Population and reproductive trends of Nene *Branta sandvicensis* in Hawaii Volcanoes National Park, 1989–1999

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The Hawaiian Goose or Nene *Branta sandvicensis* is an endangered species endemic to Hawaii. Hawaii Volcanoes National Park contains about 41% of Nene on the island of Hawaii. Population numbers, reproductive success and causes of known adult mortality of Nene in the park were summarised from 1989 to 1999 in order to determine population and reproductive trends. Reproductive data were also pooled across years to determine overall reproductive success at several sites within the park. Numbers in the park generally increased throughout the decade, from 153 birds in 1990/1991 to 203 in 1997/1998. Annual hatching success averaged 55%, whereas annual fledgling production averaged 11 birds. Fledgling production varied among sites, from 0 at Mauna Loa and Kipuka Kahalii to 32 at Pen 7. The most common cause of known adult mortality was road kill. Population numbers increased throughout the decade probably, in part, because of intensive predator control. However, recruitment remained low because of starvation, dehydration and predation on goslings. Nene at certain sites within the park had high reproductive success, perhaps because those sites contained more nutritious food for adults and goslings or had supplemental food and water provided to the birds. Managers need to continue to control predators and improve or restore habitat to maximise Nene population numbers.

Key Words: ***Branta sandvicensis,*** **Hawaiian Goose, Nene, population trends, reproductive success**

The Hawaiian Goose or Nene *Branta sandvicensis* is an endangered species endemic to Hawaii. Nene were perilously close to extinction in 1950, when only 17 wild birds were known to exist, all on the island of Hawaii (Elder & Woodside 1958). To help increase Nene numbers, the state of Hawaii initiated a captive colony in 1949, with the goal of re-establishing self-sustaining wild populations. Beginning in 1960, captive birds were released at several sites on Hawaii, including Hawaii Volcanoes National Park (HVNP) (Kear & Berger 1980). Captive birds have continued to be released at HVNP throughout the past 45 years. Nene currently found in HVNP descend from these captive-released birds, as well as from the last remaining wild Nene found on the island in the 1950s.

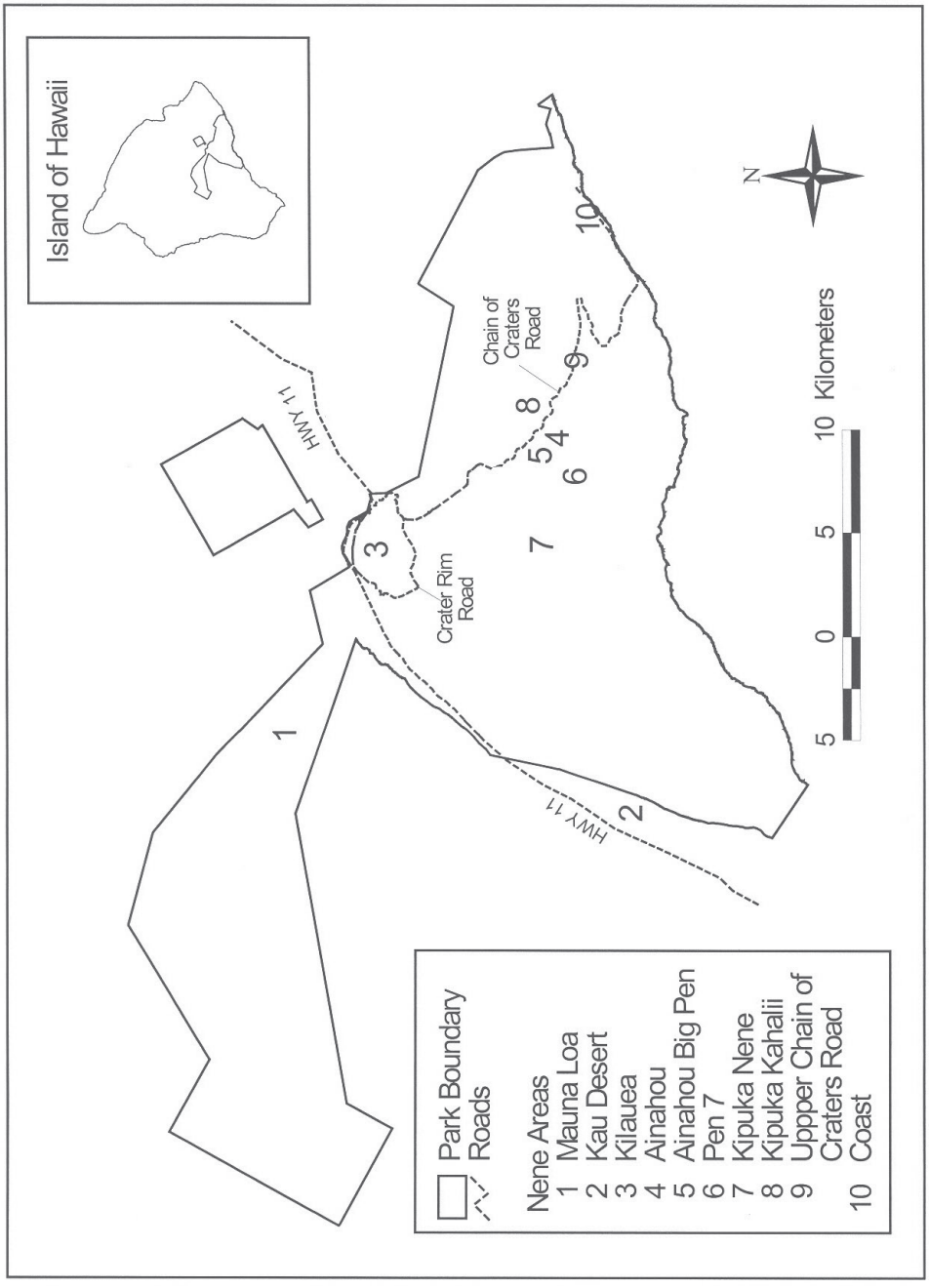
Today, about 41% of the island's Nene population resides in and around HVNP (U.S. Fish & Wildlife Service 2004). Management practices such as predator control, habitat restoration and reducing the birds' contact with humans have concentrated on enhancing reproductive success and survival of wild Nene. In order to determine whether management practices are working, Nene numbers in HVNP have been surveyed. Surveys conducted in the 1970s showed a substantial decrease in Nene numbers in HVNP, from 300 birds in 1975 to 50 in 1979 (W.S. Devick, Hawaii Department of Land and Natural Resources, unpublished data). However, numbers increased throughout the 1980s, from 75 birds in 1981 to 179 birds in 1988 (Hoshide *et al*. 1990).

To determine numbers and reproductive trends of Nene in HVNP throughout the 1990s, population estimates, reproductive success and causes of known adult mortality of Nene were summarised from 1989 to 1999. It is hoped that any trends observed will assist park personnel in managing Nene better in HVNP.

Methods

This study was conducted in HVNP, a 930-km^2 park located on the island of Hawaii (**Figure 1**). From 1989 to 1999, yearly numbers of Nene in HVNP were determined. Because Nene breed on a declining day length (Kear & Berger 1980), and thus begin to breed in October, years were defined as 1 October to 30 September. During each year, all ringed wild and captive-released birds were counted. (Wild birds were caught and ringed opportunistically, and captive birds were ringed prior to their release.) Unringed birds were counted by their affiliation with their ringed mates, as Nene usually pair for life (Black *et al*. 1996). Unringed birds without ringed mates were counted on the one day each year when the greatest number of unringed birds was seen. These measures ensured that a high proportion of the population was counted. Captive birds located in HVNP were also counted because they contributed offspring to the park's Nene numbers. All ringed birds counted in a given year were also included in the estimate for the following year, even if they were not sighted the following year. However, if two years elapsed without sighting a specific bird, it was considered dead and was removed from that year's estimate. Additionally, if a bird was known to have died during

Figure 1. Location of the 10 study sites within and adjacent to Hawaii Volcanoes National Park, Hawaii. Sites reflect nesting and brooding areas historically used by Nene.



a given year, it was not counted in that year's estimate.

Similar to the methods of Hoshide *et al*. (1990), the number of breeding pairs and the number of nesting attempts of wild and captive-released Nene were determined each year in HVNP by counting (1) number of known nests, (2) birds associated with goslings or newly-fledged young, and (3) females that were gravid (based on abdominal profile, Zillich & Black 2002) or had brood patches. Yearly egg production and hatching success were determined by finding nests and counting the number of eggs laid and the number of eggs that hatched. Because nests were often difficult to find, egg and hatching data from known nests were a subset of total nesting attempts. Fledgling production was determined by following the fate of all known goslings, regardless of whether the nests from which they came were found.

Reproductive data across all years were pooled to determine overall reproductive success for each of 10 sites within and adjacent to HVNP. The chosen sites reflected nesting and brooding locations historically used by Nene. Sites were (1) Mauna Loa (2,012 m), (2) Kau Desert (726–914 m), (3) Kilauea (1,220 m), (4) Ainahou (726–838 m), (5) Ainahou Big Pen (838 m), (6) Pen 7 (729 m), (7) Kipuka Nene (900 m), (8) Kipuka Kahalii (853–945 m), (9) Upper Chain of Craters Road (31–1,128 m), which includes all non-coastal areas along the road, and (10) Coast (<31 m), which includes the coastal region of Chain of Craters Road and all other regions along the coast (**Figure 1**). Ainahou Big Pen (5 ha) and Pen 7 (0.5 ha) are both fenced, open-topped enclosures that were built to enhance reproductive success of Nene nesting within them. Supplemental food and water are provided to Nene inside the pens, and a fence and a perimeter trapline protect nests and birds from introduced predators such as Indian Mongoose *Herpestes javanicus*, rats *Rattus rattus*, *R. exulans* and *R. norvegicus*, Feral Cat *Felis catus* and Feral Pig *Sus scrofa*. Although Ainahou Big Pen (constructed in 1994) is still in use, Pen 7 was built at a time when little was known about appropriate habitat for Nene. Consequently, it was constructed in sub-optimal habitat and used by nesting Nene only through the 1996/1997 breeding season.

Additionally, causes of known adult mortality were summarised across all years of the study.

Results

Numbers of Nene generally increased throughout the study, from 153 birds in 1990/1991 to 203 birds in 1997/1998. However, numbers declined approximately 10% during the last year of the study (**Table 1**).

Reproductive success fluctuated greatly throughout the study. The percentage of the population that bred each year varied from 26% to 46% (**Table 1**), with an overall mean of 35%. The number of nesting attempts varied from 22 to 48, with some pairs attempting more than one nest per year (**Table 1**). Of those nests that were found, the mean clutch size was 2.7 eggs. Yearly hatching success of known nests varied from 44% to 77% (**Table 1**); of these hatchlings, only 30%, on average, fledged (range = 0–50%).

Table 1. Yearly Nene population numbers (N) and numbers of breeding pairs, nesting attempts, eggs laid, eggs hatched and goslings fledged in Hawaii Volcanoes National Park, Hawaii, 1989–1999.

Year	N	Breeding pairs	Nesting attempts	Eggs laid[a]	Eggs hatched[a]	Goslings fledged[b]
1989/1990	166	25 (30)[c]	26	31 (10)[d]	24 (77)[e]	2
1990/1991	153	24 (31)	24	11 (4)	6 (55)	0
1991/1992	154	25 (32)	27	43 (16)	22 (51)	11
1992/1993	157	21 (27)	22	42 (16)	19 (45)	12
1993/1994	153	23 (30)	24	50 (18)	25 (50)	13
1994/1995	171	36 (42)	38	46 (21)	26 (57)	15
1995/1996	172	37 (43)	37	43 (15)	27 (63)	16
1996/1997	192	37 (39)	38	33 (12)	16 (48)	18
1997/1998	203	47 (46)	48	40 (16)	24 (60)	15
1998/1999	182	24 (26)	25	27 (10)	12 (44)	11
Total			**309**	**366 (138)**	**201 (55)**	**113**

[a]Eggs laid and eggs hatched are from known nests.
[b]Goslings fledged include data from all known goslings in the population.
[c]Percentage of Nene in the population attempting to breed.
[d]Number of known nests found.
[e]Percentage of eggs that hatched from known nests (# of eggs hatched/# of eggs laid).

Yearly fledgling production varied from 0 to 18 birds (**Table 1**), with an annual mean of just 11. Of those fledglings that were ringed and whose fate could be followed, 42% eventually attempted to breed. Thus, overall recruitment of Nene into the population was generally low throughout the study.

Some sites in HVNP were used more frequently than others by Nene during the reproductive season. Based on the number of breeding pairs and nesting attempts, the most frequently used sites were Kipuka Nene, Kau Desert, Kilauea and Ainahou (**Table 2**). Although Kipuka Nene had more breeding pairs and nesting attempts than any other site, only 16 birds fledged from the site throughout the 10-year study period (**Table 2**). The highest number of birds fledged from Pen 7 (32), even though this site had less than half the number of nesting attempts as Kipuka Nene (**Table 2**) and was used only through the 1996/1997 breeding season.

Forty-nine known adult Nene are known to have died during this study. Of those, 30 birds (61%) were killed by vehicles, seven (14%) were depredated (two by Feral Cats, one by an Indian Mongoose, one by either a feral cat or dog, and three by unknown predators), six (12%) were struck by golf balls, one (2%) was caught in a small mammal trap, one (2%) died after ingesting fertiliser, and four (8%) died of unknown causes.

Discussion

Numbers of Nene in HVNP generally increased throughout the 10 years of the study. Indeed, numbers have been increasing since 1979, when only 50 birds were counted at Ainahou (W.S. Devick, Hawaii Department of Land and Natural Resources, unpublished data). By 1988, Nene numbered 179 birds, an increase of 258%; however, much of this increase resulted from a high number of captive birds that were released during the 1980s (Black *et al*. 1991; Hoshide *et al*. 1990). Captive releases declined to fewer than 60 birds throughout the 1990s. Over 80% of these releases occurred in the first five years of the decade (U.S. Fish & Wildlife Service 2004), a time when population numbers remained relatively stable. Although these birds may have contributed to some of the observed population increase during the last half of this study, an important contributing factor was probably intensive predator control. In 1995, a large-scale predator control effort using trapping and the anticoagulant diphacinone began. Thereafter, numbers of Nene increased until 1998. In 1998/1999, however, numbers declined by 10%, perhaps due to the drought that affected HVNP during the last two years of this study. Although the population decline was within an expected range of yearly variation for Nene (U.S. Fish & Wildlife Service 2004), it is nevertheless problematic in an endangered population with such low recruitment rates.

The mean percent of the population that bred each year was only 35%. This low number may be caused by low food availability, which results in insufficient body reserves for egg production by females (Banko 1992). Hu (1998) concluded that a larger proportion of females must breed each year to establish self-sustaining

Table 2. Numbers of Nene breeding pairs, nesting attempts, eggs laid, eggs hatched and goslings fledged from each site within Hawaii Volcanoes National Park, Hawaii, 1989–1999.

Site	Breeding pairs	Nesting attempts	Eggs laid[a]	Eggs hatched[a]	Goslings fledged[b]
Mauna Loa	4	4	8 (3)[c]	0 (0)[d]	0
Kau Desert	61	64	41 (16)	25 (61)	28
Kilauea	49	50	68 (28)	37 (54)	10
Ainahou	47	47	40 (16)	23 (57)	17
Ainahou Big Pen	9	11	28 (10)	8 (29)	2
Pen 7	32	34	84 (26)	51 (61)	32
Kipuka Nene	74	75	75 (31)	41 (55)	16
Kipuka Kahalii	9	9	6 (2)	4 (67)	0
Upper Chain of Craters Road	4	4	3 (1)	3 (100)	1
Coast	5	5	13 (5)	9 (69)	7
Area Unknown	6	6	---	---	0
Total		**309**	**366 (138)**	**201 (55)**	**113**

[a]Eggs laid and eggs hatched are from known nests.
[b]Goslings fledged include data from all known goslings in the population.
[c]Number of known nests found.
[d]Percentage of eggs that hatched from known nests (# of eggs hatched/# of eggs laid).

numbers of Nene in HVNP. To achieve this, improved quality and quantity of food may be necessary (Banko 1992; Black & Banko 1994; Black *et al*. 1994; Woog & Black 2001).

Hatching success of known nests was relatively high in some years, though on average approximately 45% of the eggs failed to hatch throughout the study. Eggs failing to hatch were infertile, broken or depredated (HVNP, unpublished data). Although infertility can be caused by inbreeding, this may not be a major factor limiting reproductive success of Nene. For example, Nene numbers on Kauai have increased dramatically since 1985 (U.S. Fish & Wildlife Service 2004) despite the low genetic diversity and high levels of inbreeding found in those birds (Rave 1995). Population increases have been attributed to good lowland habitat and lack of mongooses (Black *et al*. 1991). Thus, low hatching success of Nene in HVNP may be caused more by introduced predators than by inbreeding. Predators that take Nene eggs include Indian Mongooses, rats, and Feral Pigs, with mongooses being particularly important (Banko 1992; Black & Banko 1994; Hoshide *et al*. 1990; Stone *et al*. 1983a). Indeed, Banko (1992) found that mongooses accounted for 62% of unsuccessful clutches on Hawaii and Maui between 1978 and 1981.

In contrast to the relatively high hatching success, fledgling production was consistently low. However, the total number of Nene that fledged during this study (113) was more than twice that of the previous 15 years (48) (Hoshide *et al*. 1990). This was probably due to the increased intensity and duration of predator control and to supplemental feeding during the breeding season. Nevertheless, few Nene were recruited into the population during this study. High gosling mortality was caused by starvation, dehydration and predation. Indeed, Hu (1998) found that the primary cause of gosling mortality in HVNP during the mid-1990s was starvation and dehydration. Other researchers also found inadequate nutrition to be a large factor contributing to gosling mortality on Hawaii (P. Baker & H. Baker, Hawaii Department of Land and Natural Resources, unpublished data; Banko 1992; Woog 2002) and Maui (Banko 1992). Additional gosling mortality is caused by predators (Banko 1992; Hoshide *et al*. 1990; Kear & Berger 1980) such as mongooses, cats, rats, pigs and dogs, all of which are controlled in HVNP. The continued and expanded control of introduced predators and the increased availability of nutritious food may help to improve fledging success, thereby enhancing the recruitment rate of Nene into the population.

The sites that Nene used during the reproductive season influenced their overall reproductive success. For example, no goslings fledged from Mauna Loa or Kipuka Kahalii because both sites are sparsely vegetated (Woog 1999) and lack the nutritious forage that goslings need in order to grow.

Although a high number of nesting attempts (75) occurred at Kipuka Nene, a result also reported by Hoshide *et al*. (1990) and Woog (2002), the fledgling production (16 birds) was low. Food supply and quality for goslings at this site are low (HVNP, unpublished data). Additionally, low fledgling production

could have been due to frequent human disturbance, as there had been a public campground located within Kipuka Nene. To reduce this potential problem, the campground was closed permanently in 1999.

The number of goslings that fledged from Kau Desert was relatively high (28), probably because this area contains a large pasture where goslings frequently forage. Indeed, Banko (1988) found that gosling survivorship is positively correlated with the nearness of nests to grass pastures. Additionally, Kau Desert has a relatively low density of mongooses (Hoshide *et al*. 1990; Stone *et al*. 1983b), further contributing to the survivorship of goslings.

Kilauea had a high number of nesting attempts (50); however, gosling mortality was high, with only 10 birds fledged from the area. Though Nene are not discouraged from nesting here, broods are sometimes translocated to more suitable habitat, where there is better forage and less disturbance from people. Unfortunately, long-distance translocations may not always be advisable because they can destroy pair bonds and disrupt family groups (HVNP, unpublished data).

Many nesting attempts occurred at Ainahou (47). However, few nesting attempts were made inside Ainahou Big Pen (11), which is located within the Ainahou area, in spite of supplemental food and water supplied to Nene and perimeter traplines protecting them from predators. The success of Pen 7 (32 fledglings during the decade) indicates that Ainahou Big Pen should be successful, as it is bigger and situated in better nesting and foraging habitat (Woog & Black 2001) than Pen 7. Ainahou Big Pen was built in 1994, and perhaps Nene will use it more in the future after females that fledge from the pen attain breeding age (females generally breed close to their natal sites, Stone *et al*. 1983a).

While high gosling mortality is a serious problem and one that needs to be rectified before the population can increase (Hu 1998), the influence of adult mortality on population size in HVNP is poorly understood. Of the known causes of adult mortality, road kill was the most common, a result also reported by Hoshide *et al*. (1990). Vehicles killed 30 adult Nene in the 1990s, a large number for a small population, especially if some of those killed are breeding. Indeed, one female killed by a vehicle had an egg in her reproductive tract (HVNP, unpublished data). The number of Nene hit by cars could probably be reduced if more park visitors obeyed the posted speed limits, noted the "Nene Crossing" signs posted at various locations in HVNP, and did not feed Nene, which attracts them to roads and parking areas.

Continued management is necessary to increase population numbers and reproductive success of Nene in HVNP. Predator control efforts should be improved so that fewer eggs, goslings and adults are depredated. To increase food availability for goslings and breeding females, habitat restoration efforts should be expanded. Lastly, continued public education is necessary to reduce harmful human–Nene interactions. With these management strategies in place, perhaps the survival of Nene within HVNP will be ensured.

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