Keeping Hawai'i's Forest Birds One Step Ahead of Avian Diseases in a Warming World: a focus on Hakalau Forest National Wildlife Refuge

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Introduction

This report is a product of a one-week workshop on using Structured Decision Making to identify and prioritize conservation actions to address the threat of climate change on Hawaii's native forest bird community. Specifically, this report addresses the issue of global warming's likely role in increasing disease prevalence in upper elevation forests of Hawaii, negatively impacting native bird populations susceptible to the disease but currently disease-free because of the cooler temperatures at high elevations.

Structured Decision Making (SDM) is a formal method for analyzing and making decisions by breaking the problem and solution into components that are weighed in a transparent, replicable, and systematic manner. Basically, the steps in SDM are to articulate the problem, identify desired goals (objectives) and management actions (alternatives) for addressing the problem, and develop models (conceptual to mathematical) to weigh alternative management actions in terms of achieving goals to make "smart decisions". For this effort, we developed a framework for addressing the problem, specifically by identifying potential management actions and research needs, and identified a potential framework in which

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management and research activities can proceed. The issues are complex, the research needs great, and outcomes of management actions difficult to assess; as a result, the efforts of the group are only the beginning stages of the process. No final product or final decision was reached, but we hope this effort will be the first steps on the path to developing conservation actions that effectively address the serious threat of climate change to Hawaii's forest birds.

Decision Problem

Hakalau Forest National Wildlife Refuge (HFNWR) was created specifically to be a high-elevation refuge for Hawaiian forest birds and their habitat, including three endangered species, with a mandate to protect these threatened birds, as well as all the native species the Refuge harbors. Hakalau Forest NWR provides a critical refuge for native birds from vector-borne diseases, but global warming is predicted to facilitate the encroachment of mosquitoes and diseases into increasingly higher elevations of the refuge, while intensifying disease at lower elevations. As a result, identifying and prioritizing alternate management actions at HFNWR are needed to ensure viability of the refuge's native birds due to avian disease threats which will be exacerbated by future global warming. However, management actions may be constrained by budgets, knowledge, land availability (e.g. jurisdictional issues and habitat availability), and public perception and cooperation. While refuge managers have direct control over on-the-ground actions at the refuge, some actions require cooperation from surrounding land managers and the community. Actions to confront these threats to native bird populations may need to be started now, even though the actual peril could be years in the future. The two key components to this issue are the speed at which disease will intensify or move up in elevation, and the effectiveness of various management actions in slowing or preventing the incursion of disease, or increasing resiliency of existing populations to disease. Although these management strategies will apply specifically to the HFNWR and to surrounding landholdings, lessons learned from HFNWR should be applicable to other areas in Hawaii facing similar threats to their forest birds.

Background

Hakalau Forest NWR Description

The 13,355 ha HFNWR was created in 1985 to protect rain forest that supports endangered forest birds. Located on the windward slope of Mauna Kea Volcano on Hawai'i Island (Figure 1), the refuge contains some of the best remaining examples of native rain forest in the state. However, at the time of purchase, there was approximately 1,620 ha of once-forested pasture on these lands. In 1989, refuge staff began restoring habitat, both in the pasture area and open forest adjacent to pasture land. After fencing and removing ungulates from most of the refuge, the restoration efforts expanded to include control of exotic plants and planting of native trees, mostly koa and endangered plants. Much of the work has been done by volunteers ranging from school groups to off-island service groups.

The HFNWR is one of the only places in the state where native forest bird populations are stable or increasing (Camp et al. 2010). Annual forest bird surveys indicate that the numbers of some endangered species are increasing. Annual surveys show that the number of Hawai'i Amakihi, I'iwi, and Apapane have also increased in koa reforestation areas (Camp et al. 2010). In addition to native forest birds, endangered Hawaiian Geese (Nene) and 29 rare plant species also can be found in the refuge.

Legal, regulatory, and political context

Hakalau Forrest NWR exists to provide federal protection to native Hawaiian flora and fauna on the windward slopes of Mauna Kea. The overriding principle of the Refuge is to protect the fauna and flora within its boundaries and surrounding areas, and conduct management actions consistent with the preservation of native bird populations as typically required by policies and rules the Refuge must act under. Multiple Executive Orders and legislative acts apply to the management of HFNWR including at least 11 broad federal regulatory requirements (see Appendix 1 for details), specific rules governing National Wildlife Refuges, and guidance specific to HFNWR (see Appendix 2). These rules and regulations provide a multi-tiered policy framework designed to guide refuge management.

Ecological context

The Hawaiian Islands have evolved a highly endemic avifauna as a result of geographical isolation, diverse topography ranging from sea level to mountains exceeding 4000 m above sea level (asl), and habitats ranging from tropical lowland rain forests to subalpine tundra over distances as small as 40 km. Unfortunately, native Hawaiian forest birds have experienced one of the highest rates of extinction in the world (Pratt 2009) because of habitat loss and the introduction of alien plants and animals. Two factors have particularly shaped the distribution and abundance of native forest bird communities so that the greatest richness and densities occurs in native forest above 1500 m asl (Scott et al. 1986). First, habitat loss has largely removed low elevation native habitats, leaving remaining intact lowland forests scattered and fragmented. Secondly, introduced diseases, specifically avian malaria and avian pox, along with an introduced mosquito (Southern House Mosquito, *Culex quinquefasciatus*) that efficiently transmits these diseases (LaPointe et al. 2006), have largely displaced native birds from remaining low-elevation forests where rampant disease transmission occurs throughout the year (Atkinson & LaPointe 2009, Samuel et al. 2011). In mid-elevation forests, avian malaria is seasonally dynamic with infection rates and peak mortality in fall corresponding with increased mosquito abundance from favorable climatic conditions (Atkinson and Samuel 2010). These elevational disease patterns are driven, in part, by the effects of temperature and rainfall on mosquito dynamics (Ahumada et al. 2004, Samuel et al. 2011) and sporogonic development of the avian malaria parasite (*Plasmodium relictum)* within the mosquito vector (LaPointe 2010) across an elevational gradient. The threshold temperature for malarial development is 13°C which coincides with the 1,800 m asl elevation contour (mean annual temperature); this temperature threshold creates a disease-free refuge in forests above approximately 1,800 m asl (Benning et al. 2002, Atkinson and LaPointe 2009). Furthermore, at temperatures between 17°

and 13°C, transmission of avian malaria is limited to warmer seasons of the year (LaPointe et al. 2010).

Because avian malaria and pox are primarily spread through mosquitos, distribution and abundance of mosquitoes is key to understanding the distribution of these avian diseases. In most mid- and high-elevation Hawaiian forests, *Culex quinquefasciatus* populations are limited by the availability of aquatic larval habitat; on Hawai'i Island primarily rain-filled tree fern (hapu`u) cavities created by foraging feral pigs and rock pools along the margin of intermittent stream beds (Atkinson and LaPointe 2009). Unmanaged artificial water impoundments can also contribute significantly to available larval habitat (Reiter & LaPointe 2009). Approximately 95% of HFNWR lands lie at elevations above the 17°C isotherm for seasonal disease transmission, effectively creating a refugia from year-round disease, although periodic disease outbreaks may occur in the lower and mid parts of the refuge (VanderWerf 2001, Benning et al. 2002). Thus, the refuge preserves habitat for limited but stable populations of three endangered, island endemic forest birds the `Akepa *Loxops coccineus*, Hawai`i Creeper *Oreomystis mana* and Akiapola`au *Hemignathus munroi;* as well as larger populations of non-endangered I`iwi *Vestaria coccinea*, `Apapane *Himatione sanguinea*, Hawai`i `Amakihi *Hemignathus virens*, `Elepaio *Chasiempsis sandwichensis*, and Oma`o *Myadestes obscurus* (Camp et al. 2010).

Because temperature is a critical element in Hawaii's disease-bird cycle, global warming is considered a grave threat to the disease-free sanctuaries of high-elevation forests for native forest birds. Current rates of disease exposure of HFNWR forest birds are unknown, but surveys in the mid-1990s estimated malarial prevalence for resident native species such as `Elepaio and Hawai`i `Amakihi at approximately 6% near Nauhi Cabin (1,600 m), but approximately 23% at the lower elevation (1,200 m) Maulua and Pua Akala Tracts, supporting the idea that limited transmission of malaria takes place within upper elevations of the refuge. Prevalence for `Apapane is higher (19%) at upper elevations which may be a reflection of this species' movements in search of nectar resources at lower elevations outside the refuge (C.T. Atkinson unpublished data). Current climate change models (e.g., A1, B1) suggest mean temperatures in Hawaii may increase by at least 2°- 3°C by 2100 (IPCC 2007), effectively eliminating this high-elevation transmission-free habitat within the current boundaries of the refuge (Benning et al. 2002) and likely increasing the rate of malaria transmission in mid-elevation forests. Without control measures to mitigate disease transmission, mortality from mosquito-borne disease is predicted to drive HFNWR populations of endangered species (`Akepa, Akiapola`au, Hawai`i Creeper) and highly susceptible species (I`iwi) to local extinction. In addition, climate change will likely have negative population impacts on many native forest birds that are also susceptible to malaria and pox, such as `Apapane and Hawaiian `Amakihi, but with lower mortalities than the other forest birds. Recent evidence of disease resistance in some species (Woodworth et al. 2005, Foster et al. 2007), however, demonstrates that at least some species, in at least some areas, are developing resistance or tolerance to disease, and such evolution may be occurring in other species and populations.

Decision Structure

Objectives

We identified four fundamental objectives (measurement criterion listed in parentheses):

1. Maintain each forest bird species at or above their estimated abundance in 2007 (most current population estimate; Camp et al. 2010) in Hakalau Forest Unit over a 200 year period. This objective is evaluated as a threshold of whether species abundance is above or below the target number, below (Yes/No species *i* is at or above N threshold).
   a. Maintain ‘Akiapola’au at or above 410 adults
   b. Maintain Hawai’i ‘Akepa at or above 6,839 adults
   c. Maintain Hawai’i Creeper at or above 5,956 adults
   d. Maintain I’iwi at or above 61,253 adults
   e. Maintain ‘Oma’o at or above 8,134 adults
   f. Maintain Hawai’i ‘Elepaio at or above 15,347 adults
   g. Maintain ‘Apapane at or above 41,278 adults
   h. Maintain Hawai’i ‘Amakihi at or above 27,206 adults

2. Minimize cost of management ($)

3. Maximize probability of acceptance by the public (expert opinion, 0-1)

4. Abide by all relevant legal statutes (yes/no)

Objective 1, *maintain each forest bird species at or above their current (2007) abundance*, captures our decision problem explicitly in that the *abundance* of all species is considered and each species is given equal importance. If the step utility function (Yes/No) was above abundance N for species *i*, then the alternative management action was accorded full value/utility (=1); if below N, then it received zero value. This utility function implicitly captures the *biological richness and diversity* aspect of our decision problem: if the abundance of all species is maintained over the threshold abundance, then richness is maintained. If any species’ abundance drops below the threshold, the action portfolio is not meeting our goal of maintaining species richness. However, it may be that the best action portfolio simply maximizes richness (keeps as many species as possible above N); in that event, we may have to reformulate our decision statement to have a multi-level criterion.

Objective 2, *minimizing cost of management*, was a key objective to recognize the reality that funds are limited, and all else being equal the set of alternative actions that cost the least amount would be favored.

For the purpose of decision making, we decided that Objective 3, *maximizing probability of acceptance by the public*, was a means objective (an objective that helps to achieve the fundamental objective, in this case maintaining bird abundances at the refuge) that increased or decreased the likelihood of achieving the benefit of Objective 1. The probabilities of public support for each portfolio will be determined, either by eliciting expert opinion or through a formal survey, and the results (as a percent likelihood, 0-1) used to weight the benefit of each action in terms of Objective 1. Therefore, they were encompassed within the decision analysis (see Decision Analysis Section).

In addition, we identified Objective 4, *abide by all relevant legal statutes*, as a yes/no constraint. No actions would be considered that violated any legal statutes, and this also ensures that any actions to help forest birds do not negatively impact other native species and habitat. See Background (Legal, regulatory, and political context) and Appendices for more information.

Alternative actions

Accomplishing the primary objective (to maintain current population levels of the eight forest birds native to HFNWR for 200 years) in the face of rising temperatures and disease risk would require the adoption of new, landscape-scale management initiatives of unknown efficacy. Without such initiatives, the disease-free area of the refuge will contract as global temperatures rise, until at some future time when no areas within the refuge boundary will be disease-free, and birds sensitive to disease will suffer population declines or local extinction. Alternative actions would need to provide new disease-free refugia, render existing habitat disease-free, or strongly reduce the effect of disease on native forest birds.

A wide range of alternative actions were considered, falling into five broad categories:

1. *Low tech*: Ungulate control, ungulate-proof fencing, mosquito control (larval or adult).
2. *High tech*: Sterile male mosquito release, bio-engineered mosquitoes or *Plasmodium* parasite.
3. *Habitat manipulation*: Removal of mosquito larval habitat, reforestation of Refuge or adjacent lands (expansion areas or corridors), removal of gorse and other weeds, enhancement of food resources.
4. *Population manipulation*: Removal of mammalian predators, augmentation of bird populations to increase genetic diversity, and translocation of individuals from disease tolerant or resistant populations to HFNWR.
5. *Land management arrangements*: co-management with adjacent landowners, purchase of key land parcels.

Strategic combinations of these actions resulted in twelve portfolios, of which five were examined in detail, as they represented distinct approaches to the problem. Four new strategies were compared to the current set of management actions (‘Status Quo’); however, all of the new portfolios assume continuation of the current actions (i.e., the new actions plus the ongoing status quo actions). The cost of each portfolio is estimated for 15-year increments, detailed in Table 1; these costs are estimates, presented to give general costs of actions and not detailed costs with economic discounting that would be included in the final model. Each portfolio varied in terms of the area affected (e.g., upper refuge, entire refuge), whether management was directed at improving habitat, directly targeted at bird populations, and whether management with surrounding landowners was necessary. The portfolios examined were:

A. Status Quo. Portfolio A describes current management activities designed to benefit native forest birds at HFNWR; this level of activity is envisioned to continue for perpetuity, and therefore represents a baseline-level of management activity.
   a. *Area*: Current 8 fenced units, largely disease-free, 14,000 total acres in the upper portion of the Refuge.
   b. *Habitat Management*: Reforestation of former pasture with koa and understory plant species, maintain fences and ungulate control efforts.
   c. *Population management*: None
   d. *Co-management*: None
   e. *Cost (15 yrs.)*: $10,954,000

B. **Reserve-wide Mosquito Kill Plus.** Portfolio B aims to provide a disease-free safe haven by completely removing larval mosquito habitat from across the entire Refuge. The mosquito-free area would be less than the total Refuge area due to the ability of adult mosquitoes to penetrate some distance (approx. 1 km) from bordering unmanaged lands, but the reduction of disease transmission (regardless of temperature) would allow vulnerable species to expand or at least maintain their current distribution.
   a. *Area*: Full refuge extent, 32,000 acres + intervening 4,000 acres in Piha.
   b. *Habitat Management*: Status quo actions plus new fencing and pig removal from lower portions of Refuge, removal of artificial habitat for mosquitoes, larvicide treatment of streambeds and hapu'u cavities.
   c. *Population management*: None
   d. *Co-management*: Management of Piha parcel consistent with Refuge management.
   e. *Cost (15 yrs.)*: $15,203,000

C. **New Refugia Mauka.** Portfolio C would expand the forested area of the Refuge upslope, providing more high elevation disease-free habitat to compensate for the encroachment of disease into lower areas of the Refuge that are currently disease-free. This expansion is limited by the trade-wind inversion, which determines the tree line through precipitation and is expected to continue to confine forests below approximately 2500 m.
   a. *Area*: Current 8 fenced units (14,000 ac) in upper portion of refuge + 2000 ac upslope of Refuge.
   b. *Habitat management*: Status quo actions plus new fencing, cattle and pig removal, reforestation with koa and understory, removal of artificial larval habitat.
   c. *Population management*: None
   d. *Co-management*: Co-management for wildlife with landowners of adjacent upslope lands.
   e. *Cost (15 yrs.)*: $5,925,000

D. **Disease Compensation/Facilitating Evolution.** Portfolio D implements predator management and enhancement of food resources to increase survivorship, productivity, and carrying capacity for bird populations with the intent that the increase in demographic rates would offset disease-related mortality and decrease the risk of population declines. One approach would be to target mid-elevation populations where there is moderate disease transmission, with the hope that disease-resistant or disease-tolerant genotypes may be more likely to survive and become more abundant in the population (Kilpatrick 2006). This action assumes that increasing the population size of native birds should slow disease-driven declines, providing time for disease resistance/tolerance to develop.
   a. *Area*: Focused on area of Refuge with seasonal disease transmission (mid-elevation), which will vary over time.
   b. *Habitat management*: Status quo plus enhancement of food resources through outplanting of understory and artificial feeders.
   c. *Population management*: Intensive suppression of mammalian predators.
   d. *Co-management*: None
   e. *Cost (15 yrs.)*: $4,875,000

E. **Building Resistant Genotypes.** Portfolio E uses a different strategy to promote the evolution of disease resistance. Translocations to the Refuge would be used to maximize genetic diversity of resident bird populations, and to augment their gene pools by introducing disease-resistant individuals from other populations.
   a. Area: Entire Refuge (32,000 acres)
   b. Habitat management: Status quo, only in current 14,000 acres.
   c. Population management: Translocate cohorts of all eight species into Refuge to increase genetic diversity, including the translocation of disease-resistant birds of any species with populations persisting at low elevations.
   d. Co-management: None.
   e. Cost (15 yrs.): $2,400,000

These four new portfolios represent different approaches to maintaining bird populations in the face of the almost certain failure of the status quo approach over the long-term. Formal assessment of the ability of any of these portfolios to accomplish the objective requires a disease model that can predict the potential outcome of each management action based on the changing effects of elevation on disease transmission over time. To evaluate portfolios D and E would also require incorporating evolution of disease resistance as a sub-model. A spatially-explicit model is needed to help account for refuge boundary, management area effects, and impacts of bird and mosquito movement across the landscape. Because many of the actions would take decades to have their full effect, the rate of temperature (and rainfall) change due to global warming is a critical variable in modeling the potential of each portfolio to achieve the long-term objectives. Past mid-century (2050) this rate becomes more uncertain due to wide differences in possible greenhouse gas emission trajectories (IPCC 2007).

Predictive model

Samuel et al. (2011) developed an epidemiological model of avian malaria (*Plasmodium relictum*) across an altitudinal gradient on the central windward side of Hawaii Island that connects the dynamics of Hawaiian forest birds (the host), mosquitoes (the vector), and avian malaria (the parasite) (Figure 2). The goal of this model is to better understand how biotic and abiotic factors influence the intensity of malaria transmission and impact susceptible populations of native Hawaiian forest birds. The model demonstrates key patterns in the malaria-forest bird system: intense malaria transmission in low-elevation forests with minor seasonal or annual variation in infection; episodic transmission in mid-elevation forests with site-to-site, seasonal, and annual variation depending on mosquito dynamics; and essentially disease-free refugia in high elevation forests with only slight risk of infection during summer. These landscape-level infection patterns are driven by temperature and rainfall effects on the parasite's extrinsic incubation period and mosquito dynamics across an elevational gradient, and the availability of larval habitat, especially in mid-elevation forests. Model results indicate that disease is a key factor in causing population declines or restricting the distribution of many susceptible Hawaiian species and preventing the recovery of other vulnerable species. The model also provides a framework for the evaluation of climate change on future disease transmission and bird populations, and for evaluating alternative management actions to address the threats of disease.

The Samuel et al. (2011) model describes the population dynamics of female Southern House mosquitoes, three endemic Hawaiian honeycreepers, the Hawaii Amakihi, Apapane, and Iiwi, and the most common introduced bird in Hawaiian forests, the Japanese White-eye (*Zosterops japonicus*). Other native and introduced bird species were not considered in the model due to low abundance, limited distribution among elevations, or inapparent susceptibility to avian malaria. This model was implemented using Ordinary Differential Equations (ODEs) for Susceptible, acutely Infected, and Recovered (SIR) birds and Susceptible, Exposed (Latent), and Infectious (SEI) mosquitoes. The model incorporates dynamics and demographics of the host, vector, and parasite in daily time steps. Local environmental conditions such as temperature, rainfall, mosquito larval habitat, and other local factors can be included to make the model site-specific. Model input and output is at a spatial scale of 1 km^2 and this area is assumed to be closed for immigration and emigration of mosquitoes and birds. Mosquitoes and all bird species are divided into immature and adult stages. Immature mosquitoes consist of eggs, larvae, and pupae which have the same mortality and development rates (Ahumada et al. 2004). Adult mosquitoes are divided into susceptible, latent, and infectious disease stages. Juvenile (susceptible when hatched) and adult birds are tracked by susceptible, acutely infected, and recovered stages. Acutely infected birds suffer from disease-induced mortality and have a high parasitemia (Yorinks and Atkinson 2000). Recovered (chronically-infected) native birds are immune to subsequent infection (Atkinson and Samuel 2010); however, they remain infectious and able to transmit malaria parasites to mosquitoes with only slightly lower probability than the acutely infectious stage based on experiments with chronically infected Amakihi (C. Atkinson, unpublished data). The Japanese White-eye, which is characteristic of most introduced birds, does not suffer from disease-induced mortality (van Riper et al. 1986) nor is it infectious to mosquitoes beyond 34 days post infection (C. Atkinson, unpublished data). By convention, juvenile birds become adults on 1 January of the year after they fledged.

Many of the alternative actions described in this report can be evaluated quantitatively and qualitatively using this modeling framework. Management actions related to pig control can be indirectly evaluated via changes in mosquito larval habitat. Spraying of adult mosquitoes or larva can be evaluated directly via increases in mortality rates. The impact of pigs on food resources for birds or reforestation of habitat can be modeled indirectly through bird carrying capacity. The impact of predation on bird nests can be evaluated indirectly by changes in productivity and juvenile survival of birds. Augmentation of bird populations and changes in malaria resistance can be modeled by increases in bird abundance or by changing disease mortality rates. However, evolution of disease resistance/tolerance is not currently incorporated in the model and would need to be addressed by development of a submodel for the evolution of disease resistance or by an alternative approach. The overall model can also be used to project the impact of climate change on Hawaiian forest birds from malaria infection either with or without potential management actions. To conduct these model predictions it will be necessary to establish baseline climate data for the specific areas to be evaluated and to describe alternative climate change scenarios that will be evaluated.

Decision Analysis

A structured decision making approach to this complex issue requires good estimates of how the different portfolios of alternative actions will likely meet the identified objectives. A number of uncertainties (discussed below) prevent "good estimates" of the effect of different actions, and therefore a formal analysis of a structured decision. However, we identified a framework in which to proceed with structured decision making when the information needed becomes available.

The main approach we identified for making structured decisions is via the SMART table (Simple Multi-Attribute Rating Technique). This allows us to normalize all attributes to a 0-1 scale so that objectives are comparable to one another (bird abundance versus cost of alternative actions), and therefore we can rank the effectiveness of each alternative action portfolio in reaching the stated objectives. Additionally, this approach allows us to weight the importance of each objective in terms of the final outcome. For example, while minimizing cost is important, if a particular alternative fails to keep current population levels of birds at HFNWR, then it is not a desirable alternative regardless of cost. In our initial effort, we chose to have Objectives 1 and 2 (maintaining abundance of all birds and minimize cost) as the main objectives, with maintain bird abundance weighted at 0.8, and minimizing cost weighted at 0.2. These normalized and weighted scores can be summed across alternatives, with the highest score being the recommended alternative given the objectives and models used to determine outcomes. To incorporate Objective 3, likelihood of a particular alternative being adopted by the broader conservation community, we determined that expert opinion would be used to develop weighting of each alternative based on how likely it is to be adopted. This weighting could then be applied to the summed scores of Objectives 1 and 2, or alternatively could be applied to Objective 1 as a binary filter where unlikelihood of implementation would result in a rejection of the alternative. Finally, objective 4, abiding by all legal and regulatory requirements, is simply a binary filter, where those alternatives that do not meet legal and regulatory requirements are not considered further.

We discussed several ways to deal with the considerable uncertainties that exist in this complex system. One approach would be to use a sensitivity analysis on the SMART table, where weighted scores for each alternative action would be varied to see whether changes in expected outcomes would change overall decisions. If changes in the weighted score of an alternative action do not change the ultimate decision, then uncertainty in that alternative action (i.e., changes in its weighted score) do not matter for the purposes of making structured decisions. Likewise, there are many climate change scenarios predicting different changes in the climate depending on future carbon output and various model assumptions. Would these different climate scenario predictions change the decisions made under the framework outlined in this report? To evaluate this concern, the SMART table modeling exercise could be conducted under a reasonable range of climate scenarios. If the decision outcome was the same under different climate scenarios, then that would suggest that climate change uncertainty could be removed from the decision process; alternatively, if the exercise indicated that different climate scenarios would affect the decision process, then clearly climate change uncertainty would need to be considered when deciding which alternatives to adopt.

Another important consideration is the time scales used for the evaluation and decision process. For example, some alternative actions involve fencing new areas. The initial cost of building the fences can be millions of dollars, with subsequent annual monitoring and maintenance being only a small fraction of the initial investment. Therefore, the longer the time period considered, the less expensive fencing appears to be within a specific management alternative. Likewise, how far into the future is reasonable for estimating the effects that different alternative actions will have on bird population abundances will influence the accuracy of the decisions. As time increases, climate prediction certainty decreases. However, the effects of climate change may not be realized for 100-200 years, indicating this time frame needs to be incorporated into the decision process. Therefore, an adaptive management approach may be the best long-term approach to facilitate the decision process given the many uncertainties. An adaptive management approach could be employed (e.g., Nichols et al. 2011) for a fixed set of conditions (e.g., predicted climate in 200 years under a particular climate change scenario) over a time scale relevant to management (such as the 15 year period covered by the refuge's Comprehensive Conservation Plan). At the end of this time period (e.g., 15 years), the models would be revisited to determine if 1) the predicted conditions have changed, and 2) whether models should be updated with new and informative information. If so, then a revised set of models would be run for the next management period (e.g., 16-30 years).

Uncertainty

Climate

In Hawaii, both mosquito dynamics and malaria parasite development respond positively to increased temperatures. Higher temperatures increase mosquito abundance, increasing the rate mosquitoes become infectious, and therefore increasing malaria transmission to birds (Ahumada et al. 2004; Samuel et al. 2011). Perhaps one of the greatest uncertainties confounding the decision making process is the accuracy of the downscaled climate models projecting future rainfall and temperature patterns for the Hawaiian Islands. This uncertainty will significantly influence the time horizon and magnitude of disease impact that is likely to occur at HFNWR, and therefore the potential success of management efforts to mitigate the loss of disease-free habitat. Both temperature and rainfall are significant drivers of mosquito and avian malaria dynamics in the Hawaiian forests; of these two climate parameters, temperature projections can be estimated with more certainty. We expect that temperature change in Hawaii will produce a significant increase in malaria transmission throughout mid- and high-elevation forests in Hawaii; low-elevation forests are already saturated with intense malaria transmission. Projected future temperatures in Hawaii depend on global climate change emission scenarios and interpretation of long-term (1919-2006 = +0.04°C/decade) vs. recent (1975-2006 = +0.16°C/decade) temperature trends in Hawaii (Giambelluca et al. 2008). However, a complicating factor is that downscaling of Atmosphere-Ocean General Circulation Models (AOGCMs) predicts a 5-10% decrease in wet season precipitation and a 5% increase in dry season precipitation (Timm et al. 2009). Thus moisture availability may shift as temperatures rise. How these changes will impact malaria dynamics and Hawaiian forest birds is not straightforward and will require the modeling of alternative climate scenarios and their potential effects for the next 100 to 200 years.

Management Actions

Climate uncertainties add to the uncertainties associated with the efficacy and feasibility of proposed management actions. For example, we do not know if there is adequate time to reforest barren land or at what forest stage or age habitat will be suitable for each of the eight avian species considered. Akiapola`au may move into and become established in relatively young koa *Acacia koa* forests but Akepa would require mature ohia *Metrosideros polymorpha* trees to provide nest cavities (Freed et al 1987). Connected to a successful reforestation effort is the uncertainty regarding the stability and average elevation of the Trade Wind Inversion (TWI) which will ultimately determine the timberline on Mauna Kea (Cao et al. 2007). Should average height of the TWI decrease there would be inadequate precipitation to sustain upper elevation rain forest habitat. A lower TWI would also increase mean daily temperatures, accelerating the loss of potentially disease–free habitat.

A major uncertainty regarding vector control is the significance of rock pools along intermittent streams in supporting mosquito populations and whether effective control measures can be developed and supported into the distant future. In a drier future with fewer high precipitation events, permanent streams on Mauna Kea may become intermittent and thereby provide more larval mosquito habitat. Aerial applications of bio-pesticides would be necessary to control stream-produced mosquitoes, but it is uncertain if this approach would be accepted by the public or fiscally viable over time.

Management actions to enhance forest bird habitat within the current refuge boundaries have the potential to increase availability of food resources to maintain or increase populations' carrying capacity. However, it is uncertain if understory restoration can provide enough alternative nectar sources to prevent Apapane and Iiwi movements into areas of higher disease transmission outside refuge boundaries. It is also unknown whether the improvement of existing habitat can increase bird abundance in the face of significant malaria transmission.

The amount of genetic variation retained in Hakalau Forest's bird populations is unknown, but genetic variation is likely to be an important determinant of a species' ability to develop tolerance or resistance to disease; therefore, measuring genetic variation in Hakalau Forest NWR bird populations should be a priority for future funding.

The ability of managers to control predators is a significant area of uncertainty. Large-scale control efforts (such as the broadcasting of rodenticide over large areas) needs further development, testing, and certification. Predator-proof fencing is expensive and would require constant maintenance; however, a demonstration predator-proof fence in native forest should be considered to document the effects of pest and predator removal on both forest birds and the plants and arthropods they depend on.

Predictive Model

There are a number of ecological processes that are not currently included in the predictive model of forest bird-malaria dynamics which can produce uncertainty in model predictions. Of potential importance is how movement of birds or mosquitoes would spatially impact transmission dynamics or potential source/sink dynamics for either vectors or birds. In addition, little is known about mosquito feeding preferences among bird species, host defensive behavior, or biting rates on non-avian hosts. Environmental effects (such as temperature and rainfall) can be particularly important for the dynamics of mosquito larval cavities and carrying capacity, yet data related to both of these factors is also limited. The ability of either birds or malaria parasite to evolve host resistance/tolerance and/or parasite virulence, respectively, is both scientifically unknown and absent from the predictive model. Of the eight native bird species of management importance at HFNWR only three are included in the predictive model of Samuel et al. (2011), although there is other published information on the demographics of the remaining species that can be incorporated into models (e.g., VanderWerf 2001, Woodworth et al. 2001). Finally, the model does not consider avian pox which is an additional disease threat to native Hawaiian birds, nor does it consider other forested habitats, such as riparian systems, which are also important for native birds throughout the Hawaiian Islands. Further research is needed on all these topics to improve our understanding of vector-borne disease threats to the endemic Hawaiian avifauna and to reduce uncertainty in model prediction.

Within the current predictive model a number of parameters are poorly estimated. Model uncertainty analysis indicates that predications are reasonably precise for measures of mosquito abundance, and disease prevalence in birds and mosquitoes, but imprecise for bird abundance and malaria infection. Further research including assessing improved model performance from model simplification and increased precision of model parameters may help reduce bias and increase confidence in some model predictions. As an example, rainfall is predicted to affect adult mosquito mortality and larval development/survival; however, the importance of rainfall in mosquito dynamics suggests that improved data is needed to model mosquito population responses, especially if future climate changes are expected to impact rainfall patterns.

Discussion

Threats to Hawaiian Forest Birds

A multi-agency comprehensive analysis of the state of our Nation's bird reports that Hawaiian birds are in crisis (North American Bird Conservation Initiative 2010). Since passage of the Endangered Species act in 1973, numerous factors have continued to weaken the viability of Hawaii's birds and currently more than 30% of U.S. endangered species listed are Hawaiian birds. While the conservation efforts have been substantial and have achieved successes, the scale of action has not matched either the scale of the threats nor the conservation goals. Unfortunately, we are losing, not gaining ground, in the race against extinction (Scott 2009). In the past 25 years, 10 species of endemic Hawaiian birds have been lost to extinction and only 24 of the 46 historically known forest bird species still survive, with 13 listed as endangered. Given this record, is it possible to save the remaining Hawaiian forest birds (Pratt et al. 2009)?

The answer depends on what actions can be taken in the near future to address the substantial issues of avian disease, habitat restoration and viability, and predator control. Although there are many factors influencing these actions the lack of conservation funding is the primary limiting factor and is also related to the lack of public awareness of the issue (Leonard 2009). In large measure, the lack of conservation funding commensurate with the large scale of the problem (Pratt et al. 2009) has likely limited both the amount and scope of management action that has been undertaken; however, the window of opportunity to effectively act on behalf of Hawaii's forest birds is rapidly declining with time (Scott 2009). Renewed efforts at the scale of thousands of acres, are needed to recover viable populations, rather than maintain (or lose) populations that are currently on the brink of extension. These future actions will require collaboration of researchers and managers to jointly develop conservation management objectives, design actions to accomplish these objectives, implement at ecologically meaningful scales, and in an adaptive management framework which reduces uncertainty about the impacts of threats and the efficacy of management actions (Scott 2009).

Value of Decision Structuring

The complexity of the avian disease problem facing Hawaii's native birds is exceptional, involving multiple species, multiple temporal and spatial scales, multiple climatic scenarios, and few well defined options for resource managers to control the problem. Research over the past 30 years has provided a better picture of the epidemiology and impact of introduced avian diseases on Hawaii's native avifauna, but there have been no coordinated efforts between research and management agencies to develop landscape scale approaches to the problem. While resource managers have recognized the importance of addressing this issue to prevent further avian extinctions, an overall sense of exasperation over the complexity and scale of the problem coupled with limited financial resources for integrative research and adaptive management have hindered progress in developing practical solutions. However, the conservation and management communities are increasingly aware that this problem can no longer be ignored and that it needs to be addressed at a landscape level to be effective. This workshop was the first time that resource managers and scientists sat at the same table to discuss and prioritize potential strategies to solve this problem. The SDM process provided a framework for identifying goals, and ranking potential solutions that has not been previously attempted for this issue.

Prototyping Process:

We were fortunate in having a detailed model of the avian disease system to assist with identifying key epidemiological and demographic sensitivities of the system. Even with this model, however, we identified a number of important uncertainties that will require additional information to improve predictions for different portfolios or to assign weights to different strategies. Ideally, future model developments and improvements can be imbedded within an adaptive management process combining both research and management programs to continually improve our knowledge about system dynamics and simultaneous evaluating different management strategies.

A key weakness that was evident was the absence of data to evaluate effectiveness of different management actions in the various portfolios and whether these were the best available based on cost and public acceptance. Additionally, we placed several potential high technology disease control strategies (e.g., genetically modified vectors) in the "parking lot" to be considered at later times. As new information or technology emerges, revisiting the prototyping exercise may be warranted to see if alternative approaches might be warranted.

Further Development Required:

A point was made during the close of the meeting about the importance of broad representation of all stakeholders at the table to prevent biases toward research or management. Our group did an excellent job of this with an equal representation of decision makers with a resource management background and scientists who develop new knowledge to aid decision makers' management decisions. Additional rounds of decision making should focus on development of effective strategies for adaptive management that can measure whether control/management efforts are having an impact on disease transmission and long-term sustainability of forest birds while simultaneously enhancing our scientific and predictive knowledge about the system. Missing were landowner stakeholders from several important State and private groups, including Department of Hawaiian Home Lands, Kamehameha Schools, The Nature Conservancy, the Department of Land and Natural Resources Natural Area Reserves and local Division of Forestry and Wildlife personnel. Additionally, at the time of the workshop the Mauna Kea Watershed Alliance was not yet formed, but does now exist. A balance of representatives from agencies and organizations with an interest in these issues needs to be carefully preserved as the process moves forward in order to assure that recommendations and strategies can move beyond the planning, conceptual, and modeling phases.

At the close of the workshop, the group was pleased with the progress, but clearly recognized this was only the first step towards a more detailed process of stakeholder meetings, acquisition of information to inform existing models, and additional research to improve current models and develop new models for assessing evolution of disease resistance under different scenarios of both selection pressure and genetic diversity. In particular, it was agreed that the number of stakeholders should be expanded in the next meeting to include additional landowners and resource managers.

Recommendations

This group recommends the following questions be answered to take this problem to the next step:

- What is the information to be gathered? Identify the knowledge gaps that may be needed to run models and facilitate collaborative partnerships. This may include existing data that has not been analyzed (population data, predator effects, etc.), is outdated or data that has not been collected.
- What tools to use? Identify the appropriate tools for evaluating options including SMART tables, Optimal Pareto Curve; use sensitivity techniques to evaluate uncertainties and understand model outcome changes under different climate change scenarios.
- Determine actions and efforts needed to implement an adaptive management strategy to address this problem.
- Who should be involved? Identify who best to include to take model forward (agency leaders, landowners, decision makers) and what resources are needed to get to the next step (statistical, capacity building, political support).
- How do we get people to care? Evaluate public support and how to gain it.
- What will this cost? Draft accurate annual budgets outlining cost of proposed program in today’s dollars.
- How do we reduce uncertainties in our current model? Identify methods to get more information that doesn’t require significant additional time or money (compile data, for example, on predator effects on nests, Hakalau demographic research, etc.).

This group has identified the following as actions we can take now that will move the strategy and goals outlined in this document forward:

- Secure funding to continue development of the malaria-forest bird model (at least $100,000).
  - Develop future climate change scenarios and integrate these with the malaria-forest bird model. As a pilot project, run model predictions for species we have in the Volcano area where the biological model was designed.
- Plan and implement a series of pilot management actions that could alleviate threats to forest birds, with monitoring to assess effectiveness of different approaches and techniques.
- Initiate a Forest Bird Recovery Team meeting to discuss management and regulatory actions needed to address climate change threats.
- Initiate a research program to measure genetic variability in forest bird populations and develop models to look at genetics of resistance.
- Plan an expert workshop weekend (similar to SDM workshop) where experts in the field gather to brainstorm and plan projects.
- Identify a champion for this issue, who can coordinate and help move forward the process.
- Facilitate discussion and action planning through consultation workshop, expanded stakeholder meetings, published reports of SDM workshop, and other methods of communication and coordination.
- Create link to Pacific Island Climate Change Center and other organizations leading efforts on climate change adaptation and management to highlight this effort.

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Tables

Hakalau Forest NWR Annual Management Costs (15 year timeframe)
Under 5 alternative portfolios

*A -Status quo**	
Ungulate control ($175k/yr)	$2,625K
Fence maintenance/replacement ($175k/yr per 20 year replacement cycle)	$2,625Kr.
Reforest koa ($75K)	$1,125K
Habitat enrichment ($75K)	$1,125K
New Fencing per CCP (18.5 mi./5,600 add'l.acres)	$1,953,600
Weed Control ($100K/yr)	$1,500K
	$10,954K
B -Status quo +Refuge wide mosquito control	
Additional ungulate control ($175K/yr)	$2,625K
Additional fence maintenance/replacement ($175K/yr)	$2,625K
Hapu'u cavity removal (eliminate larval habitat; $600k/yr)	$9,000K
Streambed spray (product 2X/yr., $51K/yr)	$765K
(heli- time@$ 775/hr/2Xyr., $15.5K/yr))	$188K
Acquire or land swap for Piha GMU land	Unknown
	$15,203K +
C -Status quo + New mauka forest habitat (4000 acres DHHL Humu'ula lands)	
New fencing (10 miles @ 100K/mi.)	$1,000K
Fence Replacement (50 year cycle/3x)	$900K
Ungulate eradication (DHHL-1yr ungulate free)	$175K
Reforest koa and native understory ($2000/acre)	$600K
Water system development	$1,000K
Cooperative management (100k/yr x 50 years joint restoration and coordination)	$1,500K
Weed control (DHHL – 50k/yr x 20 years)	$750K
	$5,925K
D -Status quo + Disease compensation	
Predator control ($200K/yr)	$3,000K
Enrich natural food source ($75K/yr)	$1,125K
Artificial food source ($50K/yr)	$750K
	$4,875K
E-Status quo +Building resistance	
Augment native birds (n=20/yr.@$3,000per; $60k/yr.)	$900K
Augment w/ dis. resistance birds (n=100@$1,000per; $100k/yr)	$1,500K
	$2,400K

(*$1,160,000= Hakalau Forest NWR budget in FY2010. Does not include costs for weed control program. Items listed are assumed to be recurring annual costs except where otherwise noted)

Figures

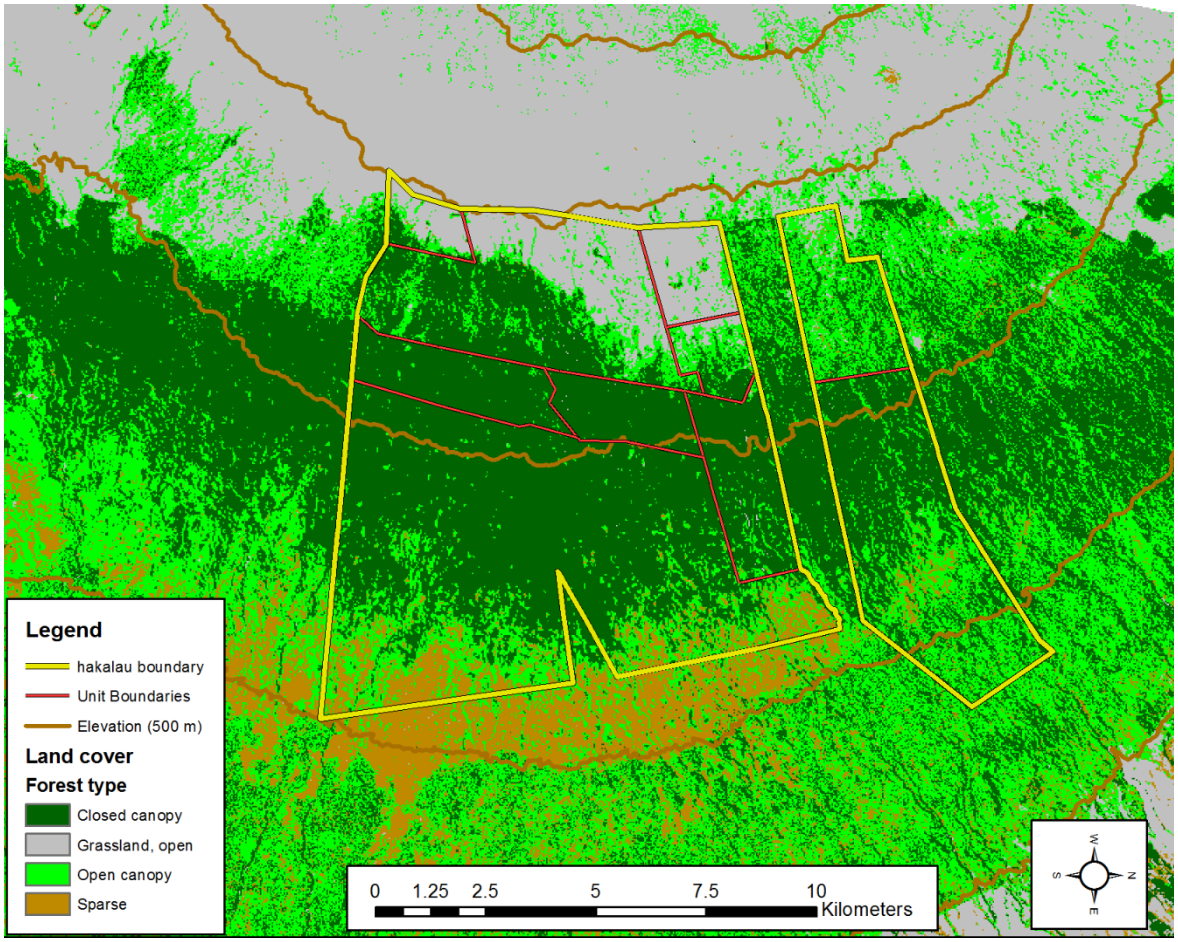

Figure 1: Map of Hakalau Forest NWR Hakalau units. Grey area within refuge is area of active reforestation with koa trees. Active ungulate control is in the upper units (bordered in red). Area between the two parcels is Piha Forest Reserve.

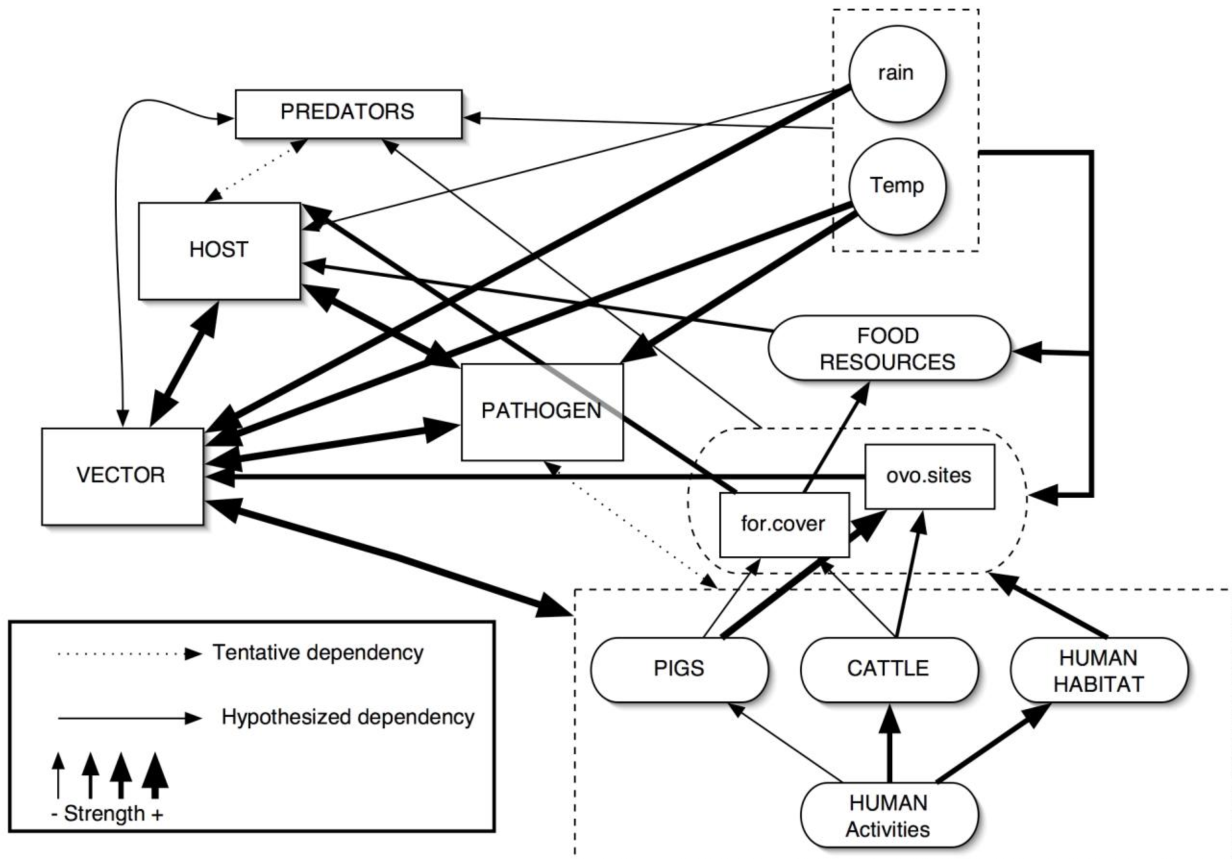

Figure 2. Conceptual model of avian malaria in the Hawaiian forest bird ecosystem. Arrows denote dependencies between components of the system. The current model includes vector, host, pathogen components and the direct influence of temperature, rainfall, elevation, and mosquito oviposition sites on the dynamics of avian malaria.

Appendix 1: Compliance with regulatory requirements for Implementation of the Hakalau Forest National Wildlife Refuge Comprehensive Conservation Plan

The following Executive orders and legislative acts apply to implementation of the Comprehensive Conservation Plan (CCP) for Hakalau Forest National Wildlife Refuge (NWR).

National Environmental Policy Act (1969) (42 U.S.C. 4321 et seq.). The CCP planning process has been conducted in accordance with National Environmental Policy Act implementing procedures, Department of the Interior and U. S. Fish and Wildlife Service procedures, and has been performed in coordination with the affected public. Procedures used to reach this decision meet the requirements of the National Environmental Policy Act and its implementing regulations in 40 CFR Parts 1500-1508.

National Historic Preservation Act (1966) (16 U.S. C.470 et seq.). The management of historic, archaeological, and cultural resources of Hakalau Forest NWR complies with the regulations of Section 106 of the National Historic Preservation Act. No historic, archaeological, and cultural resources are known to be affected by the implementation of the CCP based on the criteria of an effect or adverse effect as an undertaking defined in 36 CFR 800.9 and Service Manual 614 FW 2. Should historic properties be identified in the future, the Service will comply with the National Historic Preservation Act if any management actions have the potential to affect any of these properties.

Executive Order 12372. Intergovernmental Review. Coordination and consultation with other affected Federal, State, and County agencies have been completed through personal contact by Service planners, the Refuge manager and supervisors.

Executive Order 12898. Federal Actions to Address Environmental Justice in Minority and Low-Income Populations. All Federal actions must address and identify, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations, low-income populations, and Indian Tribes in the United States.

Executive Order 13186. Responsibilities of Federal Agencies to Protect Migratory Birds. This Order directs departments and agencies to take certain actions to further implement the Migratory Bird Treaty Act (MBTA). The CCP is consistent with this Executive Order because management actions are consistent with the provisions of the MBTA and the CCP and NEPA analysis evaluated the effects of such action on MBTA species.

Endangered Species Act (ESA) (16 U.S.C. 1531-1544). This Act provides for the conservation of threatened and endangered species of fish, wildlife, and plants by Federal action and by encouraging the establishment of state programs. It provides for the determination and listing of endangered and threatened species and the designation of critical habitats. Section 7 requires refuge managers to perform consultation before initiating projects which affect or may affect endangered species. The Refuge will conduct consultation under Section 7 of the Endangered Species Act for any Refuge management program actions that have the potential to affect listed species.

Coastal Zone Management Act, Section 307. Section 307(c)(1) of the Coastal Zone Management Act of 1972 amended, requires each Federal agency conducting or supporting activities directly affecting the coastal zone, to conduct or support those activities in a manner that is, to the maximum extent practicable, consistent with approved State coastal management programs.

National Wildlife Administration Act of 1966, as amended by the National Wildlife Refuge System Improvement Act of 1997 (16 U.S.C. 668dd-668ee). During the CCP process, the Refuge Manger evaluated all existing and proposed Refuge uses at Hakalau Forest NWR. Priority wildlife-dependent uses (hunting, fishing, wildlife observation and photography, environmental education and interpretation) are considered automatically appropriate under Service policy and thus exempt from appropriate uses review. Appropriate Use Findings have been prepared for the following uses: commercial photography, videography, filming or audio recording; commercial tour operation/conservation and education group visits; the University of Hawaiʻi Field station; and research, scientific collecting, and surveys. Compatibility Determinations have been prepared for the following uses: hunting, wildlife observation and photography, commercial photography, videography, filming or audio recording, commercial tour operation/conservation and education group visits, the University of Hawaiʻi Field Station, and research, scientific collecting, and surveys.

Integrated Pest Management (IPM), 517 DM 1 and 569 FW 1. In accordance with 517 DM 1 and 569 FW 1, an integrated pest management (IPM) approach has been adopted to eradicate, control or contain pest and invasive species on the Refuge. In accordance with 517 DM 1, only pesticides registered with the U.S. Environmental Protection Agency (EPA) in full compliance with the Federal Insecticide, Fungicide, and Rodenticide Act and as provided in regulations, orders, or permits issued by the EPA may be applied on lands and waters under Refuge jurisdiction.

Executive Order 11990. Protection of Wetlands. The CCP is consistent with Executive Order 11990 because CCP implementation would protect existing wetland at the Refuge (e.g., *Carex* bogs).

Wilderness Preservation Act of 1964 (Wilderness Act). The Wilderness Act requires the Service to evaluate the suitability of Hakalau Forest NWR for wilderness designation. A Wilderness Review is included as Appendix D to the CCP.

Appendix 2: Regulatory…

National Wildlife Refuge System

The Refuge System is the world's largest network of public lands and waters set aside specifically for conserving wildlife and protecting ecosystems. From its inception in 1903, the Refuge System has grown to encompass 552 national wildlife refuges in all 50 States, 4 U.S. territories and a number of unincorporated U.S. possessions, and waterfowl production areas in 10 States, covering more than 150 million acres of public lands. It also manages four marine national monuments in the Pacific in coordination with the National Oceanic and Atmospheric Administration (NOAA) and affected States/Territories. More than 40 million visitors annually fish, hunt, observe and photograph wildlife, or participate in environmental education and interpretive activities on these NWRs.

Refuges are guided by various Federal laws and Executive orders, Service policies, and international treaties. Fundamental are the mission and goals of the Refuge System and the designated purposes of the Refuge unit as described in establishing legislation, Executive orders, or other documents establishing, authorizing, or expanding a refuge.

Key concepts and guidance for the Refuge System derive from the Administration Act, the Refuge Recreation Act of 1962 (16 U.S.C. 460k-460k-4), as amended, Title 50 of the Code of Federal Regulations, and the Fish and Wildlife Service Manual. The Administration Act is implemented through regulations covering the Refuge System, published in Title 50, subchapter C of the Code of Federal Regulations. These regulations govern general administration of units of the Refuge System. This CCP complies with the Refuge Administration Act.

National Wildlife Refuge System Mission and Goals

The mission of the Refuge System is:

"to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans" (National Wildlife Refuge System Administration Act of 1966, as amended)(16 U.S.C. 668dd).

Wildlife conservation is the fundamental mission of the Refuge System. The goals of the Refuge System, as articulated in the Mission, Goals, and Refuge Purposes Policy (601 FW1) are:

- Conserve a diversity of fish, wildlife, and plants and their habitats, including species that are endangered or threatened with becoming endangered;

- Develop and maintain a network of habitats for migratory birds, anadromous and inter-jurisdictional fish, and marine mammal populations that is strategically distributed and carefully managed to meet important life-history needs of these species across their ranges;

- Conserve those ecosystems, plant communities, wetlands of national or international significance and landscapes and seascapes that are unique, rare, declining, or underrepresented in existing protection efforts;

- Provide and enhance opportunities to participate in compatible wildlife-dependent recreation (hunting, fishing, wildlife observation and photography, and environmental education and interpretation); and

- Foster understanding and instill appreciation of the diversity and interconnectedness of fish, wildlife, and plants and their habitats.

National Wildlife Refuge System Administration Act

Of all the laws governing activities on refuges, the Administration Act exerts the greatest influence. The National Wildlife Refuge System Improvement Act of 1997 (Improvement Act) amended the Administration Act by including a unifying mission for all refuges as a system, a new process for determining compatible uses on refuges, and a requirement that each refuge will be managed under a CCP developed in an open public process.

The Administration Act states the Secretary of the Interior shall provide for the conservation of fish, wildlife, and plants, and their habitats within the Refuge System as well as ensure that the biological integrity, diversity, and environmental health of the Refuge System are maintained. House Report 105–106 accompanying the Improvement Act states ‘‘… the fundamental mission of our System is wildlife conservation: wildlife and wildlife conservation must come first.’’ Biological integrity, diversity, and environmental health (BIDEH) are critical components of wildlife conservation. As later made clear in the BIDEH Policy, “the highest measure of biological integrity, diversity, and environmental health is viewed as those intact and self-sustaining habitats and wildlife populations that existed during historic conditions.”

Under the Administration Act, each refuge must be managed to fulfill the Refuge System mission as well as the specific purposes for which it was established. The Administration Act requires the Service to monitor the status and trends of fish, wildlife, and plants in each refuge.

Additionally, the Administration Act identifies six wildlife-dependent recreational uses for priority consideration. These uses are hunting, fishing, wildlife observation and photography, and environmental education and interpretation. Under the Administration Act, the Refuge is to grant these six wildlife-dependent public uses special consideration in the planning for, management of, and establishment and expansion of units of the Refuge System. The overarching goal is to enhance wildlife-dependent recreation opportunities and access to quality visitor experiences on refuges while managing refuges to conserve fish, wildlife, plants, and their habitats. New and ongoing recreational uses should help visitors focus on wildlife and other natural resources. These uses should provide an opportunity to make visitors aware of resource issues, management plans, and how the refuge contributes to the Refuge System and the Service mission. When determined compatible on a refuge-specific basis, these six uses assume priority status among all uses of the refuge in question. The Refuge is then directed to make extra effort to facilitate priority wildlife-dependent public use opportunities.

When preparing a CCP, refuge managers must re-evaluate all general public, recreational, and economic uses (even those occurring to further refuge habitat management goals) proposed or occurring on a refuge for appropriateness and compatibility. No refuge use may be allowed or continued unless it is determined to be appropriate and compatible. Generally, an appropriate use is one that contributes to fulfilling the refuge purpose(s), the Refuge System mission, or goals or objectives described in a refuge management plan, such as this CCP. A compatible use is a use that, in the sound professional judgment of the refuge manager, will not materially interfere with or detract from the fulfillment of the mission of the Refuge System or the purposes of the refuge. Updated Appropriateness Findings and Compatibility Determinations for existing and proposed uses for Hakalau Forest NWR are in Appendix B.

The Administration Act also requires that, in addition to formally established guidance, the CCP must be developed with the participation of the public. Issues and concerns articulated by the public played a role in guiding the development of the CCP, and together with the formal guidance, played a role in development of the final CCP. It is the Service’s policy to invite public participation in CCP development, to carry out an open public CCP process, and secure public input throughout the process

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REFUGE PURPOSE AND GOALS:

The Administration Act directs the Service to manage each refuge to fulfill the mission of the Refuge System, as well as the specific purposes for which that refuge was established. Refuge purposes are the driving force in developing refuge vision statements, goals, objectives, and strategies in the CCP. Refuge purposes are also critical to determining the appropriateness and compatibility of all existing and proposed refuge uses.

Lands within the Refuge System are acquired and managed under a variety of legislative acts, administrative orders, and legal authorities. The official purpose or purposes for a refuge are specified in or derived from the law, proclamation, Executive order, agreement, public land order, donation document, or administrative memorandum establishing, authorizing, or expanding a refuge, refuge unit, or refuge subunit. The Service defines the purpose of a refuge when it is established or when new land is added to an existing refuge. When an addition to a refuge is acquired under an authority different from the authority used to establish the original refuge, the addition takes on the purposes of the original refuge, but the original refuge does not take on the purposes of the addition. Refuge managers must consider all of these purposes. Additionally, refuge boundaries may encompass lands that the refuge itself does not own.

Hakalau Forest Unit Purposes

Established on October 29, 1985, the purposes of Hakalau Forest Unit are:

- "… to conserve (A) fish or wildlife which are listed as endangered species or threatened species. . . or (B) plants . . . (C) the ecosystems upon which endangered species and threatened species depend . . ." (Endangered Species Act of 1973, as amended, 16 U.S.C. 1534);

- "To assure the perpetuation of native forest habitats of the Upper Hakalau Forest for the protection of a number of endangered animals and plants endemic to the area. . . ." (FONSI for the Environmental Assessment: Proposal to Establish an Upper Hakalau National Wildlife Refuge, Hawai'i County, Hawai'i, May 1985).

REFUGE GOALS

Goals and objectives are the unifying elements of successful refuge management. They identify and focus management priorities, resolve issues, and link to refuge purposes, Service policy, and the Refuge System mission.

The goal order does not imply any priority in the CCP.

Pahuhopu 1: E hoʻopalekana, mālama, a hoʻōla hou i ka waonahele ma Mauna Loa ma ke ʻano he wahi noho no nā mea a pau i mea e kūʻonoʻono hou ai ka nohona o nā mea ʻane make loa ʻo ia nō ʻo ʻoe ʻo nā manu, nā ʻōpeʻapeʻa, nā mea kanu, a me nā mea kolokolo ʻāina.

Goal 1: Protect, maintain, and restore subtropical rainforest community on the leeward slope of Mauna Loa as habitat for all life-history needs to promote the recovery of endangered species (e.g., forest birds, ʻōpeʻapeʻa, plants, and invertebrates).

Pahuhopu 2: E hoʻopalekana a mālama i nā ana kahe pele a me ke ola i ka puka mālamalama o nā ana kahe pele ma ka waonahele o Kona, e kālele ana hoʻi i ke ola o nā lāʻau ʻōiwi.

Goal 2: Protect and maintain lava tube and lava tube skylight habitat throughout the Kona Forest Unit, with special emphasis on their unique and endemic flora and fauna.
Pahuhopu 3: E hoʻopalekana, mālama, a hōʻola hou i ka waonahele ma ka ʻaoʻao koʻolau o Mauna Kea ma ke ʻano he wahi noho no nā mea a pau a me ko lākou pono ʻoia nō ʻoe ʻo nā manu, nā ʻōpeʻapeʻa, nā mea kanu, a me nā mea kolokolo ʻāina.

Goal 3: Protect, maintain, and restore subtropical rainforest community, on the windward slope of Mauna Kea as habitat for all life-history needs of endangered species (e.g., forest birds, ʻōpeʻapeʻa, plants, and invertebrates).

Pahuhopu 4: E hoʻopalekana a mālama i ka ʻāina nenelu ma Hakalau.

Goal 4: Protect and maintain wetland and aquatic habitats (e.g., streams and their associated riparian corridors, ponds, and bogs) on the Hakalau Forest Unit.

Pahuhopu 5: E hoʻopalekana a mālama i ka ʻāina mauʻu i mea e kākoʻo ai i ka hoʻōla hou ʻana i ka hui manu nēnē.

Goal 5: Protect and maintain grassland habitat to support nēnē population recovery.

Pahuhopu 6: E ʻohiʻohi i ka ʻikepili ʻepekema (waihona ʻike, nānā pono, ʻimi noiʻi, ana ʻike) e pono ai ka hoʻoholo ʻana i ke ʻano o ka hoʻokele ʻana iā Hakalau ma Mauna Kea a me Mauna Loa.

Goal 6: Collect scientific information (inventories, monitoring, research, assessments) necessary to support adaptive management decisions on both units of the Hakalau Forest NWR.

Pahuhopu 7: E kipa mai ka poʻe malihini a me ka poʻe makaʻāinana no ka hana manawaleʻa ʻana i mea e kamaʻāina ai lākou i ka nohona o ka waonahele a me ka ʻoihana mālama ma Hakalau.

Goal 7: Visitors, with a special emphasis on experience gained through volunteer work groups and local residents, understand and/or value the native forest environment and management practices at Hakalau Forest NWR.

Pahuhopu 8: E hoʻopalekana a mālama i nā kumu waiwai a me nā wahi pana Hawaiʻi no ka hoʻonaʻauao ʻana i nā hanauna o kēia wā a me ka wā e hiki mai ana.