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Minimizing extinction risk in the face of uncertainty: Developing conservation strategies for 2 rapidly declining forest bird species on Kauaʻi Island

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Abstract

Many species around the world are declining precipitously as a result of multiple threats and changing climate. Managers tasked with protecting species often face difficult decisions in regard to identifying which threats should be addressed, given limited resources and uncertainty in the success of any identified management action. On Kauaʻi Island, Hawaiʻi, USA, forest bird species have experienced accelerated declines over the last 20 years, and 2 species, the ʻakikiki (*Oreomystis bairdi*) and ʻakekeʻe (*Loxops caeruleirostris*), are now at the brink of extinction. Both species face multiple threats, and managers face difficult decisions on whether to mitigate threats in the wild, establish a captive population as insurance against extinction, translocate birds to novel locations, or some combination of these actions. Each set of actions (alternatives) would require substantial resources with considerable uncertainty in success. In 2014, we brought together 14 experts representing biologists and managers familiar with the species and island to develop a conservation strategy under a structured decision making (SDM) framework, an approach for making complex decisions under uncertainty. The group's challenge was to identify a set of alternatives that reduces the risk of extinction, set the foundation for one or more genetically viable, reproducing, stable to increasing populations in 10 years, and promote conditions for long-term persistence in the wild. Multiple alternatives were evaluated, via expert judgement, in terms of the probability they would achieve the objectives concerning immediate extinction risk, near-term viability, and adequacy of habitat. Factors that might impede the success of each action were also evaluated. The process identified the establishment of a captive population and efforts to stabilize the existing wild population as the approach most likely to meet the objectives of preventing imminent extinction and ensuring long-term viability.

KEYWORDS

captive breeding, declining populations, habitat management, Kauai forest birds, *Loxops caeruleirostris*, *Oreomystis bairdi*, structured decision making, translocation

For many rare and declining species, the proximate causes of decline are unclear due to presence of multiple stressors (Owens and Bennett 2000). Additionally, the rarity of many declining species makes studies of demographic processes and identification of stressors challenging given small sample sizes, increasing uncertainty in the relative severity of different threats. Threats such as climate change are also producing novel conditions and creating shifting threats to which species may have difficulty adapting (Brook et al. 2008). For managers tasked with conserving declining species, uncertainty in the causal factors of declines carries over to uncertainty in the appropriate conservation response, and the potential effectiveness of various interventions (Nichols et al. 2011). Thus, there is risk in pursuing ineffective management actions that would consume scarce resources that could be more productively spent elsewhere. Equally important, the fear of choosing a wrong strategy can result in no action being taken.

In Hawaiʻi, developing clear conservation strategies for endemic forest birds is hampered by the complexity of multiple threats, a lack of demographic information for many species, and uncertainty regarding the most effective conservation responses. As on many Pacific islands (Steadman 2006), a large proportion (63%) of Hawaiʻi's endemic forest birds have already gone extinct, with the majority of extant species currently listed as threatened or endangered (Paxton et al. 2018). A multitude of threats have contributed to recent extinctions and the continuing decline of the remaining species, including habitat loss and degradation from deforestation, non-native ungulate grazing, and invasive plants (van Riper and Scott 2001, Banko and Banko 2009). Non-native predators can also have large impacts on some species and likely affect all species to some extent (Goltz et al. 2008, VanderWerf 2009, Mounce et al. 2013, VanderWerf et al. 2014). Additionally, introduced diseases, primarily avian malaria, cause high levels of mortality in native Hawaiian forest bird species (Warner 1968; Van Riper et al. 1986; Atkinson et al. 1995, 2014; Samuel et al. 2018). Climate change is predicted to increase the range of disease in forested areas of Hawaiʻi where it has been historically absent (Benning et al. 2002, Fortini et al. 2015), and may change the distribution and intensity of additional threats (Vorsino et al. 2014). Multiple threats may interact or have to be addressed simultaneously, making management for Hawaiian forest bird species complex (Guillaumet and Paxton 2019). Furthermore, limited resources restrict the range of conservation responses possible (Leonard 2008).

On the island of Kauaʻi, 6 of the 8 remaining native forest bird species have declined rapidly over the last 2 decades (Paxton et al. 2016), following extinctions of at least a dozen others over the last 2 centuries (Conant et al. 1998, Burney et al. 2001). In particular, 2 of Kauaʻi's endemic species, ʻakikiki (*Oreomystis bairdi*) and ʻakekeʻe (*Loxops caeruleirostris*), were widespread in the 1980's (Scott et al. 1986), but since 2000 have experienced sharp declines with recent estimated population sizes between 120–1,698 individuals (Paxton et al. 2016, 2020). Given the small population sizes and continued declines, both species face a high probability of extinction without the intervention of an effective conservation strategy. However, like all Hawaiian forest birds, what stressors are driving the decline of both species is not known with full certainty, reducing our ability to effectively implement conservation actions. The most likely stressor contributing to recent declines is increased disease prevalence driven by climate change (Atkinson et al. 2014, Fortini et al. 2015, Liao et al. 2017). However, other negative stressors include ongoing threats from predators (Foster et al. 2004, Paxton et al. 2016), and decreased habitat quality due to invasive plants, ungulate pressure, as well as considerable habitat damage from hurricanes in the 1980's and 1990's (Behnke et al. 2016).

We initiate a structured decision making (SDM) process to identify management actions (hereafter, alternatives) that could help minimize the threat of extinction, both within the context of uncertainty in the importance of different threats and the effectiveness of different management strategies. The value of the SDM process is to break complex problems into smaller, more tractable pieces that can address multiple objectives (Conroy and Peterson 2013). Structured decision making allows different types of information important for the decision process to be considered simultaneously, including scientific information, decision-maker values, and alternative management strategies. The SDM process breaks a problem into 5 fundamental components often referred to as PrOACT (Hammond et al. 1999). Problem framing, the first step in PrOACT, articulates the components of the problem and the scope of the decision space. Next, objectives are defined as the values important to achieve in the desired outcome, such as preserving biodiversity (and thus preventing extinction) and following appropriate conservation laws (such as the U.S. Endangered Species Act of 1973). With the problem defined and objectives identified, a list of alternatives can then be identified that have the potential to achieve the objectives, given the problem being considered. In natural resource management situations, there are different actions that could be taken to address complex problems with multiple objectives. Choosing among different alternatives involves evaluating the consequences of each alternative in terms of the objectives, which often involves tradeoffs. Tradeoffs can be between satisfying different objectives, choosing among outcomes with different degrees of certainty in success, and choosing between progress on short versus long-term goals (Runge and Bean 2020). Importantly, a model of the system is needed to assess the effectiveness of different alternatives to meet the one or more objectives so that tradeoffs can be considered. Models of systems can be mathematical models, general models of a system, or derived from expert judgement. Complex problems often require diverse groups (e.g., managers, scientists) to both ensure the important objectives are identified and the full suite of alternatives are considered. The process provides a transparent presentation of uncertainty and allows for well-informed decision making that has assisted in a wide range of natural resource issues (Conroy and Peterson 2013, Runge et al. 2020).

For the conservation of Kauaʻi forest birds, considerable uncertainty in the effectiveness of different actions to mitigate threats was a key part of the problem. There was structural uncertainty in the relative importance of different threats and the response of species to management actions, partial observability where we had imperfect estimates of how species were reacting to specific threats or management actions, and partial controllability in that we could not fully control the pace of technology development, funding cycles, and public support. Ranking alternatives through the SDM process, which incorporates uncertainty, was key for the development of a conservation plan to minimize the probability of extinction in ʻakikiki and ʻakekeʻe, and other Kauaʻi forest birds. In this paper, we highlight the role of SDM, the selection of preferred alternatives, and describe how the recommended actions were implemented.

STUDY AREA

Kauaʻi's native forest birds were restricted to the highest elevation forests on the Alakaʻi Plateau, which are found at approximately 900–1,500 m (Foster et al. 2004, Paxton et al. 2016). The Alakaʻi Plateau is the eroded remnant of an ancient volcano and was composed of mesic and wet native montane forests dominated by the canopy tree species ʻōhiʻa (*Metrosideros polymorpha*) and a diverse understory. There is an east-west gradient across the plateau that characterizes an elevation gradient (western areas are lower in elevation), precipitation gradient (the western portion is drier), and invasive gradient (the western portions of the plateau are more invaded by non-native plants). Areas in the western portion of the plateau have seen the greatest declines in bird communities (Paxton et al. 2016, 2020).

Until the mid-1960s, the Alakaʻi Plateau retained most of its historical avifauna (Scott et al. 1986). However, surveys from 1980 to 1990 showed multiple species persisting at small numbers that have subsequently gone extinct, including the kāmaʻo (*Myadestes myadestinus*), Kauaʻi ʻōʻō (*Moho braccatus*), ʻōʻū (*Psittirostra psittacea)*, and Kauaʻi nukupuʻu (*Hemignathus hanapepe*). Analysis of trends up to the early 2000s indicated the remaining species had stabilized (Foster et al. 2004), but in the subsequent 20 years the surviving species have experienced rapid declines (Paxton et al. 2016, 2020). The Alakaʻi Plateau is remote, difficult to access, and most demographic information on Kauaʻi's forest birds is poorly understood.

METHODS

To help guide conservation efforts for ʻakikiki and ʻakekeʻe, we brought together 14 experts from federal, state and non-government organizations (see Acknowledgments) to participate in a SDM workshop. Individuals spanned a comprehensive set of knowledge and experience, ranging from Kauaʻi land management to Hawaiʻi forest bird species and threat expertise to policy knowledge. Given a lack of quantitative data that could be used to model optimal management actions, and insufficient time to conduct necessary research, the group of experts provided guidance via expert elicitation. Expert elicitation is often used in conservation decision making when problems involve complex, dynamic systems with large gaps in knowledge and little time to conduct extensive studies (Sutherland 2006, Martin et al. 2012). This group was tasked with developing a set of alternatives that could be initiated immediately to reduce the risk of imminent extinction and pave the way for long-term recovery. The SDM group not only participated in identifying the objectives and alternatives, but also evaluated the probability that the alternatives would achieve the objectives, therefore modeling the tradeoffs and identifying preferred alternatives. Authors EHP, LHC, JPV, and ML participated as experts and SM was the facilitator for the effort.

A key component of the problem was the paucity of information on ʻakikiki and ʻakekeʻe, with only a few studies having examined habitat use and nesting ecology of these birds (Hammond et al. 2015, Behnke et al. 2016). The ʻakikiki and ʻakekeʻe occupy the same general areas across the plateau and are both insectivores but differ in a number of life history aspects, such as foraging behavior (Behnke et al. 2016), and therefore may be affected by habitat change and disturbance differently. ʻAkekeʻe abundance is generally low (0.212 birds/ha), increasing slightly from west to east across the plateau (Paxton et al. 2016), and are positively correlated with areas where trees are largest (Behnke et al. 2016). ʻAkekeʻe are very elusive, do not appear to be territorial around nests, and their nests are particularly difficult to find; therefore, there is still much unknown of their reproductive biology, movements, and dispersal (Hammond et al. 2015). ʻAkikiki overall occur at lower densities than ʻakekeʻe (0.088 birds/ha; (Paxton et al. 2016), but occupancy is clustered and appears correlated with areas of forest that have higher overall tree canopy height and more native shrub cover, resulting in similar occurrence probabilities as ʻakekeʻe in core areas (Behnke et al. 2016). Because both species have different life history characteristics that may lead to different pressures from predators and habitat degradation, we considered each species separately in terms of threats and assessment of alternatives. However, preferred alternatives were the same for both species, and synthesis of SDM results was averaged across the 2 species.

Given the recognition that there were multiple threats, but uncertainty in the relative importance of the different threats, we asked each expert to independently rank the relative importance of various threats to each species. We identified 6 threat categories: disease, primarily avian malaria (Atkinson et al. 2014) but could include avian pox; nest predation, primarily by black rats (*Rattus rattus*), which can drive population declines in some species (VanderWerf 2009); adult predation by rats and feral cats (Hess et al. 2009); habitat degradation, both from invasive species (Pratt and Jacobi 2009) actively changing the characteristics of the forest, plus possible residual damage from historic hurricanes; negative effects from small population sizes, including demographic stochasticity and inbreeding depression (Lande 1993); and environmental stochasticity, which could include risks from hurricanes and other weather extremes. Experts were asked to distribute 100 points among the 6 threat categories to indicate judgment on relative importance (for example, 60 points given to disease indicated that disease was potentially responsible for 60% of the decline of that species), and we averaged the responses to produce an overall threat index. Given differences in the 2 species' natural history, we evaluated each species separately.

The process began with several group meetings by phone where the SDM steps were explained and the problem statement articulated. We subsequently met in person for a 2-day workshop in 2014 during which we reviewed the available evidence of declines and threats, then worked on articulating objectives, identifying alternatives and possible logistical impediments to success, and assessed the likelihood of alternatives achieving the objectives (Tradeoffs). Three objectives were formulated by the group to establish the goals and values the group thought were important to address the problem but were given different weighting to recognize that some objectives may be more important than others given the problem statement. The group then identified specific alternatives, or suites of actions, which could be conducted to achieve the identified objectives. The SDM group ranked each alternative on a percentage scale (0–100%) to represent each members' assessment of the probability that a given alternative would achieve a specific objective's goal. Then, for each alternative, we averaged each member's scores for each objective, applied the weighting assigned to each objective, and added up the weighted scores to produce a single score per alternative. Thus, each alternative had a single averaged score based on the experts' average perception of the alternative's effectiveness to successfully address the problem and achieve the objectives.

Next, SDM group members were asked to identify logistical factors that would impede the success of an alternative in addressing an objective independent of the biological aspects of the alternative. For example, aerial broadcasting of rodenticide would likely be an effective method for suppressing rat populations in Hawaiian forests (Howald et al. 2007), but the regulatory process and perceived lack of public support led group members to have concerns that the tool would not be available in time to address the problem. Thus, logistical impediments to the application of an alternative represent less-tangible aspects of the perceived probability that an alternative would be successful, including speed and likelihood of implementation, societal perception, and costs. We identified 5 logistical impediments (scored 1–5, with higher values indicating greater difficulty) that could affect each alternative's ability to achieve the objectives:

1) The degree of uncertainty in achieving an objective given the current understanding of threats and the ability of the action to produce positive results. In some cases, an alternative may have had a high uncertainty of success, such as translocation to another island, and was given higher scores for that uncertainty;
2) The minimum time required to implement each alternative. Given the rapid declines of the 2 species, actions that might take years of permitting or regulatory approval were less favored and received higher scores;
3) The minimum time required for alternative to show effectiveness. Likewise, alternatives that could produce quicker results would be favored (lower scores) over those that took longer to show positive results;
4) Public aversion to alternative. Alternatives with potentially controversial elements would score higher than those likely to have broad public support; and
5) Cost. While the sole focus was the prevention of extinction, alternatives that were very expensive would have lower chance of being implemented given the limited resources available for conservation actions and were scored higher.

Each alternative received a single impediment score that was the sum of the 5 criteria as judged by the SDM group, with higher values indicating more difficulty in the alternatives being successfully implemented. At the end of the process, each alternative received 2 scores, one that indicated the probability of the alternative successfully achieving the objectives if enacted, and a second score that represented the strength of logistical impediments that could potentially constrain the success of the alternative.

RESULTS

The SDM group developed the following problem statement: identify a set of actions that prevents the imminent extinction of the species and sets the foundation for the goal of one or more genetically viable, reproducing, stable to increasing populations in 10 years and allows for their long-term persistence in the wild. All participants agreed that extinction was likely without conservation actions but did not agree universally which of multiple threats were the most important drivers. For both species, the average expert ranking placed disease as the most serious threat to persistence (50% average risk), followed by habitat degradation (19%) and nest predation (11%; Figure 1). Although overall threat rankings were similar for the 2 species, ‘akikiki were considered more vulnerable to rat predation because of nesting habits and documented nest predation (Hammond et al. 2015), and therefore the relative risks of disease and habitat degradation were considered slightly lower for ‘akikiki than ‘akeke‘e.

Objectives

Three objectives were identified as important to address the problem, and the weighing of the objectives shifted over time as the group developed insights into the problem. The first, prevent the imminent extinction of ‘akikiki and ‘akeke‘e, was articulated to prioritize immediate actions that could be enacted to prevent extinction and was given 50% of the weight. The second objective articulated the importance of setting the foundation for one or more genetically viable, reproducing, and stable-to-increasing populations within 10 years (either in captivity or in the wild). The second objective was included to reduce the probability that actions taken for immediate benefits did not come at the expense of long-term population viability and was weighted at 30%. The third objective, manage

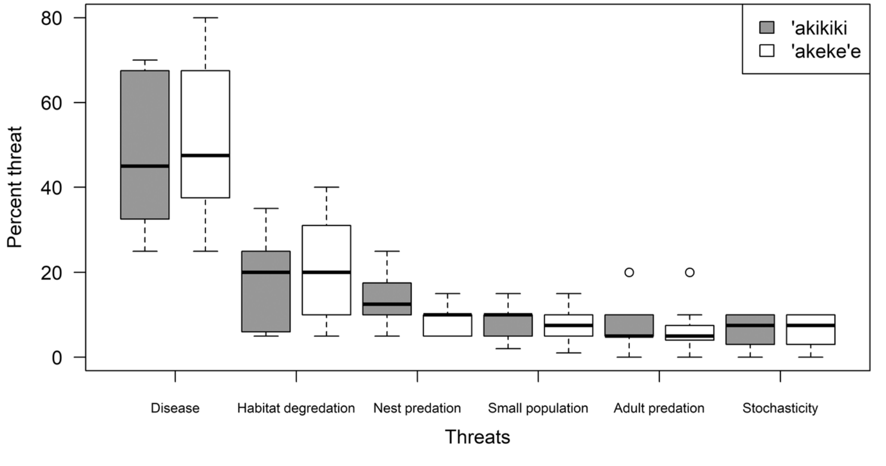

FIGURE 1 Expert judgement (from 2014 workshop) on key threats facing the Kaua‘i, Hawai‘i, USA, endemic species ‘akikiki and ‘akeke‘e. For each of the 6 threat categories identified *a priori*, each of the 14 experts distributed 100 points to all the threats to indicate the importance of each threat to observed declines in the species. Because of different natural histories, the 2 species were ranked separately despite occurring in the same locations

forests over the next 10 years to ensure adequate habitat for the remaining wild individuals on Kauaʻi, or adequate habitat for potential translocation to another Hawaiian island, was weighted at 20%. This reflected the importance of this objective for the long-term persistence of the species but not necessarily critical for preventing imminent extinction.

Alternatives

We identified 5 general conservation strategies encompassing a total of 15 different combinations of alternatives (Table 1), and which could be enacted within the 10-year timeframe that we considered was the window of time necessary for actions to take place. The first approach (alternatives 1.1–1.5) were *in situ* management strategies, where all available resources would be directed toward the remaining birds and their habitat on Kauaʻi with the goal of halting the decline, stabilizing the population, and taking the necessary conservation actions to increase population size for ultimate recovery. The second approach considered (alternatives 2.1–2.2) were *ex situ* strategies that would put all available resources into the development of a captive population to reduce the probability of extinction, with the ultimate goal of either reintroducing these birds back to Kauaʻi or introducing them to a different island at some future date. Third, 2 *ex situ* alternatives (3.1–3.2) were considered for direct translocation of individuals to another island (Maui or Hawaiʻi islands) without the intermediate step of establishing a captive population. The fourth approach (4.1) was a rear-and-release strategy where eggs would be collected from nests in the wild, chicks raised in captivity, and then the young released back into the wild. The fifth approach was a combination of various *in situ* management alternatives combined with *ex situ* captive breeding or translocation (5.1–5.5; Table 1).

The 5 *in situ* management alternatives (1.1–1.5) grouped specific management actions around perceived threats. Alternative 1.1 grouped actions aimed at reducing disease prevalence, largely through the control of vectoring mosquitoes. Specific actions associated with each alternative were ranked by potential efficacy and their readiness for implementation (Table 2). For example, Alternative 1.1 included the identification of source populations of mosquitoes and reducing mosquito larval habitat as key actions, with second tiered actions including reducing standing water and spraying for adult mosquitoes around core breeding areas for birds. The second-tier actions could be implemented with current technology but were considered more difficult to achieve success (e.g., reducing standing water) or they could be more controversial (e.g., spraying for adult mosquitoes that could affect non-target insect populations). Such actions may not be warranted unless sufficient resources were available or primary actions failed. The third category of actions were either actions that could be taken but were considered to have low efficacy (e.g., physical barrier around a nest tree, which may not be effective in a closed-canopy forest), or not currently available for implementation within the 10-year time frame of the SDM implementation process. For example, the third-tier actions for 1.1 highlight promising technological advancements to address disease (e.g., genetically modified mosquitoes, avian malaria vaccination of adult birds), but at the time of the workshop these approaches did not seem likely to be ready within the 10-year timeframe we were considering. Nonetheless, we wanted to highlight these third-tier actions so that preliminary planning and development could continue, if resources allowed, as the rewards for mitigating the threat from disease could be very significant for the conservation of these species.

The second *in situ* alternative (1.2) focused on predator control, the third (1.3) on habitat restoration and protection, the fourth (1.4) a mixture of predator control and habitat management, and the fifth (1.5) a combination of all identified actions (i.e., disease, predator, and habitat management; Table 2). Alternatives 2.1 and 2.2 focused on *ex situ* actions, specifically the establishment of a captive population. Two approaches were identified, first a slow build up approach (2.1) that would focus on harvesting eggs or nestlings only, whereas the second option (2.2) considered a more rapid buildup of a captive population by actively capturing adults (as well as eggs and nestlings) from the population. The second alternative might build up a

TABLE 1 Alternative management actions identified in 2014 for addressing declining populations of ʻakikiki and ʻakekeʻe on Kauaʻi, Hawaiʻi, USA. For each alternative, the weighted probability of success of achieving the 3 identified objectives was determined by a group of experts, as well as the accumulated logistical impediments that could inhibit success of the action. Values were similar for the 2 species and were averaged to produce one value. The 2 alternatives that ranked the highest (5.1 and 5.5) are in bold. Values are means ± standard deviation (SD) and coefficient of variation (CV), a measure of the dispersion of the variance

Alternative	Probability of success mean ± SD (CV)	Impediments
In situ		
1.1 – Initiate actions to control mosquitoes (and avian disease), including identifying source populations and treating larval breeding sites.	14% ± 8 (0.59)	8.5 ± 2.0 (0.24)
1.2 – Initiate actions to reduce predation from non-native rodents including ground-based trapping around nest trees and in larger grids.	19% ± 11 (0.55)	5.7 ± 1.8 (0.32)
1.3 – Initiate actions to improve habitat conditions, including fencing and ungulate control, invasive weed control, and supplementing food resources.	22% ± 11 (0.48)	7.1 ± 1.8 (0.25)
1.4 – Initiate all actions of alternatives 1.2 and 1.3 (control weeds, rodents, and ungulates; supplement food resources).	32% ± 14 (0.35)	6.6 ± 1.4 (0.22)
1.5 – Initiate actions of 1.1, 1.2, and 1.3 (identify and treat mosquito sources; control weeds, rodents, and ungulates; supplement food resources).	41% ± 14 (0.35)	7.4 ± 1.4 (0.19)
Ex situ – Captive propagation		
2.1 – Initiate actions to slowly build-up captive populations by collecting eggs and nestlings.	40% ± 11 (0.27)	8.2 ± 1.9 (0.23)
2.2 – Initiate actions to rapidly build captive populations, including capture and removal of adults, and egg and chick collection.	48% ± 9 (0.19)	7.6 ± 1.4 (0.19)
Ex situ – Translocation/Introduction		
3.1 – Establish a population above the disease line in suitable habitat on Maui or Hawaiʻi Island slowly through removal of young of the year (eggs, nestlings, fledglings).	24% ± 11 (0.46)	11.3 ± 1.6 (0.14)
3.2 – Establish a population above the disease line in suitable habitat on Maui or Hawaiʻi Island rapidly through removal of adults and young of the year (eggs, nestlings. fledglings).	30% ± 11 (0.36)	10.6 ± 1.8 (0.17)
Ex situ – Rear and Release		
4.1 – Remove eggs and nestlings from the wild to a location on Kauaʻi, rear and release back into the wild once birds are independent.	6% ± 5 (0.72)	7.8 ± 1.6 (0.20)
In situ and ex situ combinations		
5.1 – Initiate actions of alternatives 1.5 and 2.1/2.2 (start captive populations; identify and treat mosquito sources; control weeds, rodents, and ungulates; supplement food resources).	**65% ± 10 (0.15)**	**7.9 ± 1.4 (0.17)**
5.2 – Initiate actions of alternatives 1.5 and 3.1/3.2 (move birds from Kauaʻi to Maui or Hawaiʻi islands; identify and treat	40% ± 11 (0.28)	10.4 ± 1.5 (0.15)

TABLE 1 (Continued)

Alternative	Probability of success mean ± SD (CV)	Impediments
mosquito sources; control weeds, rodents, and ungulates; supplement food resources).		
5.3 – Initiate actions of alternatives 2.2 and 3.2 (start captive populations; move birds from Kaua'i to Maui or Hawai'i Island).	42% ± 13 (0.40)	10.3 ± 1.6 (0.16)
5.4 – Initiate actions of alternatives 1.5 and 4.1 (rear and release; identify and treat mosquito sources; control weeds, rodents, and ungulates; supplement food resources).	29% ± 15 (0.52)	8.6 ± 1.8 (0.20)
5.5 – Initiate actions of alternatives 1.5, 2.1/2.2, and 3.1/3.2 (start captive populations; move birds from Kaua'i to Maui or Hawai'i islands; identify and treat mosquito sources; control weeds, rodents, and ungulates; supplement food resources).	**62% ± 13 (0.22)**	**9.8 ± 1.6 (0.17)**

captive population quicker but would have a greater impact on the wild population, whereas the first alternative (2.1) might have less of an impact on the wild population but may not be able to build up a captive population rapidly enough. Alternatives 3.1 and 3.2 involved the direct translocation of individuals from Kaua'i to high elevation forests of Maui or Hawai'i islands, again considering either a rapid effort or a slower effort that might have less impact on the wild source population. Alternative 4.1 involved a head starting approach, where eggs would be harvested, reared, and then the young released back into the forest. The final set of alternatives (5.1–5.5) involved a combination of the *in situ* (1.1–1.5) and *ex situ* (2.1–4.1) alternatives (Table 1).

Identifying preferred alternatives

The SDM group estimated the effectiveness of each alternative on achieving the 3 objectives. Although there were slight differences in the scores for 'akikiki and 'akeke'e, given their differences in habitat, foraging patterns, and vulnerability to predators, the scores were similar and they were averaged together (Table 1). The probability of success to achieve the objectives ranged from 0.06 to 0.65, averaging 0.34 (Table 1). Only 2 alternatives were judged as having a greater than 50% chance of successfully achieving the stated objectives, and both of those (5.1 and 5.5) involved efforts to conduct both *in situ* and *ex situ* actions. The perceived logistical impediments to success varied from 5.7 to 11.3 (averaging 8.8). The highest impediment values were associated with translocations, which were perceived as risky and expensive, whereas the lowest values were associated with more routine management actions such as predator control, even if they were not rated high for achieving the objectives. For both species, 5.1 (establishing a captive population and habitat protections) was the highest-ranking alternative in terms of probability of success (65%) and had a lower-than-average impediment score (7.9). Alternative 5.5, which included a translocation component to the recovery, also ranked high in its probability of meeting the objectives (62%), but the uncertainty of success was higher as reflected by the higher impediment score (9.8). Thus, factoring in potential logistical impediments helped the group choose between development of a captive population versus direct translocations to another island, a decision that would have otherwise been tied for the top strategy.

TABLE 2 Suites of specific management actions that were considered in 2014 workshop for each identified alternative to reduce extinction risk in ʻakikiki and ʻakekeʻe on Kauaʻi, Hawaiʻi, USA. Actions were ranked as highest priority (1) because of their potential efficacy and their readiness for implementation, secondary actions (2) which could be implemented with current technology but were considered less effective than primary activities and may only be undertaken if sufficient funds were available, and tertiary (3) actions that were actions that were potentially beneficial but were considered to have low efficacy or actions not currently available for implementation within the 10-year time frame of the SDM implementation process. Actions were only ranked for the applicable alternative

Action	Alternative 1.1	Alternative 1.2	Alternative 1.3	Alternative 1.4	Alternative 1.5
Treat larval habitat sites	1				1
Identify mosquito source populations	1				1
Ground based predator trapping around bird nesting trees		1		1	1
Ground based rodent trapping in grid		1		1	1
Fencing and ungulate control	1		1	1	1
Invasive plant control			1	1	1
Supplemental feeding of birds			1	1	1
Reduce standing water, especially around streams	2				2
Spray for adult mosquitoes	2				2
Cat trapping		2		2	2
Predator proof fence		2		2	2
Barn owl control		2		2	2
Aerial broadcast of rodenticide		2		2	2
Outplanting of native understory			2	2	2
Landscape mosquito control with genetically engineered mosquitoes	2				2
Sterile mosquito suppression	3				3
Landscape mosquito control with Wolbachia	3				3
Malaria vaccines for birds	3				3
Physical barrier (i.e., metal ring around trunk) of nesting trees		3		3	3
Increase structure of forest through reforestation practices			3	3	3

DISCUSSION

The situation the SDM group faced was an all too common one in Hawaiʻi and many oceanic islands around the world: rapidly declining species, fears of imminent extinction, and no clear management action to reverse the population trends. The conservation outcome of the poʻouli (*Melamprosops phaeosoma*), the honeycreeper that was discovered in 1973 and went extinct 32 years later in 2005, was considered a cautionary outcome for the group. Initial efforts to conserve poʻouli focused on habitat protection, which did not stabilize populations, leading to plans for more invasive management actions such as translocation and captive propagation (Groombridge et al. 2004, VanderWerf et al. 2006). In the end, conservation efforts failed, with a commonly held opinion that management actions were too little too late (Black et al. 2011). The SDM group felt that immediate actions were needed to insure against extinction in ʻakikiki and ʻakekeʻe, and captive propagation was the most likely action to achieve that goal, at least in the short-term. However, the ultimate conservation goal is to have self-sustaining populations in the wild, and there is yet to be a successful reintroduction of a Hawaiian forest bird species from captive populations despite considerable effort over decades (Paxton et al. 2018). Thus, the SDM group also emphasized the importance of *in situ* actions in parallel with *ex situ* actions as necessary to achieve the 3 objectives.

The SDM group concluded that efforts to prevent extinction will require both *in situ* and *ex situ* efforts simultaneously, ranking alternatives the highest that included captive breeding (5.1) or translocation (5.5), along with mosquito control and habitat protection. The threat of increasing disease prevalence driven by climate change, where warming temperatures can facilitate the expansion of disease vectoring mosquitoes into higher elevations (Atkinson et al. 2014, Paxton et al. 2016), was difficult to directly abate given existing technology. Landscape-level mosquito control has the potential for eventually reducing or eliminating the threat of disease transmission in the forests (Caragata et al. 2020), but at the time of the SDM process the implementation horizon for such actions was deemed greater than the timescale the group was considering. Therefore, approaches that removed birds from the immediate threat (establishing captive breeding populations or translocation) ranked high, especially for objective 1, the prevention of imminent extinction. However, the SDM group believed that habitat degradation and predation by non-native mammals also played a role and should also be addressed to ensure future habitat for birds (objectives 2 and 3), favoring the inclusion of *in situ* management actions. Thus, the highest-ranking strategies were those that had a mixture of both *in situ* and *ex situ* actions, and were the only ones considered to have a greater than 50% chance of meeting all 3 objectives in the next 10 years. Given the logistical impediments we assessed, the preferred alternative was to immediately initiate captive populations of both species to serve as both a safeguard against extinction and preservation of genetic diversity, while addressing threats in the wild for the continued persistence of the wild population and eventual reintroduced populations.

Balancing the 3 objectives created a tension in terms of which alternatives were favored by the SDM group, with the participants favoring *ex situ* actions to achieve objective 1 but favoring *in situ* actions for the benefit of objectives 2 and 3. If the species went extinct before the *in situ* actions were able to begin reversing declines, then delaying the establishment of a captive population would seem a mistake in retrospect. However, with estimated global population numbers less than 1,000 for both species, the removal of individuals, especially breeding adults, from the population would have impacts on the viability of the wild population. For example, to increase the probability of objective 1 being met, a rapid buildup of a captive population, including capture of breeding adults, would be favored. However, concerns about having more than one viable population in 10 years greatly favored minimizing capture of breeding adults. In addition, there were many concerns about the feasibility of successfully reintroducing individuals from a captive population, given the past failures of such efforts in Hawaiʻi. Thus, a slow build up was favored, where the collection of eggs (vs. chicks or adults) was considered the best choice as many birds will renest after the loss of a clutch (Hammond et al. 2015). In-field management actions recommended by the SDM group to stabilize existing wild populations included identification and treatment of mosquito larval habitat, predator control to reduce nest predation, fencing and removal of feral ungulates (which can create larval habitat by wallowing), and evaluation of landscape-level mosquito control efforts. Fencing and removal of ungulates and rodents have the added benefit of improving habitat quality, providing additional ways to increase the survival and reproductive success of the birds.

A key aspect of identifying specific actions to prevent extinction was the substantial uncertainty at all levels: uncertainty derived from conflicting views of the key problems, uncertainty in the future state of the system, and uncertainty in the effectiveness of any single conservation action. The SDM process allowed for a conservation plan to proceed by facilitating the evaluation of alternatives in light of uncertainty, without paralyzing the decision-making process. Our use of logistical impediment scores to measure uncertainty led to shifts in preferred alternatives. For example, translocation of ʻakikiki and ʻakekeʻe to forests on other islands where disease is absent was considered a viable approach to remove individuals from immediate threat but still keep them in the wild. The option of translocating ʻakekeʻe to Maui was especially appealing, as environmental conditions are comparable (Fortini et al. 2017) and the Maui ʻakepa (*Loxops ochraceus*), a sister species to ʻakekeʻe (the Kauaʻi ʻakepa) is extinct (Reynolds and Snetsinger 2001). Thus, the conservation introduction of ʻakekeʻe on Maui would potentially prevent extinction of ʻakekeʻe on Kauaʻi while also providing a surrogate species to help restore historical ecological function in Maui forests. However, the number of uncertainties associated with translocation were high, including the concern that factors that drove the Maui ʻakepa to extinction just a few decades earlier might still be in force. Furthermore, the regulatory hurdles for translocation were greater than for establishing captive populations, so the translocation option also had a high impediment score for time to implementation. Ultimately, the uncertainty associated with translocations tabled this action, with the SDM group concluding that if the captive breeding program is successful in the short-term, then captive reared individuals could be translocated to other islands in future years. However, recent rapid declines in 3 Maui endemic forest birds—the endangered kiwikiu (*Pseudonestor xanthophrys*), the endangered ʻakohekohe (*Palmeria dolei*), and the Maui ʻalauahio (*Paroreomyza montana*; Judge et al. 2019) raise concern about the safety of Maui forests and likely discourage any future translocation to that island.

MANAGEMENT IMPLICATIONS

Structured decision making, as a formalized process, allowed us to identify and prioritize management alternatives and rank viable conservation strategies, given the state of knowledge (Gregory and Long 2009). In particular, the process allowed us to make progress despite considerable uncertainty (Runge et al. 2011). Using expert knowledge and judgement to rank the relative importance of threats, weight objectives, identify alternatives, and estimate the likelihood of success of alternatives in achieving the objectives provided a powerful approach to prioritizing management actions and optimizing conservation planning when time and knowledge were limited. Importantly, the process allowed for a diversity of values and perspectives to be incorporated into a decision, ensuring broader support for subsequent conservation plans. For example, if the only objective of our group was to prevent immediate extinction, captive propagation may have been the only alternative chosen. But because the SDM group expressed the importance of long-term planning and continued protection of the wild populations, alternatives focused on both *in situ* and *ex situ* actions achieved the highest support despite additional costs and complexity. Because prevention of immediate extinction was weighted above all other objectives, captive propagation was rated high despite doubts of the long-term viability of a captive flock to restore wild populations. Interestingly, translocation had strong initial support, but the consideration of logistical impediments, particularly the great uncertainty surrounding the success of a translocation, ultimately led group members to discount that option. Another important function that consideration of logistical impediments provided was the separation of shovel-ready actions versus actions that might take years to implement, either due to the time for regulatory approval or the time needed to fully develop the technique. Thus, this process helped focus on actions that had a higher success of achieving goals within the time fame being considered.

The SDM effort for ʻakikiki and ʻakekeʻe directly led to the development of a conservation strategy that was supported by federal and state wildlife managers. As a result of the SDM group's high ranking for the establishment

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of a captive population, federal and state funding was allocated for the harvesting of ʻakikiki and ʻakekeʻe eggs from 2015–2018 to establish a long-term captive population at captive breeding facilities on Maui and Hawai'i islands (Hawaii Department of Land and Natural Resources, unpublished data). At the conclusion of the egg collection phase (2018), the flocks consisted of 43 founding ʻakikiki and 9 founding ʻakekeʻe. Genomic analysis indicated that much of the genetic variation in the remaining wild populations were captured in the captive population (Cassin-Sackett et al. 2018), and initial success in captive breeding of ʻakikiki is a positive early result. The SDM effort helped support ongoing efforts to protect forest habitat, and much of the core habitat for the forest birds will be fenced and protected in the coming years, already resulting in the rapid recovery of the understory (L. Behnke, The Nature Conservancy, personal communication). Two large rodent control grids (up to 425 traps over 196 ha) have been established in core breeding areas of both species, with relative rat abundance on trap grids reduced by as much as 9-fold, although typically treatment plots had 1/3 rodent density compared to reference plots (Hawaii Department of Land and Natural Resources, unpublished data). These field-based conservation efforts may have slowed the decline of the 2 species somewhat, with 2018 counts indicating reduced rates of decline (Paxton et al. 2020), although territory mapping indicates continued declines in core areas (Hawaii Department of Land and Natural Resources, unpublished data). However, not all recommended conservation efforts have been successful, and changing technology calls for reevaluating strategies. For example, efforts to establish a captive population of ʻakekeʻe have not been successful to date, with few nests found and lower survival in captivity, indicating different approaches are needed to increase the size of the captive population (Hawaii Department of Land and Natural Resources, unpublished data). The rapid development of landscape-level vector control has presented a significant change in our understanding of available tools from the time of the initial SDM workshop was held (Alphey 2014). Although on the horizon in 2014, the successful implementation of a number of vector control projects around the world has opened the possibility of landscape-level mosquito control across the Alakaʻi Plateau (Iturbe-Ormaetxe et al. 2011, Kyrou et al. 2018, Ross et al. 2019). Overall, the SDM effort of identifying objectives and ranking alternatives served as a default conservation strategy for preventing extinction of ʻakikiki and ʻakekeʻe by providing a set of actions that managers could enact. However, this SDM effort is just one step in an iterative process where conservation strategies are ideally revisited and updated periodically as needed.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

ETHICS STATEMENT

No permit information provided.

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REFERENCES

Alphey, L. 2014. Genetic control of mosquitoes. Annual Review of Entomology 59:205–224.

Atkinson, C. T., R. B. Utzurrum, D. A. Lapointe, R. J. Camp, L. H. Crampton, J. T. Foster, and T. W. Giambelluca. 2014. Changing climate and the altitudinal range of avian malaria in the Hawaiian Islands—an ongoing conservation crisis on the island of Kauaʻi. Global Change Biology 20:2426–2436.

Atkinson, C. T., K. L. Woods, R. J. Dusek, L. S. Sileo, and W. M. Iko. 1995. Wildlife disease and conservation in Hawaii: pathogenicity of avian malaria (Plasmodium relictum) in experimentally infected Iiwi (Vestiaria coccinea). Parasitology 111:S59–S69.

Banko, W. E., and P. C. Banko. 2009. Historic decline and extinction. Pages 25–58 *in* T. K. Pratt, C. T. Atkinson, P. C. Banko, J. D. Jacobi, and B. L. Woodworth, editors. Conservation biology of Hawaiian forest birds: implications for island avifauna. Yale University Press, New Haven, Connecticut, USA.

Behnke, L. A. H., L. Pejchar, and L. H. Crampton. 2016. Occupancy and habitat use of the endangered Akikiki and Akekee on Kauai Island, Hawaii. The Condor 118:148–158.

Benning, T. L., D. LaPointe, C. T. Atkinson, and P. M. Vitousek. 2002. Interactions of climate change with biological invasions and land use in the Hawaiian Islands: modeling the fate of endemic birds using a geographic information system. Proceedings of the National Academy of Science USA 99:14246–14249.

Black, S. A., J. J. Groombridge, and C. G. Jones. 2011. Leadership and conservation effectiveness: finding a better way to lead. Conservation Letters 4:329–339.

Brook, B. W., N. S. Sodhi, and C. J. Bradshaw. 2008. Synergies among extinction drivers under global change. Trends in Ecology and Evolution 23:453–460.

Burney, D. A., H. F. James, L. P. Burney, S. L. Olson, W. Kikuchi, W. L. Wagner, M. Burney, D. McCloskey, D. Kikuchi, and F. V. Grady. 2001. Fossil evidence for a diverse biota from Kauaʻi and its transformation since human arrival. Ecological Monographs 71:615–641.

Caragata, E., S. Dong, Y. Dong, M. Simoes, C. Tikhe, and G. Dimopoulos. 2020. Prospects and pitfalls: next-generation tools to control mosquito-transmitted disease. Annual Review of Microbiology 74:455–475.

Cassin-Sackett, L., T. E. Callicrate, and R. C. Fleischer. 2018. Parallel evolution of gene classes, but not genes: evidence from Hawai'ian honeycreeper populations exposed to avian malaria. Molecular Ecology 28:568–583.

Conant, S., H. D. Pratt, and R. J. Shallenberger. 1998. Reflections on a 1975 expedition to the lost world of the Alakaʻi and other notes on the natural history, systematics, and conservation of Kauaʻi birds. Wilson Bulletin 110:1–22.

Conroy, M. J., and J. T. Peterson. 2013. Decision Making in Natural Resource Management: A Structured, Adaptive Approach. Wiley-Blackwell, Oxford, UK.

Fortini, L. B., L. R. Kaiser, A. E. Vorsino, E. H. Paxton, and J. D. Jacobi. 2017. Assessing the potential of translocating vulnerable forest birds by searching for novel and enduring climatic ranges. Ecology and Evolution 7: 9119–9130.

Fortini, L. B., A. E. Vorsino, F. A. Amidon, E. H. Paxton, and J. D. Jacobi. 2015. Large-scale range collapse of hawaiian forest birds under climate change and the need 21st century conservation options. PLoS One 10: e0140389.

Foster, J. T., E. J. Tweed, R. J. Camp, B. L. Woodworth, C. D. Adler, and T. Telfer. 2004. Long-term population changes of native and introduced birds in the Alakaʻi Swamp, Kauaʻi. Conservation Biology 18:716–725.

Goltz, D. M., S. C. Hess, K. W. Brinck, P. C. Banko, and R. M. Danner. 2008. Home range and movements of feral cats on Mauna Kea, Hawai'i. Pacific Conservation Biology 14:177–184.

Gregory, R., and G. Long. 2009. Using structured decision making to help implement a precautionary approach to endangered species management. Risk Analysis 29:518–532.

Groombridge, J. J., J. G. Massey, J. C. Bruch, T. Malcolm, C. N. Brosius, M. M. Okada, B. Sparklin, J. S. Fretz, and E. A. VanderWerf. 2004. An attempt to recover the Po'ouli by translocation and an appraisal of recovery strategy for bird species of extreme rarity. Biological Conservation 118:365–375.

Guillaumet, A., and E. H. Paxton. 2019. Evaluating community-level response to management actions across a diverse Hawaiian forest bird community. Ecological Applications 29:e01953.

Hammond, R. L., L. H. Crampton, and J. T. Foster. 2015. Breeding biology of two endangered forest birds on the island of Kauai, Hawaii. The Condor 117:31–40.

Hammond, J. S., R. L. Keeney, and H. Raiffa. 1999. Smart Choices: A practical Guide to Making Better Life Decisions. Broadway Books, New York, New York, USA.

Hess, S. C., C. E. Swift, E. W. Campbell, R. T. Sugihara, and G. D. Lindsey. 2009. Controlling small mammals. Pages 425–447 *in* T. K. Pratt, C. T. Atkinson, P. C. Banko, J. D. Jacobi, and B. L. Woodworth, editors. Conservation Biology of Hawaiian Forest Birds. Yale University Press, New Haven, Connecticut, USA.

Howald, G. R., C. J. Donlan, J. P. Galván, J. C. Russell, J. Parkes, A. Samaniego, Y. Wang, D. Veitch, P. Genovesi, and M. Pascal. 2007. Invasive rodent eradication on islands. Conservation Biology 21:1258–1268.

Iturbe-Ormaetxe, I., T. Walker, and S. L. O'Neill. 2011. Wolbachia and the biological control of mosquito-borne disease. EMBO reports 12:508–518.

Judge, S. W., R. J. Camp, C. C. Warren, L. K. Berthold, H. L. Mounce, P. J. Hart, and R. J. Monello. 2019. Pacific Island Landbird Monitoring Annual Report, Haleakalā National Park and East Maui Island, 2017. National Park Service Natural Resource Report NPS/PACN/NRR—2019/1949, Fort Collins, Colorado, USA.

Kyrou, K., A. M. Hammond, R. Galizi, N. Kranjc, A. Burt, A. K. Beaghton, T. Nolan, and A. Crisanti. 2018. A CRISPR–Cas9 gene drive targeting doublesex causes complete population suppression in caged Anopheles gambiae mosquitoes. Nature Biotechnology 36:1062–1066.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. American Naturalist 142:911–927.

Leonard, D. L. 2008. Recovery expenditures for birds listed under the US Endangered Species Act: the disparity between mainland and Hawaiian taxa. Biological Conservation 141:2054–2061.

Liao, W., C. T. Atkinson, D. A. LaPointe, and M. D. Samuel. 2017. Mitigating future avian malaria threats to hawaiian forest birds from climate change. PLoS One 12:e0168880.

Martin, T. G., M. A. Burgman, F. Fidler, P. M. Kuhnert, S. Low-Choy, M. McBride, and K. Mengersen. 2012. Eliciting expert knowledge in conservation science. Conservation Biology 26:29–38.

Mounce, H. L., K. J. Iknayan, D. L. Leonard, K. J. Swinnerton, and J. J. Groombridge. 2013. Management implications derived from long term re-sight data: annual survival of the Maui Parrotbill Pseudonestor xanthophrys. Bird Conservation International 24:316–326.

Nichols, J. D., M. D. Koneff, P. J. Heglund, M. G. Knutson, M. E. Seamans, J. E. Lyons, J. M. Morton, M. T. Jones, G. S. Boomer, and B. K. Williams. 2011. Climate change, uncertainty, and natural resource management. Journal of Wildlife Management 75:6–18.

Owens, I. P., and P. M. Bennett. 2000. Ecological basis of extinction risk in birds: habitat loss versus human persecution and introduced predators. Proceedings of the National Academy of Science USA 97:12144–12148.

Paxton, E. H., K. Brink, L. H. Crampton, J. Hite, and M. Constantini. 2020. 2018 Kauai forest bird popualtion estimates and trends. Hawaii Cooperative Studies Unit Technical Report HCSU-98. 31 pp.

Paxton, E. H., R. J. Camp, P. M. Gorresen, L. H. Crampton, D. L. Leonard, and E. A. VanderWerf. 2016. Collapsing avian community on a Hawaiian island. Science Advances 2:e1600029.

Paxton, E. H., M. Laut, J. P. Vetter, and S. J. Kendall. 2018. Research and management priorities for Hawaiian forest birds. The Condor 120:557–565.

Pratt, L. W., and J. Jacobi. 2009. Loss, degredation, and persistence of habitats. Pages 137–158 *in* T. K. Pratt, C. T. Atkinson, P. C. Banko, J. Jacobi, and B. L. Woodworth, editors. Conservation Biology of Hawaiian Forest Birds. Yale University Press, New Haven, Connecticut, USA.

Reynolds, M. H., and T. J. Snetsinger. 2001. The Hawaii rare bird search 1994–1996. Studies in Avian Biology 22:133–143.

Ross, P. A., M. Turelli, and A. A. Hoffmann. 2019. Evolutionary ecology of Wolbachia releases for disease control. Annual Review of Genetics 53:93–116.

Runge, M. C., and E. A. Bean. 2020. Decision Analysis for Managing Public Natural Resources. Pages 3–11 *in* M. C. Runge, S. J. Converse, J. E. Lyons, and D. R. Smith, editors. Structured Decision Making: Case Studies in Natural Resource Management. John Hopkins University Press, Baltimore, Maryland, USA.

Runge, M. C., S. J. Converse, and J. E. Lyons. 2011. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biological Conservation 144:1214–1223.

Runge, M. C., S. J. Converse, J. E. Lyons, and D. R. Smith. 2020. Structured Decision Making: Case Studies in Natural Resource Management. John Hopkins University Press, Baltimore, Maryland, USA.

Samuel, M. D., B. L. Woodworth, C. T. Atkinson, P. J. Hart, and D. A. LaPointe. 2018. The epidemiology of avian pox and interaction with avian malaria in Hawaiian forest birds. Ecological Monographs 88:621–637.

Scott, J. M., S. Mountainspring, F. L. Ramsey, and C. B. Kepler. 1986. Forest bird communities of the Hawaiian Islands: their dynamics, ecology, and conservation. Studies in Avian Biology 9:1–431.

Steadman, D. W. 2006. Extinction and biogeography of tropical Pacific birds. University of Chicago Press, Chicago, Illinois, USA.

Sutherland, W. J. 2006. Predicting the ecological consequences of environmental change: a review of the methods. Journal of Applied Ecology 43:599–616.

van Riper, C., III, S. G. van Riper, M. L. Goff, and M. Laird. 1986. The epizootiology and ecological significance of malaria in Hawaiian land birds. Ecological Monographs 56:327–344.

van Riper, C., III, and J. M. Scott. 2001. Limiting factors affecting Hawaiian native birds. Studies in Avian Biology 22: 221–233.

VanderWerf, E. A. 2009. Importance of nest predation by Alien Rodents and Avian Poxvirus in conservation of Oahu Elepaio. Journal of Wildlife Management 73:737–746.

VanderWerf, E. A., L. H. Crampton, J. S. Diegmann, C. T. Atkinson, and D. L. Leonard. 2014. Survival estimates of wild and captive-bred released Puaiohi, an endangered Hawaiian thrush. The Condor 116:609–618.

VanderWerf, E. A., J. J. Groombridge, J. S. Fretz, and K. J. Swinnerton. 2006. Decision analysis to guide recovery of the po 'ouli, a critically endangered Hawaiian honeycreeper. Biological Conservation 129:383–392.

Vorsino, A. E., L. B. Fortini, F. A. Amidon, S. E. Miller, J. D. Jacobi, J. P. Price, S. Gon, III, and G. A. Koob. 2014. Modeling Hawaiian ecosystem degradation due to invasive plants under current and future climates. PLoS One 9:e95427.

Warner, R. E. 1968. The role of introduced diseases in the extinction of the endemic Hawaiian avifauna. Condor 70: 101–120.

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