STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
Division of Forestry and Wildlife
Honolulu, Hawaii 96813

March 25, 2021

Chairperson and Members
Board of Land and Natural Resources
State of Hawaii
Honolulu, Hawaii

Land Board Members:

SUBJECT: INFORMATIONAL BRIEFING ON PROPOSAL TO ESTABLISH CAPTIVE POPULATION OF KIWIKIU (MAUI PARROTBILL, *PSEUDONESTOR XANTHOPHRYS*).

This Board Submittal is an informational briefing on the current status of kiwikiu (Maui Parrotbill, *Pseudonestor xanthophrys*), and potential paths forward intended to forestall extinction of the species.

BACKGROUND:

For decades, Hawai'i has implemented bold conservation actions to save some of our most endangered birds from joining the long list of those already extinct. In the face of accelerating climate change, these actions can be challenging as the landscape on which we work to save these birds is shifting under our feet. One example of this was the loss of the translocated kiwikiu (Maui Parrotbill, *Pseudonestor xanthophrys*) that were reintroduced in 2019 to the Nakula Natural Area Reserve on the leeward side of Haleakalā, East Maui.

Kiwikiu were listed as endangered in 1967 and are threatened by habitat loss, introduced diseases, and predation by rats. Kiwikiu are restricted to a small population on the windward slopes of Haleakalā that is currently in decline and at a high risk of extinction (possibly less than150 individuals). In 2006, the Hawaii Forest Bird Recovery Team, comprised of an interagency team of experts including U.S. Fish and Wildlife Service and Division of Forestry and Wildlife biologists, published the Hawaii Forest Bird Recovery Plan. The plan identified captive propagation and habitat restoration to support re-establishment of a kiwikiu population within its former and historic range as the highest priority recovery actions. The leeward Maui forests were selected for offering the highest probability of success for expansion of the population. Since the publication of the plan, the agencies and partners have worked toward that objective. The translocation of an initial cohort of kiwikiu to the Nakula Natural Area Reserve in 2019 was the culmination of more than a decade of work.

However, recent information suggests that certain critical circumstances have changed that may affect kiwikiu recovery planning and implementation. These are:

1) Demographic and survey data indicate that the existing kiwikiu population on windward Maui is declining rapidly, with an estimated time to extinction of as little as three to five years;
2) Captive propagation efforts employed have failed to achieve adequate recruitment of birds in captivity; and
3) Mosquitoes and avian disease have become more prevalent in the restored leeward forests, suggesting that they may not currently be a suitable site to re-establish kiwikiu.

The prevalence of avian malaria within these leeward forests has shifted dramatically during the short interim between when the translocation plans were finalized and carried out. These forests (and others within the current kiwikiu range) now appear unreliable for the persistence of the species due to the upslope expansion of mosquitoes carrying avian malaria into higher elevations.

In light of this significant new challenge facing kiwikiu recovery, the kiwikiu working group convened to reassess planning and implementation of kiwikiu recovery efforts. The Maui Forest Bird Working Group met on 11 March 2020 to discuss the immediate conservation priorities for kiwikiu. The purpose of the meeting was to develop a set of mutually agreed upon conservation actions for kiwikiu. Moving quickly in making such decisions is crucial, as the negative population trajectory for the species is such that too few individuals may soon be left to utilize the available management tools successfully. At least one representative from each of twelve organizations who participate in the Maui Forest Bird Working Group were present for this meeting. Attendees included a wide array of expertise from various backgrounds, and represented all of the organizations conducting active conservation for kiwikiu.

The disappointing outcome of the 2019 translocation revealed that the Nakula Natural Area Reserve is no longer suitable for future releases without effective mosquito control measures. Simultaneously, no acceptable alternative locations are available. The rapid increase in mosquito numbers at the release site within a short time frame raised additional concerns about similar expansions elsewhere on Maui within the range of the kiwikiu. These recent events highlighted the need for new strategies to prevent the extinction of kiwikiu.

From discussions on the current species status, threats, and timelines to extinction, the Working Group created a list of recommended actions that should implemented as soon as possible. These actions are not intended to be mutually exclusive. Many of these can and should be done in combination with other actions. Others may take time to enact, and preparations for these actions can occur while other steps are being taken. These actions are proposed to prevent the extinction of kiwikiu, and it is felt by the group that they should be implemented as quickly as possible.

Proposed Actions:

1. Bring birds into captivity with the intent to maintain and/or produce release-quality birds, and release birds as soon as a suitable release site(s) can be identified and managed. While captive propagation has not been successful in achieving adequate recruitment to date, alternative facilities have been evaluated and we have concluded that they hold the potential for success.
2. Ensure landscape-scale mosquito control remains a high-priority for both agencies and is expedited for implementation. This will be crucial to the birds' chances of survival in the wild.
3. Develop strategies and evaluate the feasibility of short- and long-term predator control tools to protect the wild population, including broader landscape-level methods for each predator species.
4. Continue and enhance habitat management and restoration in the current and historic kiwikiu range to ensure habitat is available into the changing future.
5. Assess potential high-elevation translocation sites on the island of Hawai'i for habitat suitability and potential impacts to or from other species.

The avian disease landscape is changing rapidly on Maui and throughout Hawai'i. The kiwikiu may only have a few years before they are functionally extinct. The timeline for effective landscape-level mosquito control in the kiwikiu range is three to five years (+/-) which may not be soon enough to save the kiwikiu in the wild. The captive propagation actions recommended are designed to forestall extinction of the species while effective disease management can be developed on the landscape.

A captive management plan for bringing birds into captivity in mainland zoos has been prepared and is attached.

RECOMMENDATIONS:

No recommendations are proposed at this time, as this submittal is for informational purposes only.

Respectfully submitted,

DAVID G. SMITH, Administrator
Division of Forestry and Wildlife

APPROVED FOR SUBMITTAL:

SUZANNE D. CASE, Chairperson
Board of Land and Natural Resources

KIWIKIU EMERGENCY CAPTURE AND CARE MANAGEMENT PLAN: ESTABLISHMENT, NEED, AND GOALS OF A CAPTIVE POPULATION TO ENSURE SPECIES PERSISTENCE

2020

MAUI FOREST BIRD WORKING GROUP

CONTENTS

Background

Kiwikiu (Maui Parrotbill; *Pseudonestor xanthophrys*) are one of the rarest and most critically endangered Hawaiian bird species. Little was known about the species until the late 20th century. We know from subfossil evidence that kiwikiu were once widespread on Maui and Molokaʻi in a wide variety of habitats (James and Olson 1991). However, the species can now only be found in a narrow band of rainforest of approximately 30 km^2 on the windward slopes of Haleakalā Volcano (Figure 1; Judge et al. 2019). Kiwikiu are highly specialized insectivores that extract their prey from woody tissue and fruits of native Hawaiian plants (Simon et al. 2020). This specialization translates into large home ranges (Warren et al. 2015) and extended parental investment; a single chick is dependent on the parents for > 6 months and parents may provision chicks for up to 18 months (Mounce et al. 2013, Simon et al. 2020). A classic example of a *K*-selected species, kiwikiu have low natural productivity and rely on high adult survivorship to maintain the species (Mounce et al. 2013, 2014, 2018). Loss of adults to invasive predators or disease is particularly detrimental to this species given its biology. Furthermore, nest failures frequently occur after heavy rainfall, which is common in the windward forests of their current range (USFWS 2006, Becker et al. 2010, Mounce et al. 2013). Inclement weather caused failures of 58% studied nests (Becker et al. 2010), which likely contributes to suppressed annual reproductive output; estimated at 46% (Mounce et al. 2013). Thus, the species has a limited capacity for population growth. Given that a single chick is reared each year, a pair of adults must reproduce three successful years to have a net positive impact on population growth, not accounting for reduced juvenile survivorship. With an annual productivity rate < 50%, adults may have to survive and attempt to reproduce for six years to achieve population growth and any losses of juveniles increases this timeline.

The biology of the kiwikiu and the causes of their population decline was intensively studied between 2006 and 2015 (Mounce et al. 2013, 2014, 2018, Warren et al. 2015). Since the late 1970s, fencing and ungulate removal, and thus forest protection from invasive ungulates, has progressively improved; leading to an increase in recovered habitat within the current kiwikiu range. In fact, their entire current range is now fenced, and the vast majority is ungulate-free. Despite this, the kiwikiu population continues to decline. A population assessment in 2017 estimated total abundance at approximately 157 individuals (95% CI = 44-312) (Judge et al. 2019). The species in its current range is threatened by invasive mammalian predators and non-native disease spread by non-native mosquitoes (Simon et al. 2020). Many of the threats in their current range are extremely difficult to control at a meaningful scale – landscape-scale predator control may require aerial broadcast of chemical control agents, a logistically challenging and possibly unpopular tool, and landscape-scale mosquito control tools are in development but not currently available. Recent research has shown that in addition to limiting the species' elevation range, disease may be driving declines in their core range (MFBRP unpublished data). Climate models predict the mosquito range to increase, exposing more birds at high elevations once thought safe from disease (Fortini et al. 2015), and these recent data may be indicative of these effects. Consequently, the small current range of the species, threats within that range, and our inability to effectively mitigate these threats at the present time support bold, hands-on management techniques to prevent the extinction of the species.

The U.S. Fish & Wildlife Service (USFWS) Recovery Plan for the kiwikiu (USFWS 2006) recommended establishing a second population within their historic range to protect the species from catastrophic loss in its small range; then estimated to be 50 km^2 (Simon et al. 2020), now considered < 30 km^2 (Judge et al. 2019). In addition to the inherent threats of a small population and small range size, the current kiwikiu population is located on the windward (northeastern) slope of Haleakalā where they are under threat from severe weather events and frequent rainfall. The Kahikinui region of Maui, specifically the Nakula Natural Area Reserve (NAR), on the leeward (southern) slope of Haleakalā was selected as the site of a new population of kiwikiu (Figure 1).

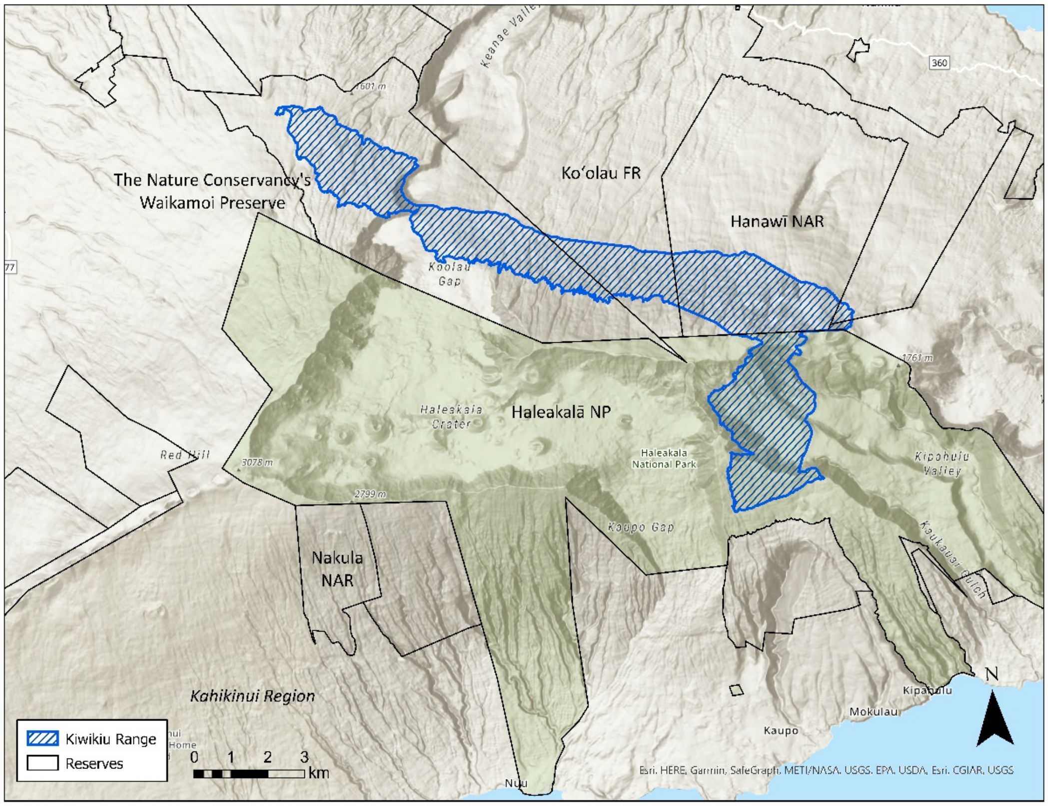

Figure 1. Kiwikiu (Maui Parrotbill, Pseudonestor xanthophrys*) species range. This 29.9 km^2 range was created for analysis of the 2017 Hawaiʻi Forest Bird Surveys based on detection data from 2006–2017.*

The Maui Forest Bird Recovery Working Group (MFBWG) wrote a comprehensive Kiwikiu Conservation translocation Plan (MFBWG 2018). After many years of preparation, which included building infrastructure, controlling predators, and reducing mosquito densities in Nakula NAR, 14 kiwikiu were transferred to the site; seven translocated from Hanawī NAR and seven from a captive breeding facility managed by San Diego Zoo Global. The captive and wild birds were moved to Nakula in mid-October 2019 and releases were completed a few weeks later. After release, birds were monitored using radio telemetry and most birds showed encouraging behavior in the new habitat, foraging independently and remaining near the release site. Unfortunately, mortalities occurred within two weeks of the conservation translocation and by late November 2019, all birds either had died (10) or disappeared (3) (except for one individual that was transferred back to captivity alive). Necropsies indicated avian malaria as the cause of death for all recovered individuals. There have been no sightings of the missing birds since, and little hope remains for their survival in the site. Unprecedented mosquito densities (7× the average rate previously recorded in the area) were later confirmed within the site shortly after the release. Further investigation revealed that the translocated wild individuals tested positive for the malaria parasite prior to the move to Nakula. This provided the first direct evidence that malaria was affecting kiwikiu in the core of the species' range. A detailed internal report on the 2019 conservation translocation can be found in Warren et al. (2020).

Clearly, the outcome of the 2019 kiwikiu conservation translocation attempt was not what we anticipated or desired. This was, in many ways, the culmination of over a decade of work by innumerable people and organizations to save the kiwikiu from extinction. The manner and scale of the kiwikiu deaths in Nakula and the ramifications for future conservation leaves us with a sense of loss and grief. However, we as a conservation community are still firmly committed to save the kiwikiu from extinction. The outcome of the 2019 conservation translocation attempt has increased our knowledge of the threats to kiwikiu and increased our resolve in meeting these challenges.

Since the conservation translocation, the Maui Forest Bird Working Group has met multiple times, compiled a post-translocation report that analyzed the results and how that informs this and possible future translocations (see Appendix A), discussed the timeline in which kiwikiu may persist (10-15 years; Mounce et al. 2018) and re-evaluated recovery options for this species. Furthermore, the working group outlined five key next steps to prevent imminent extinction. These actions are not intended to be a prioritized list, nor are they intended to be mutually exclusive. These actions will need to be swift and concerted across multiple agencies to save this species. These steps include:

1. Bring a number of birds into captivity with the intent to maintain and/or produce release-quality birds and release these birds as soon as a suitable release site(s) can be identified and managed to minimize threats.
2. Ensure landscape-scale disease vector control remains a high-priority and is expedited for implementation.
3. Develop strategies and evaluate the feasibility of short- and long-term predator control tools to protect the wild population, including broader landscape-level methods for each predator species.
4. Continue and increase habitat management and restoration in the current and historic kiwikiu range to ensure habitat is available into the changing future.
5. Assess potential translocation sites on the island of Hawaiʻi for habitat suitability and impacts to or from other species.

Curtailment of malaria through vector control is likely the single most impactful management action for the preservation of kiwikiu and other Hawaiian honeycreepers in the wild. While this tool is currently being developed and may be available before kiwkiu are functionally extinct, both the efficacy and timeline for this management tool are uncertain. Thus, the working group suggests holding some kiwikiu in captivity as a safeguard to prevent outright extinction. Further, protection of all or some portion of the wild population through predator control may prolong the viability of the wild population until disease control measures can be effectively implemented. The success of all of these actions in preserving kiwikiu is unknown but, in concert, they provide the best hope for the species.

While parts of steps 2-5 are touched on in this document, this is not intended to be a comprehensive plan for achieving all of these actions, which will be done elsewhere. This plan provides background information on captive holding and attempted propagation of kiwikiu and outlines the actions necessary to decide on Step 1 regarding captive propagation and zoo protection to prevent complete loss of the species if it disappears in the wild. Previous captive propagation of kiwikiu has had limited success, and has mostly been unsatisfactory. This species has a challenging life history that requires an adaptive management approach to encourage pair bonding and copulation and to avoid juveniles imprinting on humans. The current captive breeding program partner has suggested we find new partners that are willing and able to try to take on the challenges presented with breeding this species (Forest Bird Conservation Breeding Partnership meeting, January 30th, 2020). Capture and captive holding of kiwikiu can accomplish three main tasks:

1. to keep enough individuals alive and safe from disease to prevent the extinction of the species and maintain genetic viability,
2. to refine and improve captive rearing techniques to maintain a captive population,
3. to provide additional individuals for eventual release, and
4. to add to the wealth of knowledge pertaining to captive management of avian species through scientific study and adaptive management that can be applied to other Hawaiian honeycreepers.

Population viability

For a summary of this section, see below.

Mounce et al. (2018) published a study in the Journal of Wildlife Management that described a model that investigated the population viability of kiwikiu in the wild. This model was based on vital rates estimated from data collected from wild populations of kiwikiu between 1994 and 2014 (Mounce et al. 2013, 2014, 2015). Based on these variables, this population viability analysis (PVA) estimated that the species would go extinct within 25 years (starting in 2011). Although, there is always some uncertainty in demographic estimates, the vital rates used in this context represent the best available information on the behavior and biology of kiwikiu. Further, a sensitivity analysis of the PVA model showed that female mortality had the greatest impact on the population trajectory and of all the model parameters, this one had the least uncertainty.

The kiwikiu exemplifies a *K*-selected species; one that produces few high-quality offspring and, thus population growth is highly dependent on adult longevity. Kiwikiu produce a single chick during each successful breeding event. Multiple chicks from a single breeding attempt have never been confirmed (e.g. two chicks or eggs in a nest) despite decades of observation data (although this has been suspected in a few exceptional cases). Further, productivity data from multiple study sites within the kiwikiu range over many years demonstrate that less than half of pairs are successful at producing a fledgling each year. Thus, the capacity for population growth in this species is very low and maintaining a stable (or increasing) population requires adults surviving and reproducing for many years.

The dire predictions of the 2018 PVA were alarming and suggested rapid action was required to prevent extinction. This model received criticism at the time because previous survey data had not shown the precipitous decline predicted by the model. However, another range-wide survey conducted in 2017 estimated 157 ± 67 (95% CI: 44-312) individuals (Judge et al. 2019), quite a bit lower than the previous estimates of ~500 individuals (502 ± 116 in 1980 [Scott et al. 1986], 590 ± 208 in 2001 [Camp et al. 2009]). The PVA model presented in Mounce et al. (2018) was a female-only model and used an initial population size of 292 females, based on surveys conducted in 2011. With this initial population size, the PVA model predicted an abundance of approximately 184 individuals by 2017 (assuming Year 1 = 2011). The fact that the PVA model's prediction matches the 2017 population estimate lends credibility to the model and adds to the concern for the long-term viability of the species. The original PVA model was designed to provide a framework for predicting long-term outcomes of the species based on various management options, specifically removal of individuals from the wild for placement in captivity and/or conservation translocation.

To estimate the potential impact of placing some individuals into captivity on the viability of the wild population(s), we revisited the Mounce et al. (2018) model. We used the mean abundance estimate from the 2017 Hawaiʻi Forest Bird Survey (i.e. 157 total individuals) as the initial population size. The original model apportioned the overall abundance into two populations, East (Koʻolau Gap east to Manawainui) and West (Waikamoi west of Koʻolau Gap), based on genetic population structure data. Mounce et al. (2018) attributed 18% of the total abundance to the West and 82% to the East based on the proportion of the range in which these populations fell. Recent observations of kiwikiu in Waikamoi suggests that 18% (14 females) is an underestimate of the population in this area. Thus, for this exercise (2020 PVA model, MFBRP unpublished data) we defined the population split as 75% and 25% for the East and West populations. Thus, we set the initial population size of the (female-only) PVA model to 59 in the East and 20 in the West (total = 79 females).

This advances the Mounce et al. (2018) model based on the most recent abundance estimate from 2017. Not surprisingly, this 2020 PVA model predicts extinction within 25 years just as in the 2018 PVA model. Mounce et al. (2018) further estimated the likelihood of quasi-extinction or "functional extinction" that they defined as less than 10 females/breeding pairs per population. The idea behind quasi-extinction is that below a certain abundance, the species can no longer sustain itself and/or may be lost to stochastic events or inbreeding depression. With fewer individuals spread out across their range, mates may become more difficult to locate, further reducing reproductive output. The last known breeding attempt in the poʻouli occurred in 1995, yet individuals of the species were observed until 2004 (VanderWerf et al. 2006). Thus, it could be argued that the poʻoūli became functionally extinct in 1995 but some individuals survived for nearly ten more years. Long-lived animals like the poʻoūli and kiwikiu may also outlive their reproductive years, reaching reproductive senescence before mortality occurs. In the 2020 PVA model, functional extinction (less than10 females/breeding pairs) is predicted by 2022 in the western population and 2027 in the eastern population (Figure 2). Collectively, the 2020 PVA model would predict functional extinction of the species as a whole (both populations combined) by 2028.

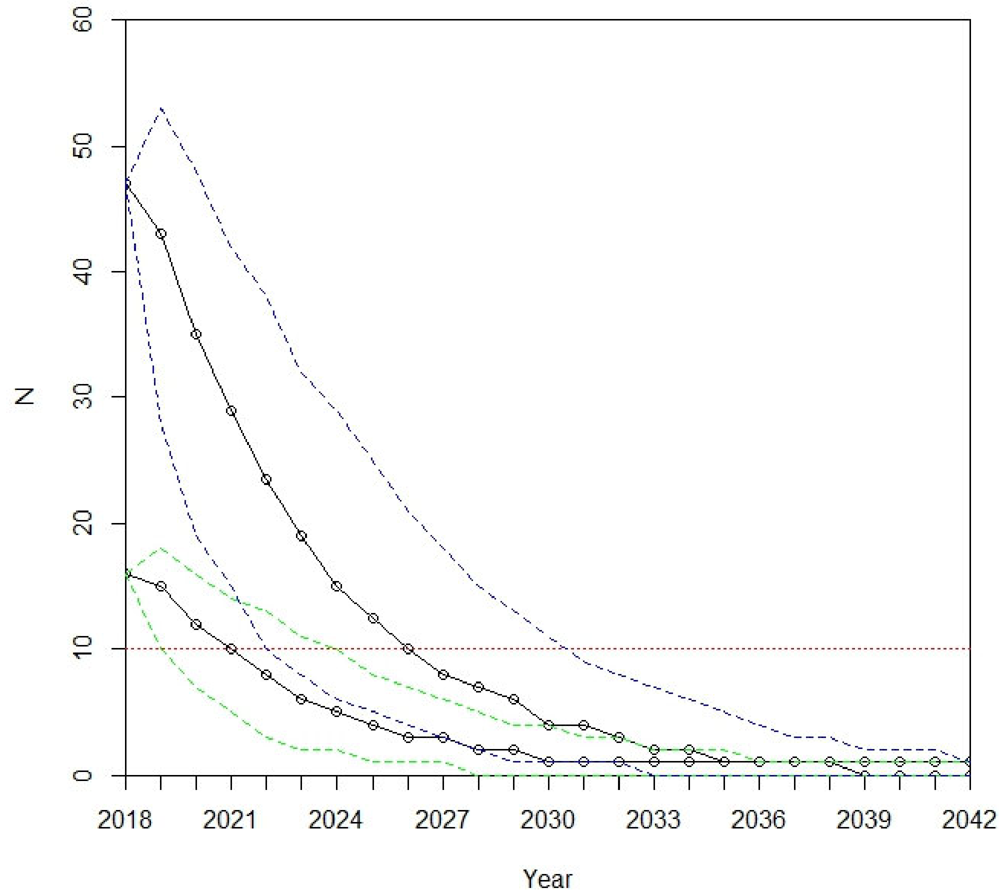

Figure 2. The Mounce et al. (2018) PVA model starting in 2017 with initial N *based on the 2017 HFBS population size (157 total, 78.5 females) showing upper- and lower-bound confidence envelopes.*

The working group proposed bringing a certain number of individuals into captivity to prevent the extinction of the species. The 2020 PVA model predicts functional extinction of the species in just seven years (2027). At that time, there may be as few as ten breeding pairs in the wild and there is no guarantee there will be an even sex ratio at that time. Captive holding and/or breeding ensures the persistence of the species. However, removing individuals from the wild may cause extinction in the wild to occur sooner than without intervention. Additionally, protecting the maximum genetic diversity may be critical to a successful captive program and re-establishment of the species in the wild. There will be a balance in capturing the number of individuals necessary to maximize the success of the captive program while also minimizing the impact on the trajectory of the wild populations and thus, preserving birds in the wild as long as possible (unless it is determined that one of these two strategies is no longer viable).

To investigate how removing individuals from the wild and placing them in captivity may affect estimated time to extinction, we ran the 2020 PVA model under three scenarios. Mounce et al. (2014) estimated genetic diversity within and among the wild kiwikiu subpopulations. From this analysis, they estimated the minimum number of individuals to represent various levels of genetic diversity within those subpopulations. For example, the authors estimated that 30 individuals from the East would represent 83% of the diversity within that subpopulation. However, in the less genetically diverse West subpopulation 15 individuals would represent 96% of the diversity. Using these estimates, we modelled the removal of:

i. 15 females from the East and 7 from the West (assuming we capture the same number of males, 30 individuals would represent 83% of the East genetic diversity and 14-15 individuals would represent 96% of the diversity in the West),
ii. 5 females from the East and 2 females from the West; 64% and ~67% of genetic diversity, and
iii. 10 females from the East and 5 females from the West; 77% and 85% of genetic diversity.

Mounce et al. (2018) modelled birds in captivity differently as these birds were not subject to the same threats as those in the wild. Population trajectory in the captive population will be based on a number of unknown factors including the age of the founding population, reproductive success, and survivorship. The previous captive population managed by SDZG had high survivorship among adults but low reproductive output and no viable offspring that could reproduce. However, for the purposes of this plan, we have assumed captive reproduction will occur at a minimum rate similar to what was produced in captivity previously and have modelled as such in the PVA.

Scenario i – Preserving the maximum modeled genetic diversity in captivity

Scenario *i* (Figure 3a) would essentially preserve the maximum amount of genetic diversity in the wild population that is practical to capture and house in captive facilities. In this scenario, functional extinction would occur in 2022 in the West, 2024 in the East. Since the original model already predicted functional extinction in the West by 2022, removing seven females would not change the functional extinction year for this population. The model would predict that removing 15 females (30 birds in total including males) would cause functional extinction to occur three years sooner, in 2024 rather than 2027 in the East. Thus, in this scenario, functional extinction would occur 3 years sooner, depending on the population, than is predicted with no action.

a)

b)

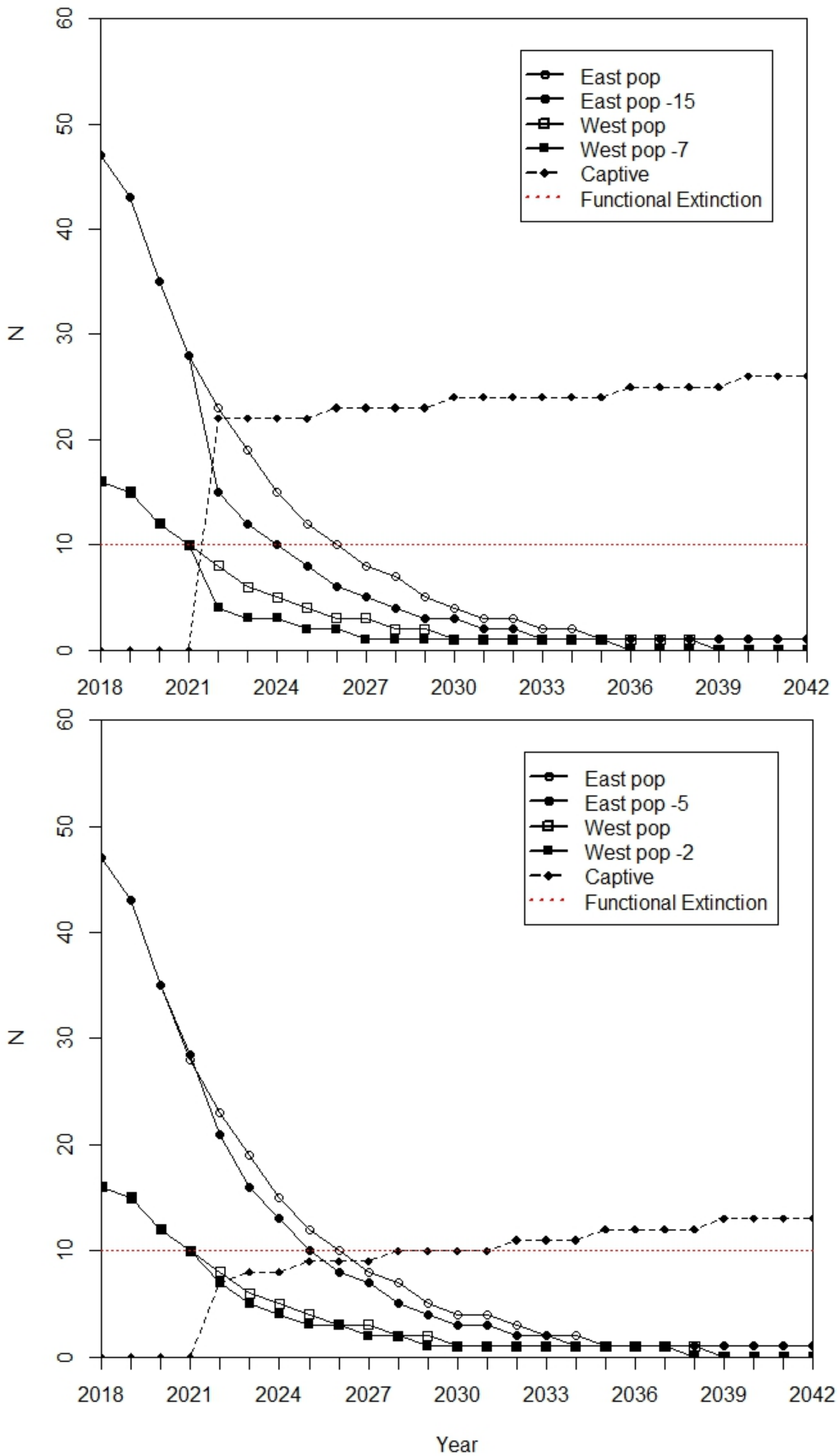

Figure 3. The 2020 PVA model showing the population trajectory with and without removing individuals for captive breeding. The top panel (a) shows scenario i *(wherein 15 females are removed from the East and 7 females from the West) and the bottom panel (b) shows scenario* ii *(5 females from the East and 2 from the West).*

Scenario ii – Preserving the minimum modeled genetic diversity in captivity
In scenario *ii* (Figure 3b), we would preserve >60% of the genetic diversity. But with only seven females, there is little room for imperfect breeding or survivorship in captivity. With so few individuals, it is possible that a future captive population will see some of the same challenges in the previous conservation breeding program, a highly skewed sex ratio and few productive pairs. If this occurred after the wild population goes extinct, options for saving the species would be extremely limited. Not surprisingly, removing fewer females results in less impact on the trajectory of the wild population. Again, there is no impact on the predicted year of functional extinction in the West. In the East, functional extinction is predicted in 2026, one year sooner than the base model. This scenario preserves birds in the wild the longest, but it also is likely to greatly limit the potential success of the captive program, which itself can be thought of as experimental due to uncertainty about breeding and reintroducing kiwikiu in captivity. This would leave an estimated 11 females in captivity in 2027, the year the same model predicts functional extinction in the wild. Thus, the survivorship of the species may then depend on 22 individuals in captivity (or more/fewer depending on the survival and reproduction of captive individuals).

Scenario iii – Modeled preserving an intermediate level of genetic diversity in captivity
Scenario *iii* (Figure 4) represents a compromise among the scenarios, preserving >75% of the genetic diversity of the wild populations and capturing enough birds to allow for difficulties in pairing and reproduction in the captive population. In this scenario, functional extinction is predicted three years before the base model in the East (2025). In 2026, this model would predict 16 females in captivity (32 individuals in total; or more/fewer depending on the survival and reproduction of captive individuals).

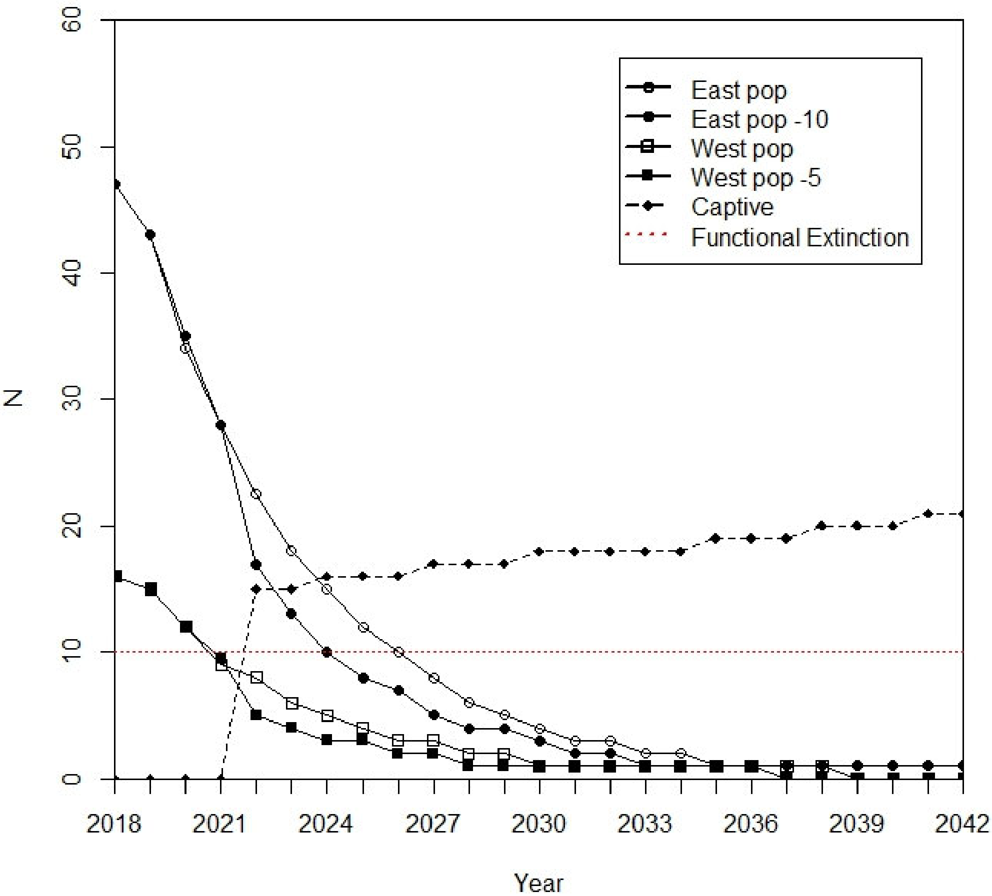

Figure 4. The 2020 PVA model showing the population trajectory with and without removing individuals for captive breeding under scenario iii *(wherein 10 females are removed from the East and 5 females from the West).*

Removing these animals from the wild is not without consequence. The best chance for species persistence is to obtain effective control of avian malaria or its vector before the species is functionally extinct. Honeycreepers have never been successfully reintroduced into the wild and prior attempts to breed kiwikiu and produce viable offspring have been unsuccessful. However, taking some into captivity will ensure that if there is a more rapid demise of wild kiwikiu or if landscape-scale mosquito control cannot be achieved in time, then we will at least have a chance to successfully reintroduce them someday. Based on this model and estimated current abundance, capturing 22 females (44 birds in total; scenario *i*) in 2022 and placing them in captivity could remove up to 58% of the population from the wild (up to 53% of the East and 70% of the West populations). Scenario *ii* could result in the removal of 18% of the East, 20% of the West, and 18% of the total wild population. Scenario *iii* may result in removing up to 35% of the East, 50% of the West populations; 39% of the total. While these percentages seem high, even in the most conservative scenario, it is important to note that the trajectory for the species is a precipitous decline over a short time period and functional extinction in less than a decade. In scenario *iii,* the model predicts that total abundance would drop by around 42% between the year of capture to the following year (modelled on captures occurring 2021–2022). Yet, the model predicts a 42% loss in the five years following 2021 without removing any birds for captive breeding. Thus, while scenario *iii* would potentially remove 39% of the species from the wild in a single year, that same number of birds is likely to be lost in the wild in the next 3-5 years if we do nothing.

This model is based on real data collected in the field over a long period. This model takes the available information and projects them forward in time. Even considering the confidence intervals and inherent uncertainty of these model estimates, there is little hope for the species in the wild. If we consider the upper-bound confidence intervals as the most optimistic scenario, functional extinction may not occur for another 3-4 years beyond what the mean projection predicts (Figure 2). However, if we focus on the upper-bound intervals, we must also look at the lower-bound projections as equally viable.

Mounce et al. (2018) experimented with increasing the vital rate parameters by 5%, 10%, and 20% to account for uncertainty or potential changes in these values. They found that these rates needed to be increased by 20% to achieve a stable population. It is possible some additional reproduction occurs between field seasons, and thus the estimate of annual productivity is higher than modelled. However, even increasing successful reproduction from 39.4% to 50% is not enough to change the predicted year of functional extinction. Conversely, it is unrealistic for the published estimates of annual female survivorship to be underestimated by as much as 20%. Annual survivorship is derived from color-band resighting data and it is not realistic to assume that birds that had been seen for years and then disappeared are somehow surviving significantly longer outside of the study sites. Increased disease transmission rates are likely to further decrease annual survivorship in the future if climate-disease models prove accurate (Fortini et al. 2015). Thus, even accounting for underestimation of vital rates, it is highly unlikely that the species is stable in the wild.

An important consideration in interpretation of these model results is that actual decline may not be linear or smoothly exponential as the model displays. Variation in seasonal and annual disease transmission at high elevations may mean that mortalities are episodic rather than constant. Linear increases in disease transmission may slowly erode populations in certain areas (e.g. lower elevations) while losses may be punctuated in others (e.g. high elevations). We may well see some populations (e.g. upper Hanawī) remain stable for several years only to lose a large number in a single high-transmission year. This may explain how we can see seemingly stable pockets of birds (e.g. western Waikamoi) while also predicting rapid extinction. As we do not have data to model variation in annual mortality, the PVA models constant mortality resulting in a smooth curve. Regardless, the outcome may be the same, fewer and fewer birds over the course of 5–8 years.

Another important finding from this modelling exercise is the persistence and viability of the wild kiwikiu population in relation to the timeline for landscape-scale mosquito control efforts, e.g. *Wolbachia* incompatible insect technique. Those working toward this important management tool estimate field trials may begin in 2022–2023. If we presume that relevant field trials in kiwikiu habitat will commence in 2023 at the earliest, this model would predict approximately 50 individuals left in the wild. This would potentially allow landscape-scale mosquito control efforts to start to make a difference before kiwikiu is functionally extinct; however, there is a lot of uncertainty with this management technique and if and how long it will take to be successful.

The bottom line is that the short- and long-term future of kiwikiu in the wild is bleak. All available data suggest the species is unlikely to persist in a meaningful way beyond five to eight years. Whether birds are brought into captivity does not change this prediction, but likely hastens it. However, if we establish a captive population with the available genetic diversity before functional extinction occurs in the wild, some individuals will still exist to re-establish a wild population. If we wait too long to establish a captive population, we may hinder the potential for successful captive propagation and eventual re-establishment of the species in the wild in the event of losing the wild populations. If we choose not to act and the species goes extinct in the wild, we have no options for future recovery at all.

SUMMARY –Mounce et al. (2018) published a population viability analysis (PVA) of kiwikiu. This model was based on vital rates measured in wild kiwikiu populations from 1994 to 2014. Based on these demographics, the PVA model predicted extinction of the species within 25 years and an abundance of 187 individuals by 2017. In 2017, the Hawaiʻi Forest Bird Survey (HFBS) was conducted including the entire kiwikiu range and estimated just 157 remaining individuals (Judge et al. 2019). The congruity between the HFBS and PVA model confirms a rapid decline in the kiwikiu population and validates the model. Starting the Mounce et al. (2018) model in 2017 and using the estimated abundance from the HFBS as starting *N*, it predicts functional extinction (less than 10 breeding pairs) in the west population by 2022 and the east population by 2027. Removing enough birds to represent more than 75% of the genetic diversity in the species may result in the preservation of 16 breeding pairs (and/or their offspring) by the year the wild population in the east becomes functionally extinct (year 2027). As modelled above, placing birds in captivity may cause functional extinction in the wild to occur up to three years sooner (depending on how many are removed). While removal of individuals from the wild is not without risk or consequence, it does not change the trajectory or the long-term outlook for the species in the wild, but it hastens it. Most importantly, functional extinction may occur before landscape-scale mosquito control using *Wolbachia* incompatible insect technique can be approved and effectively implemented in the kiwiku's range (See Mosquito control). Placing some individuals in captivity is the only way to ensure the survival of the species until such a time as landscape-level disease control measures are developed and put in place.

Take-home points:

- High agreement between PVA model and HFBS point counts in 2017
- No action leads to predicted functional extinction by 2027
- Removal of individuals for captivity reduces the time to extinction in wild by 3 years
- Placing birds in captivity does not change the trajectory or outlook for the species
- Extinction may occur before mosquito controls are available on a landscape-scale

Habitat and species management of the remaining wild population

PREDATOR CONTROL

Demographic data show us that female survivorship is driving the decline more than any other single variable (Mounce et al. 2018). Certainly, a proportion of the deaths each year is due to invasive mammals (*Rattus* spp., mongooses, cats), but we do not know the relative mortality rates caused by predators compared to other factors such as disease. Predator control has been a mainstay of bird conservation in Hawaiʻi and has been instrumental in the preservation of many species (e.g. Banko et al. 2019). In Hawaiʻi, this has typically been done through trapping and bait stations, including in portions of the kiwikiu range (Malcolm et al. 2008, Berthold et al. 2017). However, it has been difficult to demonstrate the benefits of predator control efforts on native forest birds in montane wet forests owing to demographic variability in the birds as well as the mammals themselves (Sparklin et al. 2010, Berthold et al. 2010, Nelson et al. 2002). If done effectively, predator control can undoubtedly reduce the predation risk for individual kiwikiu in localized areas. However, unless it is done at a much larger scale that has ever been attempted on Maui, predator control is unlikely to have a meaningful impact on preserving kiwikiu throughout its entire range. This tool may be best considered as part of a mosaic of tools employed, including mosquito control, in an Integrated Pest Management Plan. Such a plan is outside the scope of this document.

We do not have data to show the relative impacts of rats, mongooses, and cats on kiwikiu and each predator species may require different techniques to be effectively controlled. Trapping is currently the only available technique for control of mongooses and cats, and no landscape-scale tools exist for reduction of the threats these two species pose. As such, these species may only be effectively controlled in targeted areas. For example, deploying several maintainable trapping grids in key areas (e.g. upper Hanawī and western Waikamoi) could provide some protection to important reproductive sources of kiwikiu. Tools for successful control of cats and mongooses is currently limited to traps, though trapping methods may vary. Two general classes can be defined: live traps and kill traps. Both require forethought for placement, bait type, and resetting needs. Given the remote nature of the forests with kiwikiu and the lack of consistent field staff, kill traps are more likely to be effective and humane. Rats are considerably more difficult to control using traps alone given their higher densities and reproductive output compared to mongooses and cats. For rats, four methods have been used in some form or another in Hawaii: targeted trapping near nests or in territories (e.g. VanderWerf et al. 2011), bait station grids (e.g. Malcolm et al. 2008), A24 grids (e.g. Shiels et al. 2019), and hand or aerial broadcast of bait (e.g. Shiels et al. 2019).

The naturally low-density nature and large home ranges of kiwikiu (> 9 ha; Warren et al. 2015) means that the person effort and expense required to maintain an effective trapping grid in an area large enough to protect more than a few pairs is considerable. Targeted trapping is not likely to be effective for the larger, dispersed ranges of kiwikiu. The most successful programs have either been targeted in areas where resources are concentrated, as near nesting walls in streams for puaiohi (*Myadestes palmeri*) on Kauaʻi or in valleys where Oʻahu ʻelepaio territories are tightly packed (VanderWerf et al. 2011). Controlling predators using trapping or bait station grids is likely ineffective at a scale large enough to be meaningful for wide-scale protection of kiwikiu, but may offer protection in some areas (Malcolm et al. 2008). Newer traps, such as New Zealand's Department of Conservation (DOC) series traps (e.g. DOC250) and Automatic Traps (e.g. A24) for controlling predators are now available, but have not been implemented on a large scale in the current kiwikiu range.

Maintaining a trapping grid can have detrimental impacts on the habitat, requiring a system of trails to access the traps. For example, Maui Forest Bird Recovery Project (MFBRP) operated a predator control grid for rats and mongooses consisting of bait stations and kill traps covering approximately 32 ha within the HR3 study site in Hanawī NAR (Malcolm et al 2008). This grid required trails spaced every 50 m and each station was accessed (and therefore trails were walked) once per 1–3 months. Although the impact was limited to the trails and the habitat can recover quickly once trails are abandoned, this density of trails has the potential to affect the overall habitat quality of an area. The grid in HR3 encompassed an area that was occupied entirely or in part by 8–10 pairs of kiwikiu. Thus, a trapping grid of a size that can be reasonably maintained, may only be able to protect 15–20 individuals at a time and will likely result in some localized damage to the habitat.

The use of chemical control agents, such as diphacinone applied via helicopter is likely a much more efficient and effective technique to control rats on a landscape scale. Aerial broadcast of diphacinone may be the only reasonable option for control of rodents at the appropriate scale to have a meaningful impact on the kiwikiu population as a whole. If applied in certain population centers (e.g. upper Hanawī, Waikamoi), this could reduce the risk of rat predation in important kiwikiu source areas.

The primary limitations of aerial dispersal of rodenticides for kiwikiu management involve permitting, public acceptance, and compliance, which are likely to require significant investment of time, energy, and cost. Depending on the scale and interval for distributing the bait, either an Environmental Assessment (EA) or Environmental Impact Statement (EIS) will be required to meet State and Federal environmental compliance needs. The most recent examples of rodenticide applications via aerial methods within Hawaiʻi are on Lehua Island in 2017 and within a portion of the range of the Oʻahu ʻelepaio in the Waiʻanae range. The Lehua project completed an Environmental Assessment with an associated Finding of No Significant Impact. The action for Oʻahu ʻelepaio was generally analyzed in a Programmatic Environmental Assessment for military activities and then specifically described and analyzed in a separate Supplemental Environmental Assessment and associated Finding of No Significant Impact (FONSI). While both of these projects provide a potential blueprint for moving forward with aerial rodenticide application, significant differences exist between the locations where they were implemented and a potential project for kiwikiu conservation.

Lehua is a small, uninhabited island off the north coast of Niʻihau that is dry, covered mostly by grasses and shrubs, with no permanent water bodies, and thus provides little ecological context for an application to benefit kiwikiu. Primary impacts were mostly concerned with ocean resources and the goal was a one-time rodenticide application to completely eradicate rats from the island. The project area for the Oʻahu ʻelepaio application is much closer to what would be needed within the kiwikiu range. However, this project included avoidance measures that may not be feasible for Maui, including closed access to the area (due to its presence on a military installation), fenced and ungulate free treatment area, and an application buffer around surface waters. In the Oʻahu treatment area, only one perennial stream was present, and this stream did not flow year-round. In contrast, many of the areas where kiwikiu are present contain significant stream and surface water resources. These would likely require a buffer or a more labor-intensive hand-broadcast regime to ensure that bait does not come into contact with surface water, if an EA is pursued, which may also impact the effectiveness of the application.

The timeline and cost for planning and implementation for an aerial rodenticide project would likely depend on the scale desired, as including multiple landowners and agencies with different management strategies would complicate the process. Ideally, this would depend on community response and the need to modify project details to address concerns. Due to the sensitive resources across much of forests where kiwikiu survive, as well as the fact that these forests are headwaters for many streams that go into the Maui water supply, this may be a significant undertaking.

Currently, the bait labeled for use in aerial distribution operations by the EPA and Hawaiʻi Department of Agriculture (HDOA) are Diphacinone-50 pellets. These would be distributed by helicopter, which needs to be certified for this type of flying. An aerial application permit is also required from the HDOA. The amount of bait would be quite significant and require coordination with the distributor to procure and ship it to Hawaiʻi. Initial application may take place over the course of a week to a few weeks depending on the size of the area and favorable weather conditions to be able to implement the project. Overall, the best-case scenario is likely 2.5–3 years before this could be implemented in kiwikiu core areas. The cost of an aerial operation can be significant, especially as it would need to be done at regular and continuing intervals.

Overall, two predator control methods are likely to provide the most beneficial protection for kiwikiu from rodents. A grid of A24 and DOC250 traps could be run in important areas of the range as has been done previously with bait stations. This could be implemented on a tight timeline and provide some protection from cats, mongooses, and rodents. The traps are expensive and need to be serviced multiple times per year. Alternatively, aerial broadcast of bait could be done on a wider scale, but requires more significant regulatory lead time and may end up being more expensive due to the bait and deployment costs, depending on time needed for repeat applications. This would likely provide a larger-scale benefit, however. We do not know what the current levels of annual loss due to cats, mongooses, and rats are for the kiwikiu, but it is likely not high given some of the surrogate studies that have been done (i.e. Sparklin et al. 2010).

Mosquito control

We have long known of the devastating impacts avian malaria and other mosquito-borne diseases have on Hawaiian honeycreepers and other native birds (Warner 1968, van Riper et al. 1986). Non-native diseases vectored by non-native mosquitoes were significant factors in causing many Hawaiian birds to become extinct (Atkinson and LaPointe 2009a, 2009b). After these waves of extinction, mosquitoes and avian disease limited the range of disease-intolerant birds (i.e. most of the remaining species), restricting them to high elevation forests where mosquitoes and/or malaria could not persist due to thermal intolerance (e.g. Scott et al. 1986). Climate change models project increased habitat suitability for mosquitoes and avian diseases at higher elevations, greatly reducing the viable habitat for most of the remaining species (Fortini et al. 2015). Recent evidence has shown both disease-carrying mosquitoes and malaria-positive birds at some upper elevations within part of the kiwikiu's range (Warren et al. 2020). We do not yet know if this is a result of recent changes in mosquito densities or indicative of typical disease rates in recent decades. Regardless, it is clear that malaria is reaching, and likely impacting, the wild kiwikiu population at all elevations within their range. Rates of disease in upper elevations will likely only increase as more mosquitoes move higher up the mountain and conditions improve for reproduction of the malaria parasite (*Plasmodium relictum*) at high elevations.

Currently, the option being pursued for use in Hawaiʻi to control mosquitoes on a landscape-scale is the *Wolbachia* incompatible insect technique (IIT). This process has been effectively deployed worldwide and the regulatory approval process is clear in the United States (Mosquito-free Hawaiʻi 2016). This process will be done by inoculating mosquitoes with a novel strain of *Wolbachia* bacteria in a secure laboratory in Michigan and then rearing the mosquitoes and releasing the non-biting males into the wild in Hawaiʻi. Unique *Wolbachia* strains occur in over 60% of all insect species, including many in Hawaiʻi. When the modified male mosquitoes breed with wild females with a different strain of *Wolbachia*, the resulting eggs do not hatch. The technique has been widely used in *Aedes* mosquitoes to benefit human health and is being adapted to *Culex quinquefasciatus*, the primary vector for *Plasmodium relictum* in Hawaiʻi. Releasing *Wolbachia*-modified *Aedes* mosquitoes into the wild has been demonstrated to reduce mosquito densities in other parts of the world and the technique is expected to transfer to *Culex* mosquitoes. *Wolbachia* IIT is self-limiting and, thus repeated releases of altered mosquitoes would be required to maintain landscape-level control and ensure protection for kiwikiu and other native forest birds. The laboratory development of the mosquito has been on-going and testing its population suppression effectiveness is forthcoming.

The *Wolbachia*-modified mosquitoes are regulated as a biopesticide to reduce mosquito populations. The HDOA and US Environmental Protection Agency (EPA) are the primary regulatory agencies, and the process of securing the necessary state and federal permits is underway. In addition to the EPA permits, compliance documents to satisfy both state and federal regulations and key research needs are being developed and pursued. Final steps would be mass rearing and deployment of the mosquitoes into high priority areas. The *Wolbachia*-mosquito IIT approach is relatively unknown in Hawaiʻi, and implementing management at this scale across all the main islands will require transparency and dedicated community engagement. As such, there is significant uncertainty about when landscape-scale control of *Culex* mosquitoes can begin; at a minimum, experimental work (which would include kiwikiu range) could start in 2-3 years, although it is also possible that it takes longer.

10-year capture plan

Long-term goals for captive flocks

The overall goal of establishing a captive population is the preservation of the species given the high likelihood that the species will go extinct within 10 years under current management practices. Many of the captive programs that have saved species from extinction were established haphazardly (e.g. ʻalalā, *Corvus hawaiiensis*) or with only a handful of birds representing the last few individuals (e.g. Mauritius Kestrel, *Falco punctatus*). Any of these programs would have jumped at the opportunity to found the captive program with a larger and more diverse population in order to preserve the greatest genetic representation of the species as a whole. All evidence points to kiwikiu being in the same situation as these species within a decade and we still have the opportunity to start a genetically diverse captive population with the existing wild populations.

A primary goal of the captive program is to return the captured kiwikiu and, if possible, their captive-bred offspring to the wild as soon as reasonable. The continuation and maintenance of the captive program will depend on the status of the wild population and success or lack thereof in breeding viable kiwkiu offspring in captivity. If the wild population persists until landscape-scale mosquito control is in place, managers may decide to return all captive individuals to the wild within 10 years. However, if the threat of imminent extinction remains, and the captive breeding program finds a way to be successful, it may continue until they can be safely returned to the wild, however long that takes. Additionally, managers may deem the continuation of the captive program necessary, but that it is also safe to return some portion of the captive population to the wild, especially if viable offspring from captive pairs can be produced.

NUMBERS

In the first year of captures the goal will be to supply three pairs (6 individuals) to the Smithsonian Conservation Biology Institute (Front Royal, VA), four pairs (8 individuals) to the National Aviary (Pittsburgh, PA), and three pairs (6 individuals) to the Tracy Aviary & Botanical Gardens (Salt Lake City, UT); 20 individuals in total. These facilities may be able to build capacity to accept additional birds in subsequent years, which will be evaluated after initial captures are obtained. Additional birds may also be captured for housing at additional institutions. The overall goal is to have up to 15 pairs (30 individuals; *Scenario iii*) in captive holding. To achieve an effective population of 15 breeding pairs may require capture of more than 30 individuals as some individuals may not successfully pair, and some may not survive the transport. Capture plans will need to be adaptive based on survivorship, pairing success in this initial cohort, and on-the-ground observations of current populations. Caring for this number of individuals will require the birds to be held at multiple facilities.

BREEDING

Although the primary goal is to hold birds in captivity safe from disease, a secondary goal is to pair individuals and produce viable young, which has been achieved in a few cases with captive kiwikiu. The primary goal for captive rearing is to produce release-quality individuals. This may require parent rearing or similar techniques to allow adults to impart natural behaviors and allow offspring to mature in as much of a natural social environment as possible. Captive breeding will strive to serve two purposes 1) maintain a stable captive population so we can return the same number of individuals to the wild and 2) produce individuals to source future releases to establish and/or reestablish populations in the wild. However, it should be recognized that there is no guarantee that viable offspring can be produced in a captive setting.

RELEASES

The overall goal/ideal is to give kiwikiu a chance to circumvent extinction by being released back into the wild to either reestablish or supplement a dwindling wild population once the disease threat can be managed. The method and location of releases will depend on overall need and the conditions of the wild population. For example, if the wild population is extirpated entirely, captive birds may be released in former strongholds (e.g. Hanawī NAR). Releases may also be used to supplement remaining satellite populations (e.g. Waikamoi, Manawainui) or establish the species in historically occupied habitat (e.g. Nakula NAR).

Selection of individuals

NUMBERS

The overall goal is to capture only the number of individuals that can be safely held and maintained at captive facilities. The current capacity at the National Aviary (NA), Smithsonian Conservation Biology Institute (SCBI), and Tracy Aviary & Botanical Garden (TABG) is 10 pairs collectively. After these are obtained, additional captures and space for them should be re-evaluated based on what has been learned about the captive birds to date and status of the wild population, with the ultimate objective to be 30 pairs (*Scenario iii*).

CAPTURE LOCATIONS

There are a minimum of two genetically distinct populations of kiwikiu in the wild, divided by the Koʻolau gap (Mounce et al. 2015). There are several study sites with established trails and camps in both The Nature Conservancy's (TNC) Waikamoi Preserve and Hanawī NAR that will allow access to these two populations for captures. While the western Waikamoi population is smaller, it holds unique genetic and cultural diversity that are vital to preserve in the captive population. Topographic features and cultural variation (e.g. vocal structure) within the Kīpahulu Valley and Manawainui in Haleakalā National Park (NP) (although unanalyzed) suggest additional genetic diversity in these areas. Preserving as much diversity from the wild population as possible may be vital to a successful conservation translocation into the wild and/or the long-term success of the species in the wild.

As malaria-induced mortality is likely greater at lower elevations within the kiwikiu range, an initial strategy will be to target captures from sites at the lowest elevations possible. A downside to targeting captures at the lowest elevations is that kiwikiu in these areas typically exist in reduced densities making captures more difficult.

The number of individuals to target per population should be informed by population viability, estimated population size, and genetic diversity. See Population viability for discussion of the number of individuals that may be captured from the western and eastern populations to maximize capturing genetic diversity from each area. This analysis suggests that taking five (5) pairs from the west (Waikamoi) and 10 pairs from the East (Hanawī) would be sufficient to preserve the >75% of the genetic diversity from these areas. Since initial capacity at the captive facilities is ten pairs, it may be advisable to take three (3) pairs from Waikamoi and seven (7) pairs from Hanawī until captive capacity can be increased and the wild population reassessed. Alternatively, it may be advisable to take more from Waikamoi in the first year given the higher likelihood that this subpopulation goes extinct before the East. Additional captures may also be advisable from Manawainui in Haleakalā NP to capture the (likely) additional genetic diversity from this subpopulation. This subpopulation may be collapsing or very sparse as few observations of the species have been made in recent years. Incorporating any remaining individuals into the conservation breeding program may be the only way to save this particularly imperiled subpopulation. Birds captured from Haleakalā NP would make up a portion of the capture goal (7) for the eastern (Hanawī) population as the genetics from the few individuals tested from Kīpahulu were grouped with those from Hanawī (see Mounce et al. 2015).

TIMING

The plan for the conservation translocation of kiwikiu to Nakula NAR (MFBWG 2018) laid out criteria for the selection of individuals for translocation. One of the primary goals for these captures was to avoid taking birds in breeding condition that were likely caring for young. As such, captures were planned for October-January, outside the typical breeding season for kiwikiu. This species exhibits a very loosely defined breeding season and may attempt to breed at any time in the year if conditions are favorable. In 2019, October proved to be a good time of year to capture birds that were not in breeding condition. However, the sex ratio among captured individuals was strongly skewed toward males. Biologists felt that October may have been too far outside the breeding season and females were less stimulated to defend territories or seek out mates, and thus less attracted to playback. The sex ratio among captures during the breeding season, February-June, in previous years is typically more balanced. As such, captures should be targeted from September-March for the best chance of meeting capture goals. Birds captured during this time would likely still include a high proportion of individuals that have not started breeding that year. Targeting captures outside of peak malaria transmission periods may also be advisable. Capturing birds that have been recently exposed to malaria could result in increased mortalities after capture. Mosquito densities peak in October–November in many places in Hawaiʻi (Ahumada et al. 2004, 2009). However, managers may also decide that the high likelihood of extinction necessitates taking the maximum number of individuals into captivity regardless of breeding status or other considerations and, if so, captures may commence at any point in the year.

Logistically, January 2022 may be the earliest that captures may commence. When captures are attempted will depend on the facility capacity available at the time. The Maui Bird Conservation Center (MBCC) managed by San Diego Zoo Global (SDZG) has capacity to temporarily hold birds, but will need advance notice to prepare aviaries. Additionally, transportation to and housing at the mainland facilities will need to be coordinated to minimize the time the birds are held at MBCC to avoid over-extending the capacity and resources of SDZG. Captures and mainland transfers may also need to be staggered to reduce the number of aviaries needed at SDZG at any given time.

CRITERIA FOR SELECTIONS

The conservation translocation plan (MFBWG 2018) provided direction for what individuals can be translocated and what individuals were most ideal. Besides taking individuals not in breeding condition (see Timing), the conservation translocation plan discussed the ideal makeup of the translocation group. Many of these criteria are shared with a goal of creating a captive population.

A primary goal for the captive population, as it was for the conservation translocation, will be a balanced sex ratio. Capturing a balanced sex ratio in a single capture session will not be necessary so long as additional capture trips help to balance out the ratio. Gathering a balanced sex ratio from each subpopulation (Waikamoi, Hanawī, Haleakalā NP) is not necessary so long as the overall group from all areas is balanced. However, capturing as close to a balanced sex ratio from each subpopulation should remain a goal to maximize the chance we are preserving the available genetic diversity. It may be advisable for the captive facilities to encourage cross-population pairs (e.g. Waikamoi male and Hanawī female) to maximize genetic diversity within the captive population. Ideally, captures will include younger individuals that are, or are about to be, in prime breeding condition and who have the most years ahead of them. Kiwikiu can be reliably aged as hatch-year (< 1 yr old), second-year (1–2 years old), and after-second year (≥ 2 years old). An after-second year (ASY) may be anywhere between three and 16 years old and there is no way of knowing how many reproductive years an ASY bird has after capture. However, this age class represents the majority of individuals in the wild at a given time and most captures will undoubtedly be ASY. The most ideal age to capture is second-year (SY). These individuals are independent of their parents and looking to establish their own home range. Second-years may begin pairing but typically do not breed until at least their third year. Thus, removing second-years would do the least harm to the reproductive output of a population. Typically, younger birds are also more adaptable to new environments and may take to a captive environment faster than older birds. Additionally, subadult birds are thought to have lower survivorship in the wild possibly owing to greater dispersal rates, which may put them at greater risk of contracting malaria if they disperse to lower elevations. During the 2019 conservation translocation, two of the 13 birds captured were aged as SY and a similar ratio is likely in future captures.

Initial transport and holding

Holding on Maui

A maximum of eight individual kiwikiu can be held in quarantine at the Maui Bird Conservation Center (MBCC) at a time. Depending on the duration, behavior, and status of each bird, these individuals would each be held in enclosures as small as 24” x 36” x 30” in a small wire cage which are typically used for short term holding such as when a bird may be sick or injured, or during previous quarantine situations. Or, each bird may be held in a larger cage of approximately 8’ x 4’ x 7’, depending on the duration of holding.

Additional MBCC staff support will be needed to care for the kiwikiu in quarantine. Approximately 20 hours of labor will be needed each week to care for eight kiwikiu in quarantine. Because of the high risk of spreading infectious diseases from kiwikiu in quarantine to resident birds at the MBCC, a separate staff member would need to be dedicated to only caring for kiwikiu. Alternatively, kiwikiu aviaries would only be serviced in the afternoon after the care of other species has been completed.

The typical quarantine period for wild honeycreepers coming into the MBCC is 30 days, with three negative fecal sample examinations for intestinal parasites, no visual signs of avian pox, and positive behaviors observed over the course of this 30 days. After these 30 days and clearance from SDZG veterinarians, kiwikiu can then be moved into larger buildings with other resident birds, assuming space is available. However, kiwikiu could leave MBCC in fewer than 30 days, pending the approval of government agencies, permitting authorities, and a veterinarian from the receiving facility.

Since these birds will all be moving to mainland facilities, we envision having 3–4 cohorts of eight individuals, and all eight individuals within each cohort would be transported together to a mainland facility or facilities. Once the cohort reaches eight birds in quarantine and flights and personnel are ready, the birds could leave MBCC right away (instead of staying the full 30 days in quarantine). The total period that birds will be temporarily housed at MBCC is difficult to estimate until we know what the capture efforts yield but this duration might last anywhere from a few days to 30 days. Alternately, if more than eight kiwikiu are sent to the mainland at one time, then a new and separate quarantine/bird holding building/structure would need to be constructed at MBCC. This would add to cost and timing.

MBCC is able and willing to assist by holding kiwikiu in a quarantine situation. They will create a specific and detailed quarantine plan based on the number of birds arriving at MBCC over a specified period and based on the number of days that birds would be temporarily held at MBCC.

Mainland transport

Currently, birds can be shipped on commercial airlines out of Hawaiʻi via Alaska, American, and Delta Airlines. Alaska and American Airlines will allow the birds to be placed onto connecting flights to reach their destination, while Delta requires the birds be shipped non-stop which may not be possible from Maui to each mainland location.

In the absence of an accompanying staff member, birds are typically shipped in the cargo hold of the plane. This is not ideal for a trip of this length, especially for a species this valuable. Airlines will sometimes allow birds to accompany passengers in the cabin, but it will need to be negotiated with each airline. For example, Delta allows small household birds (up to 4 pets/flight) to travel in a carrier that fits underneath the seat in front of you at ~$125/pet. There is also an option to purchase a seat to avoid placing the crate underneath the seat. Other Hawaiian forest birds have been transported in this manner and we have a crate with six individual compartments that fits on a commercial airline seat. Prices for this would be the current passenger airline rates and cargo prices for a similar trip would be around $1,700.

To ensure kiwikiu are delivered to mainland facilities safely and efficiently, it would be beneficial to secure flight(s) from an airline that will allow the birds to travel in the passenger cabin. This way, the birds can be monitored over the entire journey and staff can be sure that environmental parameters are appropriate throughout transport. Using crates that sit on a standard airline seat, each staff member would be responsible for a seat housing six birds. This will require up to five staff members for a maximum of 30 birds if the birds are shipped all at once. If multiple trips are made, or more or less birds are captured to achieve captive targets, this will vary.

Zoo husbandry plan

EXISTING KNOWLEDGE

Kiwikiu were first brought into a managed care environment in 1997, to develop husbandry and aviculture methods for Hawaiian honeycreepers. This action to hold kiwikiu in a managed care setting did not have a specific breeding plan nor clear exit. As a result, since 1997 only a small number of kiwikiu (~10 individuals) and thus small number of breeding pairs, have been maintained at two breeding centers in Hawaiʻi operated by the SDZG. Furthermore, kiwikiu are long lived, which added to the challenge of developing successful breeding methods. Although conservation breeding of kiwikiu was attempted beginning in 2000, this species has always been a lower priority compared to other endangered Hawaiian species at the breeding centers.

Founding individuals were collected (eggs and adults) from the Hanawī NAR, part of the eastern subpopulation, in 1997 (n=1), 1999 (n=2), 2001 (n=2), and 2005 (n=2), and from TNC's Waikamoi Preserve in 2014 (n=1).

The median life expectancy of kiwikiu that hatched and died at the breeding centers is 8.6 years (13 birds total, excluding birds that did not live until at least 1 year; maximum lifespan = 18.9 years) (SDZG unpublished data). Only 28 individuals in total, including individuals collected from the wild as well as those hatched under managed care, have been cared for at the breeding centers since 1997.

Reproduction at the breeding centers has been relatively unsuccessful and inconsistent since the first full kiwikiu breeding season in 2000. From 2000-2020, 36 fertile eggs (157 total eggs laid; 23%) were laid and 67% of these hatched (SDZG unpublished data). Nearly all eggs were artificially incubated (100.5°F), after fewer than seven days of parental incubation. In total, fewer than five eggs were fully incubated by the female. Twenty-one (21) of 36 viable eggs (58%), and 21 of 24 (88%) successfully hatched eggs produced nestlings were hand-reared and survived until independence (SDZG unpublished data). Parent rearing was attempted only three times with one female, and all three attempts failed due to two mortalities and one nestling removed from the parent for concern for the survival of the young bird (SDZG unpublished data).

Only three captive kiwikiu breeding pairs have produced more than two offspring in total over the history of the conservation breeding program, and two of the three breeding pairs consisted of the same female (SDZG unpublished data). In the first 7 years of breeding (2000–2007) only three females laid eggs (SDZG unpublished data). Further detail on the conservation breeding at SDZG facilities can be found in Appendices B-K.

Various techniques such as increasing protein in the diet only during the breeding season, adding carotenoids to the diet for more natural plumage coloration, and providing insects using new distribution methods have been implemented, but reproductive input did not significantly increase. Furthermore, conclusions have been difficult to determine due to the small number of breeding pairs each year. The low fecundity (e.g. one egg per clutch and long parental dependency period) also contributed to the relatively low reproductive success within the conservation breeding program. Due to the limited reproductive success of kiwikiu at the conservation breeding centers, a detailed and specific methodology for high reproductive success under managed care is not available. However, recommendations are provided in the subsequent sections based on techniques that have worked successfully.

HOUSING

The smallest space that a single individual kiwikiu was previously housed in while at the breeding centers was 5′ × 10′ × 8′. Wild captured kiwikiu were housed in aviaries each measuring 4′ × 8′ × 7′ in 2019, and some individuals exhibited stereotypical stress behaviors while in this space. As such, we recommend using aviaries larger than this size. The typical breeding aviary (consisting of two adjacent aviaries separated by mesh wire with a door in-between) that this species was housed in was 24′ × 24′ × 8′. Aviaries should be predator and rodent proof and protected from mosquitoes because kiwikiu are highly susceptible to avian malaria. In general, kiwikiu are a relatively calm species under managed care. However, this calm behavior is particularly evident in hand-reared individuals, a negative sign of habituation which would not be positive for future releases. Wild caught individuals do exhibit stereotypical stress behaviors such as pace flying and head rolling, but holding these individuals in larger aviaries seems to help reduce stress behaviors.

Between 1997 and 2020, kiwikiu were housed in aviaries with a concrete or cinder floor. Kiwikiu typically do not spend very much time on the ground, so a concrete floor can be suitable and is easier to clean. Starting in 2020, kiwikiu have been housed in aviaries with mulch on the floor. Kiwikiu appear to do best in aviaries with lots of sun light. Without sunlight, the feather coloration appears to change from a yellow color to an increasingly gray color.

Because kiwikiu in the wild form monogamous pairs and defend territories from other individuals, we recommend providing each breeding pair with a connected pair of aviaries so birds can be housed together but separated if chasing and aggression becomes an issue.

We recommend kiwikiu are cared for at ambient temperatures above 50° F, similar to conditions they experience in the wild. A heat source (e.g. heat lamp) is not provided at the breeding centers in Hawaiʻi, because temperatures at the breeding centers are typically above 50° F. Since kiwikiu live in a wet forest environment with high humidity, misters are recommended to help recreate this environment.

Because of the extreme rarity of this species, we recommend not housing kiwikiu with any other species. Kiwikiu, like other honeycreepers, exhibits some vocal mimicry abilities and many of the birds produced in the SDZG conservation breeding program exhibited many l vocalizations not observed in the wild, especially mimicking other species housed nearby. Ensuring young birds, especially, are exposed to a Maui auditory environment including kiwikiu vocalizations (e.g. audio playback and/or housing adult kiwikiu in earshot) may be important to maintaining wild behaviors and for forming and maintaining pairs in captivity.

Care

We recommend that the aviary space simulates a native Hawaiian forest as much as possible, with naturally growing vegetation, particularly with lots of woody branches for foraging. Ideally, the vegetation would be of native Hawaiian species, although this will be extremely difficult to achieve outside of Hawaiʻi. We recommend providing logs of various sizes that are kept upright, similar to what kiwikiu would forage on in the wild. We also recommend live plants or fresh cut browse foliage is added and removed from the aviary frequently. Live plants will likely need to be rotated in and out of the aviary periodically, to allow for regrowth after kiwikiu chew on the leaves and branches. We further recommend providing some form of water baths which captive help individuals were observed to enjoy.

We recommend a primarily insectivorous diet fed to kiwikiu, similar to items that this species would forage on in the wild. Live insects are extremely difficult and restricted for importing into Hawaiʻi, and this lack of insects was likely a significant challenge for previous kiwikiu conservation breeding efforts at the centers in Hawaiʻi.

Kiwikiu readily forage out of a 4" saucer and drink out of a separate 4" saucer next to the food pan. The current diet for one kiwikiu per day is as follows:

1 tsp dried fly larvae
1 tsp mazuri zulife soft bill diet for iron sensitive birds
1g live mealworms
1g live crickets
1 tsp quicko classic egg food

In a managed care setting, kiwikiu have been fed and consumed papaya, cooked chicken egg, cede universal softbill food, papaya, apple, honeydew melon, green peas, wax moth larvae, and nekton lori complete lory diet.

Breeding

We believe that mate choice is an important component of kiwikiu breeding success in a managed care setting. Most eggs laid at the centers in Hawaiʻi were infertile, suggesting that pair compatibility may have been an issue.

Female kiwikiu build nests in browse or live plants. Grass, moss, and other fine vegetation materials appear to be preferred in a managed care setting. Pre-built nests (e.g. small basket) have been provided in the past but have not been consistently used by kiwikiu. Also, in a managed care setting, kiwikiu have laid a follow up, replacement clutch as quickly as 10 days after the previous clutch of egg(s) were removed or disappeared.

MAINTENANCE OF WILD BEHAVIORS

Husbandry and care techniques for kiwikiu should replicate conditions, experiences, and materials found in the native forest habitat as much as possible. Subsequent sections below describe specific husbandry conditions that replicate the native forest habitat as much as possible.

We recommend kiwikiu nestlings that hatch under managed care be parent-reared, not hand-reared. Hand-reared adults released into the wild in 2019 did not exhibit similar foraging behaviors exhibited by wild translocated birds. These birds also exhibited signs of habituation and sought out humans after release. Therefore, hand-reared kiwikiu may not be suitable for release. Kiwikiu offspring have a long juvenile dependency period of 5–8 months and may be provisioned by parent for up to 18 months. This may be an important period for offspring to learn crucial wild foraging behaviors from parents. SDZG attempted parent rearing only three times with a single female during their conservation breeding program with no successful outcomes. Parent rearing was not a priority for previous conservation breeding efforts. However, determining how parent rearing can be successful in captivity may be a crucial element to producing offspring that can be successfully released into the wild. This program will rely on an innovative and adaptive management plan at each captive facility to increase success. Producing birds that cannot survive in the wild is antithetical to the purpose of this program and preservation of the species.

Facilities

The facilities below will each be responsible for some aspects of holding, transport, and housing of the captive kiwikiu.

SAN DIEGO ZOO GLOBAL

As a leader in wildlife conservation, the work of San Diego Zoo Global includes on-site wildlife conservation efforts (representing both plants and animals) at the San Diego Zoo, San Diego Zoo Safari Park, and San Diego Zoo Institute for Conservation Research, as well as international field programs on six continents. The work of these entities is made accessible to over 1 billion people annually, reaching 150 countries via social media, our websites and the San Diego Zoo Kids network, in children's hospitals in 12 countries. The work of San Diego Zoo Global is made possible with support from our incredible donors committed to saving species from the brink of extinction.

NATIONAL AVIARY

The National Aviary is America's only independent indoor nonprofit zoo dedicated to birds. Located in Allegheny Commons Park on Pittsburgh's historic Northside, the National Aviary is home to more than 550 birds representing more than 150 species from around the world, many of them threatened or endangered in the wild. The National Aviary's large walk-through habitats create an experience unlike any other—an intimate, up-close interaction between visitors and free-flying birds, including opportunities to hand-feed and meet many species rarely found in zoos anywhere else in the world. The National Aviary's staff of conservationists and researchers work at home and around the world to save birds and protect habitats. The National Aviary leads, innovates, and contributes to important endangered bird breeding programs while working to preserve important bird habitats around the globe. Dynamic education programming lead by our educators brings the fascinating world of birds and their habitats to diverse audiences and instills a conservation ethic that teaches the responsibility we all share in being stewards of our planet. The National Aviary strives to present the highest quality family recreational experience that a zoological institution can offer and inspire respect through nature through an appreciation of birds in every visitor.

SMITHSONIAN CONSERVATION BIOLOGY INSTITUTE

The Smithsonian Conservation Biology Institute (SCBI) is a non-public Federal facility devoted to propagating rare species through natural means and assisted reproduction and to training wildlife professionals in conservation biology. The Smithsonian's National Zoo and Conservation Biology Institute is accredited by the AZA. SCBI spearheads research programs at its headquarters in Front Royal, Virginia, the Smithsonian's National Zoo in Washington, D.C., and at field research stations and training sites worldwide. Scientists at SCBI study and breed more than 20 species at the Front Royal location, including those that were once extinct in the wild, like Guam rails, black-footed ferrets and scimitar-horned oryx. Species are selected based on strict priority criteria, and, in virtually all cases, the ability to link *ex situ* activities to benefit *in situ* conservation. Because animal management staff collaborate directly with a diversity of scientists, SCBI offers an excellent environment for contributing to survival of threatened, difficult-to-breed species with distinctive needs and preference for an undisturbed setting. Historically, avian programs at SCBI have included a variety of endangered bird species including small passerines such as ‘'iwi, ‘amakihi, and Rota white-eyes. Current recovery and conservation translocation programs include the Guam rail, Guam kingfisher, whooping crane, and loggerhead shrike in addition to other avian conservation breeding programs for brown kiwi, red siskin, red-crowned crane, hooded crane, and white-naped crane. Emphasis on housing fewer species but larger numbers of each species allows scientists and aviculturists to conduct research and maintain successful breeding populations. Aviculturists at SCBI have extensive experience caring for and breeding rare and endangered birds including small passerines. In addition, aviculturists utilize a variety of incubation and hand-rearing techniques and are experienced in creating husbandry and breeding protocols for species who have historically been difficult to propagate and maintain in human care. In addition to an experienced animal care staff, SCBI has the resources to provide genetic assessment of wild and captive housed birds. This expertise has assisted with several endangered species breeding and conservation translocation programs.

TRACY AVIARY

Tracy Aviary, founded in 1938 by local banker and philanthropist Russell Lord Tracy, is the oldest and largest free-standing, public aviary in the United States. Tracy Aviary strives to create a passionate, environmentally literate public dedicated to conserving birds and habitats everywhere. Its mission to inspire curiosity and caring for birds and nature through education and conservation is reflected through leading many citizen science projects for native birds of Utah and its commitment to valuable breeding programs through AZA Species Survival Plan (SSP). In 2008 Salt Lake County voters overwhelmingly supported a bond initiative to "Save the Aviary." This bond opened the opportunity to rebuild most of the aged infrastructure at the Aviary, this included renovation of the historic South American Pavilion, a new temperature controlled off-exhibit holding space, an avian health center, food preparation and storage facility, walkthrough tropical rainforest, native wetlands exhibits and more. The Aviary continues to build a diverse collection plan that contributes to the mission, bringing more focus to conservation significant species in need of the skills and experience found at Tracy Aviary— such as Guam kingfishers, Bali mynas, white-rumped shama, and northern helmeted curassow which have been successfully bred at the Aviary.

Future Facility Participation

To increase the capacity of holding kiwikiu nationwide, there are numerous other mainland facilities that have the skills and facilities to care for kiwikiu. At this point, the Houston Zoo, Philadelphia Zoo, Woodland Park Zoo and White Oak Conservation have also expressed interest in future participation in this program to expand through additional wild captures or birds produced from the first facilities.

Costs of capture, transport, and management of captive population

The figures below are the best estimates to get this program off the ground for the 2021-2022 calendar year. Some costs are one-time startup expenses, and some are annual expenses that would need to be replicated if the capture and transport spanned several seasons/time periods.

Capture

Capture efforts would be completed by existing staff from MFBRP, DLNR-DOFAW, the various zoos, and other collaborating partners. If State Wildlife Grant, American Bird Conservancy, Hawaii State, and National Fish and Wildlife Foundation funding to support the current MFBRP project and staffing is not available in subsequent years, the expenses for capture will increase. There would be additional costs regarding materials, equipment, and field site access not reflected in the Capture total below.

Helicopter time $25,000
Field equipment/supplies $5,000

Capture total $30,000

Transport

Airfare and travel for 4 people travelling with 8 birds on commercial airlines, 8 seats - $8,000 per trip

Transport total for three cohorts $24,000

San Diego Zoo Global Quarantine management

Staffing ($2,300 per month) - $4,600 for two months
Maintenance costs (bird food, medications, etc.; $1,000 per month) - $2,000 for two months
Aviary setup costs - $1,500

San Diego Zoo Global for two months of care total $8,100

National Aviary management

Visitor engagement - $11,800

Breeding center equipment - $15,600
Breeding protocol development, animal care, research - $45,100 annually
Housing startup costs (2 breeding pods, $30,000 each) - $60,000

National Aviary total $132,500

Smithsonian Conservation Biology Institute Management

SCBI will commit resources to modify enclosures for, initially, three breeding pairs. Additional housing to support five breeding pairs will be evaluated and prioritized over the next several years. Maintenance costs of the birds will be secured in our federal budget and establishment of web cams for virtual visitor engagement will be pursued. Additionally, $5,000 in funds will be set aside to assist field biologist with any needed supplies.

Smithsonian contribution total -$5,000

Tracy Aviary Management

Tracy Aviary will commit resources to modify the existing Aviculture Off-Exhibit Holding space, intending to hold three breeding pairs, but willing to adapt to hold more as the program progresses. Maintenance and keeper costs will be absorbed through existing budgets intended to already manage this building, these expenses are estimated to be approximately $5,000 a month in wages and $1,000 a month in maintenance.

Exhibit modifications $1,000
Food and medical needs $2,000 annually
Visitor engagement monitoring equipment and signage $1,500

Tracy Aviary total $4,500

There are many expenses being covered by all of the partners in terms of staff already on the ground, housing and zoo facilities and gear. The estimate below would be the minimum of unmet funding needs that we anticipate for the first year.

Total estimated unmet funding needs for year 1 $194,100

Species Survival Plan

The American Species Survival Plan or SSP program was developed in 1981 by the (American) Association of Zoos and Aquariums (AZA) to help ensure the survival of selected species in zoos and aquariums. SSP programs focus on animals that are in danger of extinction in the wild, when zoo conservationists believe captive breeding programs may be their only chance to survive. These programs also help maintain healthy and genetically diverse animal populations within the zoo community. AZA accredited zoos and AZA conservation partners that are involved in SSP programs engage in cooperative population management and conservation efforts that include research, public education, conservation translocation, and *in situ* or field conservation projects.

A SSP is not required for kiwikiu, based on how SSPs currently work. Because there will only be a relatively small number of birds being housed, and a small number of zoological institutions involved, the best approach is to first establish the population with an informal partnership between the small number of institutions. A SSP is not currently required and should only be considered after the species is brought into captivity. Over time if the program grows, then consideration and decision on if a formal SSP program is needed should occur.

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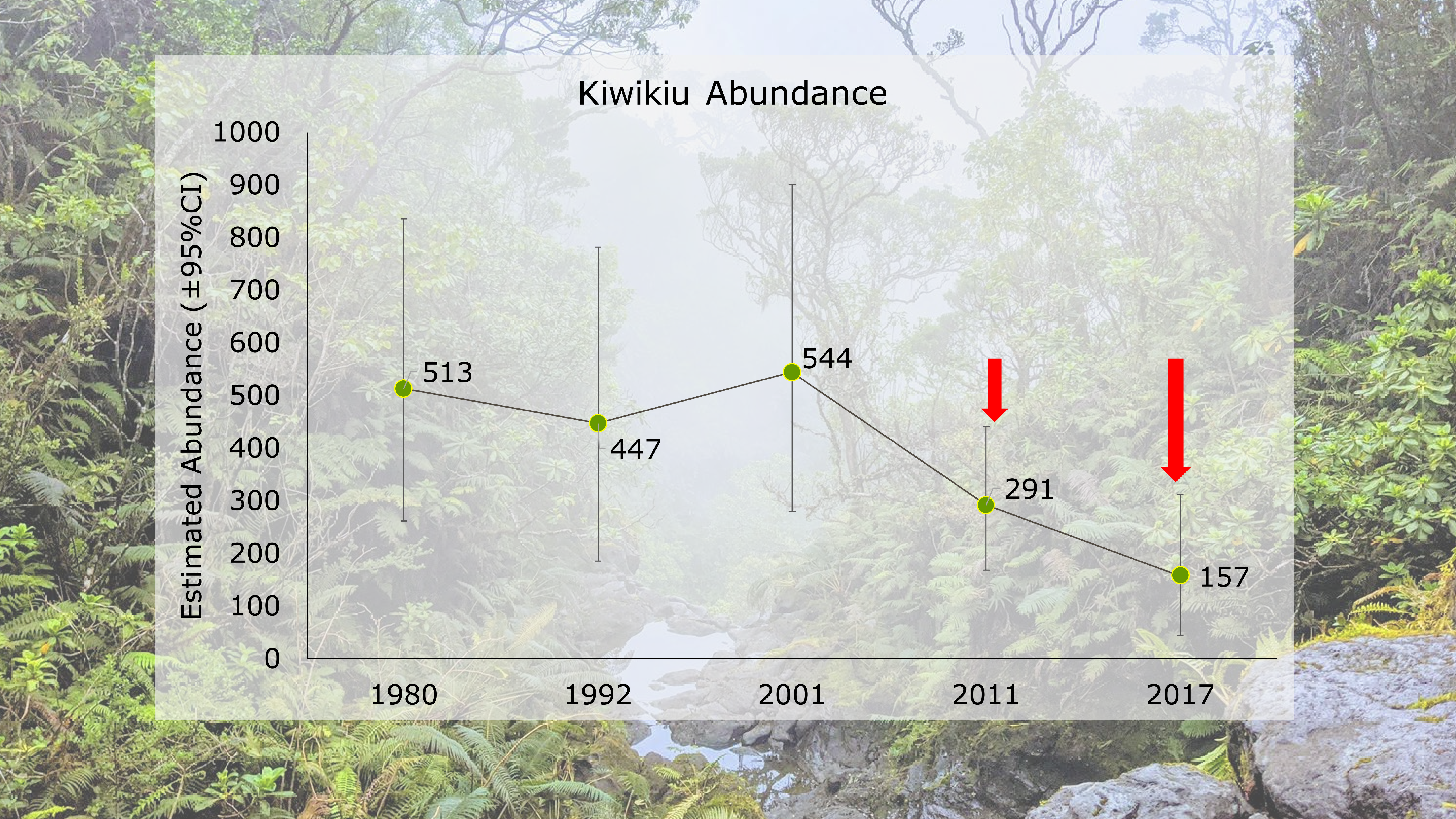
SAVING THE KIWIKIU

MEET THE KIWIKIU (MAUI PARROTBILL)

- Hawaiian Honeycreeper only found on Maui
- Insect specialist, "woodpecker niche"
- Critically endangered and declining rapidly
- Threats: habitat loss, predators, climate change, and avian disease


Kiwikiu Abundance
Estimated Abundance (±95%CI)
1000
900
800
700
600
500
400
300
200
100
0
513
447
544
291
157
1980
1992
2001
2011
2017

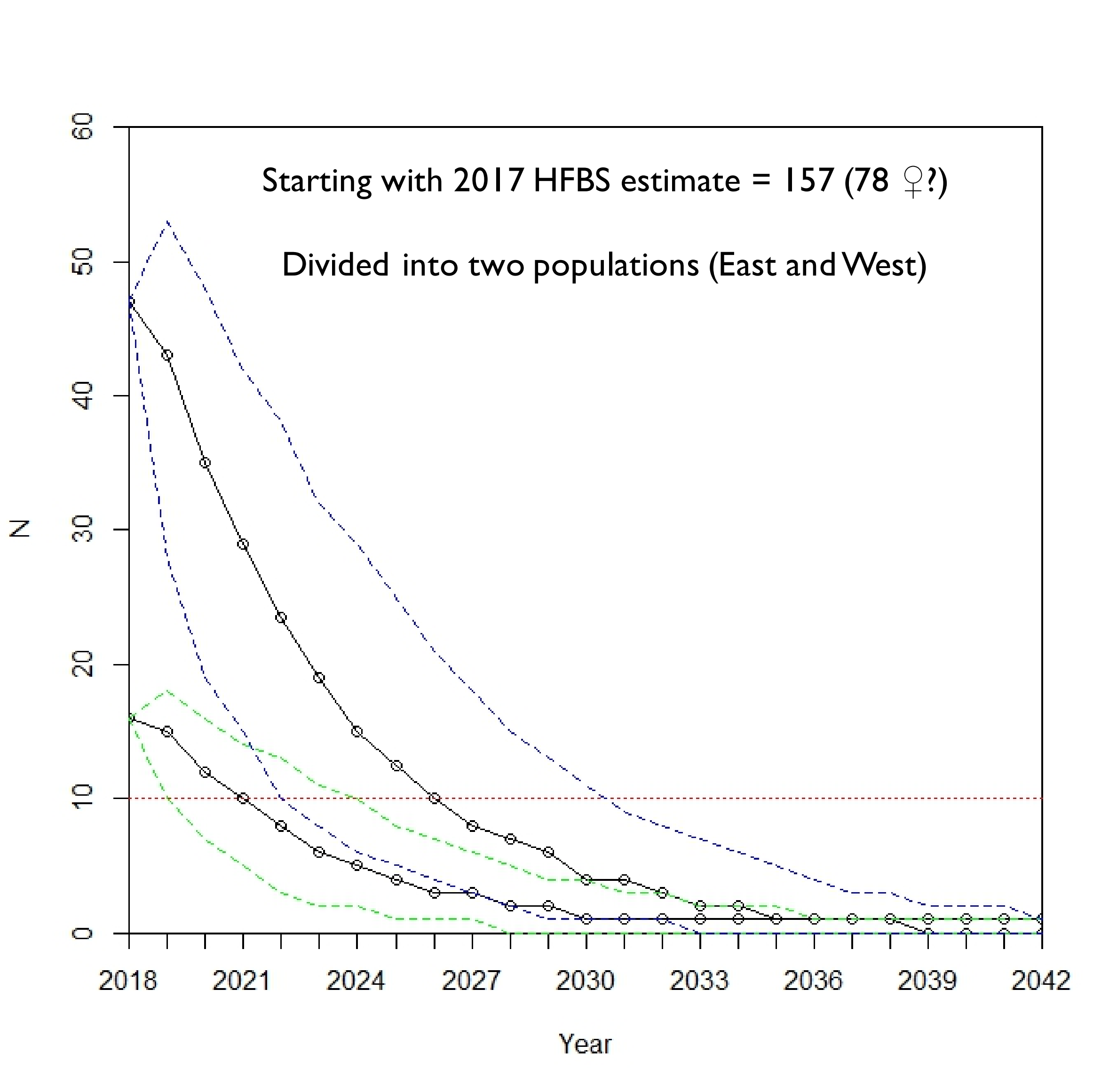
POPULATION VIABILITY ANALYSIS

Using vital rate estimates (annual survivorship, reproduction) measured in wild

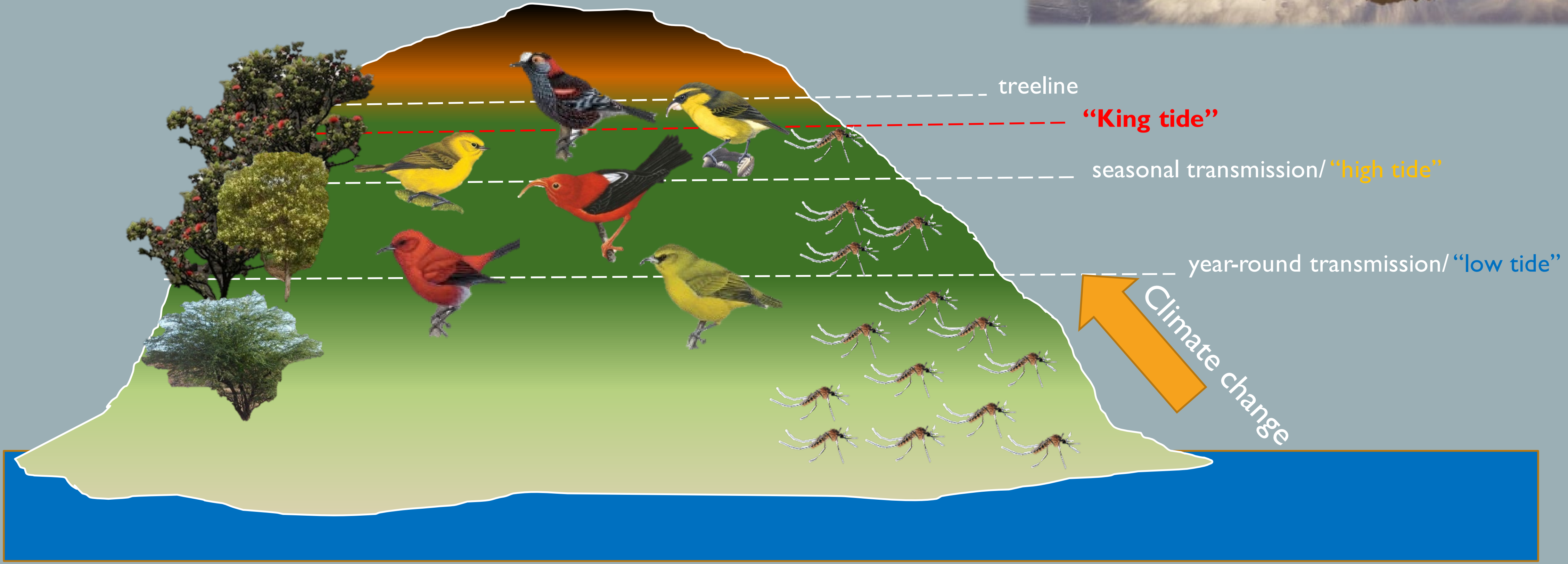
Surviving adults + births – deaths

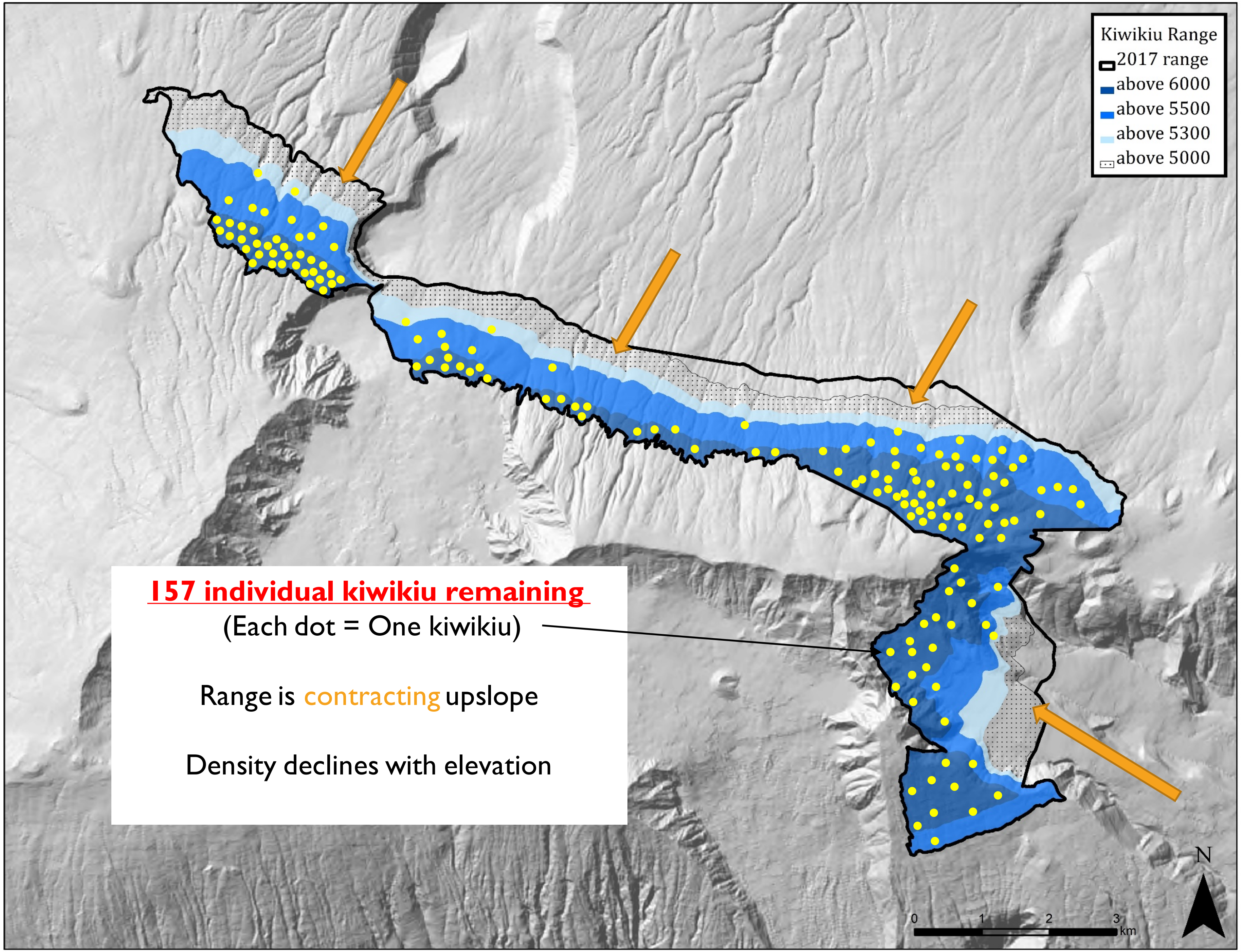
Predicting future abundance

<u>**Functional extinction (<10 pairs) by 2027**</u>



MALARIA'S RISING TIDE





<u>**157 individual kiwikiu remaining**</u>

(Each dot = One kiwikiu)

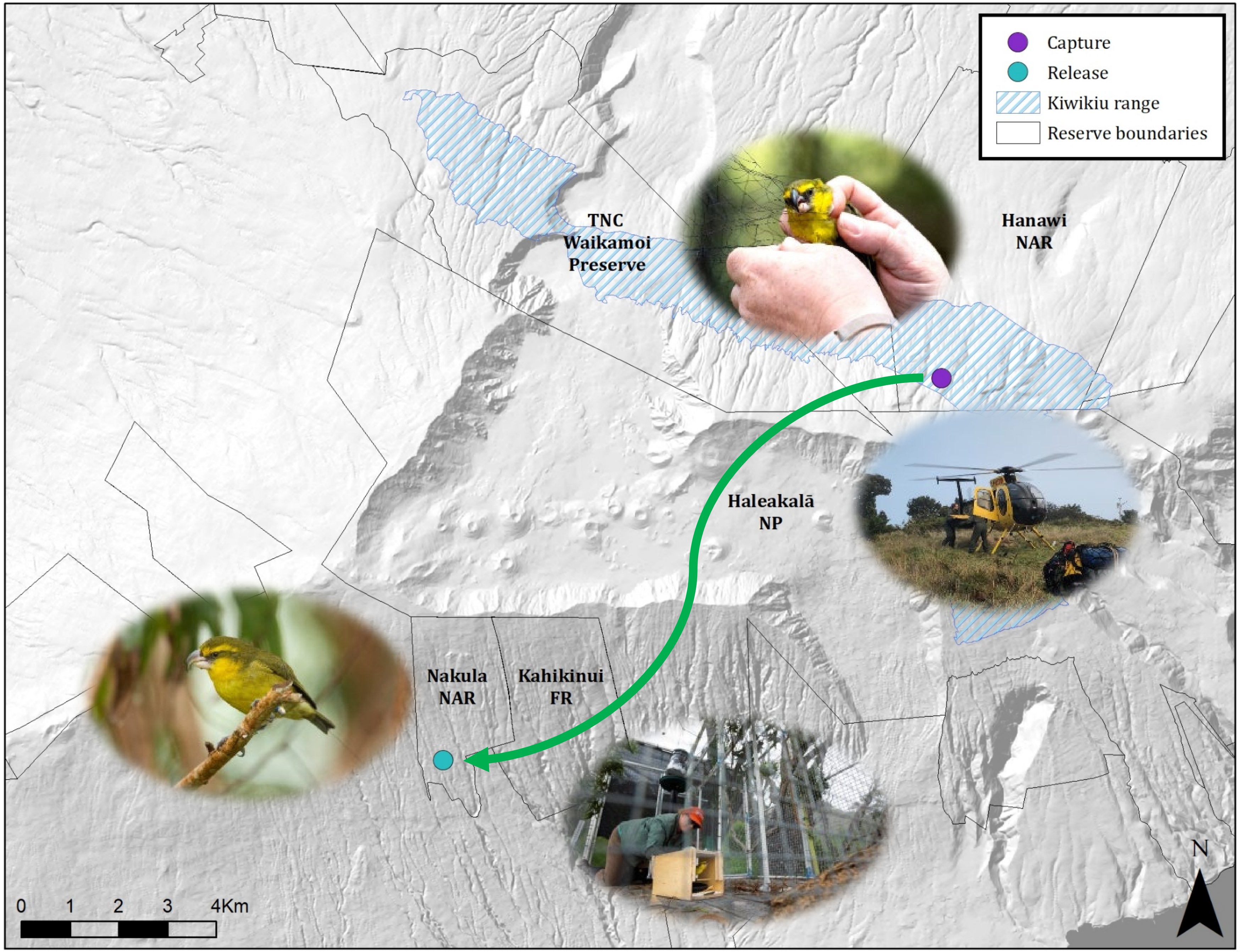
Range is contracting upslope

Density declines with elevation

<u>Recovery goal 2006-2019</u>: establish second population on leeward slope = conservation translocation

Proceeded in Oct 2019

14 birds from captivity and Hanawī NAR to Nakula NAR



WHILE PLANNING…..
THE LANDSCAPE CHANGED UNDER OUR FEET

- Translocated birds thrived in the Nakula habitat upon release, they all died very quickly from malaria
- Avian malaria appears to have increased in Nakula NAR (> 5000 ft in elevation)
- Birds in windward habitat are no longer safe and under significant threat of disease and declining rapidly
  - Mosquito density on both slopes ↑
  - Kiwikiu with malaria at high elevation

SWIFT ACTIONS TO PREVENT EXTINCTION #1

- Safe-guard species in captivity

Bring birds into captivity in the mainland to:

1. maintain and/or produce release-quality birds
2. release birds as soon as a suitable release site(s) can be identified and managed.

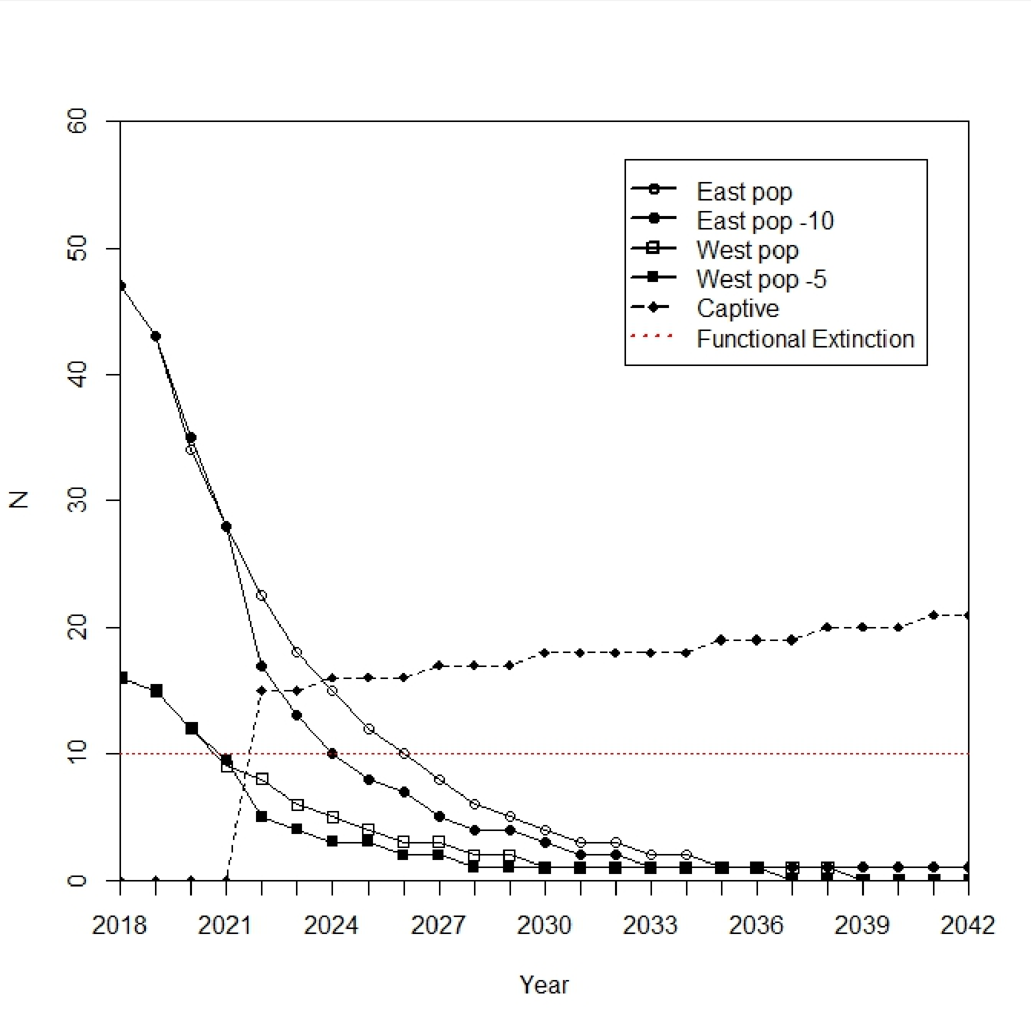
High survivorship in captivity in past.

Captive propagation has had limited success, mainland alternative facilities hold the potential for success.

MAUI FOREST BIRD WORKING GROUP IS PROPOSING BRINGING 20 BIRDS INTO CAPTIVITY ASAP

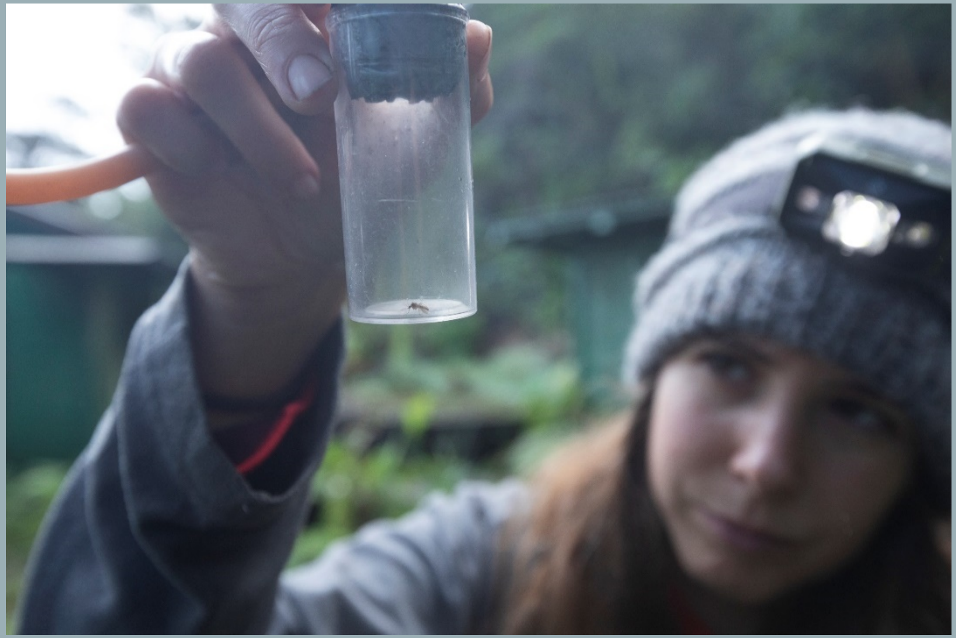
Population Viability Analysis modeled potential removals for captivity

- Little impact on trajectory
- Removals may cause functional extinction 3 years sooner
- Does not change outcome



* Model is based on removing 30 individuals, current zoo capacity is 20

SWIFT ACTIONS TO PREVENTING LOSS #2



- Landscape-scale mosquito control

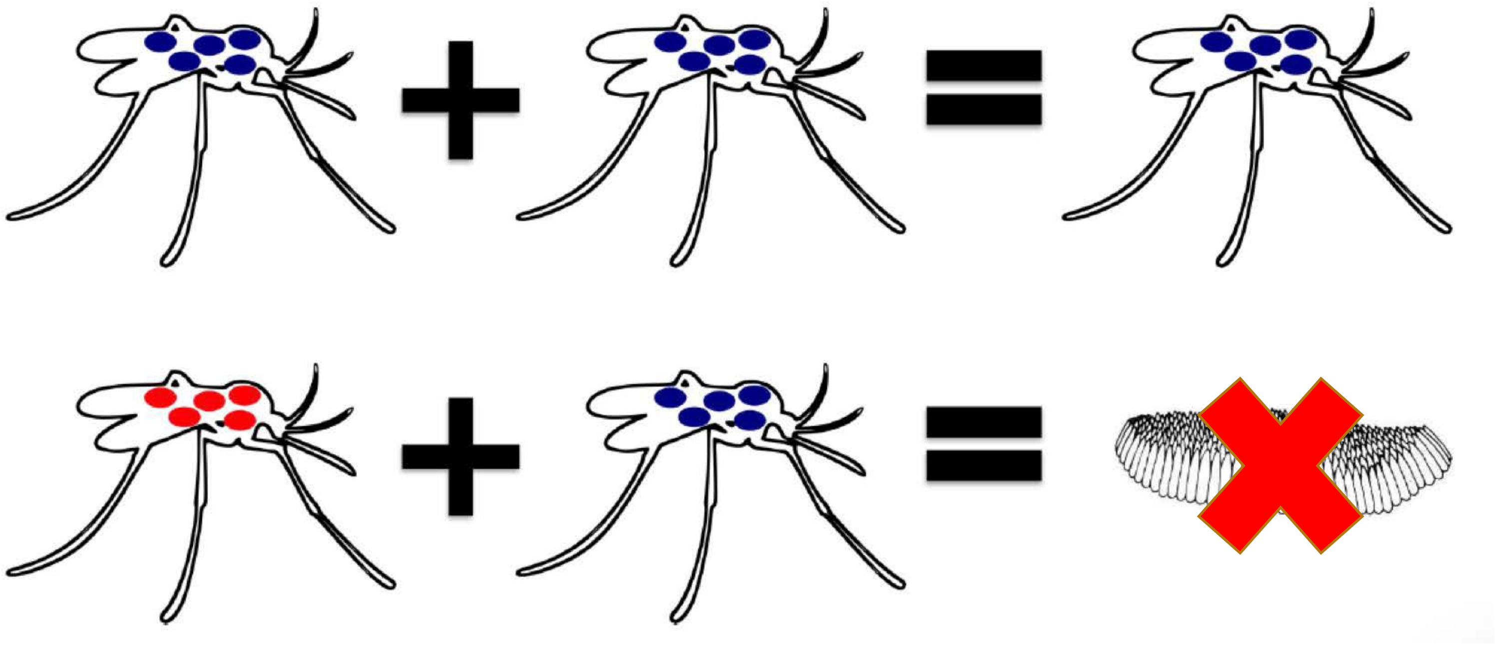
  Ensure landscape-scale vector control remains a high priority

  - Timeline to implementation (≥ 2-3 yrs to begin) is not favorable to save kiwikiu based on estimate time to extinction

WOLBACHIA

- Intracellular bacteria
- Identified in 1923 in *C. pipiens*, common house mosquito
- Found in up to 60% of all insect species
- Present in Hawai'i *Culex*
- Maternally inherited
- Maximizes its spread by manipulating reproduction of their hosts

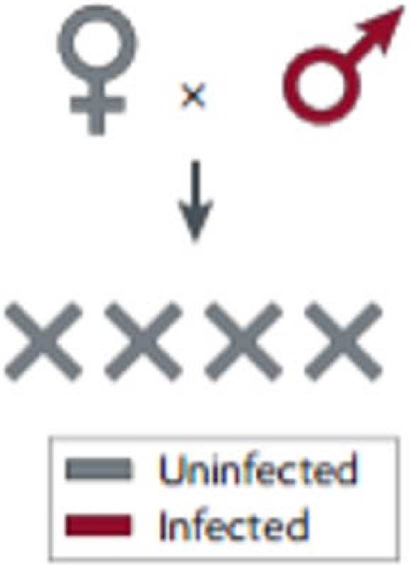
Poff et al. 2017

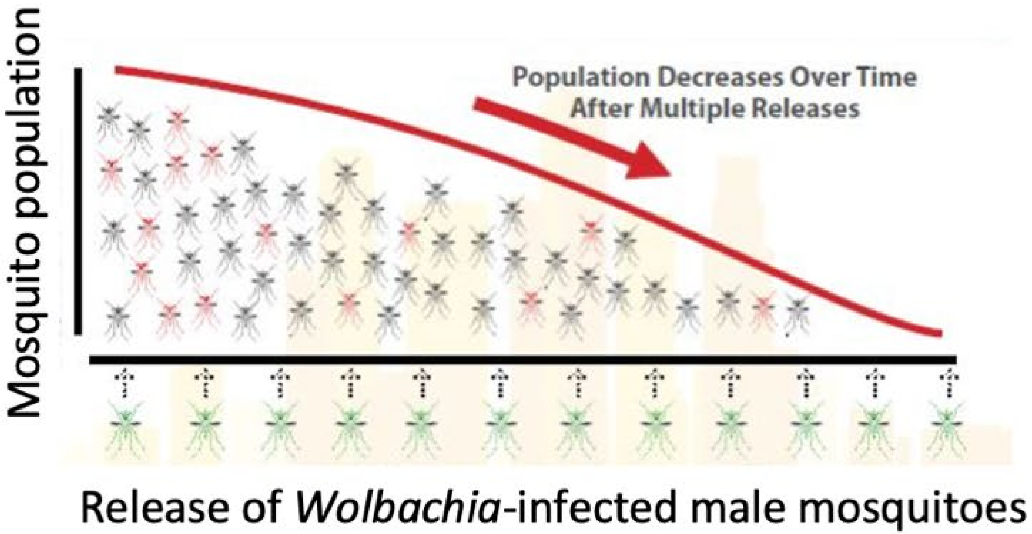


INCOMPATIBLE INSECT TECHNIQUE

.Top: two mosquitoes with the same strain of Wolbachia (blue dots) mate to produce offspring.

Bottom: By using Incompatible Insect Technique, the males have a different strain of Wolbachia (red dots). The eggs produced are inviable and will not hatch

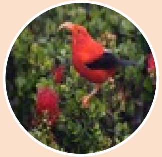

×
Uninfected
Infected


Mosquito population
Population Decreases Over Time
After Multiple Releases
Release of *Wolbachia*-infected male mosquitoes


California
New York
Kentucky
Florida
Mexico
Columbia
Brazil
India
China
Vietnam
Malaysia
Singapore
Sri Lanka
Indonesia
Vanuatu
Fiji
New Caledonia
Australia

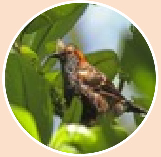
CURRENT STATUS

→ Community Engagement →



2020
Transinfection complete

2021
HDOA Import Permit
Submit EPA EUP & Emergency permits.



2022
Cage trials under EUP permit.
Pilot studies under Sec. 18

2023
Submit Sec. 3 EPA Biopesticide Registration.

Potential releases under Sec. 18.

2024
Landscape-Scale Releases

SWIFT ACTIONS TO PREVENTING LOSS #3

- Continued management in the wild

  Develop strategies and evaluate the feasibility of short- and long-term predator control tools

  - Feasibility and scale limitations, part of the suite of tools, not a solution alone

SWIFT ACTIONS TO PREVENT LOSS #4

- Reforesting high-elevations

  Continue and increase habitat management and restoration in the current and historic kiwikiu range

  - Slow process, but on-going and expanding

SWIFT ACTIONS TO PREVENT LOSS #5

- Exploring new options

  Assess potential translocation sites the island of Hawai'i for habitat suitability and impacts to or from other species.