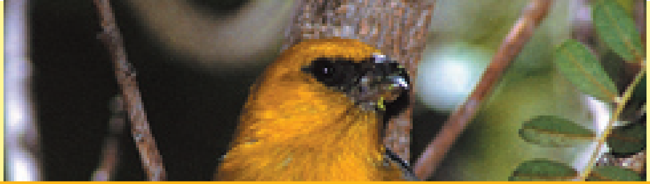
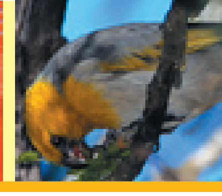




Palila Restoration: Lessons from Long-term Research

Background

The palila (*Loxioides bailleui*) is a member of the Hawaiian honeycreeper family of birds (Drepanidinae), which is renowned for the profusion of species—many with bizarre bills and specialized feeding habits—that radiated from a single ancestral type. Most of the 57 or so honeycreeper species are extinct, and the palila is endangered because of its high degree of dependence on the māmane tree (*Sophora chrysophylla*) (Figure 1) and its restricted distribution on the upper slopes of Mauna Kea (Figure 2). Three decades of research have revealed many important facts about palila, providing the foundation and impetus for conservation programs in the wild and captivity. Additionally, an ambitious public conservation campaign arose due to the land-use conflicts on Mauna Kea. Here we summarize progress in palila conservation biology and outline steps that might overcome the remaining major challenges to its recovery. We also highlight lessons learned from palila research that may help the recovery of other Hawaiian forest birds.

Palila and two closely-related species on the tiny islands of Nihoa and Laysan are the last of the seed-eating honeycreeper species in the Hawaiian Islands. About a quarter of the honeycreeper species known from living and fossil specimens had finch-like bills suited mainly for eating seeds and fruits. Because of their dietary specialization, palila are vulnerable to changes in forest size and quality, as was also likely the case for extinct species of seed specialists. Palila and many other forest bird species were once distributed in dry, lowland forests. Fossil records indicate that palila also occurred in the lowlands of Oʻahu and Kauaʻi until human settlement of those islands. However, because lowland habitats have been highly modified by humans and because māmane occurs today primarily at high elevation, palila are the only native bird species found exclusively in dry, subalpine habitat (2000–2850 m). Similar to other feeding specialists, palila lay few eggs, raise few young each year, and take a relatively long time to complete the nesting cycle. Low rates of reproduction result in low rates of population growth and low potential for recovery from disturbances.

Long-term studies of palila offer important insights into the conservation biology of all Hawaiian forest bird species, particularly feeding specialists like the palila. Palila face many challenges common to both generalist and specialist Hawaiian honeycreeper species. Habitat loss and degradation, as well as introduced avian diseases, have reduced their numbers and limited their distribution to a very small portion of their historic range. Introduced mammals prey on palila, while alien insects reduce caterpillars that are particularly important in the diet of nestlings. Securing legal protection and funding for palila restoration has been challenging. Understanding how the palila has avoided extinction can help managers plan its recovery, and better design recovery plans for species with different feeding strategies in other habitats.

Figure 1. The stout beak of the palila is well adapted for extracting and consuming seeds from māmane pods. (Photo © Jack Jeffrey.)

Challenges to Palila Recovery

Suitable Habitat Limited

Habitat loss and degradation are problems facing all Hawaiian species, but habitat degradation has been more severe in low-elevation areas, where agriculture and other human activity have been concentrated. Palila are currently restricted to subalpine māmane forest on the western slope of Mauna Kea (Figure 2). This is a small remnant of their historic range; as recently as 900 years ago palila inhabited coastal sites on multiple islands. Sites where māmane occur across a broad elevation represent better potential palila habitat than do forest fragments with a restricted elevational gradient. Because māmane flower and set seed at different times at high and low elevations, food resources are available throughout the year at sites where māmane is broadly distributed. The western slope of Mauna Kea supports the largest remaining expanse of māmane forest across an extensive elevation gradient. There are few potential reintroduction sites with appropriate forested habitat, a problem hampering recovery efforts for all endangered Hawaiian bird species.

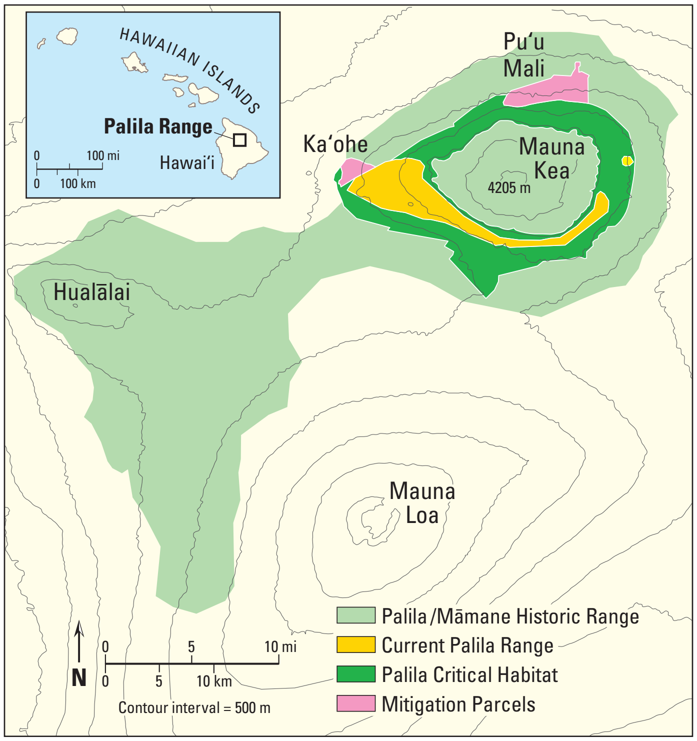


Figure 2. On Hawai'i Island, palila historically occurred throughout māmane forests on Mauna Kea, Hualālai, and western Mauna Loa. The present population is concentrated on western Mauna Kea, where the forest is most extensive. As mitigation for realigning Saddle Road through critical habitat, palila were recently reintroduced to Pu'u Mali. Palila from the main population on the western slope are expected to naturally reoccupy the lands of Ka'ohe as pastures are converted to forest (see *p. 3, Establishing Additional Populations*).

At this point in time, only high elevation habitat is suitable because palila are highly susceptible to introduced diseases, and the species survived primarily because it had a high elevation component to its historic range. The mosquito vectors necessary for disease transmission are absent or rare at high elevations, therefore exotic avian diseases (e.g., malaria and pox) currently pose little threat to palila. Although disease is not impacting palila in their current distribution, it is important to understand disease threats before trying to establish new populations at lower elevations.

Browsing Animals Damage *Māmane* Forests

Introduced ungulates (hoofed animals) are established in many Hawaiian ecosystems where they cause significant habitat degradation. These animals forage on native plants that evolved in the absence of mammalian herbivory. Sheep, goats, and cattle destroy palila habitat by damaging mature māmane trees and inhibiting their regeneration (Figure 3). In 1979 and 1986, federal courts ordered the removal of these animals from palila habitat on Mauna Kea to promote the recovery of the māmane forest. Forest regeneration in many areas where these animals were removed has been encouraging. However, there are still noticeable impacts of ungulates in palila habitat, indicating that current efforts to reduce sheep may not be sufficient to enable māmane forests to recover completely.

Alien Grasses and Fire

Invasive plants are recognized as another significant threat to Hawaiian ecosystems. Particularly in dry habitats, alien plants alter fire regimes. Alien grasses, in particular, increase the frequency and severity of fire in Hawai'i, where most native plants are not adapted to frequent fires. Alien grass cover is high in much of the palila's range, raising the risk that fires could render large areas of habitat temporarily unsuitable to palila.

Introduced Predators Threaten Palila and Their Food Resources

Having evolved in the absence of mammalian predators, native birds suffer from predation by introduced mammals, such as cats, mongooses and rats, particularly during the breeding season, when eggs and nestlings are depredated. Removing alien predators may be one of the most effective management options for protecting small populations of birds that have low reproductive capacity.

Despite specialization on māmane seeds, palila also prey on native caterpillars found inside māmane pods. The protein provided by these caterpillars is particularly important to developing chicks and possibly to adult females during the nesting season. Unfortunately, alien insects threaten this important food resource, particularly at lower elevations. Yellowjackets (*Vespula pensylvanica*) and several ant species, particularly Argentine ants (*Linepithema humile*), are voracious predators and consume many species of native caterpillars. Additionally, parasitoid wasps kill native caterpillars by laying their eggs on, or inside of, them. By limiting caterpillar abundance, these exotic insects may indirectly influence palila populations.

Legal Challenges to *Palila* Protection

The palila was federally recognized as endangered in 1966 and included in the original Endangered Species Act of 1973.

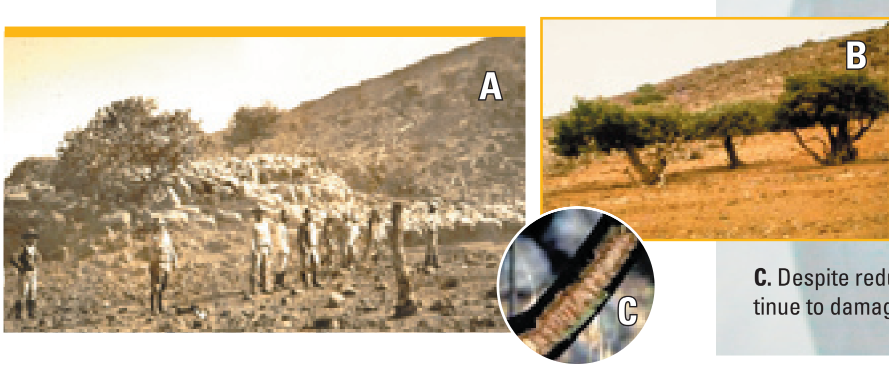


Figure 3. A. Territorial foresters removed nearly 47,000 sheep and many pigs and cattle from palila habitat on Mauna Kea during the 1930s and 1940s. The sharp reduction in browsing pressure resulted in regeneration of māmane trees and may have been the most important factor in the survival of palila. However, because not all the animals were removed, populations built up rapidly and it became necessary to again reduce their numbers. Ongoing removal efforts have resulted in increased māmane populations in many areas. However, current removal rates are unlikely to result in eradication of sheep and mouflon sheep (a non-domesticated species) from palila habitat. (Photo by L. W. Bryan, December 1936, courtesy of Jon G. Giffin.) **B.** Heavy browsing by sheep and mouflon sheep denudes the lower branches of māmane trees, creating a distinct "browse line." (Photo by Jon G. Giffin, 1975.) **C.** Despite reductions in their numbers, sheep and mouflon sheep continue to damage māmane trees, in this case by gnawing the bark.

Palila Tolerate Toxic Chemicals in Māmane Trees

USGS research suggests that although māmane seeds are generally toxic to vertebrate species, palila have evolved tolerance to the chemicals contained within the seeds. While palila depend on māmane seeds for their survival, they do not eat the entire seed. Rather, they consume only the seed's embryo, removing or eating around the seed coat.

Chemical analysis has shown that māmane embryos are well-balanced nutritionally and contain protein, lipids, and carbohydrates that enable the birds to survive in a relatively harsh environment. In contrast, seed coats contain high levels of nondigestible fiber and are presumably harder to digest than embryos. Interestingly, all trees may not be equally toxic; some are more heavily exploited and are nicknamed "restaurant" trees.

Palila were unusual among endangered species in that "critical habitat" was designated for them. Critical habitat of a listed species is an area with physical or biological features essential to its conservation, whether occupied and unoccupied by that species. Within critical habitat, protection of the species and its habitat is the primary land use objective, however, other compatible land uses may be allowed. Since 1979, the protection of palila critical habitat from ungulates has been legally challenged six different times. Palila have prevailed in each case, yielding important nationwide applications of the ESA. The designation of critical habitat has played a pivotal role in justifying and funding palila restoration research.

A significant portion of recent palila research was funded to mitigate the construction of a highway through an unoccupied area of critical habitat. In December 1999, the U.S. Fish and Wildlife Service (USFWS) approved a proposal to realign Saddle Road (Highway 200), the interior connection between eastern and western Hawai‘i, through palila critical habitat on condition that the loss of habitat be mitigated (see *Biological Opinion of the U.S. Fish and Wildlife Service for the Saddle Road realignment and improvement project*, 27 July 1998, Honolulu, HI.). A key component of the mitigation plan was to temporarily suspend cattle grazing in pastures adjacent to palila range (Figure 2) to allow habitat recovery in these areas. Funding from the mitigation also enabled the expansion or continuation of studies of palila ecology and limiting factors, māmane ecology and food availability, predator ecology and management, and fire ecology. Further, mitigation funding provided for the reintroduction of palila near Pu‘u Mali, on Mauna Kea's northern slope. Additional funds were secured to initiate research into forest restoration ecology. However, these actions by themselves do not fulfill all the requirements to recover the palila, as designated in the USFWS Draft Hawai‘i Forest Bird Recovery Plan.

Establishing Additional Populations

Because palila are concentrated on the western slope of Mauna Kea, the entire species is highly vulnerable to extinction from events such as drought, fire, storms, disease, and predation. Palila have not independently resettled recovering māmane forest, so interdisciplinary teams developed techniques for bolstering wild palila populations through translocation of wild birds and release of birds bred in captivity. Creating additional populations on Mauna Kea and elsewhere in their historic range will reduce the species' vulnerability to local catastrophe.

Site Selection

The northern slope of Mauna Kea was chosen for palila reintroduction for several reasons: ungulate populations have been reduced; māmane recruitment is robust in some areas; highly invasive alien weeds are not currently threatening the forest; and it is relatively inaccessible to people. The original palila population on the northern slope was eliminated, apparently as a result of habitat degradation caused by ungulates. Hopefully, after ungulates have been removed and fenced out from the mitigation parcels, forest restoration research will reveal ways to accelerate the rehabilitation of māmane trees capable of sustaining a viable population of palila.

The southern slope of Mauna Kea also was considered for reintroduction because it supports a large expanse of high-density māmane forest along substantial elevation and rainfall gradients that could provide food to birds throughout the year. However, there were concerns regarding possible disturbance from military training and more active human use at the south site.

Estimating Their Numbers

Palila have been monitored longer than any other Hawaiian forest bird; annual surveys started just as ungulate removal began on Mauna Kea in 1980. Population estimates varied greatly until the mid-1990s, when surveys began to reflect a trend towards stability around a population of about 3,000 birds. Stabilization of the population suggests that the many young māmane trees that sprouted after sheep reduction may be slowly beginning to benefit palila during periods of drought and food scarcity, when populations formerly dipped. Palila tend to forage in larger trees, and many saplings have matured since 1980. Māmane trees grow slowly in the subalpine environment, therefore the response of palila to forest restoration efforts will also occur slowly. However, with continued and increased forest improvement, population stabilization could eventually be followed by population growth, which would signify a major milestone in the recovery of the species.

Translocation

By the end of 2005, 160 wild palila had been translocated from western Mauna Kea to the northern slope, a distance of approximately 16 km (Figure 4). Although many of the translocated birds (~ 65%) returned to the area where they were captured, a small colony of about 25 birds remains on the northern slope and at least five translocated birds moved repeatedly between the western and northern slopes. An additional 28 birds were translocated in 2006, although their rate of persistence at the site is still unknown.

Several birds from the western slope have immigrated naturally, if perhaps temporarily, to the northern slope since the establishment of the satellite colony, suggesting that these populations could become linked by normal movements. Two pairs of translocated birds are known to have nested on the northern slope: in 2004, a pair produced two chicks that were not seen after they apparently fledged from the nest; and in 2005, a pair fledged a chick that survived past independence from parental care. This milestone indicates that translocation could become an important tool for developing additional, wild populations of palila and possibly other endangered species. Increased nesting activity by translocated pairs in 2006 validates this conclusion.

Captive Breeding

Another approach to bolstering wild bird populations is releasing captive-bred birds into the wild. In 1996, staff of the San Diego Zoo began building a captive breeding flock at the Keauhou Bird Conservation Center by hatching eggs that were harvested from wild palila nests. Of 15 captive-reared palila released to the wild during 2003–2004, at least seven persisted in the reintroduction area for at least one year and some of these birds nested on the northern slope. One pair produced only an infertile egg in 2004; but a captive-reared male nested with a translocated female in 2005, and together they produced two chicks that survived approximately to independence. One juvenile was last observed 108 days after fledging and the other died after 126 days. Breeding activity since 2005 has demonstrated promise in releasing captive-reared birds to increase wild populations.

Conclusion

Extensive research into the basic ecology of the palila has provided the scientific foundation and a major impetus for recovery. The collaboration of research and management agencies continues to address the effects of ungulate browsing, exotic mammals and insects. There are two pressing areas of research, the first being to develop the most effective techniques of dry forest restoration. This complicated subject includes studies of germination rates, weed removal techniques, and fire fuels management. The second area is continued research on establishing additional palila populations, both on the northern slope of Mauna Kea and other sites within former range. Although mitigation funding for research is coming to an end, science-based approaches to restoration have produced practical results. The recent successes are encouraging for the future of the species and suggest that continued management may lead to species recovery.

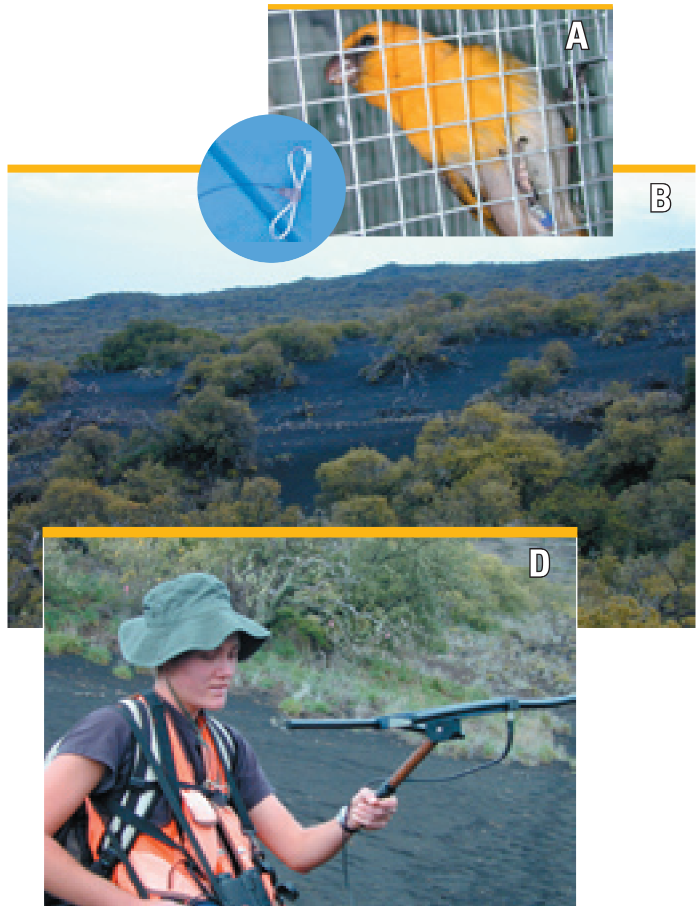
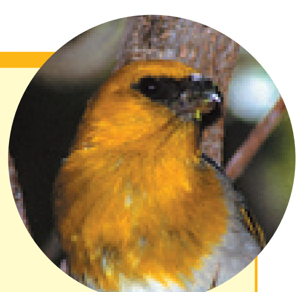


Figure 4. A. Palila captured on the western slope of Mauna Kea are banded and fitted with radio transmitters (inset) before transport to the northern slope. **B.** The *māmane* forest most frequently used by palila at the release site. **C** *(inset, page 1).* A palila is prepared for release. **D.** Following release, palila are relocated via radio receivers.

Cooperators

- Federal Highway Administration
- U.S. Army Garrison, Hawai‘i
- U.S. Fish & Wildlife Service
- Zoological Society of San Diego
- Hawai‘i Division of Forestry and Wildlife



(Photo © Jack Jeffrey.)

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  biology.usgs.gov/pierc/
- US Fish & Wildlife Service, Environmental Conservation
  ecos.fws.gov
- Hawai‘i Dept. of Forestry and Wildlife
  www.state.hi.us/dlnr/dofaw/cwcs/index.html
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  www.conservationandscience.org/projects/sp_hawaii_birds.html
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- *Feral cats: Too long a threat to Hawaiian wildlife.* USGS Fact Sheet #2006-3006