FULL PAPER *Theriogenology*

Reproductive Characteristics of the Feral Raccoon (*Procyon lotor*) in Hokkaido, Japan

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(Received 29 May 2002/Accepted 20 December 2002)

ABSTRACT. Reproduction of feral raccoons (*Procyon lotor*) in Hokkaido, Japan, was examined during a 2-year period by analysis of placental scars or fetuses in the uterus. Of 242 collected females, 69 (29%) were juveniles, 71 (29%) yearlings, and 102 (42%) adu lts. The pregnancy rate averaged 66% in yearlings and was significantly lower than the 96% average observed in adults ($p<0.01$). Litter size ranged from 1 to 7 offspring per female, and averaged 3.6 in yearlings and 3.9 in adults. There was no significant difference in mean litter size between yearlings and adults. In Hokkaido, the raccoon mating season peaked in February and the majority of litters were born between March and May, similar to patterns described in North America, but some females mated in summer. The reproductive potential of feral raccoons in Hokkaido was similar to that reported in North America. The recent increase in raccoon numbers can be explained by their high productivity. Harvest data suggest that hunting pressure on juveniles is lower than that for older age classes when using box traps in summer. In order to reduce the feral raccoon population, alternative hunting methods that increase juvenile mortality rates are needed.

KEY WORDS: feral, placental scar, *Procyon lotor*, raccoon, reproduction.

J. Vet. Med. Sci. 65(3): 369–373, 2003

Determining a population's age structure and estimating its reproductive potential are important prerequisites to assessing population dynamics. Because studies of wildlife often depend on non-random harvest data, prescriptive management programs, such as control programs for exotic species, must account for harvest selection bias when assessing mortality rates [2].

The raccoon (*Procyon lotor*) is native to North America, but many have been imported to Japan since the 1970s, mainly as pets [18]. In Hokkaido, the northernmost island of Japan, the intentional release and escape of pet raccoons over the last 20 years has led to a naturalized population, centered principally in the southern part of the Ishikari Plain. The raccoon has established itself in west-central Hokkaido because it is an opportunistic omnivorous canid that can thrive in many habitats [28, 30], and there are few native animals that will prey upon or out-compete it.

Since 1997, control kills of feral raccoons has been allowed in Hokkaido in response to agricultural and aquaculture damage. Both the harvest numbers and the number of districts conducting control kills have been increasing annually [15], prompting the Hokkaido Government to begin planning a feral raccoon management program in 1999. Although reproduction of raccoons in North America has been studied extensively [20, 22, 23, 26, 29], until recently little was known about the population established in Hokkaido.

In this study, we examine reproductive characteristics of feral raccoons in Hokkaido and evaluate field methods for estimating reproductive status of harvested raccoons. We then consider how knowledge of reproductive seasons can be incorporated in the population management plan of feral raccoons in Hokkaido.

MATERIALS AND METHODS

We collected female raccoons in west-central Hokkaido (Fig. 1) from May-November in 1999 (n=56) and March-December in 2000 (n=186). The study site was located in the central zone of feral raccoon distribution. Animals were caught using box traps (Havahart Model 1089, Woodstream, Lititz, Pennsylvania, U.S.A., or handmade by hunters) in both research and damage control actions, and were euthanized according to Beaver *et al*. [1]. In Hokkaido, about 1,200 raccoons were killed during the study period [15]. Raccoons were weighed and measured, and the uterus and skull were removed. Uteri were fixed in 10% formalin neutral buffer solution and stored for later examination.

Juveniles (young of the year) were distinguished from yearlings or adults (≥ 2-year-old) by examining tooth eruption [21] and root foramina closure of canines [12]. Yearlings and adults were aged according to the annual incremental lines in the tooth cementum of canines and/or incisors [12]. Some raccoons collected in spring had permanent canines with opened root foramina. We assumed that such raccoons had been born in the previous litter season and classified them as yearlings [12].

We assumed that the presence of placental scars in the uterus indicated implantation and the number of scars was an index of litter size in the most recent breeding season

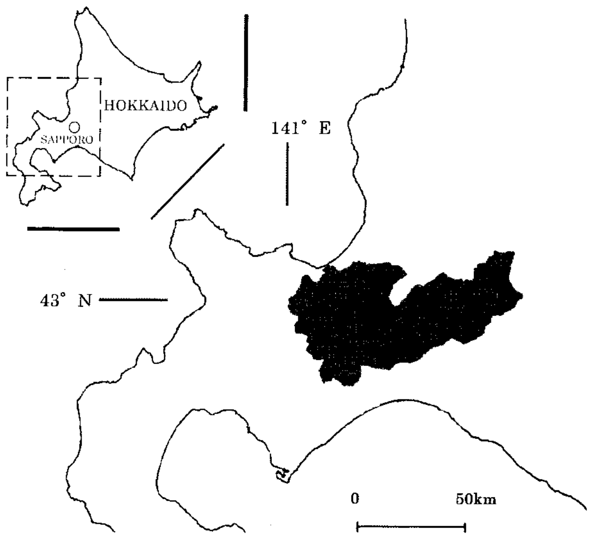

Fig. 1. Location of the study area for feral raccoon in west-central parts of Hokkaido, Japan, 1999–2000.

[16]. We calculated pregnancy rates from the proportion of females observed with placental scars or fetuses in the uterus. Mean litter sizes were calculated as an average of the number of placental scars or fetuses. When two distinct sets of scars were present in the same uterus, litter size was estimated from the darker scars only, although the number of light scars was counted and noted [5, 7, 9, 16, 26].

To estimate gestation days, the crown-rump length of fetuses was measured to the nearest mm [19]. We checked for evidence of lactation and noted nipple size when possible. These indices were used to assess sexual maturity and breeding states of females, and to estimate the mating season in Hokkaido.

Statistical significance of differences in frequencies was assessed with the *G*-test [27], and between means with analysis of variance. Values of $p<0.05$ were considered statistically significant in all comparisons. These analyses were carried out on a computer using Microsoft EXCEL 2000 for Windows.

RESULTS

We collected 242 female raccoons during the study period. Most animals were caught in July (n=74, 31%) and August (n=90, 37%). Of all samples examined, 69 (29%) were juveniles, 71 (29%) were yearlings, and 102 (42%) were adults. The age structure derived from all samples appears in Table 1. The juvenile/yearling ratio was 1.2 and 0.9 in 1999 and 2000, respectively.

Age specific pregnancy rates differed (Table 1). The pregnancy rate of yearlings plus adults averaged 84% (n=145) over the entire study period, based on 140 postnatal females with placental scars and 5 antenatal females. In adult females, average pregnancy rates were 95%, 96% and 96% in 1999, 2000 and combined, respectively. There were no significant differences in the pregnancy rates of adults between ages. The percentage of reproducing yearlings was 59% (G=6.81, d.f.=1, $p<0.01$), 69% (G=20.26, d.f.=1, $p<0.001$) and 66% (G=28.05, d.f.=1, $p<0.001$) in 1999, 2000 and combined, respectively, each significantly lower than for adults in the same periods. Statistically significant differences in annual pregnancy rates were not found for either yearlings or adult females.

Table 1. Comparison of the age related pregnancy rate and mean litter size of feral raccoons collected in west-central parts of Hokkaido, 1999–2000

Age (years)	N	Pregnancy		Mean litter size (± SD)
		N	%	
0	69	0	0	
1	71	47	66	3.6 ± 1.3
2	43	41	95	3.7 ± 1.2
3	27	25	93	4.1 ± 1.2
4	18	18	100	3.7 ± 1.5
≥ 5	14	14	100	3.8 ± 1.3
Total	242	145	84	3.8 ± 1.3

Table 2. Number of the sets of placental scars of feral raccoons collected in west-central parts of Hokkaido, 1999–2000

Age (years)	N[a)]	Number of sets placental scars[b)]			Two sets
		0	1	2	scars (%)
1	68	24	31	13	30
2	42	2	27	13	33
3	26	2	19	5	21
4	18	0	10	8	44
≥ 5	14	0	9	5	36
Total	168	28	96	44	31

a) Excluded antenatal females.
b) Classified according to the darkness of scars.

Estimated litter size ranged from 1 to 7 offspring per female and averaged 3.8 (n=145, SD=1.3). Mean litter sizes of adult females were 3.6 (SD=1.1) in 1999, 4.0 (SD=1.3) in 2000, and 3.9 (SD=1.3) combined, with no significant differences in litter sizes between ages. Mean litter sizes from yearlings were 4.2 (SD=1.2) in 1999, 3.4 (SD=1.2) in 2000 and 3.6 (SD=1.3) combined. Mean litter size of yearlings in 2000 was significantly lower than adults (F=5.79, d.f.=1, p=0.018), but there were no significant differences in mean litter sizes between yearlings and adults when combining 2 years' data, although the mean tended to be lower for yearlings. From the five pregnant females collected, the mean number of fetuses was 3.2 (SD=1.8).

When all data were combined, the proportion of parous females with 2 sets of scars was 30% in yearlings and 32% in adults (Table 2), but this difference was not statistically significant. The number of pale scars ranged from 1 to 5 per female and averaged 1.4 (SD=0.8) in yearlings and 1.6 (SD=1.1) in adults. There were no significant differences in the mean number of pale scars among different age classes. Of 44 females with two sets of scars, 33 (75%) had one pale

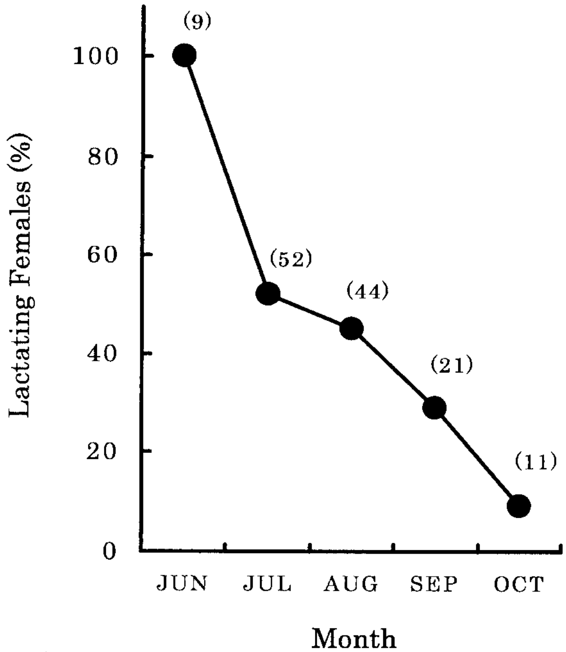

Fig. 2. Monthly variations of proportion of lactating females collected in west-central parts of Hokkaido, 1999–2000. Numbers are sample sizes.

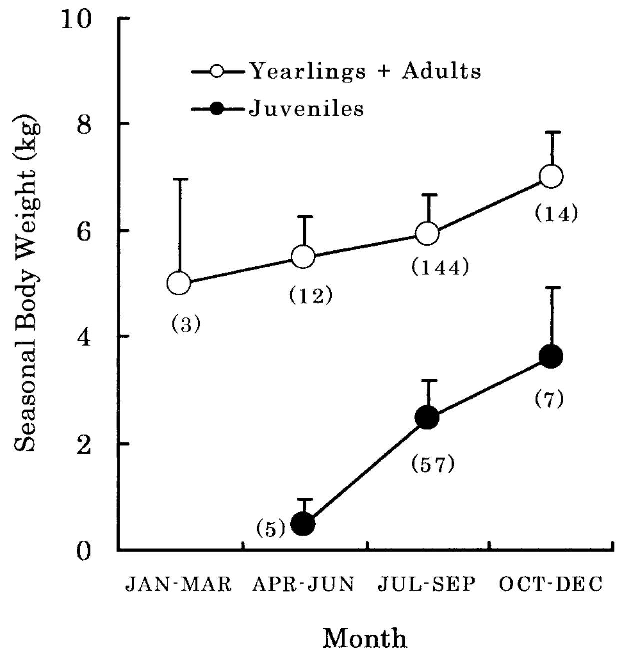

Fig. 3. Average weight of female raccoons collected in west-central parts of Hokkaido, 1999–2000. Vertical bars represent standard deviations and numbers are sample sizes.

scar. The proportion of pale scars to all scars (pale plus darker scars) averaged 10% in yearlings and 11% in adults, and there were no significant differences across age classes.

During the study period, five pregnant females were obtained in March (n=2), April (n=1) and July (n=2). From the measurements of crown-rump length of all fetuses, we estimated that the pregnant females collected in March and April had mated in January to February, and those collected in July had mated in May to June. Lactation was observed only in animals with placental scars and females in the later stage of pregnancy. All females collected in June (n=9) had been lactating, but the proportion of lactating females decreased by month to 9% in October (n=11) (Fig. 2). Juveniles, non-parous yearlings, and adults with no scars tended to have smaller teats than those of lactating females in spring and summer especially. Teat pigmentation was apparent only in parous and pregnant adults. Mean seasonal body weight was significantly different between juveniles and older animals ($p<0.02$) (Fig. 3). Juveniles did not weigh over 4.1 kg during study period except for one 6.2 kg individual trapped in October.

DISCUSSION

Estimating litter size: Measures of average litter size are indispensable for estimating population growth rates for wildlife management. In our study, we estimated litter size and pregnancy rates from uterine scars and fetal counts [16, 26]. Helle and Kauhala [14] proposed that counts of fetuses are the most reliable measure of litter size, but this requires intensive sampling to obtain significant counts. They also reported that counts of corpora lutea might overestimate litter size because of lost ova and intrauterine mortality. Placental scars also potentially overestimate parturition, because some scars may have resulted from fetuses that died before birth or from pregnancies in previous seasons [14, 16, 26]. Nevertheless, counts of placental scars have been used for estimating litter size and productivity rates in many wildlife species that have one litter per year [13] because of the method's relative accuracy and practicability [14, 16, 24, 26]. Most of the samples used in our study were collected from July to September, a period when reproductive females were mostly postnatal, limiting our ability to estimate litter size based on fetal numbers. However, damage control harvests of raccoons in Hokkaido have been conducted mainly in early summer; more thorough research sampling during this period would make fetal counts more practical.

Litter size: In North America, reports of average raccoon litter size vary widely with area and year, ranging from 2.0 to 4.8 [22]. Some studies report that yearling raccoons have smaller litters than older females [5, 6, 9]. Although the estimate of mean litter size (3.8) for our survey falls within the range reported for North America, we found no significant differences in mean litter size between yearlings and adults. However, annual variation in mean litter size was more pronounced for yearlings than for adults. A two-year study with relatively small sample sizes may have been too limited to reveal significant differences in litter size between the two age classes.

Post implantation loss: Neither the percentage of parous females with two sets of scars nor the proportion of pale scars to all scars counted was significantly different between yearlings and adults. Our findings support earlier reports that in raccoons most scars do not persist from 1 year to the next [16]. If scars persisted for several years, the incidence of 2 sets of scars in adults would be higher than that in yearlings. If we assume that the presence of scars of different darkness in a uterus indicate the absorption or abortion of some litters [16, 26], our study found a 30% post-implantation loss of fetuses for both yearlings and adults.

Pregnancy rate: In our study, the reproduction rate for yearlings in Hokkaido (66 %) was comparable to those reported in North America (54% [29], 73% [16], 38-77%, [9]). Because yearlings make up the largest segment of the breeding population [5, 9], estimates of yearling birth rates are critical to understanding raccoon population dynamics. Although pregnancy rate of yearlings was lower than all adult segments, yearlings accounted for 32% of the reproductive population in our study. Pregnancy rates of adults averaged 96% and remained high even in the oldest individuals sampled.

Mating season: Typically in North America, raccoons breed in February and March, give birth in April and May after a 63 day gestation period, and wean their young after about three months [6, 11, 20, 23, 26, 28, 29]. Based on radio-tracking observations of 11 individuals, Kurashima and Niwase [18] reported that the mating pattern of raccoons in Eniwa, Hokkaido, was similar to that reported for North America. Most sexually mature females sampled in this study were postnatal when trapped in summer. The proportion of lactating females per reproductive females was 100% in June and then decreased gradually by month. The first capture of juveniles in box traps never occurred before June. According to area farmers, crop damage begins to increase in July each year, a time that coincides with our estimate of the weaning period in Hokkaido. Judging from these and other qualitative data, we propose that in Hokkaido the mating season peaks in February and litters are born between March and May as in North America. Given variations in winter temperatures and snow cover in Hokkaido, the beginning of the mating season might vary substantially from year to year.

The capture of two pregnant females in July indicates that later season mating can occur. Second estrus or late litters for raccoons in North America have been reported [8, 10, 26, 29], but ours is the first confirmation of summer breeding in Japan. This factor should be considered in discussions of population control of feral raccoons in Hokkaido.

Management implications: Our study demonstrates that the reproductive potential of feral raccoons in Hokkaido is similar to populations in North America. Recent increases in the number of feral raccoons in Hokkaido can be attributed to their high productivity. The harvest of raccoons during the hunting season has been allowed in Japan since 1994, but sports harvests are rare in Hokkaido [15]. Damage control and research harvests account for most of the human-caused mortality of raccoons, but are conducted mainly in summer before the hunting season. Clark [4] reported that summer harvest levels between 20 and 40% were compensatory for a fall raccoon population in Iowa. Chamberlain *et al.* [3] also concluded that summer raccoon hunting would not result in population reductions. Although we do not yet have enough data to estimate the total population of feral raccoons in our study area, based on our estimates of reproductive rates, current levels of harvest mortality are unlikely to reduce the feral raccoon population on Hokkaido.

The impacts of harvest on population growth rates might increase if capture methods increased juvenile harvest pressure. Without bias for trapping, the more numerous juveniles should be captured in large numbers rather than yearlings. The fact that similar proportions of juvenile and yearling females were harvested during our study suggests low hunting success for juveniles in summer, at least when using box traps. Increasing juvenile mortality with improved harvest methods may help reduce feral raccoon numbers in Hokkaido. Management plans should include monitoring programs for population age structure, reproductive ratios, and litter sizes in harvested raccoons. Further studies of body weights, lactation and nipple conditions in Hokkaido might also help managers distinguish juvenile females from the older animals or estimate sexual maturity and breeding states in the field [17, 24–26, 28].

ACKNOWLEDGEMENTS. We wish to thank many trappers and farmers who helped collect raccoons and provided useful information about raccoons for us. We are also grateful to local government offices, EnVision, and the Hokkaido Forest Management Corporation that provided us with raccoon samples. Mr. N. Hachiya offered precise advice on age determination. This study was carried out in association with the Management Plan for the Feral Raccoon Population in Hokkaido, and was funded by the Nature Preservation Division of the Hokkaido Government and the Hokkaido Environmental Foundation.

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