution
recent records (1977-2000)
Sincock records (1968-1973)
historical records
1000 foot contour
coastline
HAWAII FOREST BIRD INTERAGENCY DATABASE PROJECT
0 25 50 Kilometers
1 : 3,110,000
N
Sources: HFBIDP; Hawaii Natural Heritage Program
Kaua`i
O`ahu
Moloka`i
Lana`i
Kaho`olawe
Maui
Hawai`i

Perkins 1903, Scott *et al.* 1986). The `ō`ū is currently one of the rarest birds in Hawai`i, and may possibly be extinct, although past survey efforts have been insufficient to determine its status (Reynolds and Snetsinger 2001). The most recent observations indicate any remaining populations are extremely localized in occurrence, and are restricted to only a fraction of their former range in the mid-elevation `ōhi`a forest on the islands of Kaua`i and Hawai`i only (Figure 10). During the Hawai`i Forest Bird Survey from 1976 to 1981 (Scott *et al.* 1986), fewer than 40 `ō`ū were detected during 13,500 count periods on Hawai`i Island. `Ō`ū were detected during the Hawai`i Forest Bird Survey on the eastern slopes of Mauna Kea and Mauna Loa on Hawai`i and in the Alaka`i Wilderness Preserve on Kaua`i. Population estimates during the Hawai`i Forest Bird Survey in the late 1970s indicated 400 ± 300 (95 percent confidence interval) birds on Hawai`i Island and 3 ± 6 (95 percent confidence interval) birds on Kaua`i (Scott *et al.* 1986). More recent surveys have failed to detect any `ō`ū on either island, although occasional unconfirmed sightings are reported (Reynolds and Snetsinger 2001; U.S. Fish and Wildlife Service, unpubl. data). Reexamination of past survey data indicates the level of survey effort has to date been insufficient to confirm the status of the species (Scott *in litt*. 2006), and Reynolds and Snetsinger (2001) concluded that important habitat areas for `ō`ū were not searched adequately or under appropriate weather conditions during the Hawai`i Rare Bird Search in the mid-1990s. Additional targeted searches are needed to confirm the status of the `ō`ū, especially in the Ka`ū, Upper Waiākea, and Pu`u Maka`ala Districts of Hawai`i (Reynolds and Snetsinger 2001, Scott *in litt*. 2006).

REASONS FOR DECLINE AND CURRENT THREATS

Modification and loss of habitat have played a significant role in the decline of the `ō`ū. Forest degradation by introduced ungulates has reduced or eliminated forest habitat and food resources by converting vast areas of koa and `ōhi`a forest to pasturelands. Feral pigs have caused degradation of the understory in wet forests, destroyed food plants such as `ie`ie and *Clermontia* species, and have created mosquito breeding sites (Stone 1985).

`Ō`ū primarily inhabited the lower to mid-elevation forests (Perkins 1903), where the impact on native forest birds from introduced diseases transmitted by mosquitoes was most severe (Warner 1968, van Riper *et al.* 1986). `Ō`ū also moved seasonally to lower elevations to take advantage of abundant food resources (Perkins 1903), which may have increased their exposure to mosquitoes and hastened their decline.

Predation by cats and rats on eggs, young, and adults has contributed to the decline of many forest birds, probably including the `ō`ū. Herbivory by introduced black rats on the fruits and flowers of `ie`ie and other native fruiting plants also may have reduced food resources for native birds in forests throughout Hawai`i (Banko and Banko 1976).

Recent natural disasters may have affected some of the last remaining `ō`ū populations. On the Island of Hawai`i, a large portion of the Upper Waiākea Forest Reserve, location of some of the last observations of `ō`ū and considered prime habitat for the species, was inundated by the 1984 Mauna Loa lava flow, destroying thousands of acres of forest and creating a treeless corridor over a kilometer (0.62 mile) wide. On Kaua`i, two strong hurricanes, Iwa in 1982 and Iniki in 1992, had devastating effects on native forest habitat and native bird species. Three native bird species, `ō`ū, `ō`ō, and kāma`o, have not been seen since Hurricane Iniki.

CONSERVATION EFFORTS

The `ō`ū (*Psittirostra psittacea*) was federally listed as an endangered species on March 11, 1967 (U.S. Fish and Wildlife Service 1967), and it became protected under the State of Hawai`i endangered species law on March 22, 1982.

No conservation efforts have been initiated specifically targeting `ō`ū, but several research projects and Federal and State land management programs aimed at removing limiting factors for endangered birds and plants have been undertaken since 1985, and these provide some benefits to `ō`ū. On Hawai`i Island, large tracts of State and federally owned land are being intensively managed for habitat restoration. Hawai`i Volcanoes National Park, Hakalau Forest National Wildlife Refuge, Pu`u Maka`ala Natural Area Reserve, and the `Ōla`a/Kīlauea Forest Partnership area have been known to harbor `ō`ū in the past 25 years, and each area currently has management programs aimed at removing feral ungulates to restore native forest habitat and ongoing research into eliminating other threats.

On Kaua`i, liberal public hunting has been in place for many years, which has assisted in the control of feral pigs and goats in the more accessible western Alaka`i. Unfortunately, public hunting succeeds only in the more accessible areas of the preserve, and ungulate populations in more remote areas remain quite high. Alternatives are of limited effectiveness, expensive, and logistically difficult. Very limited aerial reconnaissance and aerial shooting of feral goats and pigs has been attempted in the most remote regions, but has not been economically effective. The Alaka`i Wilderness Preserve was established by the State of Hawai`i in 1964. It recognizes the fragile pristine ecosystem there and has provided some legal protection from potentially damaging developments as well as regulating unnecessary human activity. On Kaua`i, no large scale management actions have taken place in the Alaka`i Wilderness Area, primary habitat for the `ō`ū. The Hawai`i Rare Bird Search Team made an intensive systematic effort to locate any surviving endangered forest bird populations, but no `ō`ū were found during this search project (Reynolds and Snetsinger 2001).

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

7. Palila, *Loxioides bailleui*

DESCRIPTION AND TAXONOMY

Male palila. Photo © Jack Jeffrey.

The palila was first collected in the Kona region of Hawai`i by T. Ballieu in 1876, and was scientifically described in 1877 by Oustalet (Wilson and Evans 1890 to 1899). Amadon (1950) included the genus in *Psittirostra*, but *Loxioides* was restored later (American Ornithologists' Union 1983). Similarities in bill structure between *Loxioides* and *Telespiza* may warrant merging the two genera (James and Olson 1991). The palila is in the family Fringillidae, subfamily Drepanidinae.

The palila is one of the larger Hawaiian honeycreepers with an overall length of 15.0 to 16.5 centimeters (6.0 to 6.5 inches) and an adult weight of 38 to 40 grams (1.3 to 1.4 ounces). Adult palila have a yellow head and breast, greenish wings and tail, and are gray dorsally and white ventrally (Jeffrey *et al.* 1993). Adult females have less yellow on the nape and the lores are gray rather than black as in males. The head and upper breast of both sexes of juvenile birds are dull yellow-green, and juveniles have double wingbars formed by pale green tips on the greater and middle coverts until the first prebasic molt (Jeffrey *et al.* 1993).

LIFE HISTORY

The palila is an extreme food specialist, preferring unhardened māmane (*Sophora chrysophylla*) seeds in green pods or in pods that are just beginning to turn brown (Banko *et al.* 2002). Seeds in small developing pods and in hardened brown pods are rarely eaten, but very small pods with unexpanded seeds are sometimes eaten whole. Palila also eat māmane flowers, buds, and leaves, and naio (*Myoporum sandwicense*) berries, especially when other foods are in short supply. Seeds, fruits, flowers, and leaves of other species are rarely eaten (U.S. Geological Survey, unpubl. data). Caterpillars and other insects are important in the diet of nestlings and are eaten frequently by adults (Perkins 1903; U.S. Geological Survey, unpubl. data). Preliminary studies suggest that māmane seeds are nutritious, but they contain high levels of alkaloids that are generally toxic to vertebrates (U.S. Geological Survey, unpubl. data). Observations indicate that birds are selective about which trees they exploit for seeds, suggesting that levels of alkaloids may vary significantly among individual trees (U.S. Geological Survey, unpubl. data).


Palila feeding on māmane seed pod. Photo © Jack Jeffrey.

Palila move in response to the availability of māmane seeds, and fledglings and hatch-year birds sometimes disperse widely in search of food (Hess *et al.* 2001; U.S. Geological Survey, unpubl. data). Nevertheless, there is no evidence that birds move more than about a third of the way around Mauna Kea during their entire lives, and those hatched on the western slope may travel even less (U.S. Geological Survey, unpubl. data). Home range sizes and movement distances, therefore, are small relative to the potential mobility of the species, and palila have poor recolonization potential (Fancy *et al.* 1993).

Nesting may begin in January or February, but palila usually start nesting from March to early May; egg-laying continues through August or mid-September (van Riper 1980a; Pletschet and Kelly 1990; Pratt *et al.* 1997a; U.S. Geological Survey, unpubl. data). From 1996 to 2000, mean length of the egg-laying season was 113 ± 25.1 days (range 53 to 205 days) (U.S. Geological Survey, unpubl. data). Peak nesting usually occurs in May or June (U.S. Geological Survey, unpubl. data). The number of nesting attempts each year is strongly influenced by the availability of green māmane pods. In years of poor māmane pod production, initiation of nesting may be delayed, fewer palila attempt to nest, and fewer re-nesting events occur (Pratt *et al.* 1997a; U.S. Geological Survey, unpubl. data). Forest composition also affects nesting behavior: from 1996 to 2000, nesting density averaged 6 ± 2 nests per 100 hectares (247 acres) in māmane-dominated forest, whereas 4 ± 1 nests per 100 hectares (247 acres) were found in mixed naio/māmane forest (U.S. Geological Survey, unpubl. data).

Palila are monogamous, but other adult males often help the pair by feeding the female and chicks (Pratt *et al.* 1997a; Miller 1998; U.S. Geological

Survey, unpubl. data). It is not yet known whether male helpers copulate with the female and sire some of the nestlings they help raise, but some male helpers are chased by the nominal male. Although the nominal male defends a small territory around the nest tree, the pair forages over a larger area. Male home range size during nesting averaged 9.5 ± 1.96 hectares (23.4 ± 4.8 acres), and the mean distance between the center of daytime locations and the nest was 73 ± 12.1 meters (241 ± 40 feet; n = 6 males in māmane-dominated forest, n = 2 in naio-dominated forest) (U.S. Geological Survey, unpubl. data). The female selects the nest site and constructs the nest, which takes from 1 to 3 weeks to complete. Preferred nest sites are in forks near the ends of higher branches in medium to large māmane trees; however, nests have been found in a variety of sites within relatively small māmane trees, in other tree and shrub species, and even in a clump of grass on the ground (van Riper 1980a; Pletschet and Kelly 1990; U.S. Geological Survey, unpubl. data). Materials used for the body of the nest are usually grass and large dead twigs; lichens and rootlets form the lining (van Riper 1980a). The use of sheep's wool in some palila nests (van Riper 1977) has been used by some to justify maintaining feral animals in palila habitat; however, the notion that birds require this material is false, and there is no evidence to suggest or reason to believe that productivity is higher at nests containing wool. Lichen may be important in helping to maintain humidity in the arid conditions often encountered on Mauna Kea, but temperature and humidity are unlikely to contribute to nest failure except during heavy storms (Pratt *et al.* 1997a).

Modal clutch size is two eggs (usual range one to three; four reported in one nest). Eggs require 16 to 17 days to hatch, and nestlings fledge at 25 days (Pletschet and Kelly 1990). Palila may re-nest after failure, and some palila are able to raise two broods during the same year. Palila show high nesting site fidelity, particularly among females. Subsequent nests of individual females within nesting seasons range on average from 120 to 141 meters (394 to 463 feet) of each other, but distances between years tends to be greater (Pratt *et al.* 1997a; U.S. Geological Survey, unpubl. data).

Male palila have a 1-year delay in plumage maturation (Jeffrey *et al.* 1993). Males do not begin breeding until at least their third year (0 percent of second years breed; n = 99), but about 10 percent of females breed in their second year (n = 111; Pratt *et al.* 1997a). Both sexes are productive until at least 11 years of age, and a male ≥ 13 years of age helped at a nest. Annual survival averages

0.63 ± 0.05 (standard error), which is similar to other Hawaiian honeycreepers (Lindsey *et al.* 1995). Survival of juveniles is significantly lower than that of adults. Using plumage characteristics to determine sex, the sex ratio of adults was thought to be male-biased (Lindsey *et al.* 1995); however, recent genetic studies suggest that the sex ratio is probably even in all age classes ranging from embryos to adults (U.S. Geological Survey, unpubl. data).

Palila have relatively low productivity due to their small population size, great annual variation in the number of pairs attempting to nest, small clutch size, and long nesting cycle. In his study area, van Riper (1980a) found 14.8 pairs per 100 hectares (247 acres) and 1.8 young per pair a year, resulting in a productivity of 26.1 young per 100 hectares (247 acres) a year. By comparison, the productivity of the Hawai`i `amakihi (*Hemignathus virens virens*) was 203.5 young per 100 hectares (247 acres) a year in the same study area. Although the number of pairs nesting varies greatly from year to year, at least half of all eggs successfully hatched in nests that were active when discovered: 54 to 66 percent from 1989 to 1993 (Pratt *et al.* 1997a), and 64 to 83 percent from 1996 to 2000 (U.S. Geological Survey, unpubl. data). Infertility of eggs was 4 to 11 percent from 1996 to 2000, suggesting that infertility is not a major problem for this species (U.S. Geological Survey, unpubl. data). At least one third of active nests produce a fledgling each year: 39 to 55 percent from 1989 to 1993 (Pratt *et al.* 1997a), and 33 to 67 percent from 1996 to 2000 (U.S. Geological Survey, unpubl. data). The year of lowest fledgling production was 1997, when cool wet weather contributed significantly to nestling mortality. On average, 1.5 ± 0.05 chicks (range 1.3 to 1.6) fledged from productive nests from 1996 to 2000 (U.S. Geological Survey, unpubl. data).

HABITAT DESCRIPTION

Palila are dependent on the māmane and māmane/naio forests for all their needs. The highest densities of palila occur in areas of greater crown cover, taller trees, and higher proportion of native shrubs near 2,300 meters (7,550 feet) elevation in māmane-dominated or mixed māmane-naio forest (Scott *et al.* 1984, 1986), and annual and seasonal density of birds is strongly related to māmane pod availability (Scott *et al.* 1984, 1986; Hess *et al.* 2001). Most nesting occurs in māmane trees (Pletschet and Kelly 1990), but naio is more frequently selected for roosting (U.S. Geological Survey unpubl. data). Up to 96 percent of the current palila population and nearly all of the successful breeding occurs on the southwestern slope of Mauna Kea, where the elevation range of the forest and habitat quality is greatest (Scott *et al.* 1984, 1986; Jacobi *et al.* 1996; Banko *et al.* 1998; Gray *et al.* 1999). The elevation range of forest was the most important variable in the analysis by Scott *et al.* (1984) of palila response to available habitat. This results from the phenological variation of māmane trees along a gradient of elevation. At different elevations, māmane trees produce flowers and fruits at different times during the year (U.S. Geological Survey, unpubl. data). A wide belt of māmane forest results in more consistent availability of seeds within the range of daily movements typically made by palila, especially during the breeding season.

HISTORICAL AND CURRENT RANGE AND STATUS

Fossil remains of palila have been found at sea level on O`ahu (Olson and James 1982a,b), suggesting that the species once occurred over a much larger range than was known historically. Before the first Polynesians arrived around 400 A.D., the lowlands of the main islands supported extensive dryland forests suitable for palila (Scott *et al.* 1984). Historically, the palila was known only from the Island of Hawai`i, were it occurred in māmane/naio forests on the upper slopes of Mauna Kea, the northwestern slope of Mauna Loa, and probably the southern and eastern slopes of Hualālai (Figure 11). In the 1890s, Perkins (1903) found the palila to be "extremely numerous" in the māmane belt of the Kona region between 1,210 and 1,830 meters (4,000 to 6,000 feet) elevation. Palila were still locally common in the 1940s between 2,360 and 2,530 meters (7,800 to 8,350 feet) on the western and northeastern slopes of Mauna Kea (Richards and Baldwin 1953). The range of palila apparently contracted relatively quickly in the early 1900s to a small area on the upper slopes of Mauna Kea, because Munro (1944) determined that the species was in danger of extinction.

In recent decades the distribution of palila has remained fairly constant (Figure 11). The upper elevation limit appears to coincide with tree line at about 2,850 meters (9,400 feet) and the lower elevation limit is approximately 2,000 meters (6,600 feet) at the transition from māmane or māmane/naio forest to scrub forest or grassland (Scott *et al.* 1984). In the early 1980s palila occupied about 139 square kilometers (53.7 square miles) or 25.6 percent of the 545 square kilometers (212 square miles) of māmane woodlands remaining on Mauna Kea

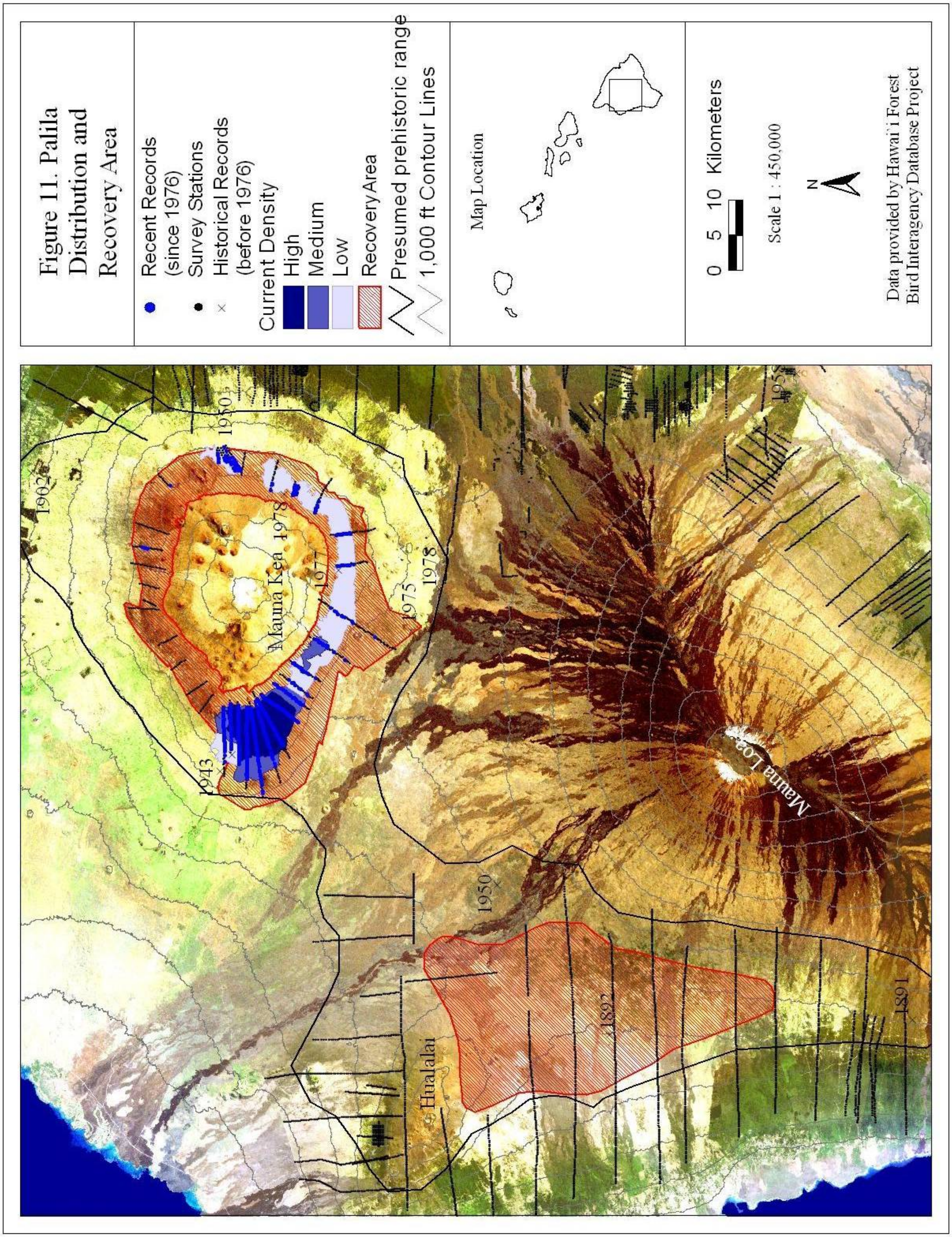


Figure 11. Palila Distribution and Recovery Area

(Scott *et al.* 1984). The range as of 2001 was essentially the same, although declining populations on the eastern and southern slopes would suggest some further range contraction.

Because the small populations on the eastern and southern slopes of Mauna Kea have been declining since 1980, estimates of the palila population depend heavily on counts centered near Pu`u Lā`au on the western slope. Annual surveys from 1980 to 1995 yielded a mean population estimate of 3,390 ± 333 (standard error) (Figure 12). From 1998 to 2005, the mean population estimate was 3,172 ± 194.6 (standard error), with a range of 2,206 to 3,901 (Banko *et al.* 2005). Much of the apparent variation in numbers of palila may be due to differences in vocal activity. Most palila detected on annual counts are heard rather than seen; therefore, population estimates are potentially sensitive to rates of singing and calling, which in turn may be affected by courtship and nesting. Annual counts are conducted prior to the nesting season, usually in January or February (Jacobi *et al.* 1996), but the timing of nest initiation and proportion of birds breeding varies greatly each year, as discussed above. Although reported declines in population size are possible due to starvation and other factors, the more dramatic increases reported could not have occurred. The reproductive potential of palila is insufficient to have produced the apparent population increases by factors of 2.9 (1986 to 1987), 2.4 (1992 to 1993), or 2.0 (1995 to 1996) (Jacobi *et al.* 1996). To understand why this is so, consider the improbable conditions that must occur for the population to double in a single year: 1) all adult birds must nest and produce two fledglings per pair, and 2) all adults and fledglings must survive until the next survey. There is some indication that annual variation in the population since 1996 may be dampening (Banko *et al.* 1998, Gray *et al.* 1999), but analyses of 1999 to 2001 data are needed to confirm this (Figure 12).

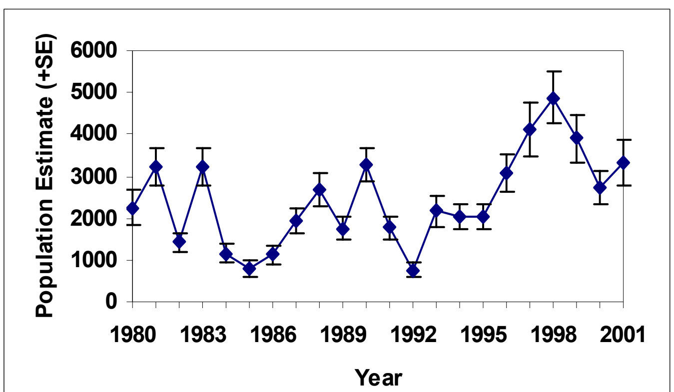


Figure 12. Population trend of palila.

REASONS FOR DECLINE AND CURRENT THREATS

Habitat loss and modification, avian disease, and predation by introduced mammals are thought to have caused the palila population to become endangered, and these factors continue to limit the palila population today (Scott *et al.* 1984, 1986; Jacobi *et al.* 1996; Pratt *et al.* 1997a). Feral ungulates first became established in the māmane forest in the early 1800s and have since caused widespread loss and modification of palila habitat. Cattle, feral sheep, mouflon (*Ovis musimon*), and feral goats all have contributed to the destruction and modification of the māmane/naio forest. Feral sheep became established on Mauna Kea in the 1820s and the sheep population had reached about 40,000 animals by the early 1930s (Bryan 1937). Heavy browsing effectively lowered the tree line and reduced tree density in other areas (Scowcroft and Giffin 1983; Scott *et al.* 1984). In addition, browsing removed lower branches of māmane trees, thus lowering the productivity of individual trees and reducing the availability of palila food resources.

Following legal rulings under section 9 of the Endangered Species Act (see Conservation Efforts), threats from feral ungulates have been reduced in palila critical habitat. As a result, recruitment of māmane and other native plants has increased and the forest is beginning to recover (U.S. Geological Survey unpubl. data). Nevertheless, palila habitat continues to be threatened by alien weeds and fire (Hess *et al.* 1999). The abundance, distribution, and impact of weeds are under investigation by the U.S. Geological Survey, but management is needed soon on species that are spreading rapidly or whose impacts are already known. Especially worrisome is the spread of alien species of annual grasses and the accumulation of fine fuels that may carry large, destructive fires. Many weeds are now established in areas where soils were highly disturbed by large populations of ungulates. Some alien species may decline in abundance as native species increase and soil disturbance by ungulates has been reduced. Other species, however, must be controlled before they spread further. For example, fountain grass (*Pennisetum setaceum*), a fire-promoting grass, is one of the most aggressive and potentially damaging introduced plants in Hawai`i. It has already become the dominant ground cover in large areas of Kona and the area between Mauna Kea, Mauna Loa, and Hualālai; colonies have also become established on the southern and western slopes of Mauna Kea (U.S. Geological Survey, unpubl. data). Cape ivy (*Delairea odorata*) is another pernicious weed that threatens palila habitat by climbing on and smothering native trees and shrubs. It was discovered as a sporadic infestation over about 500 hectares (1,235 acres) near Pu`u Lā`au (Scott *et al.* 1984) and has since spread widely on the western slope of Mauna Kea. Gorse (*Ulex europaeus*) is a highly invasive shrub that threatens māmane forest on the eastern slope. Efforts to control gorse have not been encouraging, and it will spread into palila habitat from pastures below Mauna Kea Forest Reserve unless concerted measures are taken. The threats posed by many other weed species are less known, but some likely help support invertebrate pests that threaten the insect prey of palila.

Fire is an ever-present threat to the dry forest habitat of palila, and the risk of large destructive fires is increased by the accumulation of fine leaves and stems of alien annual grasses and other weeds. The chief concern about fire is that palila could be deprived of critical food resources over large areas for several years before recovery and regeneration of māmane and other native plants occurred. Although māmane can recover quickly after fire (T. Tunison, National Park Service, pers. comm.; U.S. Geological Survey, unpubl. data), alien grasses and other weeds are likely to increase in abundance and distribution, thus increasing the potential frequency and intensity of fires. Fire-adapted fountain grass and orchard grass (*Dactylis glomerata*) are especially apt to spread; however, native grasses and shrubs may also increase after fire. For example, the native lovegrass *Eragrostis atropioides* almost completely dominated the vegetation following fires that started along Saddle Road on the western slope of Mauna Kea during the 1990s (U.S. Geological Survey, unpubl. data). Although *Eragrostis* burns readily and hotly (T. Tunison, pers. comm.), it may be less fire-prone than fountain grass.

Now that ungulate damage has been reduced, the forest must be monitored for signs of diseases that may debilitate or kill māmane. There are many dead and dying māmane trees of all age classes around the mountain, but especially on the western and southern slopes. Demographic patterns of māmane mortality are being investigated by the U.S. Geological Survey, but additional research may be warranted to identify pathogens.

Avian malaria and avian pox have had devastating effects on the numbers and distribution of Hawai`i's native birds (Warner 1968, van Riper *et al.* 1986). These diseases are spread by mosquitoes, which are uncommon at the high elevations where palila are now found. Palila are highly susceptible to malaria (van Riper *et al.* 1986), and although it is not thought to be an important mortality factor for palila because of the elevation of their current range, avian disease may prevent palila from recolonizing their former range at lower elevations, including Pōhakuloa Flats.

Predation by black rats (*Rattus rattus*), feral cats (*Felis catus*), and the Hawaiian short-eared owl or pueo (*Asio flammeus sandwichensis*) is another important factor limiting the palila population, particularly through its effects on the distribution of nesting by palila. Pletschet and Kelly (1990) attributed 5 percent of palila nest mortality to egg depredation and 35 percent to nestling depredation by black rats and feral cats, and thought that predation might have contributed to the high rate of nest abandonment they observed. Snetsinger *et al.* (1994) found that 68 percent of cat scats collected near Pu`u Lā`au contained bird remains, and thought that feral cats were an important predator on native birds. Studies by van Riper (1980a) and Pratt *et al.* (1997) have also shown that feral cats prey on palila nests and adults. Amarasekare (1993) concluded that predation had little effect on the palila, but her study focused on rat predation either in the core palila nesting area, where few rats occur, or in naio-dominated forests, where few palila attempt to nest. Rats are associated primarily with naio trees, presumably because these trees provide greater food and cover for rats, and occur only in low densities in the core palila nesting area where māmane predominates (Amarasekare 1993). Successful nesting by palila is rare where naio is the dominant tree species, and mammalian predation is thought to be the major reason.

The absence of palila in the Pōhakuloa Flats (downslope, southeast from existing populations) remains unexplained. Scott *et al.* (1984) suggested site tenacity, thermal stress, or avian disease as plausible hypotheses. However, recent studies indicate that alien ants and predatory wasps are established in the area, and other alien wasps heavily parasitize native caterpillars that are eaten by palila (U.S. Geological Survey, unpubl. data). Disturbance from military activities in the Pōhakuloa Training Area may also affect palila distribution.

Severe weather may be an important mortality factor in certain years. Populations are restricted to the higher elevations where freezing temperatures occur frequently during part of the nesting season. Rains are infrequent but can be heavy and cause eggs or chicks to die of exposure. In other years, droughts lead to low levels of māmane pod production that result in fewer nesting attempts and delayed breeding by palila. High winds can blow young out of nests, especially those placed in the terminal forks of trees (van Riper 1980a), or cause nests to disintegrate (U.S. Geological Survey, unpubl. data).

CONSERVATION EFFORTS

The palila received Federal recognition as an endangered species in 1966, and was formally listed as endangered on March 11, 1967 (U.S. Fish and Wildlife Service 1967). The primary reasons for this classification status were: (1) a significant portion of its historical range was no longer occupied; (2) its present habitat was being adversely modified by feral ungulate browsing; and (3) the total palila population at that time was estimated to be in the low hundreds.

The vulnerability of palila to extinction has been recognized since the mid-1900s (Munro 1944). Although relatively little conservation or research effort was directed specifically at the palila until recently, feral ungulate control was initiated in the early 1900s to protect the māmane woodland and watershed of the Mauna Kea Forest Reserve (Bryan 1947). The removal of over 46,000 feral sheep and smaller numbers of feral cattle, goats, and pigs retarded the severe deterioration of the forest and allowed the recruitment of a cohort of māmane seedlings that has sustained palila to the present. Populations of sheep were allowed to rebuild and mouflon sheep were introduced to promote sport hunting (Tomich 1969), again causing widespread damage to the māmane forest (Warner 1960).

Critical habitat for the palila was designated on August 8, 1977 (U.S. Fish and Wildlife Service 1977). In 1978, a ruling by the Hawai`i District Court under section 9 of the Endangered Species Act required that all feral sheep and goats be removed from palila critical habitat (Palila *et al.* v. Hawai`i Department of Land and Natural Resources *et al.*, CIV No. 78-0030; Nelson 1982). A similar ruling by the Federal Court of Appeals for the Ninth Circuit in 1987 ordered the eradication of mouflon sheep (Palila *et al.* v. Hawai`i Department of Land and Natural Resources and Hawaii Rifle Association, No. 87-2188; Pratt *et al.* 1997a). Subsequently, goats have been eliminated and sheep and mouflon have been reduced to low numbers. However, immigration and recruitment of lambs make it unlikely that sheep and mouflon will be eradicated in the near future unless more effective control measures are taken. Fencing along the southern boundary of Mauna Kea to prevent entry by feral ungulates has been improved, but animals can readily gain access to the forest reserve in many places (J. Giffin, Hawai`i Department of Land and Natural Resources, pers. comm.). In addition, animals may become increasingly difficult to control from helicopters as they learn avoidance tactics, and public hunting has been ineffective at removing significant numbers of these popular game animals from remote areas or when populations occur in low numbers (J. Giffin, pers. comm.). Therefore, new strategies and tactics are needed to comply with court-ordered eradication of sheep and mouflon.

A popular but erroneous rationale for maintaining cattle, sheep, and other ungulates in palila habitat is that they limit fire threats by reducing fine fuels. The problem with using ungulates to suppress fire fuels in native forest is that grasses and other fine fuels are reduced appreciably only when ungulates exist in such high densities that māmane and other native plants are heavily damaged and recruitment is essentially eliminated. Many fires on Mauna Kea start in pastures where grazing has reduced or extirpated native plants (U.S. Fish and Wildlife Service, unpubl. data). The principal benefit of grazing, therefore, would seem limited only to reducing fire intensity. The principal liabilities of using grazing to reduce fuels are that native plants are destroyed and soil is disturbed, increasing opportunities for undesirable grasses and other weeds to spread. Indeed, most problematic weeds proliferated on Mauna Kea when feral ungulates were abundant and widespread (Scowcroft and Conrad 1992).

Since being listed as endangered, considerable research has been conducted on the palila, including its physical characteristics (Jeffrey *et al.* 1993), population size and distribution (van Riper *et al.* 1978, Scott *et al.* 1984, Banko 1986, Jacobi *et al.* 1996, Banko *et al.* 1998, Gray *et al.* 1999), home range and movements (Fancy *et al.* 1993, Hess *et al.* 2001), breeding biology (Berger 1970, van Riper 1980a, Pletschet and Kelly 1990, Miller 1998), limiting factors and demography (Amarasekare 1993; Fleischer *et al.* 1994; Lindsey *et al.* 1995, 1997), conservation (Berger 1981, Scott *et al.* 1986, Fancy *et al.* 1997, Pratt *et al.* 1997a), and habitat characteristics (van Riper 1980b, Scowcroft 1983, Scowcroft and Giffin 1983, Scowcroft and Sakai 1983, Scowcroft and Conrad 1992, Juvik *et al.* 1993, Hess *et al.* 1999). Population size and distribution were first estimated systematically in 1975 (van Riper *et al.* 1978), and annual censuses have been conducted since 1980, allowing biologists to monitor population trends longer than for any other Hawaiian forest bird (Scott *et al.* 1984, Jacobi *et al.* 1996, Banko *et al.* 1998, Gray *et al.* 1999).

The original recovery plan for the palila was completed in 1978 and revised in 1986 (U.S. Fish and Wildlife Service 1986). These recovery plans identified a series of actions aimed at both the direct conservation of the palila and at gathering information for that purpose. Many of these actions have since been implemented, at least in part. Notable among these are increased efforts to control feral ungulates, specifically feral sheep and goats, resulting in significant habitat improvement (Scowcroft and Conrad 1992, Hess *et al.* 1999).

Building on research results of the 1970s and early 1980s, the U.S. Geological Survey Pacific Island Ecosystem Research Center began studies in 1986 that are expected to continue through 2010. This research continues investigating the basic ecology and factors limiting the palila population, including predation, disease, food availability and threats to food resources, small population genetics and demography, and habitat quality and threats. The U.S. Geological Survey will also develop restoration techniques and facilitate their implementation. Most of the updated information in this recovery plan has been collected during these studies, and much more information about palila and their habitat will be forthcoming.

In 1993, an experimental translocation of adult palila to Kanakaleonui on the eastern slope of Mauna Kea was conducted to determine whether birds would remain and breed in a new area. Although at least half of the birds returned to the western slope near Pu`u Lā`au within 1 year, two pairs successfully nested at Kanakaleonui and the density of palila there was higher after the translocation (Fancy *et al.* 1997). Additional translocations of birds from the western slope were undertaken from 1997 to 2006 with the goal of testing techniques for reestablishing a population on the northern slope of Mauna Kea, near Pu`u Mali. While 53 birds were translocated in 3 early trials, there was little to suggest that birds remained in the new area (U.S. Geological Survey, unpubl. data). Although some birds stayed in the target area for over a year, most returned to their original home ranges within a few months. Another trial was completed in 2004, when 32 birds of different age groups were translocated to test the hypothesis that a more natural social environment and a large pool of potential mates would encourage more birds to stay longer and breed. In fact, one pair formed and nested successfully, fledging two chicks. In conjunction with the 2004 translocation, 10 captive-reared palila were released near Pu`u Mali in late 2003 to compare the survival, breeding, and other behavior between the two groups. Captive-bred palila were supplied by the Zoological Society of San Diego from the Keauhou Bird Conservation Center from stock originating from wild eggs collected in 1996 and 2000 (The Peregrine Fund 1996, The Peregrine Fund and the Zoological Society of San Diego 2000). Six of the 10 captive-released birds survived through the breeding season at or near the release site and one pair formed, laying a single infertile egg. Translocations and releases of captive-raised birds were also conducted in late 2004 and 2005. Prior to translocating and releasing captive-reared birds near Pu`u Mali, predators were removed and food and habitat conditions were assessed to increase chances of success. Ten of the 21 captive-raised palila released on Pu`u Mali from 2003 through 2005 have been seen in 2006, and there have been multiple breeding events in each of the last 3 years (2004 to 2006) of both translocated and captive-bred palila, with at least 4 fledglings surviving to independence. These results suggest a combination of translocation and captive-releases has been successful at forming a second breeding population, though the number of birds in this incipient population is still very small and its long-term viability remains to be seen.

In 1996, a captive propagation program was initiated as a collaborative effort between the National Biological Survey (now the Biological Resources Discipline of the U.S. Geological Survey) and The Peregrine Fund (and later by the Zoological Society of San Diego), with the collection of wild-laid eggs, artificial incubation, and hand-rearing. A total of 11 palila and 3 palila were reared in 1996 and 2000, respectively, at the Keauhou Bird Conservation Center. In 1999, one pair of these captive-reared birds began to breed, with one chick hatched that did not survive. In 2000, 11 captive-bred palila were hatched from 2 pairs with 100 percent survival. In 2001, three chicks were reared in captivity from one pair of palila. Some progeny of the captive-propagation program were released in 2003 and there are plans for future releases of palila produced by the near Pu`u Mali and other recovery areas.

Although māmane and other native trees and shrubs have regenerated prolifically following the removal of feral ungulates, alien grasses and other factors may be suppressing regeneration in some areas (Hess *et al.* 1999). Experimentation to regenerate māmane forest by planting saplings has demonstrated that māmane grows readily near tree line and where competing ground cover is sparse. Māmane has not yet been planted where grass cover is thick.

Despite a growing list of technical and semi-technical publications about palila, a relatively limited amount of effort has gone into information and education since 5,000 copies of a small poster about palila with a description of their habitat were distributed in the 1980s (J. M. Scott, University of Idaho, pers. comm.). Presentations have been given by U.S. Geological Survey researchers and others at scientific, professional, and public venues at an increasing rate. Increasing numbers of students, from grade school to university levels and including law students, have asked for information about palila and the court orders relating to feral ungulate removal for classroom projects. Increasingly, information about palila is available on the worldwide web, and U.S. Geological Survey biologists are in the process of greatly expanding the amount and quality of information available through the internet.

RECOVERY STRATEGY

The primary problem confronting palila conservation is that the population is highly concentrated: as much as 96 percent of the population occurs within about 30 square kilometers (11.6 square miles) of forest on the western slope of Mauna Kea (Gray *et al.* 1999). Although recent estimates indicate that the western population may be stabilizing, the very small, scattered southern and eastern populations seem to be declining and heading towards extinction (U.S. Geological Survey, unpubl. data). The geographic expansion of the high-density population cell, if it is occurring at all, is imperceptibly slow, and few if any birds seem to move between the different slopes. Whether because of site tenacity or preference for more favorable habitat conditions on the western slope, immigrants from the western slope are unlikely to bolster the declining populations or recolonize vacant habitats in the near future. The most urgent goal for recovery, therefore, is to bolster or reestablish one or more self-sustaining populations while managing the primary population on the western slope for stability or increase.

The intent of both downlisting and delisting recovery criteria is that relatively large and viable (self-sustaining) populations exist in at least three areas (on the western and either the northern, eastern, or southern slopes of Mauna Kea and at least one other location on Mauna Loa or Hualālai) over sufficiently long periods to account for perturbations in weather and other environmental variables.

Determining when to downlist or delist the species depends on the reliability of population monitoring. Annual estimates (variable circular plot method) of the population since 1980 vary considerably (Jacobi *et al.* 1996), but it is difficult to know how estimates are affected by sampling error, variation in detection probability, or population change. For example, procedures for training and calibrating observers have varied over the years, although since 1997, methods have been standardized to a much greater degree. In addition, observers now count all species detected, whereas observers focused only on palila and a few other species prior to 1997. A potentially large source of variation in annual estimates is the amount of vocal activity, which may be affected by the timing of breeding and number of birds attempting to breed, as discussed above. Therefore, it cannot always be assumed that dramatic changes in annual population estimates reflect actual numbers of birds. Evaluating population status and trends by estimating the number of breeding pairs in the population is difficult because the number of pairs nesting each year varies greatly depending on the availability of māmane pods; in very dry years few birds nest because pods are scarce (Pratt *et al.* 1997a; U.S. Geological Survey, unpubl. data). Problems in determining whether populations are stable (recovery criterion 2a) can be more easily overcome if lambda (population growth rate) is known (criterion 2b).

Recovery criteria for palila are based partly on the perception that the main population on the western slope of Mauna Kea may be starting to benefit from increased māmane tree recruitment and growth, which has resulted from reductions of populations of feral sheep and goats and mouflon sheep since 1980. Ungulate eradication, removal of cattle from critical habitat (Ka`ohe Lease), and protection from fire, weeds, predators, food competitors, and disturbance likely will result in population growth and expansion over the next 10 years. However, populations in other areas on Mauna Kea will become self-maintaining only if habitat is actively restored and relict populations are vigorously protected. Populations must be reestablished in suitable areas of former range, such as the northern slope of Mauna Kea, by releasing captive-reared or translocated birds. It may also be necessary to bolster relict populations on the southern and eastern slopes. Managing these small or incipient populations should involve nearly complete eradication of major predators, particularly feral cats. Some threats to food resources (e.g., ants and predatory wasps) should be controlled to the extent possible, but there are no methods available for controlling parasitoids that reduce the availability of caterpillars. In addition, factors that destroy or alter habitat, especially feral ungulates, fire, and highly invasive weeds, must be suppressed. Māmane and other native species should be planted where regeneration is sparse.

In the long-term, restoring palila populations will be possible only if sufficient habitat is available and it is distributed along gradients of elevation or rainfall such that food resources are available throughout the year. An opportunity to expand the size and extend the elevation gradient of habitat near Pu`u Mali has arisen as part of the mitigation settlement for realigning Saddle Road through palila critical habitat in the Pōhakuloa Training Area on the southern slope of Mauna Kea. Land below the Mauna Kea Forest Reserve will be fenced and cattle will be withdrawn, beginning in late 2004 and early 2005. Natural reforestation is likely to occur in upper pastures where some māmane and other native species persist. However, lower pastures may require planting, and alien grasses and other weeds may pose a variety of management challenges. Funds for reforestation, weed control, and fire management near Pu`u Mali are limited under the terms of the Saddle Road realignment mitigation settlement; thus, supplementary funding is necessary. Cattle will also be withdrawn from critical habitat (Ka`ohe Lease) on the western slope as part of the mitigation for realigning Saddle Road. Again, extra funds will be needed to manage this area for maximum benefit of palila and other native species. In addition to funding for habitat restoration, commitments are needed to manage lands for forest and palila recovery beyond the 10-year period covered by mitigation.

Opportunities to reforest pastures on the eastern slope of Mauna Kea are limited because the lands are held privately and a large area is heavily infested with gorse. Nevertheless, it may be possible to acquire conservation easements that would extend the availability of habitat to areas below the existing forest reserve. Acquiring this habitat will only be worthwhile, however, if resources and methods are available for controlling the spread of gorse.

Privately owned pastures and gorse also are important challenges to restoring forest habitat on the southern slope. In addition, efforts to recover palila on the southern slope are hindered by military training and the realignment of Saddle Road through critical habitat. Predator populations on the southern slope are uncontrolled and insect food resources used by palila and other native birds are heavily threatened by alien parasitoids and predators, including, for example, Argentine ants (*Linepithema humile*) and yellow jackets (*Vespula pensylvanica*). The forest should be protected from ungulates, fire, weeds, and unnecessary disturbance, even though Pōhakuloa Flats cannot be managed primarily for palila recovery. It may be possible to maintain a limited population of palila on the southern slope if the forest at Pōhakuloa Flats is managed carefully and the forest above continues to recover from ungulate browsing damage.

Prospects for restoring palila to areas of its former range on Hualālai and Mauna Loa are less certain. Although māmane forest remains over relatively large areas, particularly to the south of Hualālai on the western flank of Moana Loa, habitat conditions are just now being evaluated more carefully to determine their recovery potential. Except for areas controlled by the military, lands once occupied by palila in Kona are privately owned, and conservation easements or other arrangements will be needed to carry out ungulate control and other management activities. The habitat at Kīpuka `Alalā within the Pōhakuloa Training Area may be rehabilitated sufficiently to warrant reintroducing palila. Although military training creates some disturbance in this remote, isolated area, greater impediments to recovery are posed by large herds of feral ungulates that have essentially eliminated māmane regeneration for decades, and fires. As part of the Saddle Road mitigation, however, the diverse dry forest found at Kīpuka `Alalā is being managed with the idea that palila might be reintroduced in a few decades. Palila occupied the area into the 1950s (Banko 1986); thus, the serious challenges of forest restoration should not completely discourage the notion of reestablishing a population. If areas such as Kīpuka `Alalā are not considered for long-term recovery, conservation efforts may become too focused on short-term goals.

The Saddle Road mitigation provides a valuable bridge between short-term and long-term recovery goals. It provides funding to develop and implement techniques for reintroducing palila to former habitat and for managing the primary population and habitat. It also continues research into limiting factors and habitat requirements, and it initiates research into fire ecology and behavior so that a fire management plan can be formulated. In addition, strategies and techniques for controlling predators are being developed for the western and northern slopes of Mauna Kea. Without the Saddle Road mitigation, large areas of former habitat would continue to be grazed. However, this mitigation stops well short of recovering palila.

To fully recover palila, long-term funding and effort are needed to manage ungulates, fire, weeds, predators, and food competitors over large areas of suitable habitat. Recovery can be accelerated by planting māmane and other appropriate native species in areas where alien grasses suppress regeneration (Hess *et al.* 1999), or where native forest is unlikely to regenerate quickly. Palila recovery will be enhanced if the public is constructively engaged in the process. If, for example, citizens think of palila habitat on Mauna Kea only in terms of its value for public hunting and livestock grazing, there will be little impetus for changing land-use policy, and protecting endangered species and native ecosystems will continue to be an afterthought, at best. Many areas of habitat are accessible by 4-wheel-drive vehicle and the environment is not especially difficult or harsh. In fact, commercial ecotours are regularly conducted on Mauna Kea (with observing palila as a major goal) and substantial numbers of hunters roam the slopes during game bird season. A large cross-section of the public could potentially be involved in habitat protection, restoration, and monitoring in a variety of ways and over large areas. With supervision and logistical support, citizens could contribute significantly towards palila recovery by controlling and monitoring weeds, pests, and predators; planting trees and other native species, and assisting with fuels management and fire education. There are significant opportunities to incorporate environmental education and recreation into habitat restoration activities, such as creating one or more sites on Mauna Kea as centers for education, recreation, management, and research. However, involving the public effectively in restoration will require planning, coordination, organization, and fundraising. There are few models in Hawai`i on which to base a citizen program, but among the programs that should be reviewed for insights into this approach are: the Auwahi dry forest restoration project on Maui, the koa reforestation program at Hakalau Forest National Wildlife Refuge, the silversword planting program on Mauna Kea (Silversword Alliance), the Kona TREE (Tree Restoration, Ecology, and Education) project, and the weed control program at Pu`u Huluhulu Natural Area Reserve.

Studies on fire ecology and behavior in subalpine dry forests on Mauna Kea were initiated in 2005, to provide fire management recommendations. In the meantime, there are a number of actions that should be taken to reduce the threat of fire in palila habitat. Foremost among these is controlling human activity in areas of high fire risk, in particular: 1) preventing vehicles from parking where grass can be ignited by the catalytic converter, 2) restricting access when fire conditions are extreme, and 3) educating the public about ways of preventing fire (e.g., not smoking). A forest ranger program is needed to provide a basic level of fire prevention, detection, reporting, and suppression. Maintenance of roads, fuel breaks, and water dip tanks also is important in permitting rapid access of fire fighting equipment and personnel and in limiting fires to relatively small units. As part of the mitigation for realigning Saddle Road through the Pōhakuloa Training Area, the opportunity for ignition of roadside fires will be minimized and emergency phones will be installed to enhance fire reporting. In addition, military fire suppression capabilities are being increased. Until fire and other threats become manageable on the western slope, a high priority should be placed on establishing at least one other viable population of palila on Mauna Kea.

Recovery of palila requires not only that management actions be carried out, but also that monitoring and research are used to support and assess management decisions. Although palila ecology is relatively well-known, subalpine dry forests on Mauna Kea are rebounding from severe browsing damage, and the relationship between bird populations and their habitat will likely be dynamic. Systematic monitoring to detect new threats that will inevitably emerge in this changing environment will be critically important to recovery. Reporting the results of research and monitoring will also be important in maintaining the public’s interest and concern for palila and their habitat.

8. Maui Parrotbill, *Pseudonestor xanthophrys*

DESCRIPTION AND TAXONOMY

Male Maui parrotbill. Photo © Eric VanderWerf.

The Maui parrotbill is one of the larger (20 to 25 grams [0.68 to 0.85 ounce]) and more unique of the extant Hawaiian honeycreepers (family Fringillidae, subfamily Drepanidinae). It has a large head, thick, muscular neck, a massive curved, parrot-like bill, stout legs, and short wings and tail. Adult Maui parrotbills of both sexes are olive-green on the crown, back, wings, and tail, yellow on the cheeks, breast, and belly, grading into paler yellowish and white towards the vent, with a contrasting bright yellow supercilium (line above the eye). The hooked upper mandible is dark gray, and the chisel-like lower mandible is a pale ivory color. The sexes are clearly dimorphic in size; males are heavier, larger-billed, and longer-winged than females. Males also tend to be more brightly colored than females, but not all individuals of each sex can be accurately distinguished by color (Mountainspring 1987, Simon *et al.* 1997, Berlin *et al.* 2001). Juvenile plumage can be confused with some female plumages, but usually young are duller grayish-green above and light gray ventrally instead of yellow like adults.

The Maui parrotbill is a monotypic species with no known geographic variation in plumage or morphology. Based on morphology and molecular genetics (Simon *et al.* 1997, Fleischer *et al.* 1998), it is most closely related to the \`akiapōlā\`au and the life histories of these two species are similar in many respects (Simon *et al.* in press).

LIFE HISTORY

The Maui parrotbill is insectivorous and often feeds in a deliberate manner, using its massive hooked bill to dig, tear, crack, crush, and chisel the bark and softer woods on a variety of native shrubs and small- to medium-sized trees, especially \`ākala (*Rubus hawaiensis*), kanawao (*Broussaisia arguta*), and \`ōhi\`a (*Metrosideros polymorpha*). Parrotbills also pluck and bite open fruits, especially those of kanawao, in search of insects, but do not eat the fruit itself. Especially preferred are larvae and pupae of various beetles and moths (Perkins 1903, Mountainspring 1987, Simon *et al.* 1997). The specialized foraging behavior of the parrotbill requires each pair of birds to defend a relatively large territory year-round, averaging 2.3 hectares (5.7 acres) in size (Pratt *et al*. 2001a), thus the population density of this species is relatively low. This low density translates into a small population size, since at present there is only limited habitat available for the species that is not too small and/or degraded to support parrotbills.

The ecology of the Maui parrotbill has been little studied, but recently Lockwood *et al.* (1994) and Simon *et al.* (1997) investigated aspects of its reproductive biology, reported below. Maui parrotbills are socially monogamous, and both sexes play a role in the selection of the nest site between November and June. The open cup nest composed mainly of lichens (*Usnea* sp.) and pukiawe (*Styphelia tameiameiae*) twigs is built by the female an average of 12 meters (40 feet) above the ground in a forked branch just under the outer canopy foliage. Only single egg clutches have been documented (Simon *et al.* 1997). Re-nesting occurs only after nest failures, and pairs will not raise more than one brood in a season. Only females incubate and brood. The incubation period is 16 days, and the nestling period is approximately another 20 days. Breeding males feed incubating and brooding females. Females feed nestlings with the food provided by males. Once fledged, the young are frequently fed directly by the male. Development of the large bill and specialized feeding techniques proceed slowly, and fledglings depend on their parents for 5 to 8 months (Simon *et al*. 1997). Parrotbills frequently occur in family groups due to this prolonged dependency.

Vocalizations of the Maui parrotbill include a loud song of repeated, descending "chewy" notes, and three calls given by both sexes: sharply defined chip notes, a soft "wit" contact call, and an upslurred two-part whistle (Simon *et al.* 1997). Singing occurs throughout the year, but most often in winter and spring when the birds breed. The chip notes are very similar to the chip notes of the Maui `alauahio (*Paroreomyza montana*), which occur with parrotbills in mixed-species flocks, although call delivery rates for the species can differ. The possibly extinct po`ouli (*Melamprosops phaeosoma*) also produces chip notes very similar to those of the parrotbill.

HABITAT DESCRIPTION

At present, Maui parrotbills survive in mid- to upper-elevation montane wet forest dominated by `ōhi`a, and in a few mesic areas dominated by `ōhi`a and koa (*Acacia koa*), with an intact, dense, diverse native understory and subcanopy of ferns, sedges, epiphytes, shrubs and small to medium trees. The topography in these areas is generally steep and highly dissected by deep gulches and narrow ridges. The climate is cool year-round, with frequent clouds, mist, and rain. Annual precipitation may reach as much as 8,500 millimeters (335 inches) a year. Maui parrotbills are sympatric with several other honeycreeper species, and their distribution is now limited to high elevation areas with relatively little alteration by feral ungulates (Mountainspring 1987) or encroachment of nonnative vegetation, and the absence of disease-carrying mosquitoes (Scott *et al.* 1986).

HISTORICAL AND CURRENT RANGE AND STATUS

Currently the Maui parrotbill is found only on Haleakalā Volcano in East Maui, in 50 square kilometers (19 square miles) of wet montane forests from 1,200 to 2,350 meters (4,000 to 7,700 feet) elevation (Scott *et al.* 1986, Mountainspring 1987, Simon *et al.* 1997). The current range includes the Waikamoi Drainage west of Ko`olau gap to Haleakalā National Park lands in Kīpahulu Valley and the Manawainui Drainage (Figure 13). Based on collections of subfossil bones, the current geographic range is much restricted compared to the known prehistoric range, which included dry leeward forests and low elevations (200 to 300 meters [660 to 1,000 feet]) on East Maui as well as Moloka`i (James and Olson 1991).

In 1980, the number of Maui parrotbills was estimated by the Hawai`i Forest Bird Survey at 500 ± 230 (95 percent confidence interval) birds with an average density of 10 birds per square kilometer (0.39 square mile) (Scott *et al.* 1986). Repeat surveys of the same transects conducted in 1992 (Hawai`i Department of Land and Natural Resources, unpubl. data) and limited surveys conducted from 1995 to 1997 by U.S. Geological Survey biologists indicated approximately the same densities of birds, but with perhaps some range constriction at lower elevations.

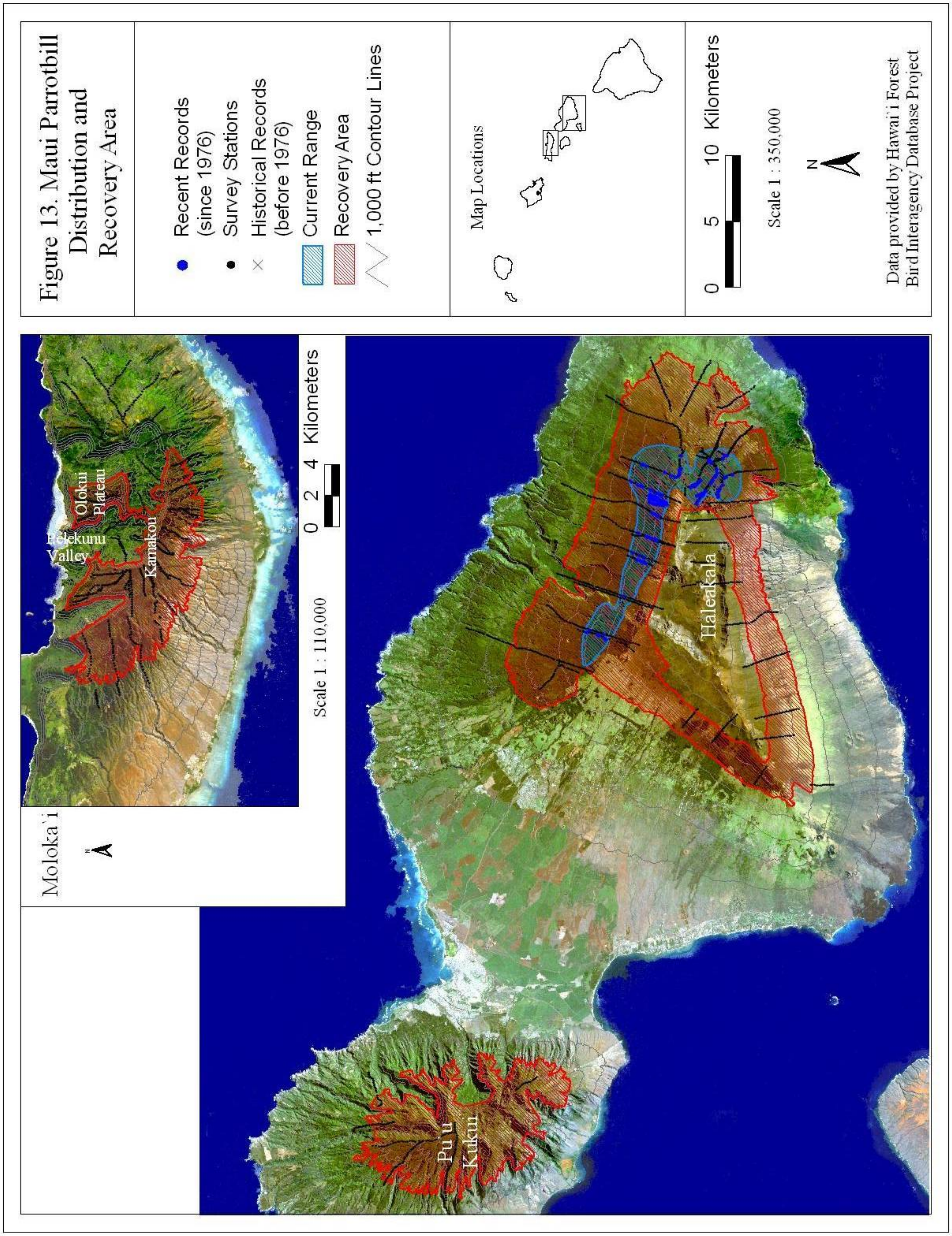


Figure 13. Maui Parrotbill Distribution and Recovery Area

REASONS FOR DECLINE AND CURRENT THREATS

The Maui parrotbill is subject to the same threats that negatively affect other forest birds on Maui, including habitat loss and degradation, predation, and introduced diseases. The parrotbill has a very low reproductive rate (see Life History), which makes it particularly vulnerable and slow to recover. Other factors, such as competition from introduced avian and arthropod insectivores, have not been documented, but purposeful and accidental introduction of alien species remains a persistent threat.

Habitat Loss and Degradation. Historically, Maui parrotbills were reported to favor koa for foraging (Perkins 1903). Widespread habitat destruction of koa forests due to logging and ranching has significantly reduced the species' range, and has been particularly severe in more mesic areas that formerly supported high densities of koa. The species' current range is restricted to wet forest areas where koa densities are relatively low. Thus, occupied habitat may be suboptimal compared to portions of the former range. Within its current range, habitat damage to the understory vegetation by feral pigs may be a significant factor contributing to reduced food availability, large territories, and low reproduction. Unoccupied but potential habitat that is currently degraded because of pigs may be suitable for reestablishment of parrotbills once pigs are removed and the areas have recovered. Low quality or damaged habitat may exacerbate the negative effects of severe weather events such as rainstorms, which are common in East Maui and have been linked to failure of parrotbill nests (Mountainspring 1987, Simon *et al.* in press).

Predation. The importance of predation in limiting parrotbill populations is not clear. However, predation of nests and adults by rats, cats, mongooses, and owls is suspected to have a significant impact on many native Hawaiian bird species (Atkinson 1977, VanderWerf and Smith 2002). Recent surveys indicate rat densities are very high in the Hanawī area where much of the parrotbill population currently occurs (Sugihara 1997; T. Malcolm, Maui Forest Bird Recovery Project, pers. comm.).

Introduced Diseases. Most Hawaiian forest birds are susceptible to introduced mosquito-borne diseases, and the Maui parrotbill may be limited to its current high-elevation distribution by these diseases (Scott *et al.* 1986, Mountainspring 1987). Despite the availability of apparently suitable habitat, parrotbills are absent from most areas below 1,350 meters (4,500 feet), where mosquitoes are common. This pattern contrasts with that of some unlisted species, suggesting that parrotbills and other endangered species are especially susceptible to disease.

CONSERVATION EFFORTS

The Maui parrotbill was federally listed as an endangered species on March 11, 1967 (U.S. Fish and Wildlife Service 1967). It became protected under the State of Hawai`i endangered species law on March 22, 1982, and was included in the Maui-Moloka`i Forest Birds Recovery Plan (U.S. Fish and Wildlife Service 1984a).

Declines of the Maui parrotbill, Maui `ākepa, Maui nukupu`u, `ākohekohe, and especially the po`ouli prompted conservation agencies to protect the habitat in which these birds persisted. Reserves were created at Hanawī by the State of Hawai`i Department of Land and Natural Resources and at Waikamoi on private lands by The Nature Conservancy of Hawai`i. In 1991, the State of Hawai`i, The Nature Conservancy, Haleakalā National Park, Hāna Ranch, Haleakalā Ranch, Alexander and Baldwin (East Maui Irrigation Company) and the Maui County Department of Water Supply joined together to protect 40,486 hectares (100,000 acres) of wet forest in East Maui under the East Maui Watershed Partnership. This large watershed area encompasses the entire current range of the Maui parrotbill.

Through ongoing fencing and feral ungulate control, the State, Haleakalā National Park, and The Nature Conservancy of Hawai`i have reduced or removed feral pigs on much of their lands ranging from Waikamoi to Kīpahulu. Recent East Maui Watershed Partnership fencing, research, and ungulate management in the State forest reserves continue to protect and restore native forest. These actions and improvements should benefit the Maui parrotbill and other forest birds. The Hawai`i Department of Land and Natural Resources and U.S. Fish and Wildlife Service jointly fund the Maui Forest Bird Recovery Project, which conducts research and habitat management in Hanawī Natural Area Reserve and other areas that will benefit Maui parrotbill and other endangered species in the Hanawī Natural Area Reserve and adjacent habitat. Activities undertaken by this project include predator and ungulate control, surveying, mist-netting, banding, and monitoring of forest birds, optimization of predator control methods, and assessment of management actions on native forest bird populations.

In 1997, a captive breeding program for the Maui parrotbill was initiated when an egg was taken to the Maui Bird Conservation Center, following the recommendations of Ellis *et al.* (1992). In 1999, two additional wild eggs were collected, hatched, and reared (The Peregrine Fund 1999). One pair formed from these eggs and this pair produced two chicks in 2000 (The Peregrine Fund and Zoological Society of San Diego 2000). In 2001, three additional chicks were produced and one wild adult male, injured in the field, was added to the captive breeding program (Zoological Society of San Diego 2001). The number of captive birds now numbers 10 (3 males and 7 females). Additional eggs may be collected in future years to enhance the captive breeding program, with the intent of producing more birds for reintroduction into managed recovery areas.

RECOVERY STRATEGY

The recovery strategy for the Maui parrotbill centers on the protection, restoration, and management of native high elevation forests on East Maui (Haleakalā), research to understand threats from disease and predation, and captive propagation to produce birds for reestablishment of wild populations. Reestablishment of parrotbills on West Maui or East Moloka`i is needed to provide a minimum of two viable populations, or to allow for a single viable metapopulation, in order to reduce the risk of extinction due to catastrophes such as hurricanes and epizootics of disease. Reestablishment in southern or western areas of Haleakalā is needed to promote natural demographic and evolutionary processes.

Recovery Areas. Parrotbills are currently restricted to the windward forests of East Maui from Waikamoi to Kaupō (Figure 13). State and Federal agencies and the East Maui Watershed Partnership have been successful in protecting much of the remaining parrotbill habitat. However, extensive work is still needed to fence and protect the lower elevation areas from Hanawī Natural Area Reserve to Waikamoi; this area is with the species’ range, and also contains potential habitat. Additional fencing and ungulate eradication in this area will facilitate the recovery of an intact and diverse native subcanopy vegetation which may in turn increase food availability. This work may also help to reduce levels of mosquito vectors.

On southern and western exposures of East Maui (Haleakalā), a continuous "lei" or ring of suitable forest should be reconnected around the mountain, especially at upper elevations where mosquitoes are rare. Although the current parrotbill population is restricted to the wet `ōhi`a forests of windward East Maui, this may represent a contraction of range into marginal habitat following widespread habitat loss and degradation (Simon *et al.* 1997). Parrotbills were once found throughout leeward areas and are thought to prefer koa for foraging (Perkins 1903). Habitat restoration and reestablishment of a population on the leeward or western exposures of East Maui is needed to help reduce extinction risk, and to increase the ecological breadth of the species to help buffer against climatic fluctuations. The restoration of koa to these montane regions is a key element of habitat restoration in these areas.

A small amount of unprotected, remnant mesic koa forest currently exists on State Forest Reserve and Department of Hawaiian Homelands properties in the Kahikinui region of southern Haleakalā. This area holds great potential to provide suitable habitat for the parrotbill. The completion of fencing projects and initiation of programs to eradicate ungulates are needed to restore the native canopy and understory. Fencing of over 2,000 acres (800 hectares) has already begun, and long-term plans involve protection of over 20,000 acres (8,000 hectares). The subsequent removal of feral ungulates would allow the natural regeneration of koa and other plant species, and ground scarification and outplanting may be used to speed habitat restoration. This work could proceed to the east and west, eventually relinking the remnant Kahikinui Forest to other forests on East Maui, possibly including Manawainui, Kaupō, and remnant koa forests near Kula.

Most of the remaining leeward montane forests on southern slopes, while believed to be largely mosquito-free, currently are degraded by ungulates. These areas, in addition to fencing and ungulate control, will require more intensive, long-term restoration to be suitable for endangered forest birds.

Although much of the potential parrotbill habitat on West Maui and East Moloka`i is mostly free of ungulates, the suitability of these areas with respect to the presence of introduced mosquito-borne diseases is not clear. Much of this habitat lies at elevations below 1,350 meters (4,500 feet), and thus likely holds mosquitoes. Ongoing habitat management and removal of ungulates may reduce mosquito densities, but surveys of mosquitoes and disease prevalence are needed prior to the reintroduction of endangered forest birds in these areas. This work should be integrated into an evaluation of the amount of suitable habitat available, estimates of the size of the population that could be supported, and a population viability analysis of the hypothetical population that would aid plans to reestablish populations in those areas. In addition, control of mammalian predators is needed at a large enough geographic scale to protect new populations.

Predator Control. An important component of parrotbill recovery should be an evaluation of the effect of rodent control on parrotbill reproduction and survival, and an expansion of the scale of work if warranted. Control of small mammalian predators may be needed throughout recovery areas and may be especially important for parrotbill populations, because this species has a low reproductive rate and thus is particularly sensitive to high rates of nest loss and adult mortality (Simon *et al.* 2000).

Disease. Protecting and restoring habitat in upper elevation disease-free areas is crucial to parrotbill recovery. The identification of disease-resistant individuals and incorporation of these individuals into captive breeding and translocation programs could greatly enhance recovery efforts. Resistance or tolerance to disease appears to be evolving in populations of some birds (Cann and Douglas 1999, Woodworth *et al*. 2005), and resistant parrotbills may exist too. Parrotbills may occur at lower elevations in Kīpahulu Valley than elsewhere, but the reasons are not clear, and this pattern may be related to habitat rather than disease resistance. Further research into the causes of this pattern is needed.

Captive Propagation and Reintroduction Programs. Captive propagation may play a significant role in the recovery of the Maui parrotbill, and there are plans to increase the captive population. Initial efforts at captive propagation of the Maui parrotbill have been successful, with the hatching of three wild eggs (one male, two females) that have bred in captivity, producing four eggs with the subsequent rearing of three chicks. Research and development of reintroduction techniques and evaluation of sites for experimental releases are needed for this species.

9. Kaua`i `Akialoa, *Hemignathus procerus*

DESCRIPTION AND TAXONOMY

Kaua`i `akialoa. © from Rothschild (1893-1900). Courtesy of Smithsonian Institution Libraries.

The Kaua`i `akialoa is a large (17 to 19 centimeters [6.7 to 7.5 inches] total length), short-tailed Hawaiian honeycreeper with a very long, thin decurved bill, the longest bill of any historically known Hawaiian passerine. Both sexes are olive-green; males are more brightly colored, slightly larger, and have a somewhat longer bill. The species was originally described by Gray in 1859, and its taxonomy and nomenclature have changed repeatedly (Olson and James 1995, Pratt 2005). It is in the Hawaiian honeycreeper family, subfamily Drepanidinae of the family Fringillidae.

LIFE HISTORY

The life history of the Kaua`i `akialoa is poorly known, based mainly on observations from the end of the 19th century (Wilson and Evans 1890 to 1899, Rothschild 1893 to 1900, Perkins 1903). The species used its long bill to probe for arthropods in bark crevices, decaying wood, epiphytes, and debris accumulated in the treetops. It also took nectar from `ōhi`a and lobelia flowers. Nothing was ever discovered about its nesting biology. The song was described as either a thin trill or canary-like, and the call as being louder and deeper than that of the Kaua`i `amakihi (*Hemignathus kauaiensis*).

HABITAT DESCRIPTION

The species was widespread on Kaua`i and occupied all forest types above 200 meters (660 feet) elevation (Perkins 1903).

HISTORICAL AND CURRENT RANGE AND STATUS

The historical range included nearly all forests on Kaua`i visited by naturalists at the end of the 19th century (see Figure 7 on page 2-21). After a hiatus of many decades, the species was seen again in the late 1960s, and one specimen was collected (Richardson and Bowles 1964). It has not been seen since, despite efforts by ornithologists (Conant *et al.* 1998), birders, and intensive survey efforts by wildlife biologists in 1968 to 1973, 1981, 1989, 1994, 2000, and 2005 (Sincock 1982; Hawai`i Department of Land and Natural Resources, unpubl. data; Reynolds and Snetsinger 2001). The Kaua`i `akialoa may be extinct, but recent reexamination of the survey data for this species indicates that additional survey effort is required to confirm its status. If the remaining population is very small, fewer than 50 individuals, the likelihood that an individual bird would be detected given the level of survey effort thus far is relatively low (Scott *in litt*. 2006). There is some possibility that the species still survives in some small, remote area, particularly given the difficulty of the terrain and the inaccessibility of many of the sites where the species would be most likely to persist. The location of one of the last reports of the species, on private land, has not been revisited. Additional targeted surveys are needed to determine the status of the species with confidence.

REASONS FOR DECLINE AND CURRENT THREATS

The Kaua`i `akialoa vanished before anything could be learned of its plight. Presumably it succumbed to the same causes responsible for the decline and extinction of other forest birds on Kaua`i: introduced avian diseases transmitted by mosquitoes, depredation of adults and nests by rats, and habitat destruction by feral ungulates. Perkins (1903) noted that it was "grievously affected by… swellings on the legs and feet, as well as on the head at the base of bill, and on the skin around the eyes," which probably were caused by pox. Avian pox lesions are also present on many old specimens (J. Lepson and E. VanderWerf, unpubl. data).

CONSERVATION EFFORTS

The Kaua`i `akialoa was federally listed as endangered on March 11, 1967 (U.S. Fish and Wildlife Service 1967), became protected under the State of

Hawai`i endangered species law on March 22, 1982, and was included in the Kaua`i Forest Birds Recovery Plan (U.S. Fish and Wildlife Service 1983b).

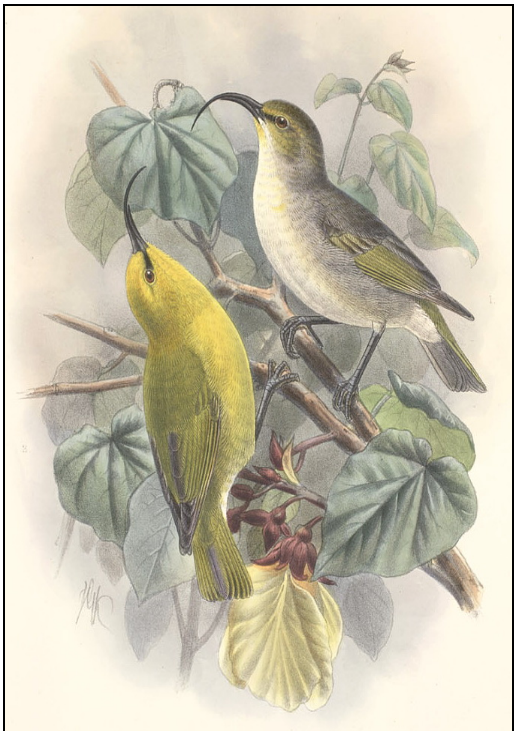
No conservation efforts have been initiated specifically for the Kaua`i `akialoa, but if the species still exists it could benefit from habit protection (see puaiohi species account). The Forest Reserve Act of 1903 was an important action that protected watersheds in Hawai`i. It was later strengthened and re-titled "Hawai`i Department of Land and Natural Resources Title 13, Chapter 104, Rules Regulating Activities Within Forest Reserves," which protects native forest habitats from certain degrading factors caused by human activities. The Hawai`i Department of Land and Natural Resources established the 4,022 hectare (9,938 acre) Alaka`i Wilderness Preserve in 1964 (Administrative Rule No. 1, Chapter 3), recognizing the value of the pristine forest of that area and the need to control potential degrading factors.

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

10. Kaua`i Nukupu`u, *Hemignathus lucidus hanapepe*

DESCRIPTION AND TAXONOMY



Kaua`i nukupu`u pair. © from Rothschild (1893-1900). Courtesy of Smithsonian Institution Libraries.

The Kaua`i nukupu`u is a long-billed Hawaiian honeycreeper (family Fringillidae, subfamily Drepanidinae), larger than the similar Kaua`i `amakihi (*Hemignathus kauaiensis*), and with an extraordinarily thin, curved bill, slightly longer than the bird's head. The lower mandible is half the length of the upper mandible and follows its curvature rather than being straight as in the related `akiapōlā`au (*Hemignathus munroi*) of Hawai`i Island. Adult males are olive green with a yellow head, throat, and breast, whereas adult females and immatures have grayish green upper parts and whitish under parts. First- and second-year males resemble females. Kaua`i nukupu`u (*H .l. affinis*) differ from Maui nukupu`u by their larger size and subtle differences in plumage (see Maui nukupu`u species account).

The Kaua`i nukupu`u is one of two subspecies of nukupu`u that may still survive (the other is the Maui nukupu`u). The Kaua`i nukupu`u was described by Wilson (1889). Evidence is mounting that the Kaua`i, O`ahu, and Maui forms of nukupu`u are distinct species (Pratt 2005; R. Fleischer, unpubl. data).

LIFE HISTORY

The historical record provides little information on the life history of the Kaua`i nukupu`u (Rothschild 1893 to 1900, Perkins 1903). Nothing is known of its breeding biology, which is likely similar to its closest relative, the `akiapōlā`au (see `akiapōlā`au species account). Kaua`i nukupu`u extract or excavate invertebrates from epiphytes, bark, and wood using their unusual bill in a manner similar to that of the `akiapōlā`au. Nukupu`u often join mixed species foraging flocks, especially with the Kaua`i creeper (*Oreomystis bairdi*). The song of the Kaua`i nukupu`u resembles the warble of a house finch (*Carpodacus mexicanus*), and both the song and the "kee-wit" call resemble those of `akiapōlā`au (Perkins 1903).

HABITAT DESCRIPTION

Historical records from the turn of the last century indicate that the Kaua`i nukupu`u was found in a small area of diverse montane mesic and wet forest at elevations of 610 to 1,220 meters (2,000 to 4,000 feet) on the southwestern slope of Kaua`i Island (Banko 1984b). All subsequent sightings, many of them doubtful, have been from the same habitat (Pratt and Pyle 2000).

HISTORICAL AND CURRENT RANGE AND STATUS

No subfossils of Kaua`i nukupu`u have been reported, so our understanding of the original distribution of this subspecies is limited to the historical record. Since 1960, the nukupu`u has been reported infrequently from Kōke`e and the Alaka`i (see Figure 7 on page 2-21; Scott *et al.* 1986, Pratt and Pyle 2000). However, some of these descriptions better match the similar Kaua`i `amakihi. Several recent intensive surveys (1981 to 2000) have failed to find the Kaua`i nukupu`u (Pratt and Pyle 2000). However, skilled observers reported three (unconfirmed) sightings of Kaua`i nukupu`u in 1995. Search results for nukupu`u on Kaua`i are currently considered inconclusive (Reynolds and Snetsinger 2001), and additional survey efforts are needed to confirm the status of the species.

REASONS FOR DECLINE AND CURRENT THREATS

In the absence of information pertaining to this species, reasons for decline and current threats are presumed to be the same as for other endangered birds on Kaua`i (see puaiohi species account).

CONSERVATION EFFORTS

The Kaua`i nukupu`u was federally listed as an endangered species on March 11, 1967 (U.S. Fish and Wildlife Service 1967), became protected under the State of Hawai`i endangered species law on March 22, 1982, and was included in the Kaua`i Forest Birds Recovery Plan (U.S. Fish and Wildlife Service 1983b).

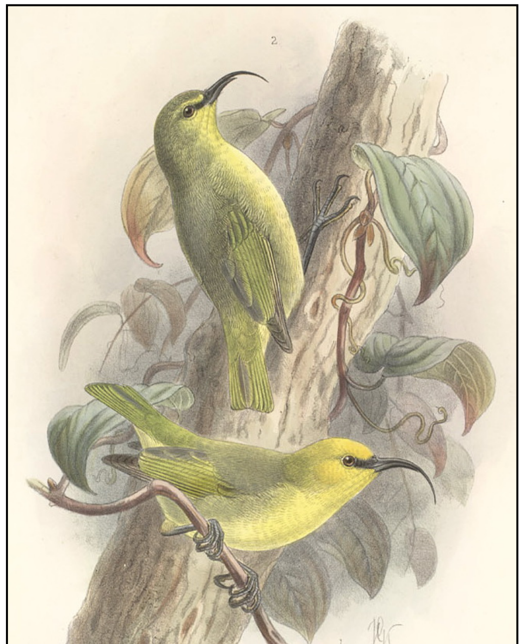
No conservation efforts have been initiated specifically for the Kaua`i nukupu`u, but if the species still exists it could benefit from habit protection (see puaiohi species account). The Forest Reserve Act of 1903 was an important action that protected watersheds in Hawai`i. It was later strengthened and re-titled "Hawai`i Department of Land and Natural Resources Title 13, Chapter 104, Rules Regulating Activities Within Forest Reserves," which protects native forest habitats from certain degrading factors caused by human activities. The Hawai`i Department of Land and Natural Resources established the 4,022 hectare (9,938 acre) Alaka`i Wilderness Preserve in 1964 (Administrative Rule No. 1, Chapter 3), recognizing the value of the pristine forest of that area and the need to control potential degrading factors.

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

11. Maui Nukupu`u, *Hemignathus lucidus affinis*

DESCRIPTION AND TAXONOMY


Maui nukupu`u. © from Rothschild (1893-1900). Courtesy of Smithsonian Institution Libraries.

The Maui nukupu`u is a medium-sized, approximately 23 gram (0.78 ounce), Hawaiian honeycreeper (family Fringillidae, subfamily Drepanidinae) with an extraordinarily thin, curved bill, slightly longer than the bird's head. The lower mandible is half the length of the upper mandible and follows its curvature rather than being straight as in the related `akiapōlā`au (*Hemignathus munroi*) of Hawai`i Island. Adult males are olive green with a yellow head, throat, and breast, whereas adult females and immatures have an olive-green head and yellow or yellowish gray under-parts. Females and first- and second-year males are nearly identical and have a noticeably pale superciliary line. Maui nukupu`u differ from Kaua`i nukupu`u (*H. l. hanapepe*) by their smaller size, yellowish rather than whitish vent, and grayish-green rather than yellowish-green back.

The Maui nukupu`u is one of three subspecies. The Maui and Kaua`i subspecies may still survive, but *H. l. lucidus* of O`ahu is extinct. Evidence is mounting that the Kaua`i, O`ahu, and Maui forms of nukupu`u are distinct species (Pratt 2005; R. Fleischer, unpubl. data). The Maui nukupu`u was described by Rothschild (1893 to 1900).

LIFE HISTORY

The historical record provides little information on the life history of the Maui nukupu`u (Rothschild 1893 to 1900, Perkins 1903). Nothing is known of its breeding biology, which likely was similar to its closest relative, the `akiapōlā`au (see `akiapōlā`au species account). Maui nukupu`u tap and probe bark, lichen, and branches to extract insects, and thus their foraging behaviors resemble those of `akiapōlā`au. Diet of the Maui nukupu`u was reported by Perkins (1903) to be small weevils and larvae of coleoptera (beetles) and Lepidoptera (butterflies and moths). Apparently they seldom forage for larvae and adults of longhorn beetles (Cerambycidae) and thereby compete little with Maui parrotbills. There is scant evidence that Maui nukupu`u take nectar from flowers. Maui nukupu`u often join mixed species foraging flocks (Perkins 1903). Their song resembles the warble of a house finch (*Carpodacus mexicanus*), but is lower in pitch. Both the song and the "kee-wit" call resemble those of `akiapōlā`au and Maui parrotbill (Perkins 1903).

HABITAT DESCRIPTION

The first historical records, at the turn of the last century, indicate that the Maui nukupu`u inhabited mixed koa/`ōhi`a (*Acacia koa*/*Metrosideros polymorpha*) forest from 1,220 meters (4,000 feet) to timberline (Perkins 1903, Banko 1984b, Hawai`i Natural Heritage Program Database) on the northwestern slope of Haleakalā. Sightings since the 1967 rediscovery of the Maui nukupu`u have been in mixed shrub montane wet forest (Jacobi 1985) in Kīpahulu Valley and the northeast slope of Haleakalā at 1,100 to 2,100 meters (3,600 to 6,720 feet), though most have been above 1,700 meters (5,500 feet; Banko 1984b). Discovery of subfossil nukupu`u on Moloka`i and Maui show that the species once inhabited dry forests (James and Olson 1991).

HISTORICAL AND CURRENT RANGE AND STATUS

Historically, the Maui nukupu`u is known only from Maui, but subfossil bones of a probable Maui nukupu`u from Moloka`i show that the species formerly inhabited that island (James and Olson 1991). A nukupu`u specimen from Hawai`i Island does not represent the Maui form and was shown genetically to be a mislabeled O`ahu bird (Olson and James 1994; Pratt 2005). All records prior to 1967 were from locations most accessible to naturalists, above Olinda on the northwest rift of Haleakalā (Figure 14; Banko 1984b). Observers at the time noted the restricted distribution and low population density of Maui nukupu`u. As on Kaua`i, introduced mosquitoes (Hardy 1960) and avian diseases may have already limited these birds to forests at higher elevations. We can presume that the Maui nukupu`u once had a much wider geographic range.

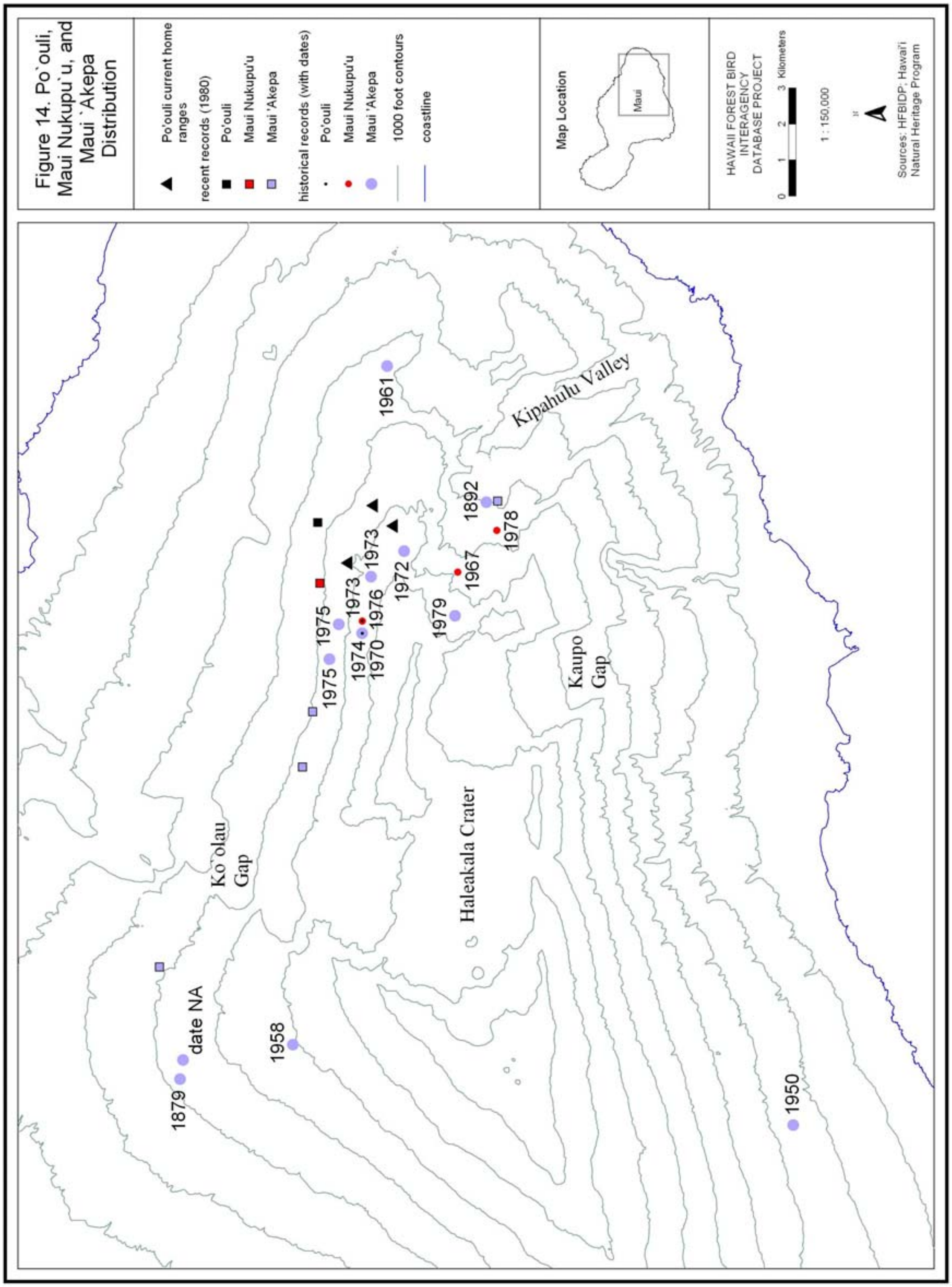


Figure 14. Po`ouli, Maui Nukupu`u, and Maui `Akepa Distribution
Po'ouli current home ranges
recent records (1980)
Po'ouli
Maui Nukupu'u
Maui 'Akepa
historical records (with dates)
Po'ouli
Maui Nukupu'u
Maui 'Akepa
1000 foot contours
coastline
Map Location
Maui
HAWAII FOREST BIRD INTERAGENCY DATABASE PROJECT
0 1 2 3 Kilometers
1 : 150,000
Sources: HFBIDP; Hawai'i Natural Heritage Program
Kipahulu Valley
Kaupo Gap
Haleakala Crater
Ko`olau Gap
date NA
1879
1958
1950
1961
1892
1978
1967
1979
1972
1973
1973
1976
1974
1970
1975
1975
1975

In 1967, W. Banko rediscovered Maui nukupu`u in the upper reaches of Kīpahulu Valley on the eastern slope of Haleakalā (Banko 1968). Since then, isolated sightings have been reported on the northern and eastern slopes of Haleakalā from below Pu`u `Alaea east to Kīpahulu Valley (Pratt and Pyle 2000). Because most of these sightings were uncorroborated by behavioral information or follow-up sightings, the recent status of the Maui nukupu`u is difficult to evaluate. Scott *et al.* (1986) estimated a population of 28 ± 56 birds based on a single sighting. One bird was detected in 1994, and was resighted in 1995 and a second time in 1996, on the northeast slope of Haleakalā (Reynolds and Snetsinger 2001). However, most recent intensive surveys (1995 to 1999) did not detect nukupu`u at locations of previous sightings (Baker 2001; Hawai`i Department of Land and Natural Resources, unpubl. data). Although it is possible the Maui subspecies may be extinct (Pratt and Pyle 2000), the relatively recent sightings of nukupu`u on Haleakalā and extensive habitat area that still exists for nukupu`u led Reynolds and Snetsinger (2001) to conclude that the nukupu`u is still extant on Maui. Further targeted surveys will be required to confirm the status of this species.

REASONS FOR DECLINE AND CURRENT THREATS

Reasons for decline and current threats are presumed to be the same as for other endangered Maui birds. See po`ouli species account.

CONSERVATION EFFORTS

The Maui nukupu`u was federally listed as an endangered species on March 11, 1967 (U.S. Fish and Wildlife Service 1967), became protected under the State of Hawai`i endangered species law on March 22, 1982, and was included in the Maui-Moloka`i Forest Birds Recovery Plan (U.S. Fish and Wildlife Service 1984a). Until 1995, no efforts had been initiated in the field specifically for Maui nukupu`u. The species has since benefited, or could benefit, from thorough surveys of the best habitat, predator control, and habitat restoration at locations where the last sightings were reported (see po`ouli species account).

RECOVERY STRATEGY

See the Rare Bird Discovery Protocol in Section III-D.

12. \`Akiapōlā\`au, *Hemignathus munroi*

DESCRIPTION AND TAXONOMY

Male (right) and female \`akiapōlā\`au.
Photo © Eric VanderWerf

The \`akiapōlā\`au is a medium-sized (14 centimeter [5.5 inch], 28 gram [0.9 ounce]), stocky, short-tailed Hawaiian honeycreeper (family Fringillidae, subfamily Drepanidinae) endemic to the Island of Hawai\`i. Its most remarkable feature is the extraordinary bill, which has a long, sickle-shaped upper mandible and a short, straight lower mandible that is only half as long as the upper. Males are larger and heavier than females and have a slightly longer bill. Adult males have a bright yellow head and underparts, a greenish back and wings, and black lores. Adult females differ in color, with a yellowish-white chin, throat, and upper breast that contrasts with a pale yellowish-gray lower breast and belly (Pratt *et al.* 1994). Fledglings have a mottled yellowish-gray or green juvenile plumage with pale under parts. Within a few months of fledging juveniles molt into a similar but unmottled first basic plumage. Most birds molt into definitive basic (adult) plumage in their second year (Pratt *et al.* 1994).

The species was described by Rothschild (1893 to 1900), who named it *Heterorhynchus wilsoni*. The \`akiapōlā\`au was later grouped with the \`amakihi and renamed *Hemignathus munroi* (Pratt 1979, American Ornithologists' Union 1983). The \`akiapōlā\`au is closely related to the nukupu\`u (*H. lucidus*; Olson and James 1994). There is no notable morphological variation with elevation or locality.

LIFE HISTORY

Ralph and Fancy (1994c, 1996) and Pratt *et al.* (2001) described most of what is known about the life history of the \`akiapōlā\`au, and important new information on habitat use and demography was reported recently by Pejchar (2004).

The aspect of `akiapōlā`au life history most important to conservation is the low intrinsic rate of reproduction, which puts a premium on success of nesting events and on adult survival. Usually only one young is fledged, followed by an extended period (more than 4 to 5 months) of juvenile dependency, so that only a single brood is typically produced per year. Annual productivity was found to be 0.86 young per pair in a declining population (Ralph and Fancy 1996), and 0.96 ± 0.79 in closed, open, and koa plantation habitats combined (Pejchar 2004).

Breeding and molting occur mainly from February to July, but `akiapōlā`au can be found breeding or molting during any month of the year. Such broad overlap of these activities is unusual among birds, and research is needed to clarify the annual cycle of the `akiapōlā`au. The majority of nests have been found in the leafy, terminal branches of tall `ōhi`a (*Metrosideros polymorpha*) trees. The nest is cup-shaped and characterized by strips of `ōhi`a bark incorporated into the exterior surface. Clutch size is either one or, rarely, two eggs (Banko and Williams 1993). The female performs all incubation and brooding, while the male provides most of her food and that of the nestlings.


Male `akiapōlā`au exhibiting cranial kinesis that allows bill manipulation. Photo © Eric VanderWerf.

The `akiapōlā`au is mainly insectivorous. Moth larvae are the most common food item in `akiapōlā`au fecal samples, followed by spiders and long-horned beetle larvae (Ralph and Fancy 1996). The bird uses its unusual "Swiss-army knife beak" as two tools deployed separately or together. With the jaws gaped open, the short, robust lower mandible is used to rapidly tap branches to locate prey beneath the bark or in the wood. Once prey is located, the lower mandible is used as a chisel in a manner reminiscent of woodpeckers. The long, curved upper mandible is used as a probe to extract insect larvae and spiders from crevices or insect borings. Despite their different lengths, a remarkable degree of cranial kinesis allows the two mandibles to work in concert as pliers or tweezers for ripping away bark and epiphytes or for handling prey.

Lichen-covered and dead branches are preferred as foraging substrates. Males tend to select taller trees and to forage more often on the trunk and larger branches, whereas females and young are more often observed foraging on small branches and twigs (Ralph and Fancy 1996). The cause of sexual foraging differences is unknown. Tree species preferred for foraging include koa (*Acacia koa*), kōlea (*Myrsine* spp.), māmane (*Sophora chrysophylla*), and naio (*Myoporum sandwicense*), while `ōhi`a is not favored. The foraging behavior of `akiapōlā`au is very specialized compared with that of other forest birds, and foraging sites and food may be limiting.

This species rarely takes nectar from flowers, but it recently has been discovered to drink sap from small wells it drills in the bark of `ōhi`a trees. Only a few trees in a bird's territory are used for this purpose, and they are defended against other `akiapōlā`au. On average sap trees are larger, have thinner bark, greater sap flow, and tend to occur on convex slopes with more light (Pejchar and Jeffrey 2004).

`Akiapōlā`au often join mixed species foraging flocks, perhaps to enhance detection of predators. In montane mesic forests, they most frequently associate with Hawai`i creeper (*Oreomystis mana*) and `ākepa (*Loxops coccineus*), whereas in subalpine dry forest they are found with Hawai`i `amakihi (*Hemignathus virens*) and palila (*Loxioides bailleui*). The importance of these flocks to `akiapōlā`au has not been studied, but may prove relevant to the conservation of this species.

The primary song is a loud, rapid warble. Calls include a loud "pit-er-eoo" and an ascending "chu-wee," louder and deeper than similar calls of other species. While `akiapōlā`au sing year round, the seasonal frequency of singing appears to vary greatly. Current survey methodology, which relies on point counts of vocalizing birds, may be accurate when birds are vocal, but may considerably underestimate population density at times when birds are quiet. It would be useful to investigate seasonality of singing so that surveys and censuses can be planned to coincide with periods of peak singing.

Home range size varies from approximately 5 to 40 hectares (12 to 100 acres), with no difference between males and females, which remain together in pairs most of the time (Pratt *et al.* 2001a). Home ranges are defended as territories, and there is little evidence of daily or seasonal movements. Some birds appear temporarily in areas where they are usually not seen, suggesting some seasonal movement; others remain on territory year-round. The factors that influence the huge range in territory size, and therefore population size, are poorly known, but recent work by Pejchar (2004) showed that home range size varied from 23.0 ± 7.2 hectares (56.8 ± 17.8 acres) in open forest to 12.3 ± 7.2 hectares (30.4 ± 17.8 acres) in closed forests, and 11.7 ± 4.3 hectares (28.9 ± 10.6 acres) in young koa plantations. Furthermore, home ranges overlapped more in koa plantations (41.2 percent), than in closed forest (22.6 percent) or open forest (9.2 percent), resulting in even higher population densities in koa plantations (13 pairs per 100 hectares), than in closed forest (10 pairs per 100 hectares) or open forest (5 pairs per 100 hectares; Pejchar 2004). With so little disease-free habitat available to this species, this information is promising because it suggests it may be possible to increase the population size of the species by increasing population density.

HABITAT DESCRIPTION

Essentially all recent observations of \`akiapōlā\`au have been in montane mesic and wet forest dominated by koa and \`ōhi\`a or in subalpine dry forest dominated by māmane and naio. Although koa/\`ōhi\`a forest occurs below 1,300 meters (4,000 feet) elevation, few \`akiapōlā\`au are found there, presumably because of the presence of mosquitoes that transmit avian malaria and avian pox. Until recently, \`akiapōlā\`au extensively inhabited wet montane forest dominated by \`ōhi\`a, with no koa. Some birds are still found in that habitat at middle elevations in Hāmākua. The recent documentation of \`akiapōlā\`au inhabiting young koa plantations demonstrates that this species is not restricted to old growth (Pejchar 2004). These results indicate the need for a better understanding of the ways that silviculture practices and plantation forest structure affect food availability for \`akiapōlā\`au, and the need for follow-up studies that document the demography of \`akiapōlā\`au populations inhabiting these habitats.

Habitat preference of \`akiapōlā\`au in primary forest is well documented, but the use and persistence of successional habitats and habitat mosaics needs further study. This is evermore important in a landscape subject to lava flows and to changing patterns of agricultural and conservation use. These environments, mainly in Upper Waiākea, Kapāpala, and Kona, could be managed to expand and connect the existing core populations of \`akiapōlā\`au. \`Akiapōlā\`au will cross gaps of 100 meters (330 feet) or more, but the frequency with which they do so and the maximum width of gaps that they regularly cross is unknown. Study of habitat use is needed at the individual and metapopulation level.

HISTORICAL AND CURRENT RANGE AND STATUS

The `akiapōlā`au is endemic to Hawai`i Island and is presently unknown from the fossil record (James and Olson 1991). Historically, the `akiapōlā`au was much more common and widespread than it is today, being found virtually island-wide in native forest (Figure 15; Pratt *et al.* 2001a). Perkins (1903) reported that they were abundant and occurred as low as 500 meters (1,650 feet) in forests near Hilo. In the 1940s, they were still present above 1,700 meters (5,500 feet) in Hawai`i Volcanoes National Park (Baldwin 1953), but by 1970 they had disappeared from Hawai`i Volcanoes National Park and were less common elsewhere (Conant 1975, Banko and Banko 1980).

In the 1970s, `akiapōlā`au were found in 5 disjunct populations with a total estimated population size of 1,500 ± 400 birds (95 percent confidence interval; Scott *et al.* 1986). Four of these populations inhabited koa-dominated montane forests in Hāmākua south to the upper Waiākea kīpuka, Kūlani, and Keauhou, in Ka`ū and Kapāpala, in southern Kona, and in central Kona (Figure 15). A fifth population occupied subalpine dry forest on Mauna Kea. Originally these populations were all connected, but they have since been isolated by clearing of forest, mainly due to grazing.

Although the most recent population estimate, based on surveys from 1990 to 1995, is 1,163 birds with a 90 percent confidence interval of 1,109 to 1,217 birds (Fancy *et al.* 1995), new survey data indicate the population may be somewhat larger than this. The largest population has long been thought to occur in the Hāmākua region, which supports an estimated 793 birds in koa-dominated forests. This population appears to be relatively stable. In the Ka`ū/Kapāpala area, the population reportedly decreased from an estimated 533 to 44 individuals since the 1970s (Fancy *et al.* 1995), but a more recent and intensive survey revealed a population in this region of more than 1,000 birds (U.S. Geological Survey, unpubl. data). The population in the Kūlani and Keauhou Ranch area was estimated at 312 birds. Thus the island-wide population for the species may actually be about 2,100 birds. Three `akiapōlā`au remained in the māmane forest on Mauna Kea in 2000, but all three of these birds are now gone. Another few

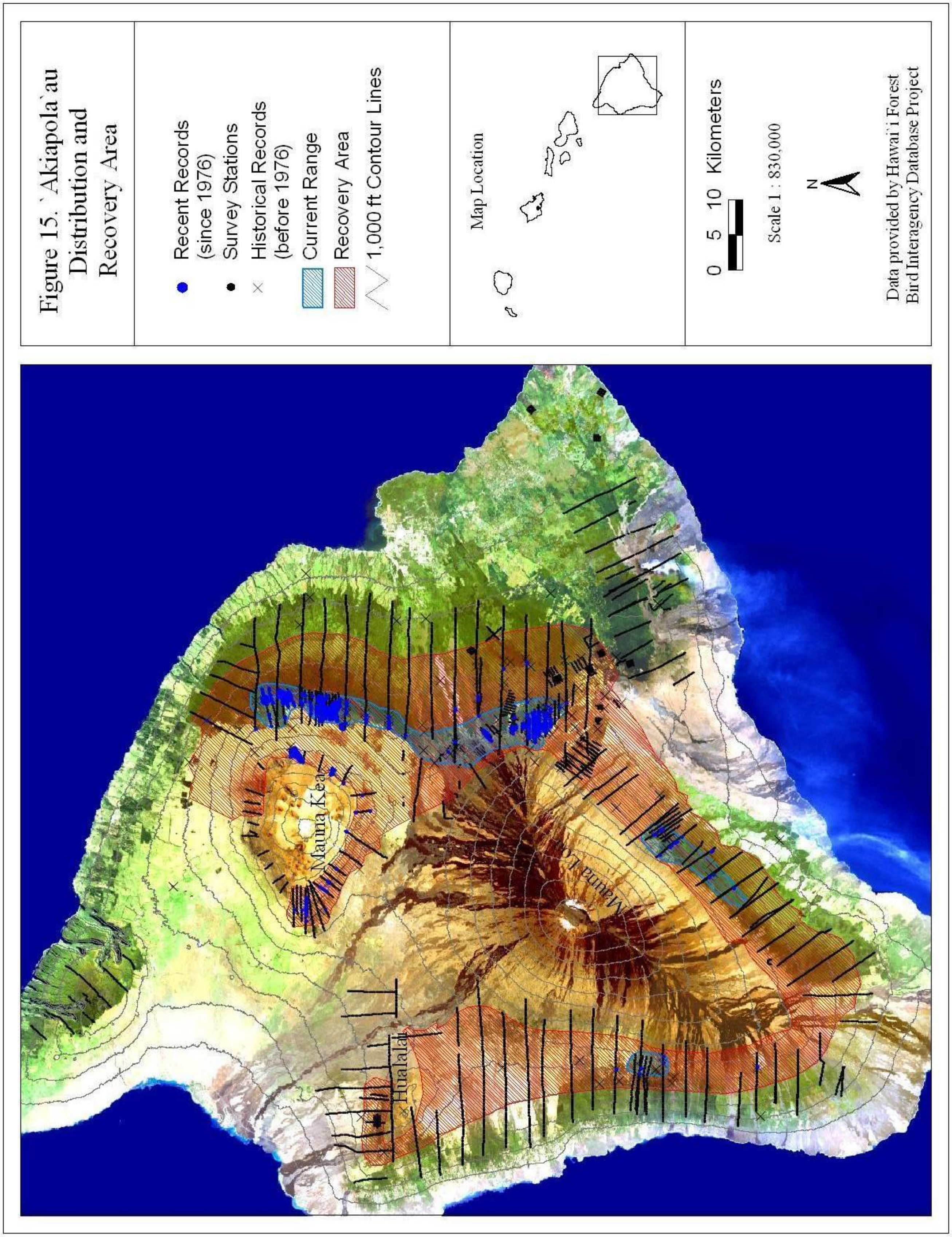


Figure 15. `Akiapola`au Distribution and Recovery Area

birds until recently inhabited koa/`ōhi`a forests of central Kona, but the current status of the birds in southern Kona is unknown.

The above-mentioned estimates serve to give an overall picture of the species' distribution and numbers. However, their precision and accuracy are poor because of the potential for inadequate sampling when birds are not singing and because of analytical problems associated with low population densities. Furthermore, the small Kona populations have never been adequately surveyed. Planning for this species' recovery would benefit from improved, up-to-date surveys and censuses. This can be achieved by determining when `akiapōlā`au vocalize most, by exploring additional survey or census methods to supplement standard point-counts, and by investigation of any metapopulation dynamics.

REASONS FOR DECLINE AND CURRENT THREATS

The `akiapōlā`au is subject to the same threats that negatively impact other forest birds on Hawai`i, including habitat loss and degradation, predation, and introduced diseases, but due to its low reproductive rate (see Life History), this species may be particularly vulnerable to these threats and slow to recover. Other factors, such as competition from introduced avian and arthropod insectivores, have not been documented, but purposeful and accidental introduction of alien species remains a constant threat.

Habitat Loss and Degradation. Destruction and degradation of forest habitat from development, logging, and ranching has greatly reduced the range of the `akiapōlā`au, and has been particularly severe in mesic and dry forest areas. Dry high elevation māmane-naio forest habitat on the slopes of Mauna Kea has been severely degraded by decades of browsing by feral goats and sheep. Designation of critical habitat for the palila (see account for that species) and subsequent court orders to remove ungulates has resulted in regeneration of this habitat, but `akiapōlā`au have already been extirpated from this area. Widespread loss and alteration of forest habitats has also led to fragmentation of the remaining suitable forest. The dispersal behavior of `akiapōlā`au is poorly known, but habitat fragmentation may isolate the remaining populations, decrease the effective population size, and hinder recolonization of areas that were formerly inhabited.

Predation. Predation of nests and adults by rats, cats, mongooses, and owls is suspected to have a significant impact on many native Hawaiian bird species (Atkinson 1977, VanderWerf and Smith 2002), but the significance of predation in limiting `akiapōlā`au populations is not clear. Recent surveys indicate rat densities are high at Hakalau Forest National Wildlife Refuge, which contains a significant portion of the largest remaining `akiapōlā`au population (U.S. Geological Survey, unpubl. data). The low population density of this species has made it difficult to locate sufficient nests for evaluating the effects of predator control. Mostello (1996) found the upper mandible of a juvenile `akiapōlā`au in a pellet from an introduced barn owl (*Tyto alba*). Juvenile `akiapōlā`au may be especially vulnerable to predators during the post-fledging period because their loud, persistent begging call makes them easy to locate. Predation, especially on adults, may impact `akiapōlā`au more than other native birds because the low reproductive rate of this species makes adults demographically more valuable (Ralph and Fancy 1996).

Introduced Diseases. Most Hawaiian forest birds are susceptible to introduced mosquito-borne diseases, and the `akiapōlā`au may be limited to its current high-elevation distribution by these diseases (Scott *et al.* 1986, van Riper *et al.* 1986, Atkinson *et al.* 1995). Despite the availability of apparently suitable habitat, `akiapōlā`au are absent from most areas below 1,350 meters (4,500 feet), where mosquitoes are common. This pattern contrasts with that of unlisted species, such as `apapane (*Himatione sanguinea*) and Hawai`i `amakihi (*Hemignathus virens*), suggesting that `akiapōlā`au and other endangered species are especially susceptible to disease.

CONSERVATION EFFORTS

The `akiapōlā`au was federally listed as endangered on March 11, 1967 (U.S. Fish and Wildlife Service 1967), became protected under the State of Hawai`i endangered species law on March 22, 1982, and was included in the Hawai`i Forest Bird Recovery Plan (U.S. Fish and Wildlife Service 1983a).

Surveys to document status and trends in the `akiapōlā`au population at Hakalau, `Ōla`a/Kīlauea, the Kona Unit of Hakalau Forest National Wildlife Refuge, and in subalpine dry forest on Mauna Kea are conducted annually, but surveys elsewhere have been infrequent and less complete. Studies of factors limiting populations of endangered Hawaiian forest birds have been conducted sporadically since the late 1980s, and a research project dedicated specifically to \`akiapōlā\`au was conducted from 2000 to 2003 (Pejchar 2004).

Conservation efforts for the species have focused primarily on protection and management of high-elevation native forests. The Hakalau Forest National Wildlife Refuge was established in 1985, primarily to protect and manage habitat for native birds, including the \`akiapōlā\`au. Almost 45 percent of the refuge has been fenced, and feral pigs and cattle have been removed or reduced greatly within fenced areas at the refuge. Planting of koa and other native plants began in early 1989, and over 350,000 koa seedlings and 30,000 other native species have been planted (U.S. Fish and Wildlife Service, unpubl. data). The \`Ōla\`a/Kīlauea Partnership and Kona Unit of Hakalau Forest National Wildlife Refuge provide protection and management of forest for habitat. Removal of sheep and mouflon from Mauna Kea, following lawsuits and court orders regarding critical habitat for the palila, has permitted regeneration of māmane forest habitat. Two other relevant conservation actions were the removal of cattle and fencing of the Kapāpala Forest Reserve and the Pu\`u Wa\`awa\`a Forest Bird Sanctuary; although the latter does not hold \`akiapōlā\`au, it could serve as a site for reintroduction. Plans to remove ungulates from the Kīpāhoehoe Natural Area Reserve and from lands at Honomalino, owned by The Nature Conservancy of Hawai\`i, would protect this recovery area and could serve as sites for reintroducing \`akiapōlā\`au. The recent purchase of the Kahuku Ranch area of the Big Island also holds promise for long-term restoration of mesic and subalpine habitat that is expected to support \`akiapōlā\`au.

RECOVERY STRATEGY

Recovery of the \`akiapōlā\`au will require protection, management, and restoration of native forests above 1,350 meters (4,500 feet), research to gain key information that is presently lacking for this species, management of threats such as predation and disease, and possibly captive breeding and release of birds to augment or reestablish wild populations.

Research. Studies are needed in four main areas: (1) testing of survey methodology, followed by surveying and mapping of all populations and long-term monitoring in representative areas in Hāmākua, upper Waiākea kīpukas, Kūlani/Keauhou, Ka`ū/Kapāpala, and southern and central Kona; (2) demographic studies to measure life history parameters such as population structure, dispersion, dispersal, adult survivorship, clutch size, nesting success, social system, and phenology of nesting and molting; (3) habitat selection and foraging ecology, including diet and food availability, particularly in regenerating forest, as well as the role that koa silviculture practices play in the creation of suitable habitat; and (4) response of `akiapōlā`au populations to control of mammalian predators, particularly in low-stature dry forests where the species has difficulty maintaining itself. This information is needed to understand the dynamics of `akiapōlā`au populations, predict the densities of birds achievable across the species' geographic range, and enhance efforts to restore and reconnect declining populations and re-establish new populations in portions of the former range.

Recovery Areas. The most important component of the recovery strategy for the `akiapōlā`au is protection, management, and restoration of koa/`ōhi`a forests above 1,350 meters (4,500 feet) elevation. High elevation forest is of primary importance because it provides the greatest refuge from mosquito-borne diseases, but forests at lower elevation also could be valuable if a means of controlling mosquitoes can be found.

Fencing and/or removal of feral ungulates from the remaining high elevation forests will protect these areas and allow natural regeneration. In previously grazed or logged areas it may be necessary to replant with koa while allowing `ōhi`a and other native species to regenerate as well, as has been done in the upper portions of the Hakalau Forest National Wildlife Refuge. It is important that this action include all recovery areas (Figure 15). Several numbers reinforce this point: the current average density of `akiapōlā`au is one pair per 20 hectares (49 acres). By comparison, the Hakalau Forest National Wildlife Refuge currently offers about 8,500 hectares (21,000 acres) of suitable habitat above 4,500 feet (1,350 meters), although additional areas are being reforested, which could support approximately 425 pairs. The identified recovery areas encompass 238,000 hectares (588,000 acres; Figure 15), much of which requires extensive restoration.

Old-growth koa/`ōhi`a forest on many parcels in the recovery areas is deteriorating due to browsing and rooting by feral pigs, sheep, or mouflon, singly or in combination. Control of these animals would improve forest conditions and possibly increase density of `akiapōlā`au populations.

To maintain or reestablish connectivity of habitat and bird populations among the currently fragmented patches of `akiapōlā`au habitat, cattle should be removed from key parcels and stock ponds should be drained to reduce mosquito breeding. Priority should be given to reforesting upper drainages of the Wailuku River, upper Keauhou Ranch, Kapāpala Forest Reserve, and numerous parcels in Kona between Hōnaunau and Manukā Natural Area Reserve. A corridor between the koa/`ōhi`a forest of Hakalau Forest National Wildlife Refuge and the dry māmane forest at Kanakaleonui upslope from the refuge could be created by removing cattle from pastures above the refuge and replanting the area with koa and māmane, and would reestablish a valuable connection between native bird populations in these two areas and habitat types.

Predator control. Control of alien predators, especially rats, has been shown to be an effective method of increasing reproduction and survival in other Hawaiian forest birds (VanderWerf and Smith 2002). However, the degree of threat from alien rodents may vary among species and locations, and rodent control programs initially should be conducted in an experimental way to document their effect on `akiapōlā`au populations. Ground-based methods of rodent control using snap traps and diphacinone bait stations have been effective on a small scale, but are labor intensive. Effective large-scale rodent control likely will require aerial broadcast methods. Registration of aerial broadcast of diphacinone for rodent control with the U.S. Environmental Protection Agency should be actively pursued and supported.

Captive Propagation and Reintroduction. Natural recovery of `akiapōlā`au and reestablishment of wild populations in portions of the former range may be slow due to the low reproductive capacity of this species. Captive propagation techniques such as collection of eggs from the wild, artificial incubation and hand-rearing, captive-breeding, and reintroduction may be required to speed recovery. Translocation of wild birds also may be valuable, but captive propagation may be a more cost-effective means of reestablishing or augmenting wild populations. Previous translocations with Hawaiian forest birds have shown that young birds are more likely to remain in an area after release

(Fancy *et al.* 2001), and `akiapōlā`au nests are difficult to locate and reach, so it may be difficult to obtain a sufficient number of young wild birds.

Feasibility should be determined for reintroducing `akiapōlā`au into now-protected areas of its former range, particularly at the Pu`u Wa`awa`a Forest Bird Sanctuary, the Kona Unit of the Hakalau National Wildlife Refuge, Mauna Loa Strip of Hawai`i Volcanoes National Park, and, if it is managed as planned, the upper forests of Kīpāhoehoe Natural Area Reserve.