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An attempt to recover the Po'ouli by translocation and an appraisal of recovery strategy for bird species of extreme rarity

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Abstract

The Po'ouli (*Melamprosops phaeosoma*), a Hawaiian honeycreeper endemic to Maui, has a population of only three known individuals; no breeding pair currently exists, and their home ranges are too far apart for breeding to occur. Without timely intervention this monotypic genus will likely go extinct. Conservationists have faced a dilemma: facilitate breeding amongst the known individuals, manage their ecosystem to benefit uncounted Po'ouli, or a combination of both? Po'ouli biology is poorly known – but their remote home ranges are closely monitored. A State and Federal Environmental Assessment in 1999 recommended that one Po'ouli be translocated into the home range of another in an attempt to facilitate breeding. This first manipulative recovery action was achieved in April 2002, and provided valuable new information for future captive management efforts, but upon release, radio telemetry confirmed that the translocated bird returned to its own home range after one day. We describe the recent progress that has been made to recover the Po'ouli, and critically evaluate the Po'ouli case study and the lessons learned from it that can help expedite recovery of other birds of extreme rarity.

Keywords: Po'ouli; Translocation; Honeycreeper; Endangered; Recovery

1. Introduction

Saving the Po'ouli, a critically endangered Hawaiian honeycreeper, from extinction is a task that has challenged conservationists since the species' discovery on Maui in 1973 (Casey and Jacobi, 1974). The Po'ouli was listed as endangered in 1975 (USFWS, 1975), and since then only two nests of this species have ever been found, both from one pair in 1986 (Engilis et al., 1996; Kepler et al., 1996). Other bird species of similar rarity to the Po'ouli have been successfully restored to populations of several hundred individuals (Butler and Merton, 1992; Jones et al., 1995; Rodda et al., 2001), but their recoveries benefited from the existence of at least one breeding pair. This is not the case for the Po'ouli; although considered rare since its discovery, only three individuals now remain, and their home ranges lie too far apart for mixing to occur naturally (Baker, 2001). Po'ouli biology and breeding behavior remain largely unknown, a consequence of the species' elusive behavior, historical rarity, and the inaccessibility of the remaining birds in remote forest at high elevation (Mountainspring et al., 1990; Kepler et al., 1996; Pratt et al., 1997). Together, these factors have presented a considerable challenge to those responsible for the species' recovery (Conry et al., 2000). In this paper we describe recent recovery efforts for the Po'ouli, and use this case study to illustrate a

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recovery strategy that we hope will be useful for other species of extreme rarity.

1.1. Background and recovery strategy

The Po'ouli (*Melamprosops phaeosoma*) is perhaps the rarest bird in the world, with only three known individuals (Baker, 2001). It is a stocky, small-sized (26 g) bird with short wings and tail, and a short straight bill, and is easily recognized by its striking black and white head plumage (Baker, 1998). Remarkably, the Po'ouli was unknown to the Hawaiians before its discovery (Casey and Jacobi, 1974). Morphological and genetic evidence indicates that the Po'ouli represents a unique lineage within the Hawaiian honeycreepers, and it has been assigned its own monotypic genus (Fleischer et al., 2001). Po'ouli are unusually quiet, and forage by gleaning, probing, and excavating for small invertebrate prey, primarily in the subcanopy and understory.

Historically, Po'ouli have been confined to a 1300 hectare (ha) area of wet montane forest on the northern and eastern slopes of Haleakala, east Maui (Mountainspring et al., 1990), but fossil evidence indicates they once also inhabited drier forests at lower elevation on the leeward slope of Haleakala (James and Olson, 1991). The population was estimated at approximately 140 ± 280 ($\pm 280 = 95\%$ C.I. calculated from pooled variance estimates obtained from transect count data) in 1980 (Scott et al., 1986), but this estimate of population size and density is likely to be imprecise because of the species' low density and cryptic behavior. Field surveys indicate that Po'ouli numbers and range declined from an estimated 76/km^2 in 1975 to approximately 15/km^2 in 1981, and to 8/km^2 by 1985 (Scott et al., 1986; Mountainspring et al., 1990; Fig. 1). The detection and monitoring of two consecutive nests constructed by a single pair in 1986 provide the only data on reproductive parameters; these nests produced one and two nestlings, respectively, but only one offspring fledged from the second nest (Kepler et al., 1996). Surveys in 1994–1995 found six Po'ouli at four locations, while surveys from 1997 to 2000 located only three birds (Reynolds and Snetsinger, 2001). No other Po'ouli have been located since these three remaining birds were color-banded in 1997 and 1998 (Hawai'i Department of Land and Natural Resources, unpubl. data). The last three birds, thought to consist of one male and two females, occur in the Hanawi Natural Area Reserve (NAR), in separate, non-overlapping home ranges between 1500 and 1950 m elevation (Figs. 2a and b). There are no known breeding pairs, and the last documented reproduction occurred in 1995 (Reynolds and Snetsinger, 2001).

The range of the Po'ouli coincides with high population densities of other honeycreeper species, a distribution believed to be delimited by habitat suitability and disease-bearing mosquitoes prevalent at elevations below 1500 m (Scott et al., 1986). Po'ouli are associated with low levels of disturbance to vegetation by feral pigs, whose damaging effects on the habitat are thought to have been an important cause of the decline in Po'ouli numbers (Mountainspring et al., 1990).

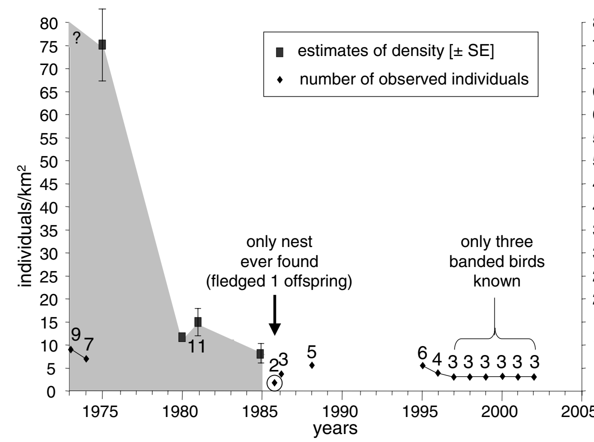

Fig. 1. Population status of the Po'ouli since 1973. Shaded area describes decline in population density (estimates derived from transect counts and given in Scott et al., 1986; no error bars available for 1980). Numbers indicate number of Po'ouli individuals that could be positively accounted for in the field. Data taken from Baker (2001), Engilis (1990), Kepler et al. (1996), Mountainspring et al. (1990), Pratt et al. (1997), Scott et al. (1986), and USFWS (1999).

With a known population of only three birds, no documented breeding of Po'ouli since 1995, and no known breeding pairs, the most urgent aspect of the recovery strategy for the Po'ouli has been to facilitate pair formation and reproduction among the three known individuals, but these immediate activities have run concurrently with larger scale habitat protection. Nine Po'ouli individuals were found at the species' initial discovery, of which two were subsequently collected as voucher specimens (Casey and Jacobi, 1974). Since then, recovery efforts and plans have followed a logical progression from less invasive strategies focusing on habitat protection, basic research, and monitoring, toward more "hands on" actions involving direct manipulation of individuals.

In 1986, the State of Hawaii DLNR established the 3035 ha Hanawi NAR to provide habitat protection for lands encompassing the known range of the remaining population of Po'ouli and other native species (DLNR, 1988). Later surveys confirmed the Po'ouli's extreme rarity, and identified a core population area within the reserve, where work began to fence and remove feral ungulates. More than 800 ha were fenced by 1996 (Fig. 2a; DLNR, 1988) and removal of all ungulates was completed by 1997 (DLNR, 1999; USFWS, 1999). Additional habitat protection was secured through acquisition and protection of adjacent forest habitat by the National Park Service, and by the formation of the East Maui Watershed Partnership (DLNR, 1996). Work and

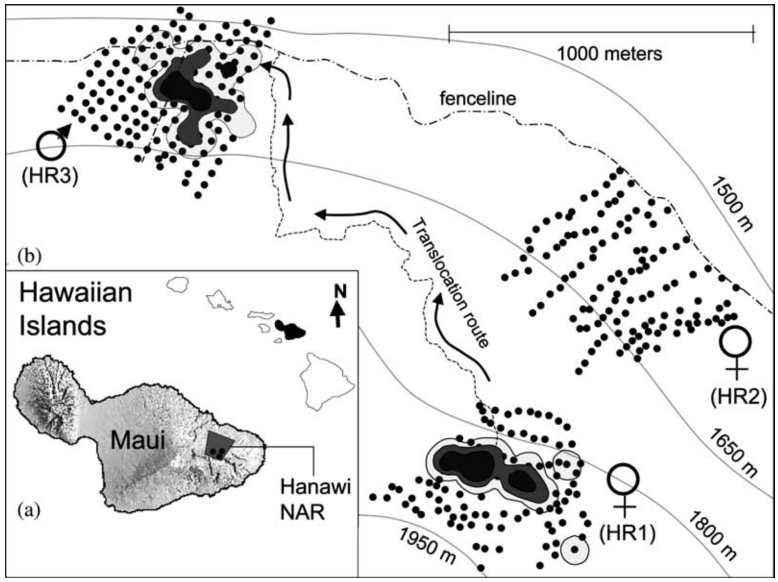

Fig. 2. (a) Location of Hanawi Natural Area Reserve, a 700 hectare fenced area of near-pristine, montane cloud forest. (b) Locations of the three Po'ouli home ranges (HR) 1, 2 and 3. Black circles show markers in a geo-referenced grid system used in monitoring of each bird. The three home ranges are separated by 1.5 and 2.5 km of steep terrain. Shaded contours describe spatial confidence limits (50%, 75% and 95%) of the space-use of the male and female based on field observations from 1999 to 2002.

funds are now currently in place to complete fencing and ungulate control for more than 7000 ha of potential habitat for Po'ouli and other native forest bird species on east Maui (DLNR unpubl. data).

Monitoring of the three remaining birds within the fenced Hanawi NAR since 1995 and their capture and banding by 1998 have confirmed that no natural mixing occurs between them (Fig. 2b; Baker, 1998, 2001). Banding records indicate that all three individuals are now at least six years old, and the duration of remaining breeding potential is unknown (Lepson and Freed, 1997; Baker and Baker, 2000; Pratt et al., 2001). Considerable search effort since 1995 has failed to detect additional Po'ouli (Baker, 2001).

In 1997, DLNR and USFWS established the Maui Forest Bird Recovery Project, a full-time field implementation team, to carry out recommended recovery strategies, begin trapping of mammalian predators within the known home ranges, control ungulates, and refine avian field techniques such as radio telemetry and translocation. In anticipation of a common need for captive propagation and reintroduction techniques for many of the avian conservation programs in Hawaii, a program began in 1994 to develop expertise in techniques for captive management of Hawaiian forest birds (Kuehler et al., 2001).

Remaining options for recovering the Po'ouli were explored in 1999 by a joint State and Federal Environmental Assessment (EA) (USFWS, 1997, 1999). The range of strategies varied in the level of manipulation of the three birds, from capture for captive propagation and reintroduction, to the more 'hands-off' approach of ecosystem-scale management. The EA recommended a translocation of one or more birds to an individual of the opposite sex in an attempt to form a wild breeding pair, in addition to continued habitat management. A translocation was considered to be the option that most effectively combined habitat management with a moderate degree of manipulation of the three individuals (DLNR, 1999; USFWS, 1999). Although successful captive propagation programs have been developed for other endangered Hawaiian forest birds, the risks of removing the birds to captivity were deemed unacceptable for the Po'ouli at that time compared to the lower risks of a translocation, and in light of the unknown but low probabilities of success for each strategy (USFWS, 1999; Kuehler et al., 2001).

Sexing of the birds proved difficult due to limited information on morphometrics and plumage dichromatism (Freed et al., 1987; Pratt, 1992; Pratt et al., 1997). However, molecular sexing techniques and limited inference from morphological data suggested that the three individuals comprised two females and one male (University Diagnostics Limited, London, UK; Griffiths et al., 1996). Consequently, translocation of a female to the single male's home range presented the least risk; in the event of a death during transit, a second female (HR2) would still exist (see Fig. 2b).

In this paper, we present the outcome of the translocation in the context of the species recovery strategy and history. We describe components of the Po'ouli recovery plan which exemplify different approaches to a species recovery, and we identify economic, and decision time-saving advantages of one formula that offer clear practical benefits when faced with a species on the verge of extinction.

2. Methods

The remote, high elevation terrain where the three Po'ouli occur on eastern Maui complicated the logistics of a translocation. Frequent clouds and unpredictable weather often preclude helicopter flights, which provide the only practical access to the area. Since timing was crucial for a successful translocation, helicopter transport was considered impractical, leaving transfer of the bird by foot as the preferred alternative.

To release the female as close as possible to the male, efforts focused first on capturing and radio-tracking the male, before transporting the female to the male's location. Radio tracking of the movements of both birds would determine the overall outcome of the translocation.

Surrogate trials using the non-endangered Maui Creeper, *Paroreomyza montana*, identified a translocation technique that would minimize stress to the Po'ouli during transit. Sixteen *P. montana* were translocated along the identical route planned for the Po'ouli using different methods of confinement during transport. All experimental trials resulted in zero mortality, and hematophil-lymphocyte white blood cell counts indicated that stress levels were reduced in those birds transported with a minimum of restriction on their movement within the confines of a hand-held container (Groombridge et al., 2003). The translocation was timed to occur during favorable weather and before the suspected breeding season (March–May, Pratt et al., 1997). Attachment of the radio transmitter (model BD-2, weight 0.73 g, pulse rate 0.57/s, frequency 164.888 MHz, Holohil Systems Ltd., Ont., Canada) to the Po'ouli followed the method of Rain (1978) and Fancy et al. (1993), but was adapted for use in wet environments. Briefly, the extent of feather trimming on the high dorsal mid-point between the wings was minimized, resulting in a mat of 5–8 mm long feather bases, which optimized the glue adhesion of a nylon-cloth contact patch to the bird before adhesion of the transmitter.

The site of the female's release was determined by two location data sets for the male; (i) the geometric mean of 19 re-sights since January 2002; (ii) five re-sights between 1600 h and nightfall during the previous 10 days.

To analyze real-time movement patterns of the Po'ouli, five tree-top radio-tracking platforms were positioned throughout the male's home range and the translocation route, and geo-referenced by GPS (Pathfinder Pro XR, Trimble Navigation Ltd., Sunnvale, CA) to enable telemetry data to be analyzed using LOAS computer software (*Location Of A Signal*; Ecological Software Solutions Ltd., NH), a program that interacts on a GIS ArcView^{TM} platform (Environmental Systems Research Institute, Inc., CA.). Signal location was estimated every 15 min, using TR-2, TR-4 and AR8200 hand-held receivers, paired with RA-14, RA-2A *H*-shaped, and 3–5-element antennas (Telonics Inc., Arizona, and AOR Ltd., UK). Spatial confidence limits of the bird's location were generated using ArcView (Animal Movement Analysis Extension, Hooge and Eichenlaub, 1997).

The necessary contingencies for holding a Po'ouli in field captivity and the associated veterinary requirements were complex. A holding-cage was designed to allow for brief observation of a captive Po'ouli, immediately after its translocation and prior to its release. A $30 \times 30 \times 60$ cm holding-cage constructed from a lightweight rigid frame and stretched white-cloth internal walls was designed to house two birds separately side-by-side (Fig. 3). If a single Po'ouli needed to be held in field captivity for several days (i.e., as a result of injury), then the holding-cage could separately house a 'tutor' individual of an ecologically-compatible species (i.e., Maui Parrotbill *Pseudonestor xanthophrys*) to encourage acclimation and feeding behavior of the compromised bird. Sliding panels partitioning the two compartments afforded a level of control over the extent to which each bird could view its neighbor. A video camera, mounted externally with a field of vision directed into the holding cage, provided continual remote monitoring of the birds' behavior via a TV video monitor 20 m away. Fig. 3 shows the equipment layout and video monitoring capability that was set up in situ for the translocation. Inside the cage, endemic Succineid snails were provided

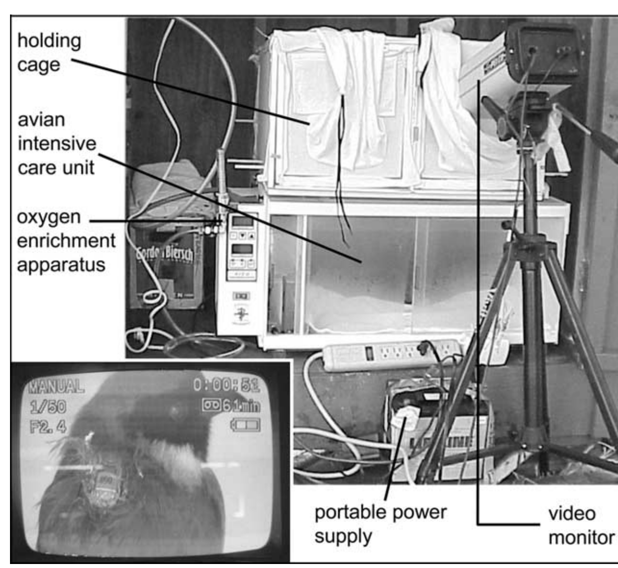

Fig. 3. Equipment set-up for veterinary care and field monitoring of Po'ouli held whilst under captive field conditions. Inset: view through remote TV monitoring system of HR1 Po'ouli individual with radio transmitter attached. Photographs by Maui Forest Bird Recovery Project.

for food, as well as sources routinely used for captive propagation of other insectivores (Baldwin and Casey, 1983; Finke, 2002).

Veterinary facilities were set up in situ to deal with possible injuries to a Po'ouli (see Fig. 3). Requirements focused on delivering a veterinary capacity that could handle critical medical requirements for a period of up to three consecutive days, a time frame considered to be a likely delay to any helicopter evacuation of an injured Po'ouli due to bad weather. Veterinary equipment consisted of an avian intensive care unit with a controlled environmental temperature and oxygen enriching capacity, general anesthesia and surgical capabilities, equipment and supplies to treat traumatic injuries, antimicrobial drugs, and diagnostic equipment required to perform complete blood counts, cytology, and harvest plasma for chemical analysis. In the event of a death of a Po'ouli, various tissues would be collected for cell culture and immediately sent to both the Zoological Society of San Diego, Center for the Reproduction of Endangered Species and the Audubon Nature Institute Center for Research of Endangered Species. Further details are available at www.mauiforestbird.org.

3. Results

The male Po'ouli avoided capture despite 157 h of mist-netting (21 days; 20 nets/day) from January 1 to February 14, 2002, but was re-sighted 18 times during that period. The female was caught on April 4 after 71 netting h (8 days; 26 nets/day). Translocation took 1 h 15 min. On arrival in the male's home range, the bird was examined for external signs of physical stress (i.e., open-mouthed breathing and rapid respiratory rate, closed eyelids, fluffed appearance) but none were found. After attachment of a radio transmitter, the bird was held in a field aviary for 2 h to observe behavior and to ensure transmitter attachment. Film footage of the bird in captivity revealed encouraging signs of acclimation to captivity and consumption of two live *Succineid* snails and 15–20 waxworms. Preening behavior focused primarily on the birds' dorsal area near the radio transmitter. Interspersed with these activities, the Po'ouli showed interest in the camera observation window, which was the brightest natural light source.

Re-sights of the male at dusk during the few days prior to the translocation suggested a probable roost-site in the southern portion of the grid-system (Figs. 4a and b). Following the female's release there at dusk (Fig. 4a), tracking of her radio signal from before dawn the following day indicated that she roosted overnight in the male's home range, but by 09:00 h triangulation of radio signals and field observations indicated that she was alone and moving back along the translocation route to her own home range, which she reached by 17:00 h that day. A further 9 days of monitoring her movement patterns revealed no novel behavior to suggest a pair-bond had been established with the male. After 9 days, the radio transmitter became detached. Nine of 21 observations of the female Po'ouli during this time confirmed its continued interaction with Maui Parrotbills in the area, with which it has a history of associative foraging behavior (Pratt et al., 1997).

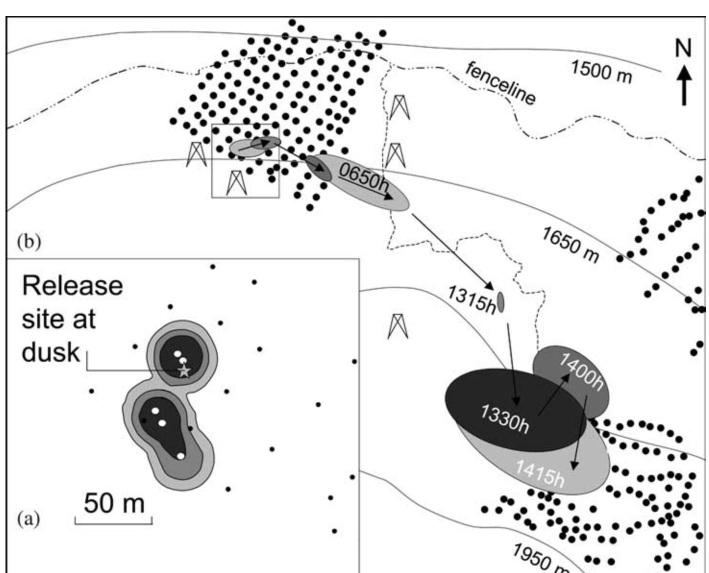

Fig. 4. (a) Site of the female's release in HR3 (star symbol); previous 10 days re-sights at dusk (hollow circles). Shaded contours describe 50%, 75% and 95% spatial confidence estimates of the male's roosting location. (b) Radio-tracking platforms (tower symbols); 75% confidence estimates (shaded elipses) describe the female's return to her home range.

4. Discussion

This translocation marks the first manipulative recovery action for the Po'ouli since the species discovery in 1973. The rapid return of the translocated female to her own home range was not, in fact, unexpected. Success rates for translocation attempts using other endangered passerines to form wild pair-bonds have been low (Butler and Merton, 1992), and the probability of a pair-bond being formed between wild Po'ouli as a consequence of the translocation was acknowledged from the outset to be small (USFWS, 1999). Additionally, Maui Creeper translocations along the same route as the Po'ouli also showed a high (72%) return rate (Groombridge et al., 2003). The female Po'ouli's rapid return suggests strong site fidelity similar to that known for palila (*Loxioides bailleui*) and Maui Creepers (Fancy et al., 1993; Baker and Baker, 2000). Whether the translocated Po'ouli was already familiar with the existence of the other individual is not clear. None of the three Po'ouli have ever been observed together (Baker, 2001), and each has demonstrated through foraging interactions a strong social bond with sympatric Maui Parrotbills (Pratt et al., 1997), bonds which may have encouraged the bird's return.

The translocation effort has demonstrated that Po'ouli are not overly stressed by captivity, and will accept novel food items in a captive setting. The successful execution of the translocation prescribed by the 1999 EA has also accelerated progress towards further initiatives for recovering the Po'ouli (VanderWerf et al., 2003), a rate of progress which – had it been in place earlier – may have been able to prevent the recent disappearance of other bird species in Hawaii.

4.1. Prevalence of US bird species of extreme rarity

Decision-makers have been faced with Po'ouli-type situations before (Table 1), and it is likely that similar circumstances will arise again with other species. Records since 1979 show that 12 (13%) out of 91 bird taxa currently listed under the Endangered Species Act fit our definition of extreme rarity ($\leqslant 7$ individuals and no captive population; we include the dusky seaside sparrow [*Ammodramus maritimus nigrescens*], despite declaration of it's extinction and delisting in 1990; Table 1). The Hawaiian Islands contain eight of these bird taxa of extreme rarity, and ongoing surveys of remote areas offer continued potential for new 'rediscoveries'. For example, the Hawaii Rare Bird Search surveys from 1994 to 1996 visually confirmed the existence of one of those seven species (Maui Nuku pu'u [*Hemignathus lucidus affinis*]), and reported auditory (i.e., unconfirmed) detections of three more: Maui 'Akepa [*Loxops coccineus ochraceus*], Kaua'i Nuku pu'u [*Hemignathus lucidus hanapepe*], and 'O'u [*Psittirostra psittacea* (Reynolds and Snetsinger, 2001)]. Some authorities have suggested that several of these may be extinct, but their presumptions have been based on arbitrary search effort (Reynolds and Snetsinger, 2001). Beyond the US, bird species previously thought extinct are being 'rediscovered' with notable frequency. For example, a male golden-crowned manakin (*Pipra vilasboasi*) was recently seen in Brazil in 2002 for the first time in 45 years (http://news.bbc.co.uk/1/hi/sci/tech/2014863.stm) and the critically endangered indigo-winged parrot (*Hapalopsittaca fuertesi*) was seen in Colombia in 2002 for the first time in 91 years (http://news.bbc.co.uk/2/hi/science/nature/2205540.stm).

Table 1
Historical summary of US bird species of extreme rarity known since 1979[a]

		Species	Number of birds	Last seen	Reference
US mainland		Dusky seaside sparrow	1–2 birds	1980	Kale (1983)
		Bachman's warbler	1 female	1981	Hamel (1986)
		”	1 bird	1988	Jackson (1991)
		Ivory-billed woodpecker	1 male, 6 females	1986	Short and Horne (1986)
Pacific Is.	Guam	Guam broadbill	1 bird	1984	Beck (1984)
	Hawaiian Is.	Oloma'o	3 birds	1980	Scott et al. (1986)
		Kama'o	2 birds	1985	Pyle (1985b)
		Maui Nuku pu'u	2 birds	1989	See Reynolds and Snetsinger (2001)
		”	1 male	1995	Engilis (1990); Reynolds and Snetsinger (2001)
		Kauai Nuku pu'u	>2 birds	1985	Pyle (1985a,b)
		”	1 bird	1987	Reynolds and Snetsinger (2001)
		O'o'a'a	1 pair	1981	Pyle (1985a)
		”	1 bird	1985	Scott et al. (1986); see also Pyle (1985a)
		O'ahu 'Alauahio	2	1985	Engilis et al. in Bremer (1986)
		Maui 'Akepa	2 birds	1988	Engilis (1990)
		O'u	1 bird	1987	Pyle (1989)
		”	2 birds	1989	Pyle (1989)

[a] Extreme rarity defined for the purposes of this paper as $\leqslant 7$ wild individuals, and no captive population.

4.2. Ecosystem-scale vs. species-level strategies

When a species becomes extremely rare or individuals of an extremely rare species are discovered, the choices available continue to polarize resource managers (see Hutto et al., 1987; Noss, 1991). Different strategies can be applied along a continuum from ecosystem-scale to species-level restoration. For example, the California Condor (*Gymngyps californianus*), although fortunately not within our definition of extreme rarity, has received extensive investment in captive propagation strategy, and consequently sits at the intensive species-level end of the spectrum (Snyder and Snyder, 2000). In a similar fashion, the Chatham Island Black Robin (*Petroica traversi*) has received intense manipulation, and likewise the Mauritius kestrel (*Falco punctatus*), both of which have been successfully recovered (Butler and Merton, 1992; Jones et al., 1995). In contrast, some managers for other extremely rare bird species have chosen a hands-off strategy, such as that for the Rodrigues Fody (*Foudia flavicans*). This forest bird is endemic to the island of Rodrigues in the Indian Ocean, and was reduced to just 5–6 pairs in 1968. However, following two decades of extensive reforestation, the population had grown to at least 900 individuals by 1999, representing a 100-fold increase in population size (Impey et al., 2002). The Rodrigues Fody stands as a rare example of a rapid bird population recovery as a direct consequence of ecosystem restoration in the absence of any manipulation of the founder individuals.

Within the US, national policy advocates an ecosystem approach (USFWS, 1994), but this policy has still drawn some criticism for its' disproportionate funding of a handful of species (Dawson and Shogren, 2001; Restani and Marzluff, 2001). At a regional level, field managers face a choice that is equally subject to criticism; a 'hands-off' ecosystem approach is widely considered to be the preferred long-term recovery strategy (Franklin, 1993; Wilcove et al., 1998), but is sometimes implemented at the expense of species-level manipulation due to funding constraints. In Hawaii, an application of ecosystem restoration alone at the expense of species-level actions may be too late for already critically rare species such as the Po'ouli (Banko et al., 2001). Here, the option of not manipulating any of the three remaining birds and focusing resources solely on restoring the montane forest ecosystem favored by the Po'ouli has received constant evaluation, alongside other alternatives requiring manipulation, since recovery efforts began (USFWS, 1997, 1999; DLNR, 1999; VanderWerf et al., 2003). However, the option of no manipulation has been consistently ruled out at each stage because options involving manipulation have repeatedly shown a better chance of a successful species recovery. Although the agencies involved are realistic about the small chances of a successful recovery of the Po'ouli, all partners have recognized the importance of the need to try (DLNR, 1999).

In practice, recovery strategies in the US are most often determined on a case-by-case basis, and the main tool for implementing them is the endangered species recovery plan. Extensive reviews of the content, expense, and effectiveness of recovery plans have highlighted specific components that most effectively enhance their performance; namely (i) an explicit use of the target species' biology, and (ii) consultation and involvement of diverse agencies (Foin et al., 1998; Boersma et al., 2001; Elphick et al., 2001; Gerber and Schultz, 2001; Restani and Marzluff, 2001). In many cases, theoretical recommendations are not practicable, as the debate over ecosystem-scale versus species-level management confirms. However, the step-by-step recovery plan for the Po'ouli has drawn clear benefits from both of these components. Large-scale fencing and removal of ungulates within the Hanawi NAR has achieved noticeable and long-term improvement of primary Po'ouli habitat, whilst a well-resourced field team has implemented, in logical order, a succession of recovery actions for the few individual birds that are known.

This formula has, however, required careful coordination among four governmental agencies and numerous private organizations and landowners. Multi-agency and private sector partnerships on Maui have integrated extensive habitat protection and management, basic research and monitoring, and development of methods for translocations and captive propagation and reintroduction. The decision processes have been carried out by a diverse working group, in consultation with a Hawaiian Forest Bird Recovery Team (USFWS, 1999) of broader remit. The decision to attempt a translocation of one of the three single adult Po'ouli to another of the opposite sex was taken following in-depth consideration of several different options, including (i) to not carry out any manipulation, and rely only on the continuing ecosystem restoration work to recover the Po'ouli population from uncounted individuals, (ii) to remove the birds from the wild and place them in captivity, and (iii) to place the birds in a field aviary, with an additional possibility (iv) of positioning this aviary at a new, more accessible location. The recent translocation reported here, and the new information that has been gained as a result of this attempt, has precipitated the next decision within the progressive recovery formula for the Po'ouli, to bring all three remaining birds into captivity. A detailed description of the factors that ultimately were judged to favour removal of the birds to captivity is given by VanderWerf et al. (2003). Additionally, the USFWS and DOFAW have produced a five-year implementation plan for the Po'ouli and other endangered Hawaiian forest birds to ensure that this current rate of progress continues for the Po'ouli and other Hawaiian bird species of extreme rarity (available at *http://www.dofaw.net/fbrp/index.php*).

4.3. Economic perspective of Po'ouli recovery efforts

From an economic perspective, our approach has placed major emphasis on habitat-based and multi-species strategies. To date, more than $8 million (M) has been spent on recovery efforts with expected benefits to the endangered bird species of East Maui (USFWS, 1999; DLNR, 1999–2002, DLNR unpublished data). This work has focused on habitat protection and management, control of alien plants, ungulates, and predators, surveys and monitoring, life history research, and the present translocation effort. The objectives have been strongly ecosystem based, benefiting more than 7000 ha (DLNR unpublished data) of one of the State of Hawaii's most diverse and pristine native ecosystems, including nine native vegetation communities, five endangered forest bird species, and numerous invertebrate and endangered plant species. In addition to these funds, more than $8 M has been spent on the development and maintenance of the captive propagation and reintroduction program, which provides recovery benefits for endangered bird species statewide (Fancy et al., 2000), including those of East Maui. Approximately $1.3 M has been spent for ongoing efforts to develop and approve aerial broadcast methods for toxicants to control rodents. Further, these figures do not include in-kind contributions from individuals and agencies that likely exceed $2 M, as well as costs incurred by the National Park Service for habitat management within the Kipahulu portion of the National Park, which borders the Hanawi NAR.

Single-species expenditures for the recovery of Po'ouli have been small in comparison to habitat-driven ventures, although an exact estimate is difficult to derive since this work has been carried out within the budgetary contexts of the larger objectives. The majority of the Po'ouli single-species expenditures have been on recovery planning, and the development and implementation of the present translocation work. We estimate the costs of these aspects of the work to be less than $500,000, or 3% of the above total expenditures. This integrated solution has improved the cost-effectiveness of overall recovery effort for Po'ouli; the valuable knowledge of the Po'ouli's behavior in captivity following the recent translocation comes at minor cost relative to the higher funding demand of large-scale fencing programs that form the major tool for ecosystem restoration in Hawaii (see Steiner, 2001). Recovery efforts that integrate progressive ecosystem management with manipulative recovery attempts at the species-level can make progress towards saving extremely rare species. Furthermore, the case study of the Po'ouli emphasizes the importance of diverse consultation, and the important role of versatile, 'high-performance', field implementation teams in these situations (Clark and Westrum, 1989; Clark et al., 1994). Similar strategies would likely be effective on the islands of Hawaii and Kaua'i where several endangered forest bird species persist in numbers sufficient to make their recoveries probable.

5. Critical evaluation

Despite the extensive and costly work to recover Maui's endangered forest birds, at least three of the five species known from the mid-1970s have apparently continued to decline (i.e., Nuku pu'u, Maui 'Akepa, and Po'ouli). Although additional work is needed to continue the ecosystem-based strategies to ensure sufficient suitable habitat, it is likely that the continued declines have resulted from time lags inherent in such work. In the case of Po'ouli and perhaps Nuku pu'u and Maui 'Akepa, more timely and aggressive single-species approaches may have succeeded in staving off these inherent time lags. Strong leadership and decision-making have been key components of the recoveries of the Mauritius kestrel and the Chatham Islands Black Robin, each successfully restored from a single pair (Butler and Merton, 1992; Jones et al., 1995), and this type of leadership, involving high-risk actions, will continue to be important when dealing with today's species of extreme rarity, where increasingly bolder strategies may be needed. In today's economic climate of finite conservation resources, intensive activities involving single species' of extreme rarity, like those we describe here for the Po'ouli, are increasingly difficult to justify, yet ecosystem-based strategies alone may not be sufficient for some rare species, as the cases of Po'ouli, Nuku pu'u, and Maui 'Akepa have shown. In these cases, hands-on intervention is critical. When faced with bird species of extreme rarity, policy-makers should not be too eager to short-change species-level intervention in favor of the ecosystem alone. Future recovery efforts will continue to involve difficult choices, especially when the need for action is driven by the longevity of the few individuals that remain.

The discovery of the Po'ouli, a species new to science in 1973, precipitated an immediate quest for collection of voucher specimens, and two were shot that same year at a time when only nine individuals had been seen (Casey and Jacobi, 1974). This fact may seem surprising in today's conservation climate, but such action was considered entirely justified at that time, and is perhaps testimony to the change in attitude amongst conservationists since then. Fortunately, there are alternative tools for the validation of newly discovered species today, such as video documentation and non-invasive genetic sampling for DNA, to negate such drastic action following future rediscoveries.

One point worthy of consideration is that despite the high return rate identified during extensive in situ translocation trials using Maui Creepers (Groombridge et al., 2003), the translocation of a wild adult Po'ouli was still carried out. The surrogate work had the duel purpose of monitoring the overall feasibility of translocating adult honeycreepers in Hanawi NAR, as well as refining transmitter attachment and radio telemetry techniques for that environment. Although evidence from surrogate trials suggested that the Po'ouli's return was likely, other information suggested a different outcome. First, the bonding effect, should both birds have met, was believed to be strong, and second, the absence of neighboring Po'ouli elsewhere and the observed frequency of mixed species feeding flocks suggested only minimal territorial displacement at the release site. In the case of the Po'ouli, these additional factors were thought to outweigh the high return rate seen in the surrogate trials, and supported an attempted translocation. In general, however, the role of surrogate work should be clearly defined, to ascertain if and how their results will determine the recovery action at a particular decision node.

One factor that cannot be ignored, and has likely contributed to the continued decline of east Maui's endangered forest birds, has been the slow pace of the decision-making process that is all too often typical of multi-agency efforts such as this one. This criticism is exemplified by the case of the Po'ouli, in which three years (1999–2002) were required to arrive at the decision to attempt a translocation, which as our results show, has required yet another decision node (USFWS, 1997, 1999; VanderWerf et al., 2003). Careful attention to planning is paramount for successful and progressive conservation of all endangered bird species. However, it is critical to translate these plans into recovery actions without delay, particularly for bird species of extreme rarity. For the surviving birds with limited productive years remaining, these delays could make the difference between extinction and recovery.

5.1. Guidelines for managing bird species of extreme rarity

1. Ecosystem restoration alone is unlikely to be sufficient. Concurrent hands-on management of remaining known individuals is critical to maximize the probability of a successful recovery.
2. Consultation between government agencies and a diversity of stake-holders, such as land owners, field recovery biologists, captive breeders, and veterinary experts, must culminate in the formation of an active, goal-orientated Recovery Team.
3. The Recovery Team must design a decision-making framework that sets a logical sequence of achievable field goals and decision nodes leading to the species' recovery, and identifies explicit time limits (e.g., breeding seasons) for the progression to each node. Ideally, this framework must remain progressive despite any incomplete information on the species' biology.
4. The Recovery Team must establish a versatile, high-performance field team to direct and carry out field recovery operations. This link between consultation and implementation ensures decisions are translated into recovery action as rapidly as possible.
5. Recovery and field teams should consider work on surrogate (non-endangered) species to optimize critical protocols for the target species. However, the anticipated benefits (i.e., additional specialized knowledge) must outweigh the costs to the species' chance of recovery (i.e., extra time, delay in recovery action), in relation to the risk of proceeding without it. Decision-makers must clearly define how surrogate results will determine a choice of recovery action.
6. Recoveries of bird species of extreme rarity will always require a level of risk, regardless of which actions are chosen. This risk can be minimized by decisive, timely intervention.

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References

Baker, P.E., Baker, H., 2000. Maui 'Alauahio (*Paroreomyza Montana*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, vol. 504. The Birds of North America Inc., Philadelphia, PA.

Baker, P.E., 1998. A description of the first live Po'ouli captured. Wilson Bulletin 110, 307–310.

Baker, P.E., 2001. Status and distribution of the Po'ouli in the Hanawi Natural Area Reserve between December 1995 and June 1997. Studies in Avian Biology 22, 144–150.

Baldwin, P.H., Casey, T.L.C., 1983. A preliminary list of foods of the Po'ouli. 'Elepaio 43, 53–56.

Banko, P.C., David, R.E., Jacobi, J.D., Banko, W.E., 2001. Conservation status and recovery strategies for endemic Hawaiian birds. Studies in Avian Biology 22, 359–376.

Beck Jr., R.E., 1984. Survey and inventory of native land birds on Guam. In: Guam Division of Aquatic and Wildlife Resources Annual Report. FY 1984. Department of Agriculture, Guam, pp. 139–150.

Boersma, P.D., Kareiva, P., Fagan, W.F., Clark, J.A., Hoekstra, J.M., 2001. How good are endangered species recovery plans? BioScience 51, 643–649.

Bremer, D., 1986. Waipio, O'ahu, Christmas bird count. 'Elepaio 46, 132–135.

Butler, D., Merton, D., 1992. The Black Robin – Saving the World's Most Endangered Bird. Oxford University Press, Auckland.

Casey, T.L.C., Jacobi, J.J.D., 1974. A new genus and species of bird from the island of Maui, Hawaii (Passeriformes: Drepanididae). Occasional Papers of the B.P. Bishop Museum 24, 215–226.

Clark, T.W., Westrum, R., 1989. High performance teams in wildlife conservation: a species reintroduction and recovery example. Environmental Management 13, 663–670.

Clark, T.W., Reading, R.P., Clarke, A.L., 1994. Synthesis. In: Clark, T.W., Reading, R.P, Clarke, A.L. (Eds.), Endangered Species Recovery: Finding the Lessons, Improving the Process. Island Press, Washington, DC, pp. 417–431.

Conry, P., Schuyler, P., Collins, M., 2000. In: Reading, R.P., Miller, B. (Eds.), Endangered Animals: A Reference Guide to Conflicting Issues. Greenwood Press, Westport, CT, pp. 235–240.

Dawson, D., Shogren, J.F., 2001. An update on priorities and expenditures under the Endangered Species Act. Land Economics 77, 527–532.

Department of Land and Natural Resources., 1988. Hanaw'I Natural Area Reserve Management Plan. Honolulu, State of Hawaii.

Department of Land and Natural Resources., 1996. Final environmental assessment for a fence project to protect the east Maui watershed. Honolulu, State of Hawaii, p. 24.

Department of Land and Natural Resources., 1999. Department of Land and Natural Resources announces its recommendations to prevent the extinction of the Po'ouli. 'Elepaio 59, 3–5.

Department of Land and Natural Resources., 1999–2002. Division of Forestry and Wildlife, ESA Section 6 reports (unpublished reports).

Elphick, C.S., Reed, J.M., Bonta, J.M., 2001. Correlates of population recovery goals in endangered birds. Conservation Biology 15, 1285–1291.

Engilis Jr., A., 1990. Field notes on native forest birds in the Hanawi Natural Area Reserve, Maui. 'Elepaio 50, 67–72.

Engilis Jr., A., Pratt, T.K., Kepler, C.B., Ecton, A.M., Fluetsch, M., 1996. Description of adults, eggshells, nestling, fledgling, and the nest of the Po'ouli. Wilson Bulletin 108, 607–619.

Fancy, S.G., Sugihara, R.T., Jeffrey, J.J., Jacobi, J., 1993. Site tenacity of the endangered Palila. Wilson Bulletin 105, 587–596.

Fancy, S., Woodworth, B., Telfer, T., 2000. Restoration techniques for Hawaiian thrushes: artificial incubation, hand-rearing, captive-breeding and reintroduction to the wild. Zoo Biology 19, 263–277.

Finke, M.D., 2002. Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biology 21, 269–285.

Fleischer, R.C., Tarr, C.L., James, H.F., Slikas, B., McIntosh, C.E., 2001. Phylogenetic placement of the Po'ouli, *Melamprosops phaeosoma*, based on mitochondrial DNA sequence and osteological characters. Studies in Avian biology 22, 98–103.

Foin, T.C., Riley, S.P.D., Pawley, A.L., Ayres, D.R., Carlsen, T.C., Hodum, P.J., Switzer, P.V., 1998. Improving recovery planning for threatened and endangered species. BioScience 48, 184–187.

Franklin, J.F., 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecological Applications 3, 202–205.

Freed, L.A., Conant, S.C., Fleischer, R.C., 1987. Evolutionary ecology and radiation of Hawaiian forest birds. Trends in Ecology and Evolution 2, 195–203.

Gerber, L.R., Schultz, C.B., 2001. Authorship and the use of biological information in endangered species recovery plans. Conservation Biology 15, 1308–1314.

Griffiths, R., Daan, S., Dijkstra, C., 1996. Sex identification in birds using two CHD genes. Proceedings of the Royal Society of London B 263, 1249–1254.

Groombridge, J.J., Massey, J.G., Bruch,. J.C., Malcolm, T., Brosius, C.N., Okada, M.M., Sparklin, B., 2003. Evaluating stress-levels in a Hawaiian honeycreeper (*Paroreomyza montana*) following translocation using different container designs. Journal of Field Ornithology, in press.

Hamel, P.B., 1986. Bachman's Warbler: A Species in Peril. Smithsonian Institution Press, DC.

Hooge, P.N., Eichenlaub, B., 1997. Animal movement extension to arcview. Ver.1.1. Alaska Biological Science Center, US Geological Survey, Anchorage, AK, USA.

Hutto, R.L., Reel, S., Landres, P.B., 1987. A critical evaluation of the species approach to biological conservation. Endangered Species Update 4, 1–4.

Impey, A.J., Cote, I.M., Jones, C.G., 2002. Population recovery of the threatened endemic Rodrigues Fody (Foudia flavicans) (Aves, Ploceidae) following reforestation. Biological Conservation 107, 299–305.

Jackson, J.A., 1991. Will-'o-the-wisp. Living Bird Quarterly 10, 29–32.

James, H.F., Olson, S.L., 1991. Descriptions of thirty-two new species of birds from the Hawaiian Islands. Part II. Passeriformes. Ornithological Monographs 46, 1–88.

Jones, C.G., Heck, W., Lewis, R.E., Mungroo, Y., Slade, G., Cade, T., 1995. The restoration of the Mauritius kestrel *Falco punctatus* population. Ibis 137, 173–180.

Kale II, H.W., 1983. A status report on the Dusky Seaside Sparrow. Bird Conservation 1, 129.

Kepler, C.B., Pratt, T.K., Ecton, A.M., Englis, A., Fluetsch, M., 1996. Nesting behavior of the Po'ouli. Wilson Bulletin 108, 620–638.

Kuehler, C., Lieberman, A., Harrity, P., Kuhn, M., Kuhn, J., McIlraith, B., Turner, J., 2001. Restoration techniques for Hawaiian forest birds: collection of eggs, artificial incubation and hand-rearing of chicks, and release to the wild. Studies in Avian Biology 22, 354–358.

Lepson, J.K., Freed, L.A., 1997. Akepa (*Loxos coccineus*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, vol. 294. The Birds of North America Inc., Philadelphia, PA.

Mountainspring, S., Casey, T.L.C., Kepler, C.B., Scott, J.M., 1990. Ecology, behavior, and conservation of the Poo-uli (*Melamprosops phaeosoma*). Wilson Bulletin 102, 109–122.

Noss, R.F., 1991. From endangered species to biodiversity. In: Kohm, A. (Ed.), Balancing on the Brink of Extinction: The Endangered Species Act and Lessons for the Future. Island Press, Washington, DC, pp. 227–246.

Pratt, H.D., 1992. Is the Poo-uli a Hawaiian honeycreeper (Drepanidanae)? Condor 94, 172–180.

Pratt, T.K., Kepler, C.B., Casey, T.L.C., 1997. Po'ouli (*Melamprosops phaeosoma*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, vol. 272. The Birds of North America Inc., Philadelphia, PA.

Pratt, T.K., Fancy, S.G., Ralph, C.J., 2001. 'Akiapola'au (*Hemignathus munroi*) and Nuku pu'u (*Hemignathus lucidus*). In: Poole, A., Gill, F. (Eds.), The Birds of North America, vol. 600. The Birds of North America Inc., Philadelphia, PA.

Pyle, R.L., 1985a. Hawaiian Islands Region. American Birds 37, 914–916.

Pyle, R.L., 1985b. Hawaiian Islands Region. American Birds 37, 964–965.
Pyle, R.L., 1989. Hawaiian Islands Region. American Birds 43, 369–371.
Rain, A., 1978. Radio transmitter attachment for small passerines. Bird Banding 49, 26–32.
Restani, M., Marzluff, J.M., 2001. Avian conservation under the Endangered Species Act: expenditures versus recovery priorities. Conservation Biology 15, 1292–1299.
Reynolds, M.H., Snetsinger, T.J., 2001. The Hawaii Rare Bird Search 1994–1996. Studies in Avian Biology No. 22, 133–143.
Rodda, D., Haverson, P., Jones, C.G., Mauremootoo, C., 2001. Echo parakeet. Psittascene 13, 10–11. World Parrot Trust.
Scott, J.M., Mountainspring, S., Ramsey, F.L., Kepler, C.B., 1986. Forest bird communities of the Hawaiian islands: their dynamics, ecology, and conservation. Studies in Avian Biology 9, 1–431.
Short, L.L., Horne, J.F.M., 1986. The ivory-bill still lives. Natural History 95, 26–28.
Snyder, N., Snyder, H., 2000. The Californian Condor: A Saga of Natural History and Conservation. Academic Press, San Diego.
Steiner, W.W.M., 2001. Evaluating the cost of saving native Hawaiian birds. Studies in Avian Biology 22, 377–383.
US Fish and Wildlife Service., 1975. Endangered and threatened wildlife, listings of endangered and threatened fauna. Federal Register 40, 44151, US Fish and Wildlife Service, Washington, DC.
US Fish and Wildlife Service., 1994. Notice of interagency cooperative policy for the ecosystem approach to the Endangered Species Act. Federal Register 59, 34272.
US Fish and Wildlife Service., 1997. Initiating recovery of the Po'ouli (*Melamprosops phaeosoma*) and other endangered forest birds in East Maui. Honolulu (unpublished report).
US Fish and Wildlife Service and Hawaii Department of Land and Natural Resources., 1999. Environmental assessment for proposed management actions to save the Po'ouli. US Fish and Wildlife Service, Pacific Islands Ecoregion, Honolulu, Hawaii, 52 pp.
VanderWerf, E.A., Malcolm, T., Fretz, J.S., Massey, J.G., Lieberman, A., Groombridge, J.J., Sparklin, B., Okada, M.M., Brosius, C.N., 2003. Update on recovery efforts for the Po'ouli. 'Elepaio 63, 25–30.
Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A., Losos, E., 1998. Quantifying threats to imperiled species in the United States. BioScience 48, 607–615.