

Is the Hawaiian goose (*Branta sandvicensis*) saved from extinction?

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22.1 INTRODUCTION

In this paper we answer the question in the title with a negative, not yet, not in the past or at current levels of management. We provide evidence that past efforts to save the Hawaiian goose (*Branta sandvicensis*), commonly known as nene, have effectively prolonged the extinction process, but potent limiting factors in its environment are still active and inhibiting recovery. As early as 1864, naturalists warned that the nene was on the brink of extinction (Baldwin, 1945) but, through the intensive rearing and release programmes some 500 nene are currently living in the wild on three of the larger Hawaiian islands, Hawaii, Maui and Kauai (Black *et al.* 1991). When restocking began in 1960, fewer than

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30 nene remained only on the island of Hawaii. In 1962, the first set of nene was released on Maui and, in 1982, a hurricane liberated 12 captive nene from a private collection on Kauai.

In the early phases of the recovery programme, managers removed the main limiting factor which affected the demise of this most tame of waterfowl by legislating a hunting ban, and setting aside several hundred acres of volcanic montane scrubland as sanctuaries (see Kear and Berger, 1980). Stone *et al.* (1983), Morin and Walker (1986) and Hoshida, Price and Katahira (1990) outlined a further set of potential limiting factors which may explain the low productivity and survival of the captive-reared nene that have been released; over 2100 individuals have been liberated between 1960 and 1990 (Black *et al.*, 1991). The potential problems include inbreeding depression, loss of adaptive skills, disease, poaching, road kills, dietary deficiencies and predation from introduced mammals. We tested the prevalence of a number of these factors by conducting a natural-style experiment where we monitored the breeding success of individuals (with the same genetic, behavioural and captive backgrounds as the now wild-type birds) in large enclosures that were erected in habitats where others have been released. We predicted that if the birds in the enclosures bred with the same or better success as those in the wild, then genetics and appropriate behaviour may not be limiting; rather, diet and/or predation would be. The enclosed areas kept predators out and we lessened potential feeding deficiencies by adding readily accessible food. To identify further the area which needs most urgent management action, we recorded all occurrences of predation throughout the study period.

Using demographic data, including numbers of females that hatch eggs, the proportion of successful broods and mortality rates, we modelled the likelihood of population growth or decline in three scenarios for the three sub-populations of nene.

- (a) The status quo scenario – data from the released wild birds and without further supplementations from captive stocks.
- (b) A repeat effort scenario – data from the wild birds (as above) but with a large-scale release programme mirroring the effort of the previous 30 years.
- (c) An optimal management scenario – data from the enclosure experiment and no further supplementations.

22.2 METHODS

22.2.1 Study sites

Extending from Kauai in the north to Hawaii in the south, the islands decrease in age and increase in size, elevation, habitat availability and

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habitat heterogeneity (Figure 22.1). The Hawaiian goose (Figure 22.2) on Kauai occupies rich coastal marshes and lowland pastures which are irrigated during dry periods. Seasonally moist, montane, volcanic shrub-grassland above about 1800 m elevation is the primary habitat of five wild populations on Hawaii, the Keauhou, Keauhou II, Kahuku, and Kipuka Ainahou sanctuaries, and one area on Maui, Haleakala National Park (HALE). The Hawaii Volcanoes National Park (HAVO) population utilizes a variety of vegetation types between about 300 and

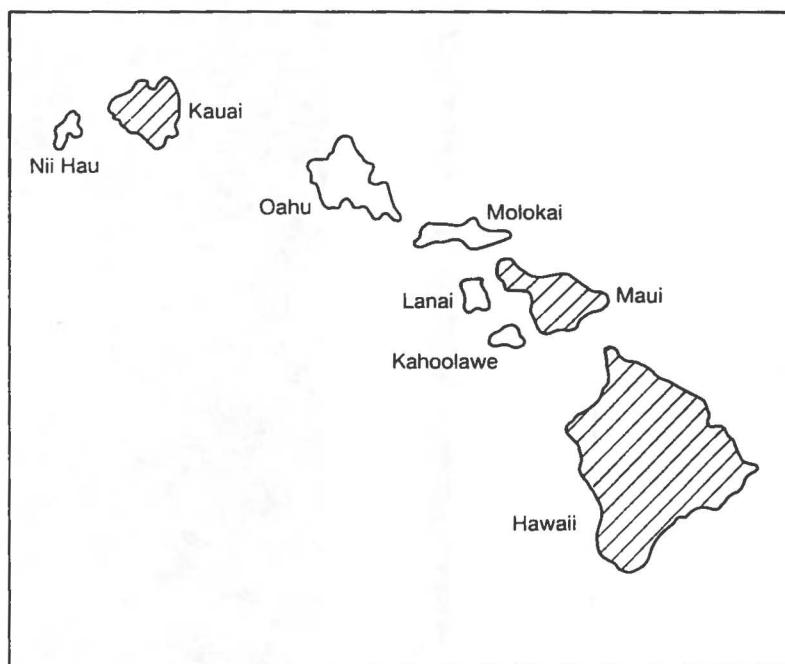


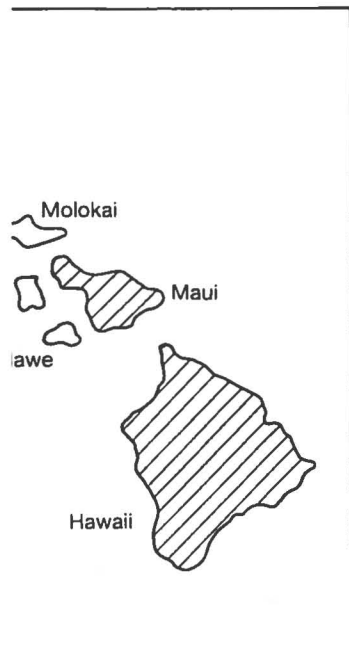
Figure 22.1 The larger islands of the Hawaii. The shaded islands are where Hawaiian geese are currently found.

1300 m elevation. Although wild populations on Maui and Hawaii generally occupy habitats dominated by native vegetation, all utilize alien plants, especially introduced pasture grasses, golf course grasses and road-side grasses.

We also studied captive nene that were placed in 10 enclosures at HAVO ranging from 0.1 to 1.5 ha in size and extending from near sea level to 1220 m elevation. Commercial poultry ration and fresh drinking water supplemented the naturally occurring vegetation in the pens.

Hawaiian goose (Figure 22.2) and lowland pastures which are usually moist, montane, volcanic vegetation is the primary habitat of Keauhou, Keauhou II, Kahuku, one area on Maui, Haleakala National Park (HAVO) in types between about 300 and

All populations were exposed to varying levels of introduced predators, including mongooses (*Herpestes auropunctatus*), feral cats (*Felis catus*) and dogs (*Canis familiaris*), although mongooses do not occur on Kauai. During the study predators were controlled by trapping around the enclosures, but not in the wild areas.



iii. The shaded islands are where

populations on Maui and Hawaii by native vegetation, all utilize pure grasses, golf course grasses

were placed in 10 enclosures at size and extending from near sea poultry ration and fresh drinking ring vegetation in the pens.



Figure 22.2 A two-year-old Hawaiian goose, commonly known as nene (pronounced neyney), with a large coded plastic leg-band (AJ).

22.2.2 Nests in the wild and enclosures

During 1978–81, nests were visited at approximately weekly intervals to determine the progress and fate of clutches. Mongooses were considered to have disturbed nests if the appearance of broken eggs was similar to chicken eggs fed experimentally to two captive mongooses and/or if eggs were away from nests; mongooses were considered responsible for the predation events if tooth marks were found on the bones of partially eaten carcasses.

22.2.3 Predation study

To identify predators and the incidence and rate of predation we placed a series of chicken egg clutches (each with three or four chicken eggs and spaced 48–83 m apart) along an elevational gradient. Four low elevation sites (213–762 m), two mid-elevation sites (1128 and 1219 m), and two high elevation sites (1950 and 2042 m) were selected in nene breeding areas in HAVO and HALE, and a total of 606 clutches were monitored in 1979 and 1980 from November through May (approximately the nene breeding season). To determine directly the identity of egg predators, 61 of the 606 artificial clutches were placed inside live-traps having 18 × 18 cm entrances. Similar traps, baited with commercial cat food, were maintained outside HAVO pens (five traps/enclosure).

22.2.4 VORTEX simulation of stochastic population change

We used the April 1991 version of the VORTEX program designed by Bob Lacy and James Grier (Grier and Barclay, 1988; Lacy, Flesness and Seal, 1989; Lindenmayer *et al.*, 1991) with the help of the Captive Breeding Specialist Group of the World Conservation Union (IUCN). The programme incorporates a number of randomly occurring events as well as environmental variation.

VORTEX simulates birth and death processes and the transmission of genes through the generations by generating random numbers to determine whether each animal lives or dies, whether each adult female produces broods of size 0 (hatches no eggs), or one, two, etc. goslings during each year, and which of the two alleles at a genetic locus are transmitted from each parent to each offspring. Fecundity is assumed to be independent of age (after an animal reaches reproductive age, set at 2–25 years for the nene) and sex-specific mortality rates were specified for each age class (see below). We specified the mating system as monogamous for nene, although 19% of the pair-units at Slimbridge (N = 45) were 2M:1F trios in 1990 and two wild trios were reported by

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Banko (1988): one 1M:2F and one 2M:1F. Due to the occurrences of trios we assumed that 98% of males sired offspring in any breeding period. The sex ratio was set at 1M:1F because the available data were variable; current ringing data 26M:26F for Maui, 385M:373F for Slimbridge, and 52M:64F for HAVO.

The computer program simulates and tracks the fate of each population, and outputs summary statistics on the probability of population extinction over specified time intervals, the mean time to extinction of those simulated populations that went extinct, the mean size of populations not yet extinct and the levels of genetic variation remaining in any extant populations. Each animal in the initial population is assigned two unique alleles at some hypothetical genetic locus. The model can include the presence of inbreeding depression – expressed in the model as a loss of viability in inbred animals. We chose to include this feature because of the possibility that a catastrophe could reduce the already small population to such a level that inbreeding could become a problem. Kear and Berger (1980) argue that the Slimbridge stock went through a temporary bottleneck leading to low productivity but this was revived after two wild-type males were incorporated. Due to the high degree of band sharing in the captive stocks (E.H. Rave, pers. comm.) we included the possibility that a lethal gene could be expressed. An example is that three of 62 eggs from the Olinda stock showed some deformity in 1990 (F. Duvall, pers. comm.).

VORTEX also models catastrophes, the extreme of environmental variation, as events that occur with some specified probability and reduce survival and reproduction for one year. We included four potential catastrophes which we assumed had the following effects. Firstly, volcanoes, 1 in 100 years, where violent eruptions of gases, ash and other pyroclastic material disrupt breeding for 5% of the population that year and kill 5% more. This was based on the facts that the flocking season lasts for 2 months (17% of a year) and that the largest flocks, at current levels, are about 30 (N. Santos and T. Telfer, unpublished data). In the other months, flock size is limited to breeding units (usually two birds), so a localized eruption will effect fewer birds. Two phreatic eruptions of Kilauea have occurred during the past 200 years (Heliker, 1989). Volcanic eruptions are not a problem for the Maui and Kauai flocks. Secondly, tsunami, 1 in 20 years, where the severity values are the same as for volcanic eruptions for the Hawaii flock but on Kauai the value of 30% mortality was used. A tsunami destroyed 31 of H. Shipman's 42 semi-captive nene on Hawaii in 1946. Tsunami are not a problem to the nene on Maui. Thirdly, hurricanes, 1 in 200 years, where all nesting attempts are destroyed in that year but all adults survive. Fourthly, disease epidemics, 1 in 50 years, were attributed with the same severity values as volcanic eruptions. We decided to write a disease

possibility in because although infrequent it can cause massive mortality in waterfowl populations (Owen and Black, 1990). However, since nene currently rarely congregate in flocks larger than 30 birds, the potential effect has been scaled down, to the severity values as volcanic eruptions.

VORTEX also allows the user to supplement the population from captive stocks. In the Repeat Effort Scenario we released birds at the same rate as in the previous 30 years of the restocking programme (on Hawaii and Maui) to simulate what would happen in the future if we were to repeat our efforts. We ran each scenario 1000 times for a 200-year period with the carrying capacity truncation set at 2000 individuals.

22.3 RESULTS

22.3.1 Predation

Nest success (at least one egg hatched) in enclosures was nearly twice as high as in the wild (Table 22.1; Banko, 1992): 83% of 30 enclosure nests vs. 44% of 70 wild nests. Predation by mongooses, the leading cause of nest failure in the wild, resulted in the loss of 28 of 70 nests (40%); they destroyed 24 wild clutches and killed four females at the nest. Predation in the enclosures was rare; only one clutch in 39 nests (3%).

Trapping and the chicken egg placements also demonstrated that mongooses were the most serious nest predators in all habitats. Artificial clutches ($N = 606$) were disturbed or destroyed by mongooses in 54% of all cases; 43% of all clutches were disturbed within 30 days (nene incubation period). Clutches at lower elevations were destroyed most rapidly; 79% of low elevation clutches ($N = 168$), 71% of mid-elevation clutches ($N = 54$) and 20% of high elevation clutches ($N = 384$) were destroyed after 30 days (Chi square = 203.9, $df = 2$, $P < 0.001$, also see Stone, Hoshide and Banko 1983). Forty-six mongooses were caught at 61 live-traps baited with chicken eggs. During 1975–80, 745 mongooses and 11 feral cats were trapped at enclosures, thus illustrating the high density of these introduced predators in low and mid-elevation habitats.

22.3.2 Simulations

(a) Values for the model

Table 22.2 lists the demographic values that changed in the various scenarios. The value for first year mortality (between hatching and 12 months) was based on two data sets. We assessed that only one gosling fledged from 56 eggs that hatched, and Hoshide, Price and Katahira (1990) reported that 48 fledglings came from 144 hatchlings. This yields

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it can cause massive mortality (K, 1990). However, since more than 30 birds, the potential values as volcanic eruptions. To complement the population from various scenarios we released birds at the same restocking programme (one would happen in the future if we simulated this scenario 1000 times for a 200-individual population set at 2000 individuals.

enclosures was nearly twice (O, 1992): 83% of 30 enclosure were lost by mongooses, the leading cause in the loss of 28 of 70 nests and killed four females at the same time; only one clutch in 39 nests

experiments also demonstrated that predators in all habitats. Artificially destroyed by mongooses in 54% disturbed within 30 days (nests destroyed were destroyed most = 168), 71% of mid-elevation nest clutches (N = 384) were lost, $t = 3.9$, $df = 2$, $P < 0.001$, also see that six mongooses were caught at the same time during 1975–80, 745 mongooses were trapped, thus illustrating the high density in low and mid-elevation habitats.

that changed in the various habitats (between hatching and 12 months) assessed that only one gosling was lost (Hoshida, Price and Katahira 1990) from 144 hatchlings. This yields

Table 22.1 Breeding demographics and breeding success of nene in the enclosures at HAVO

	1975	1976	1977	1978	1979	1980	1981
Total population ^a	2	16	21	29	14	17	20
Pairs capable of breeding	1	6	5	8	5	7	6
Pairs breeding	1	5	5	5	2	4	4
Percentage of pairs breeding	100	83	100	62	40	57	67
Percentage of total population breeding	100	62	48	34	29	47	40
Nest attempts ^b	1	5	7	5	2	5	5
Successful nests ^c	1	5	6	4	1	4	4
% Nest success	100	100	86	80	50	80	80

^aIncludes juveniles (<2 years) and adults. Juveniles were fledglings produced 1 year earlier; in reality they fledged from the enclosures before their first year. Not included in annual totals were free-flying individuals that voluntarily tested in enclosures or associated with captives; individuals from other captive flocks that were too old (>15 years); or those which had insufficient time to adjust to new conditions before the breeding season (<1 year).

^bIncludes first nests and re-nest attempts.

^cAt least one egg hatched.

Table 22.2 Demographic data used in three computer simulations: A = status quo scenario; B = repeat effort scenario; C = optimal management scenario

	Hawaii	Maui	Kauai	Source ^a
Starting pop. size	340	180	37	a,b,c
Number released				
A and C	0	0	0	
B	1560	460	—	a,d
Maximum brood size				
A and B	4	4	6	c
C	6	6	—	c
Average brood size				
A and B	2.56	1.89	3.33	c,e
C	3.00	3.00	—	
Percentage of no. hatching				
A and B	79.1	77.4	83.0	f
C	69.1	69.1	—	
First year mortality				
A and B	75.5	75.5	27.4	f
C	55.0	55.0	—	

^aa = Black *et al.* (1991). b = Natividad Hodges (1991). c = The Nene Recovery Team (unpublished data). d = Releases occurred in years 1–30 on Hawaii and in years 1–19 on Maui. Equal numbers of both sexes were released. A pair of two- and three-year olds accompanied each batch of one-year old releases to enhance survival (see Marshall and Black, 1992). e = Banko (1988); Banko (1992). f = Values calculated in the text.

a value of 75.5% mortality in the first year, the value attributed to the Hawaii and Maui flocks in the Status Quo and Repeat Effort Scenarios. In the enclosures, first year mortality was only 12.5% (30 of 241 hatched goslings) so we chose a more realistic figure of 55% for the Optimal Management Scenario, the same value as the steadily increasing population of barnacle geese (*Branta leucopsis*) (Owen 1982; Prop, van Eerden and Drent, 1984). In the second and 3+ years we attributed a 14% and 5% mortality rate, respectively, in all scenarios (Banko and Elder, 1989, unpublished data). We chose to make male mortality rates slightly lower (as for other geese: Owen, 1982); age 2 = 13% and age 3+ = 4%. The variation in each of these mortality values was set at $\pm 10\%$.

The values chosen for the proportion of nene that succeed in breeding attempts (hatching at least one egg) were calculated using the following data on numbers of non-breeders and failed breeders.

Hawaii: based on data from Banko (1992) and using the proportion of paired and unpaired birds in the population, 85% of the 340 Hawaii nene were capable of breeding and 51–62% of these attempted to breed.

computer simulations: A = status optimal management scenario

Maui	Kauai	Source ^a
180	37	a,b,c
0	0	
160	—	a,d
4	6	c
6	—	c
1.89	3.33	c,e
3.00	—	
77.4	83.0	f
69.1	—	
75.5	27.4	f
55.0	—	

c = The Nene Recovery Team
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This means between 147–179 individuals or 73–89 pairs tried to breed each year. One or more eggs hatched in 44% of 70 nests. This means that 32–39 nests hatched one or more eggs (mean of 35.5 broods), and this involves 64–78 individuals. Therefore, 262–276 nene, or a mean of 79.1% of the population, did not successfully hatch eggs. We set the value for environmental variation (EV) at 18.5% based on the extreme proportions of breeders in the population; 44% in 1978 and 54% in 1979 (Banko, 1992); $EV = (0.44/0.54) - 1 \times 100$.

Maui: based on Banko (1992), 81% of the Maui flock (N = 180) were capable of breeding and 24–76% of these attempted to breed. This means between 35–111 individuals or 18–56 pairs bred and 44% of these hatched one or more eggs, yielding 8–25 successful nests or 16–50 successful individuals. Therefore, 96–130 nene or a mean of 77.4% of the population did not hatch eggs. We set EV at 68.3% based on the extreme proportions of breeders in the flock; 24% in 1979 and 76% in 1981. In addition, due to the high elevation and location of Haleakala, entire cohorts face cold, wet conditions in some years, thus causing early mortality. For example, in 1989 it snowed and hailed for 12 days during the hatching or brooding period (C. Natividad Hodges, pers. comm.).

Kauai: based on T. Telfer (unpublished data), 86% of the Kauai flock (N = 37) were capable of breeding; so eight birds or four pairs bred (24%) and 73% of these succeeded in hatching one or more eggs. Therefore, 31 birds or 83.7% of the population did not hatch eggs. We set EV at 28% based on the extreme proportions of breeders in the flock; 21.6% in 1990 and 30% in 1987.

The enclosure value: including juveniles produced the previous year, 51% of the captive flock was capable of breeding and 40–100% (mean = 73%) of these attempted to breed (Table 22.1). Five of 30 (17%) nesting attempts failed. Thus, in the model 69.1% of the population did not hatch eggs, when the mean value used for non-breeding was 63%. We set EV at 54.2% based on the extreme proportions of breeders in the flock; 28.6% in 1979 and 62.5% in 1976.

(b) Status Quo Scenario

In this model we found that the Kauai flock was the only one to survive, although in only 91% of the simulations (Figure 22.3; Table 22.3). Numbers on Kauai rose throughout the 200-year period, peaking at 1400 (18 SE) individuals. The number of alleles in the Kauai flock was preserved quite well over time; 37 birds and 74 alleles at the start and 23 alleles preserved (31%) in 200 years. In contrast, only 41% and 2% of Hawaii and Maui populations, respectively, survived the 200-year period. Even in these surviving cases numbers were approaching extinc-

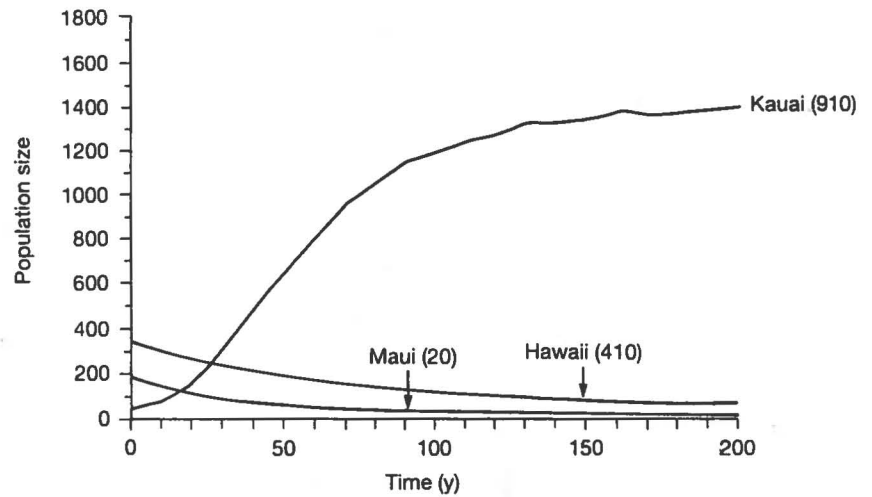


Figure 22.3 A model showing population change in the Status Quo Scenario over a 200-year period without further supplementations. The curves are based on the means of the 1000 simulations for each population. The figures in parentheses indicate the number of simulations when the population did not go extinct. The arrows indicate the mean year of extinction for the unsuccessful simulations (see Table 22.3).

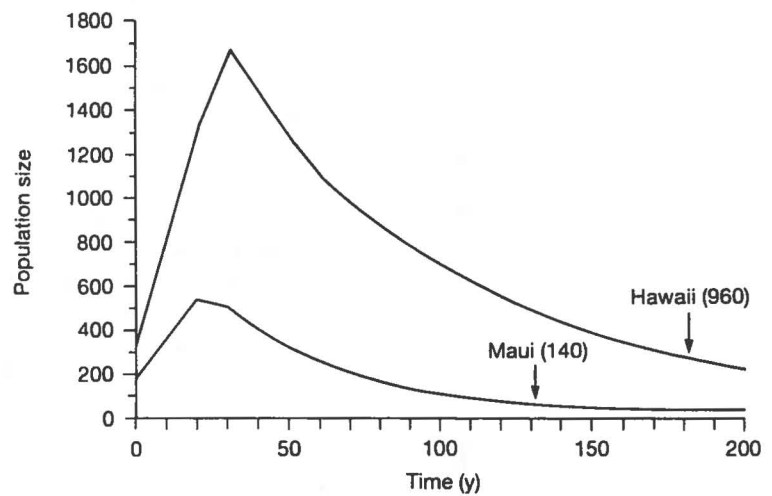


Figure 22.4 A model showing population change in the Repeat Effort Scenario over a 200-year period with initial supplementations. The curves are based on the means of the 1000 simulations for each population. The figures in parentheses indicate the number of simulations when the population did not go extinct. The arrows indicate the mean year of extinction for the unsuccessful simulations (see Table 22.3).

Kauai (910)

Hawaii (410)

150 200

age in the Status Quo Scenario
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Hawaii (960)

Maui (140)

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tion. The populations on Hawaii and Maui declined throughout the period (Maui at a faster rate than Hawaii) and on average went extinct by year 149 (1 SE) and 91 (1 SE), respectively.

(c) Repeat Effort Scenario

In this scenario 1560 nene were released over a 30-year period on Hawaii and 460 nene were released over 19 years on Maui, which closely matches the previous release efforts (Black, Duvall and Hoshide, 1991). Annual releases included 25:25 (female:male) one-year-old geese together with a 1:1 two-year-old pair. With these additional releases, the livelihood of the Hawaii and Maui flocks was prolonged for 33 and 41 years (the mean time till extinction), and increased final population size (at the end of the 200 year period) by 171 and 33 individuals, respectively (Figure 22.4; Table 22.3). However, in all cases, numbers were declining and extinction was approaching.

On both islands numbers peaked in the year of the final releases and thereafter declined. This repeated release effort was more successful on Hawaii than on Maui (final populations of 234 vs.44, respectively).

(d) Optimal Management Scenario

In this model the values for numbers successfully hatching, brood sizes and survival reflected a situation where predation was reduced and feeding opportunity was enhanced. The values we chose were based on real situations within the enclosure experiments (Table 22.1). In this enhanced environment both the Hawaii and Maui flocks quickly flourished to self-sustaining levels and approached the level of carrying capacity truncation at 2000 individuals (Figure 22.5; Table 22.3). By the 40th and 50th year the Hawaii and Maui populations, respectively, rose to above 1600 individuals and continued to rise at a slower rate for the remaining period.

We checked the effect of each of the three parameters in turn (Table 22.2); only when all three were incorporated did the population reach a self-sustaining level. The preservation of original alleles was 18% for Hawaii and 27% for Maui birds (Table 22.3).

22.4 DISCUSSION

The situation which has arisen on Kauai gives grounds for optimism. Our model shows that even with status quo demographic data the Kauai flock grew toward carrying capacity in 91% of the simulations. Recent counts support this result; 12 birds in 1982, 27 in 1987 and 75 in 1992 (T. Telfer, pers. comm.). However, the population went extinct in the other 9% of the simulations. It could be argued that only a 100% chance of

Table 22.3 Summary statistics of three scenarios for the three nene populations: in each case 1000 simulations were run and the carrying capacity truncation was set at 2000 individuals

	<i>Status quo</i>			<i>Repeat effort</i>		<i>Optimal mangt.</i>	
	<i>Kauai</i>	<i>Hawaii</i>	<i>Maui</i>	<i>Hawaii</i>	<i>Maui</i>	<i>Hawaii</i>	<i>Maui</i>
Starting population	37	340	180	340	180	340	180
Final population ^a	1400	63	11	234	44	1631	1673
Probability of extinction (%)	9	59	98	4	86	1	0
Mean years to extinction	64	149	91	182	132	115	—
Growth rate (r) ^b	0.05	-0.02	-0.04	-0.02	-0.04	0.08	0.09
Mean lambda	1.08	0.98	0.96	0.98	0.96	1.10	1.11
Final heterozygosity							
expected	0.86	0.78	0.68	0.94	0.80	0.98	0.98
observed	0.88	0.87	0.84	0.98	0.90	0.99	0.99
Final number of alleles	23	12	6	51	14	119	98

^aMean of the extant populations after 200 years.

^bMean growth rate in years with supplementation, prior to carrying capacity truncation.

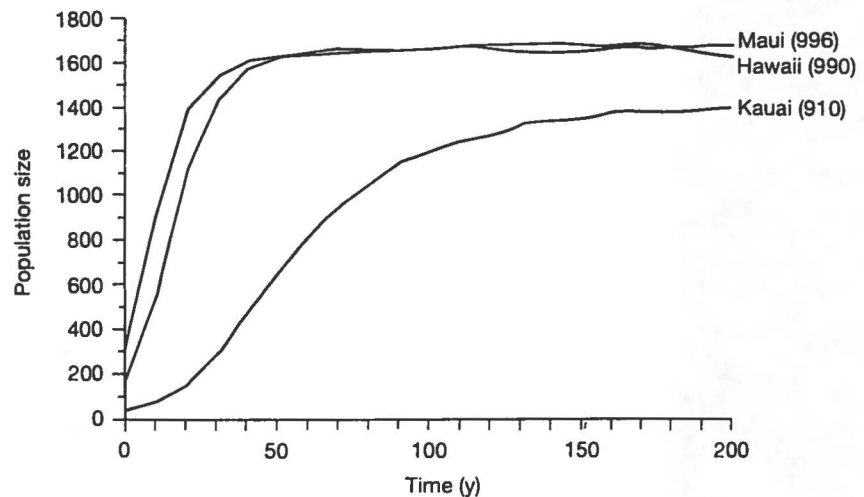


Figure 22.5 A model showing population change in the Optimal Management Scenario over a 200-year period without further supplementations. The curves are based on the means of the 1000 simulations for each population. The Kauai curve is from the Status Quo Scenario (Figure 22.2) for comparison. The figures in parentheses indicate the number of simulations when the population did not go extinct, which was nearly 100% in this model.

success is acceptable and that further management is needed. On Kauai habitat suitability and predators are not apparently limiting the nene. Instead, the genetic management of the flock could be improved; the flock was founded by three breeding pairs which may themselves have been related. The Nene Recovery Team has realized the potential significance of the Kauai population and has begun a programme to increase the genetic diversity. Seven birds with different origins were released at a refuge on the northern coast of the island in 1991, and further releases are planned until the full component of genetic lineages have been included on the island – a positive step towards a healthier population (see Tomlinson *et al.*, 1991).

The finding that the median time to extinction for the nene on Hawaii was increased by 31 years after a further 30 year release programme indicates that the extinction process is being held at bay by the captive breeding and release scheme. The modelling shows that a further period of releases on Hawaii maintained numbers above 200 individuals, and that the population survived in 96% of the simulations. This suggests that reintroduction as a management tool may continue to be effective in prolonging extinction on Hawaii, but it will not enable the population to achieve self-sustaining status. Actual counts at HAVO reveal that

Mean lambda	1.08	0.98	0.96	0.98	0.96	1.10	1.11
Final heterozygosity							
expected	0.86	0.78	0.68	0.94	0.80	0.98	0.98
observed	0.88	0.87	0.84	0.98	0.90	0.99	0.99
Final number of alleles	23	12	6	51	14	119	98

^aMean of the extant populations after 200 years.

^bMean growth rate in years with supplementation, prior to carrying capacity truncation.

numbers have apparently declined by 15% since 1989 (159 then and 135 in 1991) (Katahira, pers. comm.).

In retrospect, therefore, it appears that management efforts in the first 30 years of the nene recovery programme have prolonged extinction of the original 30 nene that remained in the uplands of Hawaii in the 1950s. The Repeat Effort Scenario for the Maui population, on the other hand, was not so successful as on Hawaii; in only 14% of the simulations did the populations survive. In this model we used a large value for environmental variation due to the annual variation in the proportion of non-breeders (suggesting that breeding condition is sometimes not achieved), and to the harsh weather conditions during the breeding season, which can limit the survival of young goslings. In spite of this, recent counts from this area have been consistent at about 150 individuals in recent years (Natividad Hodges, 1991; Black *et al.*, 1991). This stability may be due to the large-scale predator control programme that was instigated in the Haleakala Crater in 1981 (see below).

Our enclosure and non-enclosure comparison shows that when mongooses and feral cats were removed from current nene habitats, then and only then could the population become self-sustaining. The Optimal Management Scenario model showed that after the first 10 years under an enhanced management both the Hawaii and Maui flocks tripled in size. This indicates that large-scale predator control on behalf of the nene could be an effective conservation action. Managers in Haleakala National Park, Maui, where about 35% of wild nene live, have begun such a programme. They work a series of about 400 live-traps throughout the crater. Managers on Hawaii are seeking support to enable them to increase their predator control effort to similar levels.

We have ruled out the possibility that inbreeding depression is limiting productivity and survivability in nene. The model shows that, even when including the inbreeding depression feature, numbers can increase to safe levels. The data from the enclosures show that nene do have the necessary skills to establish partnerships, copulate, incubate and rear offspring. However, our model does not reflect how naïve captive-bred nene cope once released. Marshall and Black (1992) showed that the early experiences of nene, whether reared by parents, foster parents or without parents, can affect their social development, reactions to predators and ability to integrate with adult nene after release. Managers and aviculturists in Hawaii have acted on these findings and are attempting to offer nene more appropriate early experiences prior to release.

In addition, an intensive series of field studies has begun to assess the current feeding and energetic constraints of nene in different habitats (Black, 1990; Black *et al.*, 1991). Banko (1988) showed that the nene in enclosures had larger clutches, took fewer and shorter nest

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recesses and slept for shorter periods than those nesting in the wild. He attributed these differences to the fact that supplemental feed was available to the geese in the enclosures. By enhancing the feeding opportunities for nene the number of potential breeders, successful breeders and surviving offspring will increase. Providing predation is kept to a minimum, these revived demographic parameters will enable the nene to reach a self-sustaining level.

In conclusion, the Hawaiian goose is once again in danger of extinction. However, we predict that when management efforts are enhanced to include an appropriate predator control effort the nene flocks in the Hawaiian state will be able to thrive. When predation levels are kept to a minimum, as on Kauai, managers will look forward to a new set of challenges as numbers increase and individuals disperse.

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