Studies in Avian Biology No. 22:319–328, 2001.

FORAGING BEHAVIOR AND TEMPORAL USE OF GRASSLANDS BY NĒNĒ: IMPLICATIONS FOR MANAGEMENT

FRIEDERIKE WOOG AND JEFFREY M. BLACK

Abstract. We studied foraging behavior of Hawaiian Geese (*Branta sandvicensis*) hereafter referred to as Nēnē, visiting a variety of grasslands in Hawai'i Volcanoes National Park. For the purpose of this study, two overgrown sites were mowed and subsequently compared with established sites that had previously been mowed or grazed by livestock. Relative grazing pressure varied among sites and at different times of the year. Sites differed in plant species composition and quality, seedhead production, grass height, and rainfall. Most of the plants were introduced species. Nēnē grazed more in areas with the sward-forming Kikuyu grass (*Pennisetum clandestinum*) than in areas with bunch grasses, selecting sites that had grass with a high water content. Water content in the grass was correlated with protein content. Grazing pressure decreased in grass taller than 11 cm and geese used grasslands less during dry periods. Plant quality in the newly mown sites was relatively low and did not attract birds. Nēnē remained in established sites and did not move to newly managed sites. Based on our results, we suggest that grasslands could be managed at a height below 11 cm, irrigated in drought periods, and fertilized to encourage feeding opportunities for this endangered species.

Key Words: *Branta sandvicensis*; endangered species; foraging; grassland management; habitat use; Hawaiian Goose; Nēnē.

In spite of major conservation efforts, the Hawaiian Goose, hereafter Nēnē, (*Branta sandvicensis*), is still one of the most endangered waterfowl species in the world. The Nēnē's breeding success in the wild remains low, and without releases of captive-bred birds, its numbers may rapidly decline (Black and Banko 1994). Predation by introduced mammalian predators and the poor availability of food are thought to be the main obstacles on the Nēnē's route to recovery (Baldwin 1947a, Stone et al. 1983, Banko 1992, Black 1995). The low incidence of nesting suggests that many females cannot accumulate sufficient body reserves for egg laying and incubation due to poor foraging conditions (Banko 1992). Recent studies on gosling mortality showed that lack of adequate nutrition is especially detrimental for young birds (P. Baker and H. Baker, pers. comm.).

We do not know what habitats Nēnē used in the times prior to Polynesian and European settlement. Today, birds nest and roost in open shrubland in lava deserts where they feed on berries and on grasslands created by humans, such as ranches, golf courses, and lawns near housing areas and campgrounds, where they fatten up prior to breeding and rear their goslings (Black et al. 1994). This pattern follows that of many Arctic geese that forage on agricultural fields and pastures during migration and at their wintering grounds (reviewed by Black et al. 1994). After removal of ungulates within Hawai'i Volcanoes National Park, previously grazed pastures, mainly consisting of introduced grass species, have become overgrown (Cuddihy and Stone 1990) and thickets have formed, which are not used by the geese. We studied the foraging behavior of the Nēnē at several of the sites that had been mowed. We asked whether the vegetation composition and cover, seedhead abundance, grass height, protein and water content of grass, rainfall, temperature, and time of year contributed to the variation in grazing pressure.

We discuss the implications of our findings for grassland management and the role managed grasslands could potentially play in the recovery of Nēnē.

STUDY AREA AND METHODS

We collected data at Hawai'i Volcanoes National Park and the adjacent Kapāpala Ranch (Fig. 1). Hawai'i Volcanoes National Park comprises an area of 85,000 ha and holds a population of about 160 Nēnē. We studied grazing behavior in the breeding season from December 1994 to March 1995 and in the pre-breeding and breeding season from August 1995 to March 1996. The grasslands varied in size, boundary type, management regime, soil, and other environmental factors. We measured the size of the grasslands with the Global Positioning System 'Pathfinder.' The grasslands ranged in size from 0.1–4 ha and were mowed or livestock-grazed periodically. A boundary index was recorded ranging from open to very enclosed (1 = open, short grass; 2 = open, surrounded by tall grass and bushes; 3 = open, tall grass and bushes surrounding and within; 4 = closed, a few trees surrounding and within; 5 = closed, many trees surrounding and within; Table 1). Most soils were porous, not holding water.

Sites 2 and 6 were previously overgrown with mainly Kikuyu grass (*Pennisetum clandestinum*) until they were mowed in November 1994. Site 7 was initially mowed in 1992, whereas the other sites were mowed or grazed much earlier. Site 3 has been a recreational picnic area since the early 1940s, and later became a campground, and the grasslands at sites 5 and 8 were

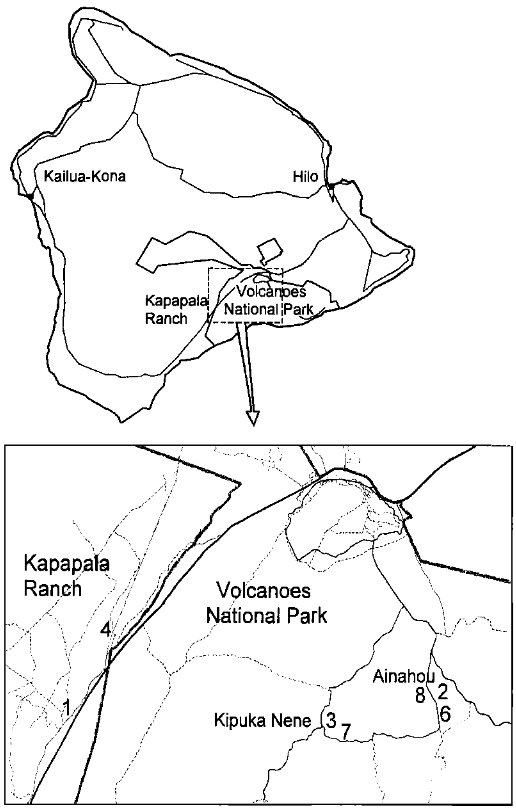


FIGURE 1: Location of Hawai'i Volcanoes National Park, Kapāpala Ranch, and study sites.

periodically mowed for geese by the National Park Service since 1992.

We made observations of the behavior of the geese at sites 2 and 8 during 13 days between November 1994 and March 1995 (149 hours), and during 11 days between August 1995 and March 1995–1996 (119 hours). Observations were spread throughout the season. The majority of birds observed were nonbreeders or failed breeders. The behavior of all geese present in an area was scan sampled from dawn to dusk (for a daily average of 11 hours, total of 268 hours). An audio beeper gave a signal every 10 minutes and the behavior of all individually marked birds visible at that instant was recorded (Martin and Bateson 1986). Behaviors included vigilance, feeding, loafing, preening, walking, and social interactions (courtship, aggressive encounters; Inglis 1977).

We measured weekly grazing pressure by counting and removing droppings, which had accumulated in seven days prior to measurement, within a 1.12 m radius of randomly placed stakes (each plot covering an area of 4 m^2; Owen 1971, Summers and Stansfield 1991). The number of plots ranged between 9 and 25, according to area size. We visually estimated percentage of vegetation cover to the species level in each dropping plot to the nearest 5%. Species covering <5% were estimated to the nearest percent. We subsequently classified vegetation types using TWINSPAN (two-way indicator species analysis; Hill 1979). This allowed us to distinguish two vegetation types at each site, which we refer to as patch types (Table 2). All scientific names and families (Wagner et al. 1990a,b) of the prevalent plant species are listed in the Appendix. Grass species growing in tufts are called bunch grasses as opposed to sward-forming species. All plants under study were introduced species.

Hawai'i Volcanoes National Park was dominated by the sward-forming Kikuyu grass and the Kapāpala Ranch was dominated by grass of the genus *Paspalum*. In Hawai'i Volcanoes National Park most of the Kipuka Nēnē area contained bunch grasses; the 'Āinahou area had less bunch grasses and was dominated by Kikuyu grass and the sedge *Kyllinga brevifolia*. Plant species with high average cover were also widespread and abundant, but some of the species with a low average cover occurred regularly.

In the 1994–1995 Nēnē breeding season, we took 10 random measurements of grass height in each dropping plot every three weeks and calculated a mean for each plot. The grass height measurements were divided into three classes: short (1.6–5.5 cm), medium (5.6–11.5 cm), and tall (11.6–23.5 cm). We determined the production of seedheads in the 1995–1996 breeding season once a month, by counting them in a 50 cm × 50 cm area in each dropping plot. In the same time period we collected fresh Kikuyu grass monthly in each of the grasslands. Samples were sorted, weighed, and dried at 70°C overnight for subsequent analysis of crude protein (nitrogen × 6.25, Kjehldahl; Wagner 1970), and expressed as percentage dry weight (Owen

TABLE 1. AREA SIZE, BOUNDARY INDEX, AND MANAGEMENT REGIME OF THE STUDY SITES ON THE ISLAND OF HAWAI'I

Site	Area size (m^2)[a]	Boundary	Management	
1	'Āinapō Corral (Kapāpala Ranch)	29,110	1	overgrazed by cattle
4	Halfway House (Kapāpala Ranch)	40,000 (est.)	1	overgrazed by cattle
3	Kipuka Nēnē Campground	1,520	5	mowed/goose grazed[b]
7	Kipuka Nēnē mowed area	2,140	2	mowed
8	'Āinahou, Pen 11	5,200	3	mowed/goose grazed
5	'Āinahou, Pine area	1,160	4	mowed
2	'Āinahou, Big Pen	5,290	4	mowed/horse grazed[b]
6	'Āinahou, Lower mowed area	5,210	5	mowed

[a] Area sizes only account for managed grassland; islands of tall vegetation within the grasslands were excluded.
[b] Areas that were kept at least partially short by the geese were considered to be goose grazed.

TABLE 2. Patch types and total mean vegetation cover for the study sites described in Table 1

Site	Patch	Prevalent plants	% Vegetation cover
1	1 (10)[a]	*Paspalum*, some *Lotus* and *Sporobulus*	102 ± 6
	2 (5)	*Eleusine*, some *Solivia* and *Portulaca*	101 ± 9
2	1 (11)	*Pennisetum*, *Kyllinga*	106 ± 3
	2 (6)	*Pennisetum*, *Kyllinga*, some *Digitaria*	114 ± 3
3	1 (7)	*Pennisetum*, some *Sporobulus*	119 ± 7
	2 (8)	*Sporobulus*, some *Chloris* and *Vulpia*	87 ± 11
4	1 (10)	*Paspalum*, *Desmodium* and *Kyllinga*	115 ± 1
	2 (10)	*Paspalum*, *Desmodium*, *Trifolium*, and *Kyllinga*	115 ± 2
5	1 (9)	*Paspalum*, *Kyllinga*, *Desmodium*, some *Trifolium*	120 ± 7
6	1 (19)	*Pennisetum*, *Kyllinga*	83 ± 2
7	1 (4)	*Pennisetum* and *Desmodium*, some *Melinis*	95 ± 9
	2 (9)	*Digitaria*, *Andropogon*	59 ± 10
8	1 (13)	*Pennisetum*, *Kyllinga*	116 ± 5
	2 (12)	*Pennisetum*, *Kyllinga*, some *Desmodium*	88 ± 6

[a] Numbers in parentheses indicate number of plots.

1971). The water content of the samples was obtained by subtracting dry weight from fresh weight. We focused on Kikuyu grass because it is readily eaten by the geese and is widespread, allowing a comparison among sites (Black et al. 1994).

To examine the effects of rainfall and temperature on grassland usage, we placed minimum-maximum thermometers and rain gauges in each area and checked them weekly. At Kipuka Nēnē and ʻĀinahou we used weather data collected by the National Park Service.

STATISTICAL METHODS

All analyses were undertaken using general linear models, with either binomial or Poisson error structure. The resultant changes in deviance are equivalent to the chi-squared statistic and were tested accordingly (Crawley 1993, NAG 1993).

Diurnal patterns of grassland usage

We used the maximum count within each hour to reflect the number of birds present in the course of a day (Black et al. 1991). To compare the yearly, seasonal, and daily variation in the time the geese spent grazing, we used an analysis of variance with a binomial error distribution in GLIM (Crawley 1993, NAG 1993). The average number of birds feeding within an hour was the response variable, and the average number of birds within an hour was the binomial denominator. Factors were location, date, year, and hour (time of day). Small sample sizes (e.g., hours with only 1 scan and days with <25 scans) were excluded from the analysis. We tested differences among sites and categories of behavior with nonparametric chi-square tests.

Grazing pressure

We employed several analyses of variance and covariance models to determine which variables affected grazing pressure. Initial fits to the models indicated that the dropping count data were over dispersed, and consequently the constraints imposed by the declaration of Poisson error distribution were modified by adjustment of the scale parameter. This was achieved by dividing the Pearson chi-square statistic of the final model by the residual degrees of freedom (Crawley 1993). Explanatory variables were location, date, season, protein and water content of the grass, grass height, vegetation type and cover, elevation, number of seedheads, rainfall, and temperature. Not all of these were fitted to the same model. Variables that caused a significant increase in deviance were retained in the model. Insignificant terms were removed. We also tested all biologically meaningful interaction terms.

To reduce effects of data dependency, only the number of droppings accumulated over certain time periods were used for analysis (monthly, per season, and over an entire year). Each season amounted to 23 weeks: the 1994–1995 breeding season (24 Oct 1994–29 Mar 1995), the 1995 summer (19 Apr 1995–18 Sept 1995) and the 1995–1996 breeding season (10 Oct 1995–13 Mar 1996). Sample sizes indicate the number of plots.

GLIM was also used to compare differences among classes. In multiple comparisons, significance levels were controlled by using sequential Bonferroni tests; otherwise, the significance level was set at $P < 0.05$. Percentage data were arcsine transformed prior to analysis.

RESULTS

DIURNAL PATTERNS OF GRASSLAND USAGE

Birds flew from their desert roosting places to the grasslands between 0615 and 0730 hours, and left the grassland between 1600 and 1745 hours. Numbers of geese varied throughout the day, ranging between 1 and 24. The mean maximum number of geese per hour (Fig. 2), reached a peak at 1400 hours, and then declined until the geese left the area. At site 8, goose numbers varied throughout the day ($F = 7.2$, $df = 12$, $P < 0.01$) and with date ($F = 8.56$, $df = 20$, $P < 0.01$). There was no difference between the two breeding seasons (1994–1995 and 1995–1996), or between arrival and departure times of the geese between the two years (Mann-Whitney U-tests for flying in: $W = 135$, $N = 12$ and 7,

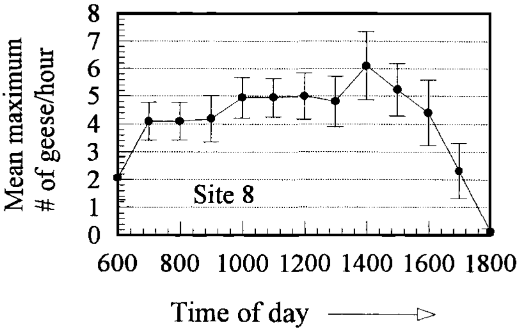


FIGURE 2. Mean maximum number of Nēnē per hour counted on 24 observation days at study site 8.

$P < 0.022$; and departing: $W = 98$, $N = 10$ and 8, $P < 0.82$. The percentage of birds feeding peaked at 800 and 1500 hours and was lowest at 1200 hours (Fig. 3). The percentage of geese feeding and loafing varied throughout the day. The hourly pattern of use was significant for loafing ($\chi^2 = 24.78$, df = 12, $P < 0.025$).

The percentage of birds feeding varied between sites 2 and 8 ($\chi^2 = 5.63$, df = 1, $P < 0.025$) and dates ($\chi^2 = 38.18$, df = 21, $P < 0.025$), but there was no significant difference between the two breeding seasons. The geese spent more time feeding and less time loafing at the newly established site 2 (inside the enclosure; $\chi^2 = 6.14$, df = 1, $P < 0.025$), compared to the more established site 8 (Fig. 4). The time spent feeding at site 2 decreased from 57% in 1994–1995 to 47% 1995–1996.

GRAZING PRESSURE

The yearly grazing pressure varied among sites ($\chi^2 = 228.7$, df = 7, $P < 0.001$; Fig. 5). Grazing pressure was highest at sites 2, 3, and 8, intermediate at site 7, and low at sites 1 and 4 (Kapāpala Ranch); site 6 had the lowest grazing pressure. Some of the between-site variation in grazing pressure might be explained by differences in management and boundary type (Fig. 6). All management types were significantly different from each other ($\chi^2 = 6.94$–80.96, df = 1, $P < 0.01$–0.001). There were significant differences in yearly grazing pressure among sites with different boundary types. Sites 2 and 3, 2 and 4, and 4 and 5 were significantly different ($\chi^2 = 4.$–13.36, $P < 0.001$–0.03). The geese apparently selected the mowed and grazed grassland sites (Fig. 6a) and used open sites less than closed ones (Fig. 6b). Sites with an extensive tree canopy were used less than sites with only a few trees ($\chi^2 = 12.49$, df = 1, $P < 0.001$). Area size did not affect grazing pressure. At some sites, goose-grazing pressure increased after mowing or horse-grazing.

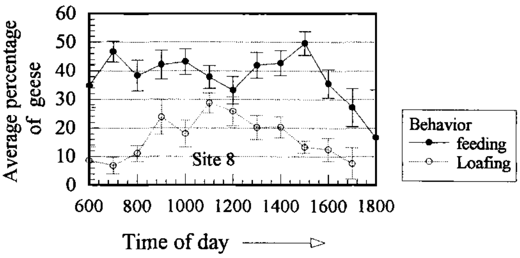
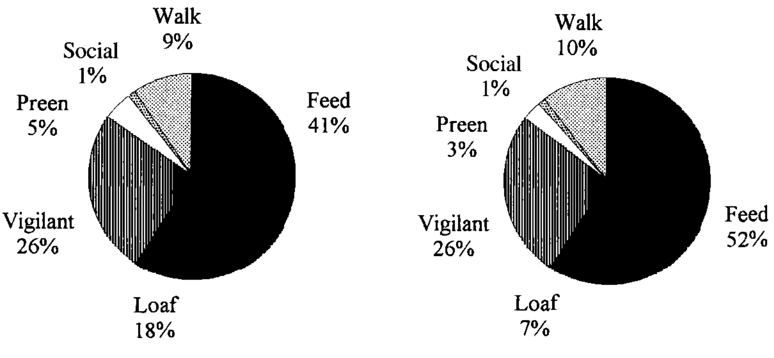


FIGURE 3. Average percentage of Nēnē scanned for behavior (feeding or loafing) throughout the day.

The observed preferences for a certain vegetation type were persistent through all seasons (Table 3). Grazing pressure was higher in the Kikuyu grass patch compared to the bunch grass patch ($\chi^2 = 22.09$, df = 1, $P < 0.001$; Fig. 7). When having the choice between a mixed patch type with Kikuyu and a legume (*Desmodium sandwicense*) and pure Kikuyu, the geese grazed



Site 8 (n=21 days) Site 2 (n=10 days)

FIGURE 4. Activity budgets of Nēnē at sites 2 and 8.

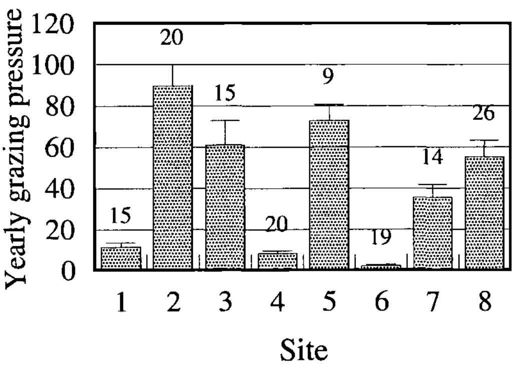


FIGURE 5. Variation in yearly Nēnē grazing pressure by sites. Values indicate the yearly accumulated number of droppings/4 m^2, sample sizes indicate the number of plots in each location, means are among plots.

more in the mixed type ($\chi^2 = 5.4$, df = 1, $P < 0.025$; Fig. 7).

Vegetation cover may also explain grazing pressure variation in some sites. In areas with short Kikuyu, the geese grazed more in dense grass cover ($\chi^2 = 14.87$, df = 1, $P < 0.001$; Fig. 8a), whereas in areas with taller grass, they grazed more in less dense grass cover (Fig. 8b). The association with a lower cover of *Kyllinga* (Fig. 8c) was detected at site 4 ($\chi^2 = 9.37$, df = 1, $P < 0.005$), and of *Sporobulus* (Fig. 8d) at site 8 ($\chi^2 = 5.48$, df = 1, $P < 0.01$).

At site 4, the grazing pressure was also influenced by the topography; it varied between vegetation patch types, but the elevation of the plots explained more of the variation. The higher-elevated plots were grazed more ($\chi^2 = 13.09$, df = 1, $P < 0.001$).

Seedheads of grasses were most abundant in winter months (October–January; Fig. 9), however, in general, a higher number of seedheads did not attract more geese. We tested this by fitting the number of droppings accumulated in the four weeks prior to the seedhead count as a response variable, and the number of seedheads in each plot as an explanatory variable. Site 4 on Kapāpala Ranch was an exception to the general finding, but only in August ($\chi^2 = 4.23$, df = 1, $P < 0.05$, $N = 18$), when a high number of seedheads apparently attracted more geese.

The use of different grass heights varied among sites. In Hawai'i Volcanoes National Park, grazing pressure was greatest in grass of medium heights (5.6–11.5 cm; $\chi^2 = 16.61$, df = 2, $P < 0.001$; Fig. 10). The tallest grass height class (11.6–23.5 cm) had by far the least goose usage. Shorter grass heights were used on the intensively cattle-grazed Kapāpala ranch (2.4–7.9 cm).

The correlation between protein and water content of grasses was significantly correlated at site 3 ($r = 0.782$, df = 6, $P < 0.05$), site 8 ($r = 0.831$, df = 6, $P < 0.02$), and site 2 ($r = 0.742$, df = 6, $P < 0.05$) and for all locations combined (Fig. 11). Kikuyu grass with low water content was also low in protein. Water content in the grass and monthly precipitation were not correlated.

Protein and water content in Kikuyu grass changed over the study period and differed among sites (Fig. 12). Paired t-tests showed that the grass at the newly managed site 6 had a significantly lower protein content than the established site 8 ($t = 2.58$, $N = 8$, $P = 0.036$) and also a significantly lower water content ($t = 2.6$, $N = 8$, $P = 0.035$). Nēnē rarely used site 6. The minimum temperature ranged between 6 and 8°C and did not influence grazing pressure.

To test for regular grazing cycles at the different sites, we plotted autocorrelation functions (ACFs) of the weekly grazing pressure using SYSTAT. There was no regular cyclical pattern to the observed fluctuations in grazing events.

Variation in grazing pressure might be explained by more factors than the quality of the grassland alone. Birds might be absent because

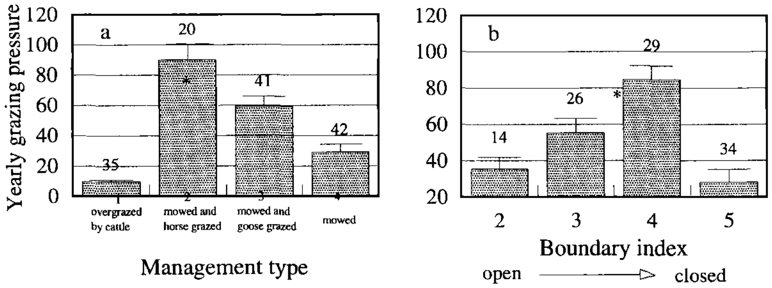


FIGURE 6. (A) Yearly grazing pressure by management types. (B) Yearly grazing pressure by types. Sample sizes indicate the number of plots, * indicates the periodic presence of captive birds; the yearly grazing pressure is expressed as the mean number of droppings/4 m^2 accumulated over a year, means are among plots.

TABLE 3. COMPARISON OF DROPPINGS ACCUMULATED OVER A PERIOD OF ONE YEAR (24 OCTOBER 1994 – 24 OCTOBER 1995) IN TWO DIFFERENT VEGETATION TYPES WITHIN A SITE, DF = 1

Site	χ^2	P<	Type with higher dropping density	Type with lower dropping density
2	9.31	0.05	*Pennisetum, Digitaria*	*Pennisetum, Kyllinga*
3	22.09	0.001	*Pennisetum*	*Sporobulus, Chloris, Vulpia*
4	6.27	0.025	*Paspalum, Desmodium, Trifolium*	*Paspalum, Desmodium, Kyllinga*
8	5.40	0.025	*Pennisetum, Desmodium*	*Pennisetum, Kyllinga*

they are nesting or molting, or because there are seasonally better resources in the neighbouring shrublands. In our final models we included these variations as an intrinsic date or season effect. At all sites, grazing pressure varied significantly among months. At many sites either year or rainfall caused a significant change in deviance, but year and rainfall were not significant in the same model (Fig. 13; Table 4). After controlling for location (χ^2 = 853.4, df = 7, P < 0.001), the grazing pressure was different between months (χ^2 = 76.26, df = 17, P < 0.001). At most locations grazing pressure varied also between season and/or years and/or with rainfall (see Table 4). There was an intrinsic seasonal pattern and a departure from that pattern caused by rainfall. It is, however, difficult to tease them apart, as rainfall itself followed a seasonal pattern.

DISCUSSION

Managers once believed that Nēnē would thrive in volcanic shrubland at high elevation, where the last remaining birds were found. However, birds reintroduced into these areas had poor survival rates compared with those in mid and low elevations where they had access to managed agricultural habitats (Black et al. 1997). Many healthy goose populations throughout the world are making use of man-made sites to meet their daily energetic requirements (reviewed by Black et al. 1994). Nēnē have adapted to man-made habitats and readily use introduced plant species for foraging.

Understanding variation in grazing pressure in geese is not an easy task, as it cannot be explained by a single factor. In our study, Nēnē selected habitats with food plants of a high protein content. They favored vegetation patches with Kikuyu grass sward as opposed to patches with bunch grasses, and grazed more in mixed grass-legume than in pure grass sward. Kikuyu grass sward is higher in protein than bunch grasses, and legumes have even higher levels of protein than Kikuyu grass (Black et al. 1994). Research on many herbivores, including other geese, has confirmed the suitability of crude protein as an indicator of forage quality (Owen 1981, Sedinger and Raveling 1984, Festa-Bianchet 1988), and geese are able to select forage of high nutritional quality when available (Owen 1971, Sedinger and Raveling 1984, Prop and Deerenberg 1991). Our study indicates that Nēnē are no exception to these findings.

That the geese used most grasslands less during dry periods could have two explanations. Grass with a low water content is proportionally higher in fiber (Owen 1981) and, as shown in this study for Kikuyu grass, lower in protein, which increases the physical effort of grazing and digestion (Prop and Vulnik 1992). Especially in periodically dry areas, the amount of rainfall may explain plant quality and quantity, and the subsequent grazing behavior of geese. Further research is needed into the short-term effects of rainfall on the vegetation (daily measurements) and the effects of rainfall duration on grazing pressure.

Nēnē used newly managed sites less than other, longer established ones. The new sites may

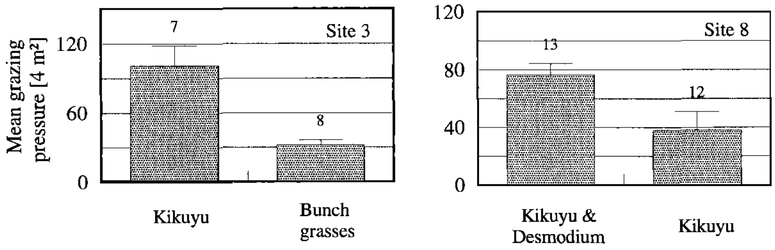


FIGURE 7. Variation of yearly grazing pressure with vegetation type (droppings accumulated between October 1994 and October 1995). Species names indicate plants with the highest cover, sample sizes indicate the number of plots.

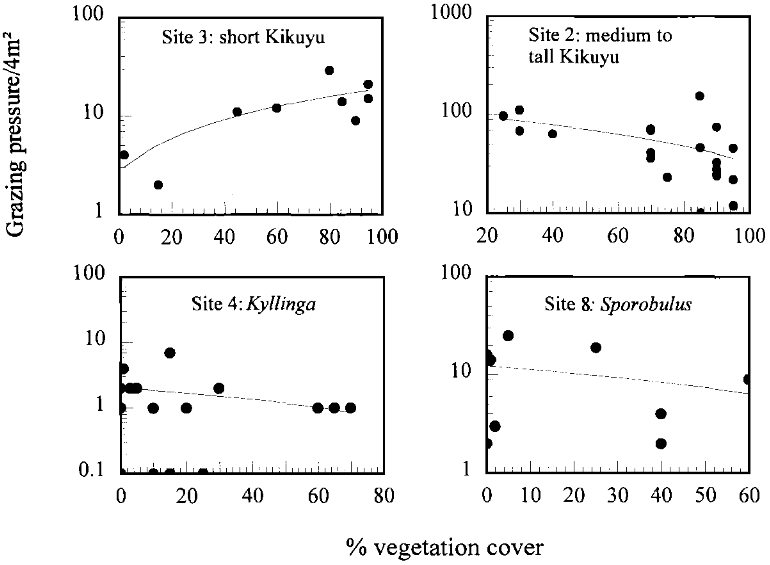


FIGURE 8. Nēnē grazing pressure in Kikuyu grass, *Kyllinga* and *Sporobulus* with varying cover. The dropping density accumulated eight weeks before and after the vegetation cover assessment (between 18 Jan 1995 and 3 May 1995) was used to indicate relative grazing pressure.

have been unfamiliar to the birds; furthermore, the protein content in Kikuyu grass was lower. In other goose species, individuals using sites with a high forage quality spend less time feeding (Bédard and Gauthier 1989, Black et al. 1991). In our study, Nēnē spent less time feeding in the established site, suggesting the plant quality and abundance was better than at the newly managed site. From 1994 to 1995, we found a decrease in feeding time by 10% in the newly managed site. This might be explained by an increasing forage quality after repeated mowing of this previously unmanaged site. In many grass species, repeated mowing or grazing increases the protein content (Ydenberg and Prins 1981, Sedinger and Raveling 1986, Gadallah and Jefferies 1995). Thus, given good initial forage quality and sufficient rainfall, geese may themselves be able to improve the quality of the sward to a certain extent.

Colonization of new habitats is likely to occur with a change in selection pressure. Many Arctic geese shifted to new habitats after their populations had increased and some of their traditional habitats had deteriorated (Owen and Black 1991, Black et al. 1991). In contrast, the Nēnē population in our study is in danger of further decrease, and although more extensive measurements are needed, we provided data that new sites were nutritionally less attractive than estab-

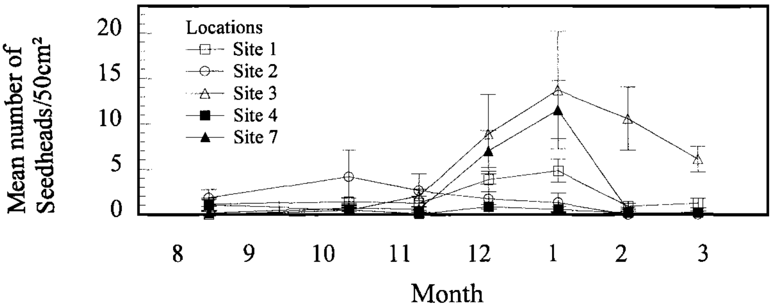


FIGURE 9. The change of the mean number of seedheads over time (August 1995–March 1996). Predominant species at site 1 and 4: *Paspalum* and *Digitaria,* at site 3 and 7: *Sporobulus* and other mixed bunch grasses and at site 2: *Digitaria.* In February site 7 was mowed, hence the sudden absence of seedheads. Sample sizes are equal to the number of plots in each site.

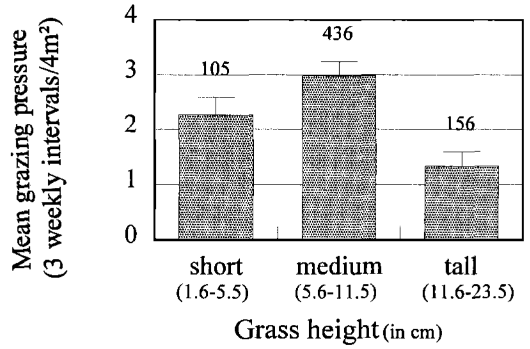


FIGURE 10. Nēnē grazing pressure in different grass heights in Hawai'i Volcanoes National Park. Measurements were taken at 3-week intervals at five locations over a period of 21 weeks. The droppings accumulated in the three weeks prior to the grass height measurements indicated the relative grazing pressure. Sample sizes indicate the number of plots the grass height was measured in.

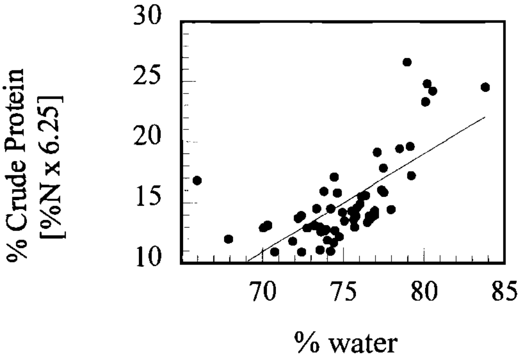


FIGURE 11. Correlation of protein and water content in Kikuyu grass (all locations: $r = 0.688$, $df = 52$, $P < 0.0001$)

lished, traditional ones. To attract Nēnē to new sites, they must offer a higher-quality forage, and even then geese might not shift to them, especially if the established sites are not overcrowded. The size of the managed areas has to be adapted to the population size.

Nēnē are faced with a variable climate, and hence fluctuating forage quality. Droughts are a fairly common phenomenon in the normally wet winter months, but they are unpredictable. If the vegetation quality deteriorates during the critical time of incubation and brood rearing, birds might not be able to successfully rear their offspring. An adequate growth rate for goslings is only possible if accessible supplies of high quality forage are available (Gadallah and Jefferies 1995). Black et. al (1994) showed that the forage plants of Nēnē are depleted throughout the season and do not regenerate quickly, especially in unmanaged areas. Reduced supplies of forage due to earlier grazing are thought to cause reduced growth rates in Black Brant (*Branta bernicla*; Sedinger and Flint, 1991) as well as in Snow Geese (*Chen caerulescens*; Cooch et al. 1991). Adult Nēnē fly to better sites when food resources get low (Black et al. 1994); when leading goslings, however, they cannot travel far and must use what is available in the area. The nutritional inadequacy of the grasslands seems especially detrimental for goslings (P. Baker and H. Baker, pers. comm.) and may be the key factor in limiting population growth.

Today, most endangered species recovery plans emphasize the importance of an ecosystem approach (Martin 1994), but little attention is given to the management of disturbed habitats which are used by endangered species. Species like the Nēnē utilize disturbed habitats and benefit from introduced plants as a food resource (Black et al. 1994). Although the restoration of disturbed habitats remains a long-term objective (Stone and Scott 1985a,b), the adaptability of the Nēnē can be turned into an advantage for the recovery of the species. Managing grasslands adjacent to nesting areas is a quick and comparatively inexpensive means of providing the birds with food. By managing grasslands that are overgrown by introduced grass species like Kikuyu, molasses grass (*Melinis minutiflora*), beard grass (*Schizachyrium condensatum*), and broomsedge (*Andropogon virginicus*) for the geese, some disturbed ecosystems may benefit. Corridors of short grass serve as effective firebreaks in areas with high fire risk. Most native plant species are not adapted to fire (Mueller-Dombois 1981), and fire also facilitates invasion by alien species (National Park Service 1989). From a conservation point of view, a reduction in the seed production of introduced grass species is favorable as it reduces the spread of these species into noninvaded areas.

Golf courses meet our criteria of grasslands as they have short, nutritious grass, and many Nēnē use them. However, various problems are

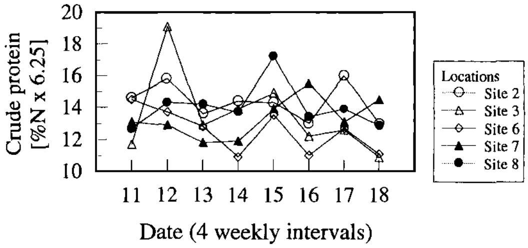


FIGURE 12. The change of protein content in Kikuyu grass over time (July 1995–March 1996).

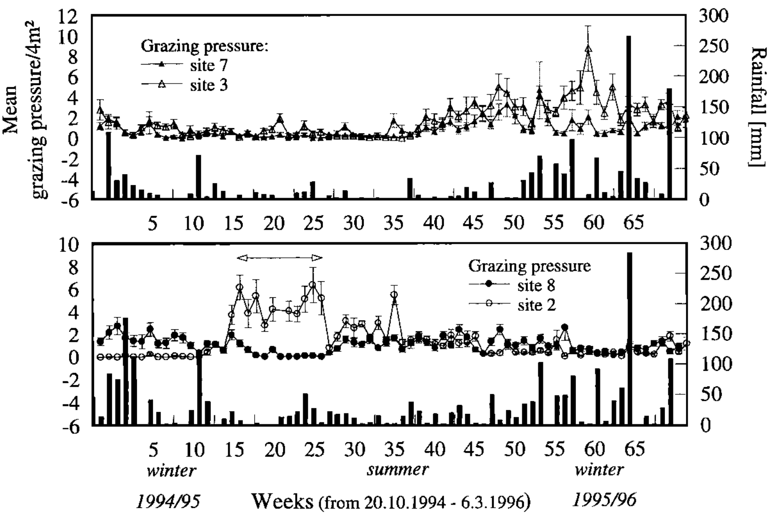


FIGURE 13. The change of mean weekly grazing pressure (lines) by Nēnē and rainfall (bars) over time. Sample sizes correspond with the number of plots in each site (site 2: N = 20, site 3: N = 15, site 7: N = 14, site 8: N = 26). Weekly values are presented for detail, because of temporal autocorrelation between the weekly data, however, only monthly accumulated values were analyzed. The arrow indicates a periodic presence of semicaptive birds at site 2.

associated with this use. Geese get killed or crippled by golf balls, the adjacent nesting sites are usually cut off by roads, which causes roadkills, pesticides are used freely, and parent geese leading goslings are vulnerable to disturbance. A possible solution would be to create areas on golf courses that are set aside for geese and are nutritionally more attractive and concentrate geese away from human activity.

In 1997, the State of Hawai'i passed the Hawai'i Endangered Species Recovery Act, which allows incidental take of an endangered species on private land. The act opens new possibilities for the reintroduction of endangered species on private land. Some ranches, for example, provide excellent feeding opportunities for Nēnē. Prior to future reintroductions, however, the vegetation and seasonal local rainfall patterns should be assessed and only adequate grasslands with adjacent shrubland for nesting habitat should be considered. Dry habitats should be avoided. Adequate predator control in these areas remains vital to ensure breeding success of the geese.

The population of the Nēnē on Kaua'i is increasing steadily for two apparent reasons: (1) they use lush, cattle grazed and irrigated pasture vegetation in the lowlands, and (2) the number of introduced predators is low. Providing high quality pastures enables more birds to accumu-

TABLE 4. THE EFFECT OF MONTH, YEAR, RAINFALL, AND PATCH TYPE ON GRAZING PRESSURE (OCTOBER 1994-MARCH 1996) BY NĒNĒ

Site	Month χ^2	(df = 12) P<	Year χ^2	(df = 1) P<	Rainfall χ^2	(df = 1) P<	Patch type[a] χ^2	(df = 1) P<
1	47.94	0.001	39.84	0.001	—	n.s.	5.51	0.025
1	48.16	0.001	—	n.s.	32.9	0.001	5.51	0.025
2	342.9	0.001	21.34	0.001	—	n.s.	25.06	0.001
2	303.6	0.001	—	n.s.	41.39	0.001	24.6	0.001
3	192.9	0.001	26.4	0.001	5.086	0.025	131.3	0.001
4	26.74	0.01	—	n.s.	—	n.s.	14.91[b]	0.001
5	310.8	0.001	—	n.s.	—	n.s.	only 1 type	
6	132.2	0.001	—	n.s.	—	n.s.	only 1 type	
7	78.01	0.001	14.23	0.001	—	n.s.	18.67	0.001
7	82.37	0.001	—	n.s.	15.27	0.001	18.79	0.001
8	105.9	0.001	13.39	0.001	—	n.s.	50.35	0.001

[a] Patch type was characterized by the vegetation type.

[b] At site 4 the elevation of the plot is used instead of the vegetation type.

late sufficient body reserves for breeding and results in higher fledgling success. Furthermore, strong and healthy birds may be more likely to escape predation.

Increased breeding success in the wild is the main goal for recovery. To achieve that goal, we emphasize the importance of large-scale sanctuaries in the wild, including both intensively managed grasslands and natural shrubland nesting habitats coupled with predator control. To determine the required size of sanctuaries, we recommend detailed studies on the carrying capacity of Nēnē habitat. Good management can result in doubling the carrying capacity of grasslands (Owen 1977). Furthermore, a study on different management regimes including mowing, livestock grazing, irrigation, fertilization, and burning treatments could reveal which treatments yield the highest carrying capacity and are most applicable financially.

IMMEDIATE MANAGEMENT IMPLICATIONS

Our immediate conclusions and implications for grassland management include the following:

1. Nēnē grazed most heavily on an intermediate grass height (approx. 5–11 cm). Mowing or grazing grass higher than 11 cm will optimize grasslands for the geese.
2. The geese used grasslands less during drought periods. Irrigation could be useful as a management tool, especially during the breeding season.
3. The geese grazed more in grass sward than in areas with bunch grasses. Although seedheads of bunch grasses are eaten by the geese, they are only seasonally plentiful, whereas short grass sward is scarce but with adequate management could be available year-round. Repeated mowing favors grass sward growth and reduces bunch grasses.
4. Geese grazed more in areas with grass high in protein. Fertilizer application is likely to improve grassland quality.
5. Management activities in grasslands should be carried out when bird numbers using the area are low (e.g., during molting), or after 1600 hours, when most birds leave the grasslands and fly to roosting sites.

ACKNOWLEDGMENTS

We are grateful to the Resources Management and the Research Division of Hawai‘i Volcanoes National Park, the State Division of Forestry and Wildlife, the U.S. Geological Survey, The Wildfowl and Wetlands Trust, Slimbridge, The Peter Scott Trust for Education and Research in Conservation, and Sandy and Jill Friedman, Honolulu, for financial and logistical support. British Airways Assisting Conservation sponsored our flights between Europe and the United States. The German Academic Exchange Service (DAAD) kindly financed Friederike Woog in 1996. Many people helped in the field; M. Pfiz, M. Fujura, C. Walz, J. Edwards, A. Böhmler, and S. Straub were of invaluable assistance. L. Katahira, D. Hu, H. Hoshide, C. Terry, and P. C. Banko were very supportive throughout the study. The laboratory of the Agricultural Extension Service at University of Hawai‘i at Manoa analyzed the protein content in the grass samples. Special thanks go to R. Pettifor, M. Rowcliffe, M. Kershaw, J. Bowler, A. Lang, and J. Hutchinson for statistical advice and to E. Zimmermann, M. Rowcliffe, and U. Zillich for commenting on earlier drafts.

APPENDIX. SCIENTIFIC AND COMMON NAMES OF PREVALENT PLANT SPECIES (WAGNER ET AL. 1990A,B)

Family	Latin name	Common name
Poaceae	*Pennisetum clandestinum*	Kikuyu grass
	Melinis minutiflora	Molasses grass
	Andropogon virginicus	Broomsedge
	Eleusine indica	Wiregrass
	Paspalum conjugatum	Hilo grass
	Sporobulus africanus	Rattail grass
	Digitaria violascens	Violet crabgrass
	Vulpia bromoides	Brome fescue
	Chloris virgata	Finger grass
Cyperaceae	*Kyllinga brevifolia*	Kaluhā
Fabaceae	*Lotus subbiflorus*	
	Desmodium sandwicense	Spanish clover
	Trifolium repens	White clover