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Development of Restoration Techniques for Hawaiian Thrushes: Collection of Wild Eggs, Artificial Incubation, Hand-rearing, Captive-breeding, and Re-introduction to the Wild

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From 1995 to 1999, two species of endemic Hawaiian thrushes, `Oma`o (*Myadestes obscurus*) and Puaiohi (*M. palmeri*), were captive-reared and re-introduced into their historic range in Hawai`i by The Peregrine Fund, in collaboration with the U.S. Geological Survey–Biological Resources Division (BRD) and the Hawai`i State Department of Land and Natural Resources. This paper describes the management techniques that were developed (collection of wild eggs, artificial incubation, hand-rearing, captive propagation, and release) with the non-endangered surrogate species, the `Oma`o; techniques that are now being used for recovery of the endangered Puaiohi. In 1995 and 1996, 29 viable `Oma`o eggs were collected from the wild. Of 27 chicks hatched, 25 were hand-reared and released into Pu`u Wa`awa`a Wildlife Reserve. Using the techniques developed for the `Oma`o, a captive propagation and release program was initiated in 1996 to aid the recovery of the endangered Puaiohi. Fifteen viable Puaiohi eggs were collected from the wild (1996–1997) to establish a captive breeding flock to produce birds for re-introduction. These Puaiohi reproduced for the first time in captivity in 1998 (total Puaiohi chicks reared in captivity 1996–1998 = 41). In 1999, 14 captive-bred Puaiohi were re-introduced into the Alaka`i Swamp, Kaua`i.

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These captive-bred birds reproduced and fledged seven chicks in the wild after release. This is the first endangered passerine recovery program using this broad spectrum of management techniques (collection of wild eggs, artificial incubation, hand-rearing, captive-breeding, and release) in which re-introduced birds survived and bred in the wild. Long-term population monitoring will be published separately [BRD, in preparation]. Zoo Biol 19:263–277, 2000.

Key words: avian restoration; captive propagation; conservation; recovery program

INTRODUCTION

Modification of the Hawaiian Islands due to increased human activity and introduced non-native insects, plants, birds, and mammals is causing the extinction of endemic bird populations. More than half of all the endangered species in the United States inhabit the dwindling rain forests of this island state, and Hawai`i is considered one of the extinction capitals of the world [U.S. Fish and Wildlife Service, 1992; Jacobi and Atkinson, 1995].

Six taxa of *Myadestes* thrushes from five different islands have been described in Hawai`i: `Oma`o (*M. obscurus*), Puaiohi (*M. palmeri*), Oloma`o (*M. l. lanaiensis* and *M. l. rutha*), Kama`o (*M. myadestinus*), and `Amaui (*M. oahuensis*). Oloma`o and `Amaui are probably extinct and Kama`o, once the most common bird on Kaua`i, is now extremely rare or extinct. Approximately 300 Puaiohi survive in the Alaka`i Swamp on Kaua`i [Perkins, 1903; Scott et al., 1986; Reynolds et al., 1997; Conant et al., 1998; T. Snetsinger, unpublished]. Of the remaining forms (`Oma`o, Kama`o, and Puaiohi), the `Oma`o is the only non-endangered species in this group, and this species occupies only 30% of its historic range on Hawai`i.

Avian disease, habitat degradation, and introduced alien species have all contributed to the demise of these populations [Van Riper and Scott, 1979; Ralph and Fancy, 1994].

For many bird species in Hawai`i, habitat enhancement and protection may not occur quickly enough to guarantee a safe haven for populations on the verge of extinction. In these critical cases, manipulation of wild birds and hands-on intervention are being used as recovery tools [Kuehler et al., in press]. Collection of wild eggs to establish captive-breeding programs and produce birds for re-introduction has proven to be a valuable conservation strategy for peregrine falcons (*Falco peregrinus*), California condors (*Gymnogyps californianus*), and San Clemente Island loggerhead shrikes (*Lanius ludovicianus mearnsi*) [Cade et al., 1988; Kuehler and Witman, 1988; Kuehler et al., 1993]. However, propagation of birds in captivity is labor intensive, costly, and not necessarily an effective recovery tool for all species [Conway, 1986].

For some island endemics, such as Hihi (*Notiomystis cincta*), Ultramarine lories (*Vini ultramarina*), Seychelles warblers (*Acrocephalus seychellensis*), New Zealand saddlebacks *(Philesturnus carunculatus rufusater*), and Chatham Island black robins (*Petroica traversi)*, cross-fostering and/or translocation to secure habitat on another island is a preferable option [Komdeur, 1991; Butler and Merton, 1992; Serena, 1995; Kuehler et al., 1997; Lieberman et al., 1998]. But recovery strategies involving translocation/cross-fostering require a) founder populations large enough to support collection of wild adults, b) the availability of surrogate foster species (e.g., Chatham Island tits, *Petroica macrocephala chathamensis*, were used as foster parents for robins), and c) site fidelity of translocated individuals to the new release area. For some species, suitable habitat may be available for translocation, but wild

birds may return to their site of origin, especially if the site is on the same island, as in the case of the endangered Palila in Hawai`i [Fancy et al., 1997b].

To determine the most efficacious conservation strategy for Hawaiian thrushes (captive propagation/release vs. translocation), an experimental surrogate program was initiated in 1995, in collaboration with U.S. Geological Survey–Biological Resources Division (BRD) and Division of Forestry and Wildlife (DOFAW) biologists to develop recovery techniques for endemic thrush populations in Hawai`i. The pilot program had two goals: 1) develop restoration techniques involving captive propagation/release (collection of wild eggs, artificial incubation, hand-rearing, and re-introduction) and 2) evaluate translocation of wild birds versus re-introduction of captive-reared birds as a potential recovery strategy for endangered Hawaiian birds in protected habitat. The `Oma`o was chosen as the surrogate species because it is a non-endangered, sedentary, frugivorous, vocal passerine, and large enough to carry a transmitter. The `Oma`o was the ideal candidate to evaluate potential recovery strategies for the endangered, congeneric Puaiohi. Additionally, recent field studies reported that the forest within the Pu`u Wa`awa`a Forest Reserve (PWW) was recovering from past cattle grazing and would support the return of `Oma`o into this unoccupied portion of the species historic range [Ralph and Fancy, 1994; Wakelee, 1996].

The results of the surrogate work with `Oma`o comparing potential recovery strategies demonstrated similar survival rates for both groups of birds, but the fidelity to the protected (predator-controlled) release site was higher for captive-reared birds than translocated wild birds [Fancy et al., in press]. Based on the captive propagation/release techniques developed for `Oma`o, a recovery program for the endangered Puaiohi (in predator-controlled habitat) was initiated in 1996 and is ongoing. This paper describes the restoration techniques that were developed for `Oma`o and

Puaiohi (collection of wild eggs, artificial incubation, hand-rearing, captive-breeding, and release). Long-term population monitoring and reproductive activity of re-introduced birds will be published by BRD [in preparation].

METHODS

Collection of Wild Eggs

Nest searching and collection of `Oma`o eggs was accomplished by biologists from BRD in collaboration with The Peregrine Fund (TPF) at three different sites in windward forests on Hawai`i: Pu`u Maka`ala Natural Area Reserve/Upper Waiakea Forest Reserve boundary (1,100–1,150 m), Keauhou Ranch (1,800 m), and Hakalau Forest National Wildlife Refuge (1,570 m). Nests were located by observing the behavior of nesting birds (e.g., vocalizations, carrying nesting material). Eggs were collected, transferred to a portable incubator (Dean's Animal Supply, Orlando, FL, U.S.A.), and transported at 37.2–37.8°C to the Keauhou Bird Conservation Center (KBCC), Volcano Hawai`i (1,372 m).

Puaiohi eggs were collected from seven different nesting pairs in the Alaka`i Swamp, Kaua`i (1,200 m). Unlike `Oma`o, Puaiohi often nest in mossy overgrown alcoves in stream-side cliffs [T. Snetsinger, in preparation]. Puaiohi eggs were transported by helicopter to temporary incubation/chick-rearing facilities on the island of origin (Kaua`i).

Artificial Incubation of Eggs

Upon arrival at the respective incubation facilities, `Oma`o and Puaiohi eggs were set in forced-air incubators (Humidaire models 20 and 21; Humidaire Incubator

Co., New Madison, OH, U.S.A.). Eggs were artificially incubated and hatched using parameters modified from experience incubating other species of passerine eggs: 37.2–38.1°C (dry bulb), 26.7–31.1°C (wet bulb) [C. Plasse, unpublished; Kuehler and Good, 1990; Kuehler et al., 1993; 1994; 1996]. Mass (water loss) was monitored by weighing the eggs daily. Eggs were transferred to forced-aired hatchers when the chicks pipped the aircell (AB Incubator Co., Moline, IL, U.S.A.). Tape-recorded parental vocalizations were broadcast into the hatcher to stimulate hatching during the pip to hatch interval.

Hand-rearing of Chicks

`Oma`o and Puaiohi chicks were hand-reared using parameters modified from husbandry techniques used for other species of passerines, incorporating foraging information provided by biologists familiar with Hawaiian thrushes in the wild [Kuehler et al., 1993; 1996; Wakelee, 1996]. Chicks were hand-reared on a high protein diet (insects and egg), and fruit was gradually introduced to simulate the wild diet. The initial feeding frequency was hourly from 0600 to 2000, gradually decreasing in frequency as the chicks developed. Solid food was minced and dipped into liquid containing vitamin (Nekton-I; Nekton USA, Clearwater, FL, U.S.A.) and mineral supplements (calcium carbonate and bone meal). Food items were offered with small forceps [Kuehler et al., 1993; 1996]. Initially, chicks were brooded and maintained at approximately 35.0–36.1°C in plastic nest cups. The temperature was adjusted in response to the chicks' behavior (shivering vs. panting) as they matured. Chicks were hand-reared in sibling groups with tape-recorded vocalizations to minimize imprinting and expose young birds to adult songs during the nestling/fledging phase. Young birds fledged in small 0.6 × 0.9 × 1.2 m cages.

Data collected included chick weight, food intake, percentage weight gain, vitality (activity level and begging response), and the amount and consistency of fecal output. Food intake was adjusted in response to hydration levels, determined by weight gains and visual analysis of the chicks' skin folds and mouth lining. For example, if a chick appeared dehydrated, had a large weight gain from the previous day, and decreased its begging response, the food intake was decreased. Nutrient analysis of the diet consumed was evaluated using the N2 Animal Nutritionist software program (N-Squared Computing and Durango Software, Silverton, OR, U.S.A.) [Kuehler et al., 1993; 1994; 1996].

Captive Breeding of Puaiohi

In 1998, five pairs of adult Puaiohi (hand-reared from eggs collected from the wild in 1996 and 1997) were housed for captive-breeding to produce chicks for reintroduction. Single pairs were selected by using mean kinship/inbreeding genetic analysis of the studbook (SPARKS Software; ISIS, 12101 Johnnycake, Apple Valley, MN, U.S.A.) and maintained in 3.0 × 6.5 × 4.5 m planted aviaries at the KBCC. Genetic diversity retained in the captive flock was 92.0%.

The captive adult diet was composed of native and domestic fruits, insects, egg, and vitamin/mineral supplements. Nesting opportunities were provided by mounting triangular wire baskets 30 × 30 × 30 cm in a protected corner of the aviary (3 m high). Nesting material was available in the aviary: leaf litter, fern rootlets, raffia, mosses, grasses (fresh and dry), and lichens. Breeding pairs were monitored by video cameras and eggs were collected after 3 to 7 days of parental incubation or if the female demonstrated inconsistent nest attentiveness.

Release of Birds to the Wild

All birds were disease screened before re-introduction to the wild [Chacon et al., 1996].

`Oma`o

In January 1996, two `Oma`o were re-introduced into the PWW Reserve as a preliminary test release. From August to October 1996, 23 birds were released in four cohorts of four to seven birds. `Oma`o were banded and released between 66 and 157 days of age. Before and during the release, ground predators were reduced by BRD biologists using diphacinone poison, Victor snap traps (rats), and cage traps (feral cats and mongoose) [Fancy et al., in press].

Before re-introduction, the birds were conditioned in large aviaries at the KBCC to a) develop flight and foraging capabilities and b) assess compatibility of birds housed together as release cohorts (`Oma`o can show intra-specific aggression in captivity). Native fruits were provided by hanging berries throughout the aviary to simulate natural foraging opportunities. The birds were transported to the two hacking towers at the release site in small wooden carriers (36 × 20 × 20 cm) cushioned with foam padding. Two hack towers were built 1,200 m apart at approximately 1,645 m elevation. One structure was built with a small aviary (2.4 × 2.4 × 2.1 m) on top of a platform (4.3 × 4.3 m) elevated 3.7 m off the ground. The second hack tower consisted of an aviary (2.4 × 3.7 × 2.4 m) built on a 4.3 × 4.9 m platform elevated 3.7 m off the ground. The support posts were wrapped in metal flashing to prevent predators from climbing to the aviary. Small cages (46 × 91 × 61 cm) were placed inside the platform aviary to separate aggressive birds during the release process.

Native fruits were provided during a 6–9-day conditioning period to enhance site fidelity to the hack tower. Two days before release, the `Oma`o were fitted with a 1.7-g backpack-transmitter attached by an elastic leg harness (total wt. = 1.9–2.1 g with harness) (Holohil Systems Ltd, Woodlawn, Ontario, Canada) [Rappole and Tipton, 1991]. Birds were banded with both color and service aluminum bands.

During the first 10–14 days after release, supplemental food was provided on the landing platform and/or in the aviary. Supplemental food was decreased gradually as the released birds weaned, in response to their ability to forage on native foods. For the first 30 days after release (release independence), daily attempts were made by TPF biologists to locate all `Oma`o by radiotelemetry and visual tracking. After supplemental feeding was discontinued and birds were fully independent of human care, BRD biologists monitored the birds until mid-December. An `Oma`o was considered to have "dispersed" if it was located by radiotelemetry outside the PWW Reserve and if changes in the location and amplitude of its signal (over 1–2 days) indicated that the bird was moving its position.

Puaiohi

In January and February 1999, 14 Puaiohi, captive-bred at the KBCC, were re-introduced into the northern section of the Alaka`i Swamp, Kaua`i. A recovery goal is to establish additional disjunct breeding populations of Puaiohi in native habitat within the species' historical distribution. Puaiohi were released using the same techniques developed in 1996 for the `Oma`o except that birds were held in hack towers for 8–14 days. A predator control grid system was established before release and was maintained by BRD biologists to decrease the risk of predation [BRD, unpublished].

Two temporary hack towers similar to those used for the `Oma`o release were constructed approximately 480 m apart in the Alaka`i Swamp, Kaua`i.

The Puaiohi were conditioned in large aviaries at the KBCC to develop flight and foraging skills. They were transported to Kaua`i via airplane in a padded wooden carrier and then carried to the release site. Like `Oma`o, all birds were fitted with transmitters and bands and monitored by TPF for 30 days after release. Unlike `Oma`o, where daily monitoring was discontinued in mid-December, endangered Puaiohi were continuously monitored by BRD biologists during the breeding season in the Alaka`i Swamp. Detailed long-term monitoring and reproductive behavior will be published separately [BRD, in preparation].

The release site location and the timing of the release were based on recommendations from BRD and TPF biologists taking into consideration wild population distribution, accessibility, flooding risks, wild fruit abundance, potential nest sites, and the capability to construct a temporary hack tower in difficult terrain. Although Hawaiian thrushes can survive mosquito-transmitted malarial infection [C. Atkinson, personal communication], birds were released during the non-malaria season on Kaua`i to decrease the risk of disease infection during the high-stress period of re-introduction. Re-introduction techniques were similar for both the `Oma`o and Puaiohi but, the timing of releases (age at release) varied due to mosquito seasonality/prevalence differences on Kaua`i vs. Hawai`i.

RESULTS

Collection and Artificial Incubation of Eggs

`Oma`o

In 1995 and 1996, 36 `Oma`o eggs were collected from wild nests (Table 1). The eggs were ovoid in shape, tannish colored with reddish/brown speckling on the aircell end (mean length ± SD = 26.5 ± 2.1 mm, mean breadth ± SD = 19.1 ± 1.3 mm). Twenty-nine eggs were viable at the time of collection and 27 chicks hatched (mean hatch weight ± SD = 4.1 ± 0.6 g; known fertility = 93.5%; hatchability = 93.1%) (Table 1). Most eggs received some parental incubation before transport, therefore the approximate incubation length of 14–15 days was determined by candling. The pip to hatch interval was 24–48 hours and mean water/weight loss during artificial incubation was 14.1%.

Puaiohi

During the period 1995–1998, 19 Puaiohi eggs were collected from the wild and 39 eggs from captive birds for artificial incubation (total = 58). Puaiohi eggs were ovoid in shape, tannish colored with reddish/brown speckling on the aircell end (mean length ± SD = 24.4 ± 1.7 mm; mean breadth ± SD = 18.1 ± 0.9 mm). Forty-three eggs were viable at the time of collection and 39 chicks hatched under artificial conditions (mean hatch weight ± SD = 3.6 ± 0.5 g; known fertility = 81.1%; hatchability = 90.7%) (Table 2). Most artificially incubated eggs received parental incubation before transport, therefore the approximate incubation length of 14–15 days was determined by candling. The pip to hatch interval was 24–48 hours. The mean water/weight loss during artificial incubation was 15.6%. Two chicks hatched under incubating parents (hatchability for parent-incubated eggs = 40.0%).

TABLE 1. Summary of wild `Oma`o (*Myadestes obscurus*) eggs artificially incubated, chicks hand-reared, and birds re-introduced in Pu`u Wa`awa`a Wildlife Reserve, Hawai`i, by The Peregrine Fund, 1995–1996

	1995	1996	Total
No. of wild eggs collected	5	31	36
No. of captive eggs collected	—	—	—
No. of viable eggs known	2	27	29
No. of infertile eggs	—	2	2
No. of eggs viability unknown	3	2	5
No. of chicks hatched	2	25	27
No. of chicks survived 30 days post-hatch	2	23	25
No. of birds died in captivity after 30 days of age	—	—	—
No. of birds retained for captive-breeding flock	—	—	—
No. of birds released to wild	—	—	25
No. of birds survived 30 days post-release	—	—	20

Eggs were considered viable if they were fertile (unincubated) or contained a living embryo at the time of collection. Release independence/survivability was designated as 30 days post-release (after birds were weaned from supplementary food provisioning in the wild).

Hand-rearing of Chicks

`Oma`o

Twenty-five `Oma`o chicks were successfully hand-reared using the artificial diet and fledged at 19–20 days after hatch (Tables 1, 3, 4; Fig. 1). Chick survivability was 92.6% (30 days post-hatch).

Puaiohi

In 1996 and 1997, 17 wild Puaiohi eggs were collected to establish a captive-breeding flock; 15 eggs were viable and 15 chicks hatched. In 1998, four pairs of Puaiohi successfully reproduced in captivity. In total (1996–1998), 38 Puaiohi chicks

TABLE 2. Summary of wild and captive Puaiohi (*Myadestes palmeri*) eggs incubated, chicks reared, and birds re-introduced in the Alaka`i Swamp, Hawai`i, by The Peregrine Fund, 1996–1999

	1996	1997	1998	Total
No. of wild eggs collected	7	12	—	19
No. of captive eggs collected	—	—	39	39
No. of viable eggs known	5	10	28	43
No. of infertile eggs	—	—	10	10
No. of eggs viability unknown	2	2	1	5
No. of chicks artificially hatched	5	10	24	39
No. of chicks survived 30 days post-hatch	5	10	23	38
No. of eggs incubated by parents in captivity	—	—	5	5
No. of chicks hatched under parents in captivity	—	—	2	2
No. of birds died in captivity after 30 days of age	1	1	3	5
No. of birds retained for captive-breeding flock	4	9	8	21
No. of birds released to wild	—	—	14	14
No. of birds survived 30 days post-release	—	—	14	14

Eggs were considered viable if they were fertile (unincubated) or contained a living embryo at the time of collection. Release independence/survivability was designated as 30 days post-release (after birds were weaned from supplementary food provisioning in the wild).

TABLE 3. Mean food intakes (g/d) for diet consumed by hand-reared `Oma`o (*Myadestes obscurus*) (n = 25), 1995–1996

	No. of days since hatching		
Food item	1–3	4–6	7–10
Bee larvae	0.8	1.7	2.7
Crickets	0.6	1.3	2.3
Egg (hard-boiled)	0.5	1.0	2.1
Papaya		0.6	1.6
Mealworms		0.6	1.5
Waxworms		0.2	1.4
Fruit cocktail		0.1	1.1

were hand-reared using the artificial diet and fledged at 19–20 days after hatch. Chick survivability was 92.3% (30 days post-hatch)(Tables 2, 5, 6; Fig. 2). Two additional chicks hatched by the parents were successfully parent-reared to 30 days (Table 2).

Release of Birds to the Wild

`Oma`o

In January 1996, two `Oma`o were re-introduced as a preliminary test release from August to October 1996, 23 birds were released in cohorts of four to seven birds into PWW (Fig. 3). Of the 25 released birds, the two birds released in early 1995 were observed 1 year later, and 20 of the birds hatched in 1996 were monitored and known to have survived for at least 30 days post-release (post-release survivability = 80%)(Table 1). The mean daily ranging distance from the hack tower during the release period 30 days post-release) is shown in Fig. 4.

A follow-up survey was conducted in December 1996, and 25 `Oma`o were estimated in the PWW Reserve. During the week of June 8–10, 1997, seven captive-reared birds were identified by bands within the 150-ha study area surrounding the hack towers, although most birds had moved to higher elevation areas where fruit was more abundant. Successful breeding was reported (July 11–13, 1998): one first-year bird with a captive-reared male in attendance and an independent second-year bird [Nelson and Fancy, in press]. The long-term monitoring and dispersal of both the captive-reared and translocated population will be reported separately [Nelson et al., in preparation].

Puaiohi

In January 1999, 14 captive-bred Puaiohi were re-introduced into the northern section of the Alaka`i Swamp (Kawaikoi Drainage) Kaua`i (Fig. 3). The Puaiohi

TABLE 4. Dry matter composition of diet consumed by hand-reared `Oma`o (*Myadestes obscurus*) (n = 25), 1995–1996

No. of days since hatching	Protein (%)	Fat (%)	Calcium (%)	Phosphorus (%)	Water (%)
1–3	64.3	22.2	0.1	0.5	74.3
4–6	56.3	21.0	0.4	0.6	73.4
7–10	39.3	18.9	0.7	0.5	67.9

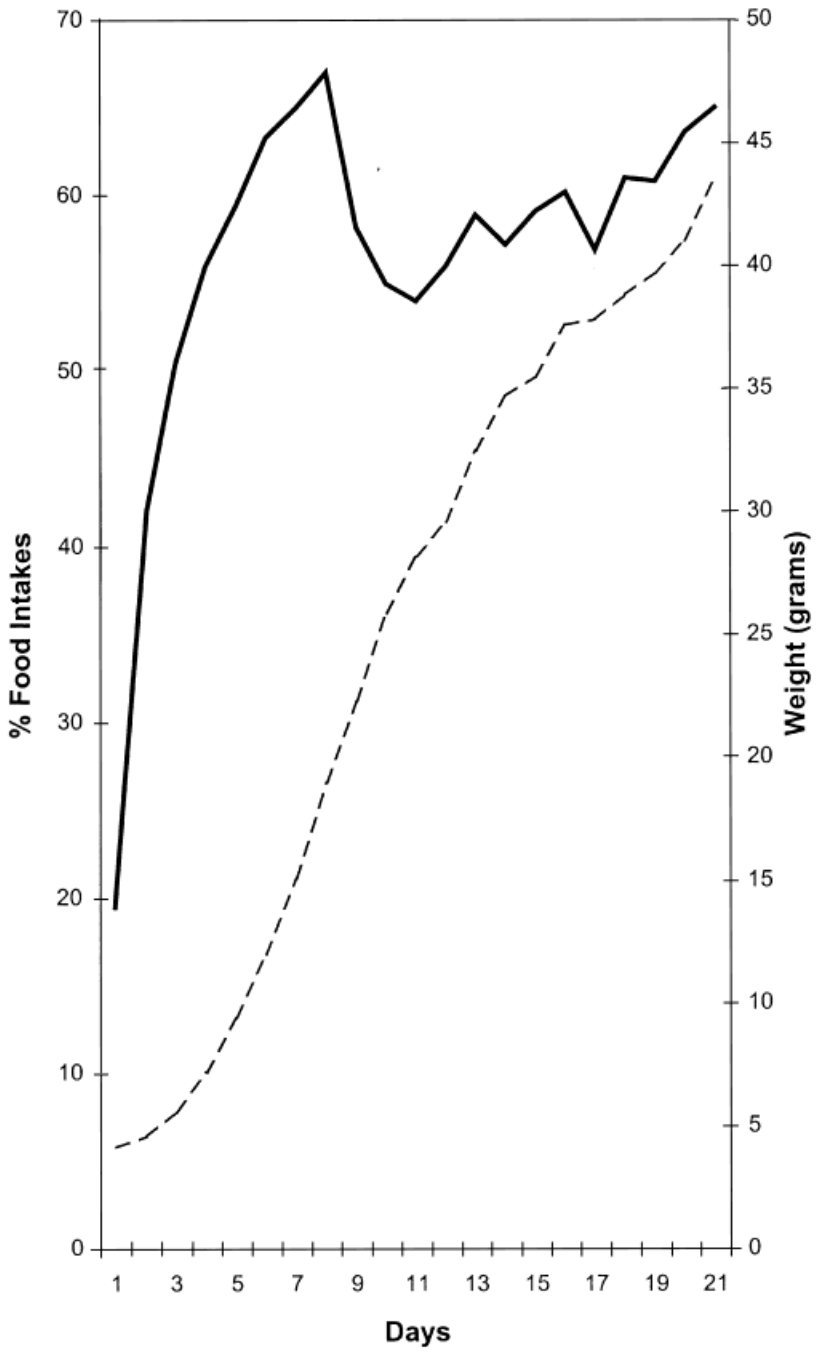

Fig. 1. Mean growth rate (broken line) and food intake (solid line) (% of chick weight) for `Oma`o chicks (*Myadestes obscurus*) (n = 25) hand-reared by The Peregrine Fund (1995–1996).

TABLE 5. Mean food intakes (g/d) for diet consumed by hand-reared Puaiohi (*Myadestes palmeri*) (n = 30), 1998–1999

	No. of days since hatching		
Food item	1–3	4–6	7–10
Bee larvae	0.7	1.7	2.7
Crickets	0.5	1.3	2.1
Egg (hard-boiled)	0.4	1.0	2.1
Papaya		0.6	1.6
Mealworms		0.4	1.5
Waxworms		0.01	0.91

were older than the `Oma`o at release, and the daily ranging distance during the re-introduction period was greater (Fig. 4). All 14 birds survived for 30 days after release (post-release survivability = 100%). Six pairs nested and at least seven chicks have successfully fledged to date [BRD, unpublished data]. Long-term monitoring, habitat utilization, and reproductive success of re-introduced birds will be published separately [BRD, in preparation].

DISCUSSION

In 1995, BRD, DOFAW, the Service, and TPF began a cooperative project to develop recovery techniques for endemic Hawaiian thrushes and to establish additional breeding populations of the critically endangered Puaiohi in the Alaka`i Wilderness Area on Kaua`i. These results indicate that it is feasible to incorporate techniques for collecting wild eggs, captive-breeding, and subsequently releasing passerines as potential management tools for conserving and recovering endangered Hawaiian birds.

However, recovery techniques involving captive propagation are costly strategies and can only be effective conservation tools when 1) knowledge of a species' biology exists, 2) the causes of decline are understood and ongoing programs to reverse the trend are being implemented, 3) captive propagation technology and expertise are available, 4) release techniques exist that result in behaviorally competent birds, 5) adequate funding and facilities are available, 6) recovery objectives and goals are clear, and 7) acceptable, secure release sites are available in the wild. These recovery strategies are being used as stopgap measures to increase reproductive output in rare bird populations during this period of environmental crisis in Hawai`i. Intervention techniques provide a means to preserve options while the habitat is secured and wild populations are stabilized. Continual commensurate action to protect

TABLE 6. Dry matter composition of diet consumed by hand-reared Puaiohi (*Myadestes palmeri*) (n = 30), 1997–1998

No. of days since hatching	Protein (%)	Fat (%)	Calcium (%)	Phosphorus (%)	Water (%)
1–3	64.5	21.9	0.1	0.5	74.3
4–6	59.9	22.6	0.2	0.5	74.7
7–10	55.3	27.6	0.8	0.6	73.2

Diet analysis does not include calcium and phosphorus values for bee larvae (data unavailable).

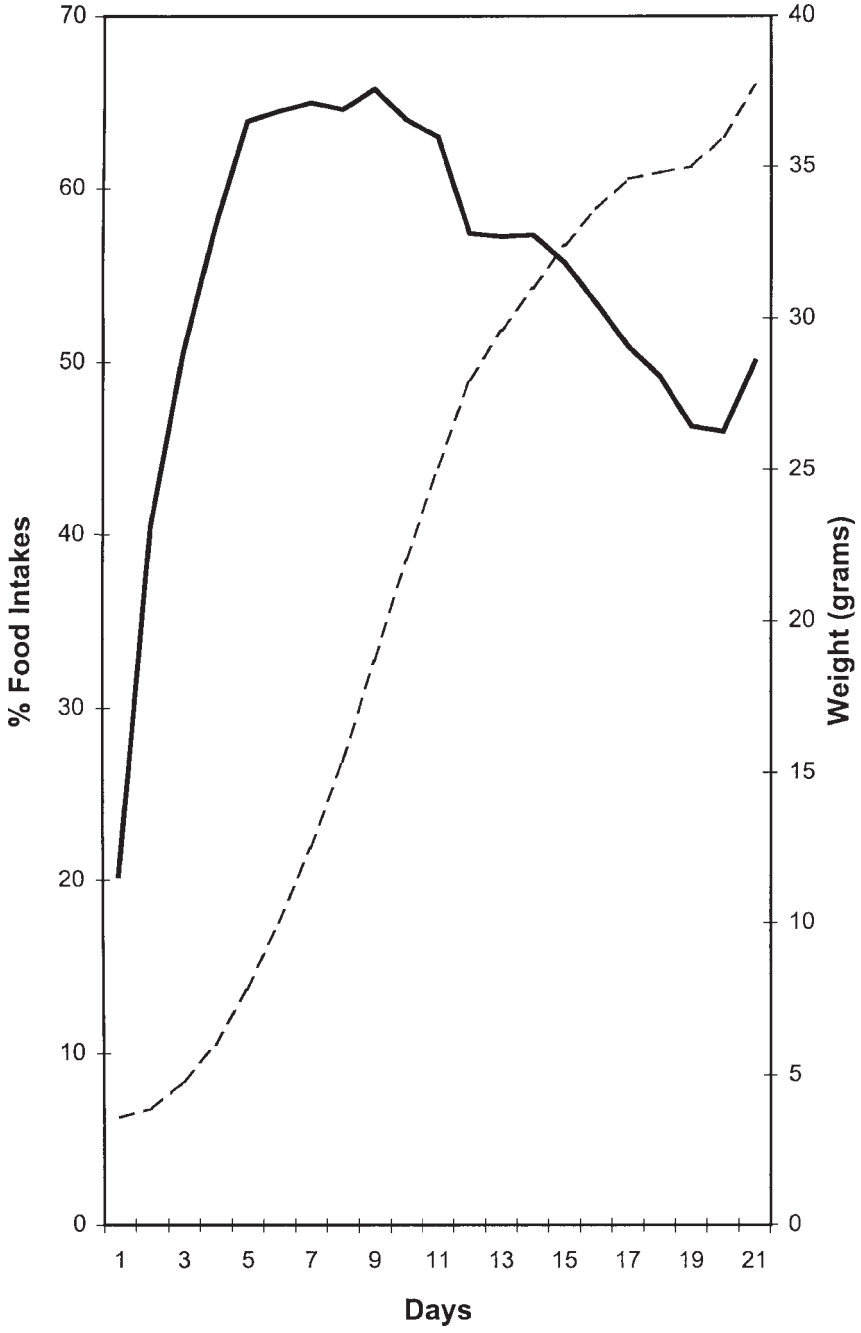

Fig. 2. Mean growth rate (broken line) and food intake (solid line) (% of chick weight) for Puaiohi chicks (*Myadestes palmeri*) (n = 36) hand-reared by The Peregrine Fund (1996–1998).

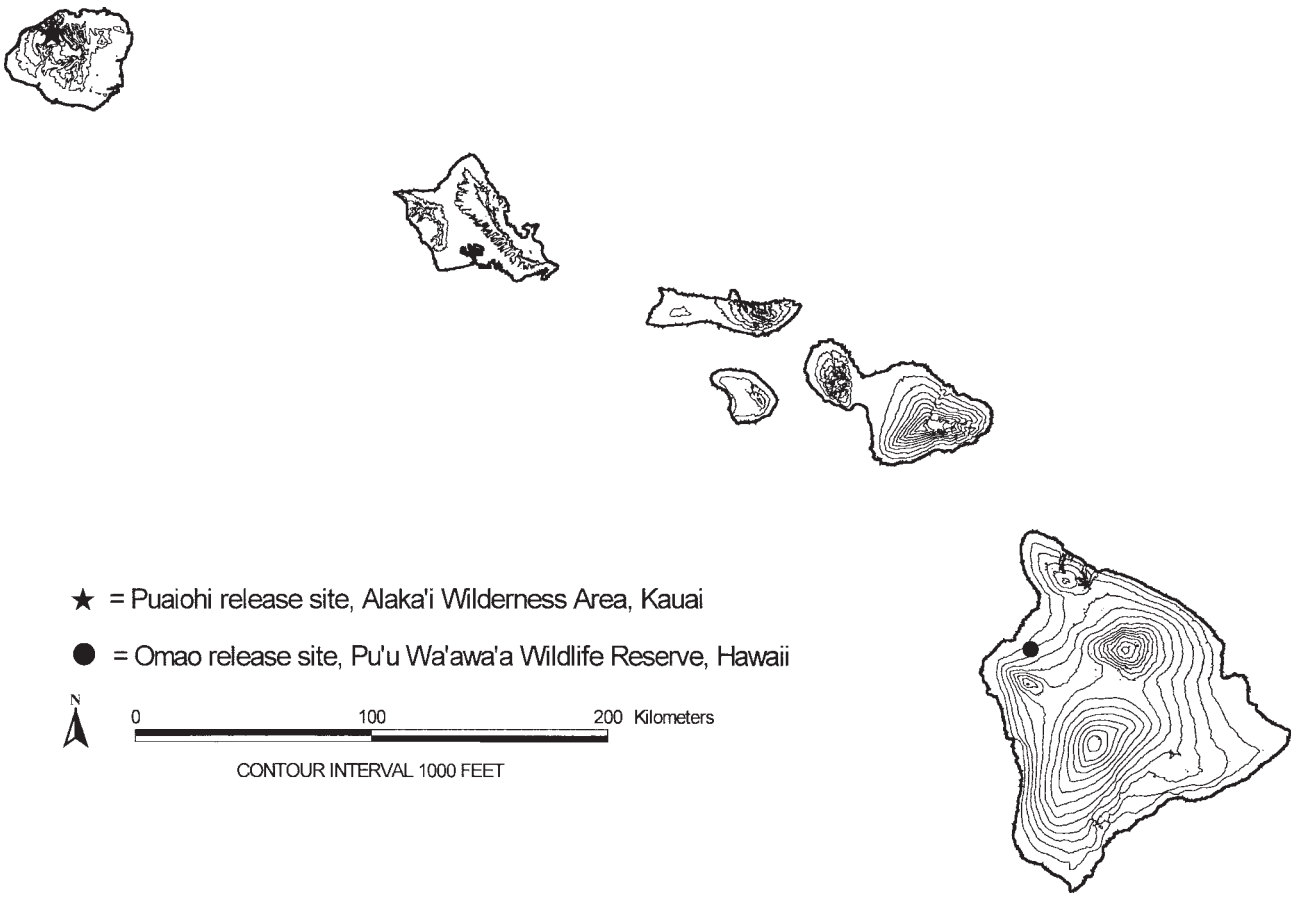

Fig. 3. Release sites for `Oma`o (*Myadestes obscurus*) (solid line) and Puaiohi (*Myadestes palmeri*) (broken line) in the Hawaiian Islands.

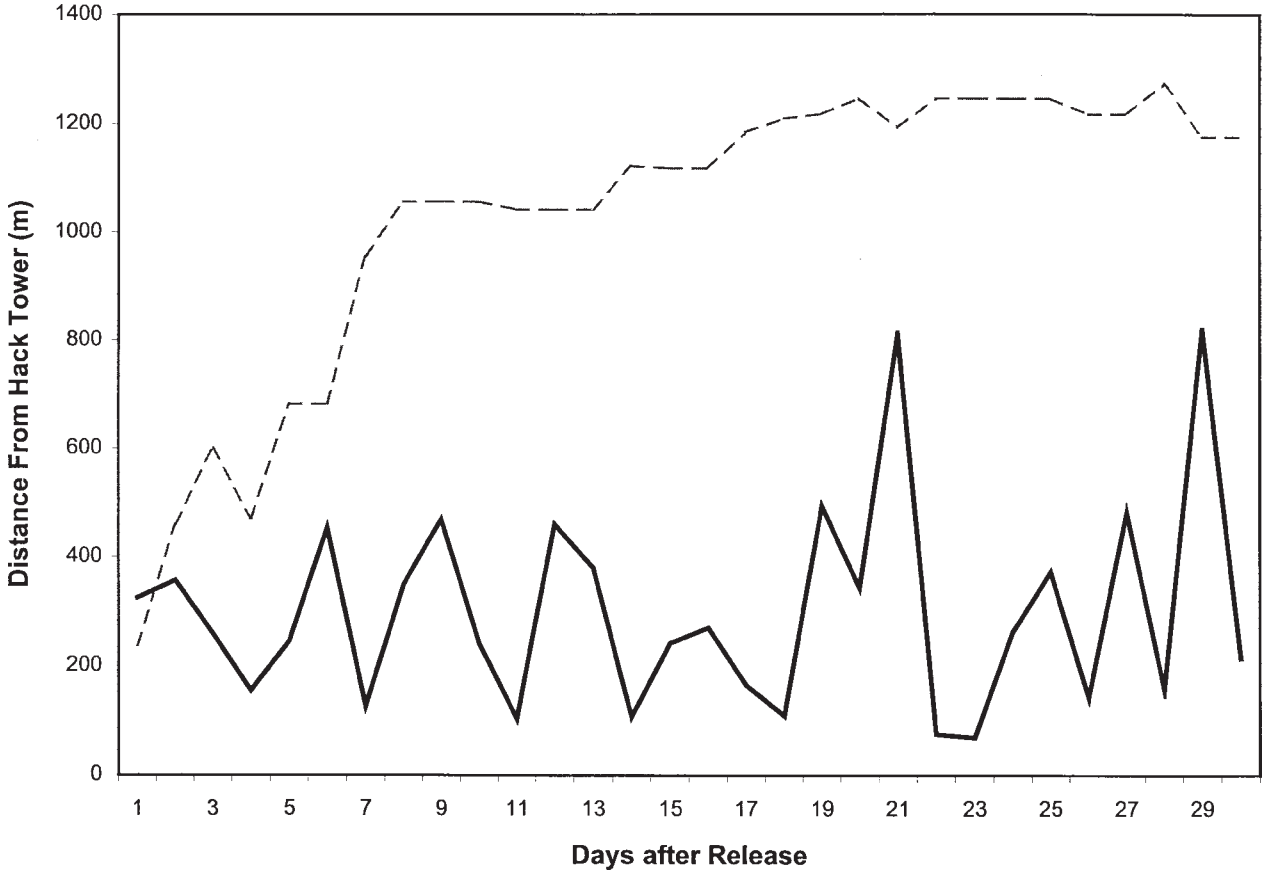

Fig. 4. Mean daily ranging distance (m) from the hack tower until release independence (30 days) for `Oma`o (*Myadestes obscurus*) (solid line) (n = 23) and Puaiohi (*Myadestes palmeri*) (broken line) (n = 14) re-introduced in Hawai`i by The Peregrine Fund (1995–1999).

and enhance the habitat is required for restoration efforts to establish viable self-sustaining wild populations.

CONCLUSIONS

1. Wild egg collection, artificial incubation, hand-rearing, and propagation techniques developed were satisfactory for producing Hawaiian thrushes in captivity for subsequent re-introduction to the wild.

2. Release techniques developed were satisfactory for re-introducing captive-reared Hawaiian thrushes, which then are capable of successfully breeding and fledging chicks in the wild.

3. This is the first passerine conservation program using a broad spectrum of recovery management techniques that include collection of wild eggs, artificial incubation, hand-rearing, captive-breeding, and release in which re-introduced birds subsequently survived and bred in the wild.

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REFERENCES

Butler D, Merton D. 1992. The black robin*:* saving the world's most endangered bird. New York: Oxford University Press. 294 p.

Cade TJ, Enderson JH, Thelander CG, White. 1988. Peregrine falcon populations: their management and recovery. Boise: The Peregrine Fund, Inc.

Chacon S, Chow L, Harrity P, Holley J, Kuehler C, Kuhn J, Kuhn M, Lieberman A, McIlraith B, Oesterle P, Powers T, Turner J. 1996. Annual report to the U.S. Fish and Wildlife Service. Hawaiian Endangered Bird Conservation Program. The Peregrine Fund.

Conant S, Pratt HD, Shallenberger RJ. 1998. Reflections on a 5 day expedition to the lost world of the Alaka`i and other notes on the natural history, systematics, and conservation of Kaua`i birds. Wilson Bull 110:1–22.

Conway WG. 1986. The practical difficulties and financial implications of endangered species breeding programmes. Int Zoo Yearbk 24/25: 210–9.

Fancy S, Kuehler C, Giffin J. 1997a. Highlights of the `Oma`o translocation, 1997. U.S. Geological Survey–Biological Resources Division Memorandum.

Fancy SG, Snetsinger TJ, Jacobi JD. 1997b. Translocation of the Palila, an endangered Hawaiian honeycreeper. Pacific Cons Biol 3:39–46.

Fancy SG, Nelson JT, Harrity P, Kuhn J, Kuhn M, Kuehler C, Giffin JG. Re-introduction and translocation of a Hawaiian solitaire: a comparison of methods. Studies Avian Biol, in press.

Jacobi J, Atkinson CT. 1995. In: Our living resources: a report to the nation on the distribution, abundance and health of U.S. plants, animals and ecosystems. U.S. Dept. of the Interior. Biological Resources Division of U.S. Geological Survey. Washington, DC.

Komdeur J. 1991. Inter-island transfers and population dynamics of Seychelles warblers. Bird Cons Int 7:7–26.

Kuehler C, Witman P. 1988. Artificial incubation of California Condor (*Gymnogyps californianus*) eggs removed from the wild. Zoo Biol 7:123–32.

Kuehler C, Good J. 1990. Artificial incubation of bird eggs at the Zoological Society of San Diego. Int Zoo Yearbk 29:118–36.

Kuehler CM, Lieberman A, McIlraith B, Everett W, Scott TA, Morrison ML, Winchell C. 1993. Artificial incubation and hand-rearing of loggerhead shrikes. Wildl Soc Bull 21:165–71.

Kuehler C, Kuhn M, McIlraith B, Campbell G. 1994. Artificial incubation and hand-rearing of `Alala (*Corvus hawaiiensis*) eggs removed from the wild. Zoo Biol 13:257–66.

Kuehler C, Kuhn M, Kuhn JE, Lieberman A, Harvey N, Rideout B. 1996. Artificial incubation, hand-rearing, behavior, and release of Common `Amakihi (*Hemignathus virens virens*): surrogate research for restoration of endangered Hawaiian forest birds. Zoo Biol 15:541–53.

Kuehler C, Lieberman A, Varney A, Unitt P, Sulpice RM, Azua J, Tehevini B. 1997. Translocation of ultramarine lories (*Vini ultramarina)* in the Marquesas Islands: Ua Huka to Fatu Hiva. Bird Cons Int 7:69–79.

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

Lieberman A, Kuehler C, Varney A, Unitt P, Sulpice RM, Azua J, Tehevini B. 1998. A note on the 1997 survey of the translocated ultramarine lory (*Vini ultramarina*) population on Fatu Hiva, Marquesas islands, French Polynesia. Bird Cons Int 7:291–2.

Nelson JT, Fancy SG. A test of the variable circular-plot method where exact density of a bird population was known. Pacific Cons Biol, in press.

Perkins RCL. 1903. Vertebrata (aves). In: Sharp D, editor. Fauna Hawaiiensis, Vol. 1, part 4. Cambridge: The University Press. p 368–465.

Ralph CJ, Fancy SG. 1994. Demography and movements of the `Oma`o (*Myadestes obscurus*). Condor 96:503–11.

Rappole JJ, Tipton AR. 1991. New harness design for attachment of radio transmitters to small passerines. J Field Ornithol 62:335–7.

Reynolds MH, Snetsinger TJ, Herrmann CM. 1997. Kaua`i's solitaires: update on population status and distribution. Trans West Sect Wildlife Soc 33:49–55.

Scott JM, Mountainspring S, Ramsey FL, Kepler CB. 1986. Forest bird communities of the Hawaiian Islands: their dynamics, ecology, and conservation. Studies Avian Biol 9:93,96,101.

Serena M. 1995. Reintroduction biology of Australian and New Zealand fauna. Chipping Norton: Surrey Beatty & Sons.

U.S. Fish and Wildlife Service. 1992. Endangered and threatened wildlife and plants. 50 Code of Federal Regulations 17.11 and 17.12.38.

Van Riper C III, Scott JM. 1979. Observations on distribution, diet and breeding of the Hawaiian thrush. Condor 81:65–71.

Wakelee KM. 1996. Life history of the `Oma`o (*Myadestes obscurus*) [M.S. thesis]. Manoa (HI): University of Hawaii.