Jpn. J. Vet. Res. 50(4) : 165-173, 2003

FULL PAPER

Growth pattern and seasonal weight changes of the feral raccoon (*Procyon lotor*) in Hokkaido, Japan

Makoto Asano[1)]*, Yohei Matoba[2,3)], Toru Ikeda[4)], Masatsugu Suzuki[1)], Mitsuhiko Asakawa[2)] and Noriyuki Ohtaishi[1)]

(Accepted for publication : January 9, 2003)

Abstract

The growth pattern and seasonal weight fluctuations of feral raccoons in Hokkaido were evaluated between 1999 and 2001. The growth rates in body length and body weight were described for juveniles (young of the year) and yearlings (animals born in the previous season) using the Gompertz growth model. The asymptotic body sizes for males were greater than those for females. Young raccoons born during spring in the study area could potentially grow up to their asymptotic size at the beginning of their first winter, but they would not reach their full adult sizes until at least their second fall. Adult raccoons (animals ≥ 2 -year-old) had seasonal weight fluctuations with annual weight loss of 25% to 28% of mean maximum weights in west-central Hokkaido, but these result would be an underestimate of the degree of annual weight fluctuations. Juvenile raccoons can be distinguished from the older animals by measuring body length or body weight during fall in Hokkaido.

Key words : body size ; growth ; *Procyon lotor* ; raccoon ; seasonal change

Introduction

The raccoon (*Procyon lotor*) has a vast transcontinental distribution, occurring throughout most of North America and Central America[19,28,32)]. Since the 1970s, many raccoons have

[1)]Laboratory of Wildlife Biology, Department of Environmental Veterinary Sciences, Graduate School of Veterinary Medicine, Hokkaido University, Sapporo, 060-0818, Japan
[2)]Department of Veterinary Parasitology (Wildlife Zoology), School of Veterinary Medicine, Rakuno Gakuen University, Ebetsu, Hokkaido 069-8501, Japan
[3)]Raccoon Research Society, Office in Department of Veterinary Parasitology (Wildlife Zoology), School of Veterinary Medicine, Rakuno Gakuen University, Ebetsu, Hokkaido 069-8501, Japan
[4)]Research Group of Regional Sciences, Graduate School of Letters, Hokkaido University, Sapporo, Hokkaido 060-0810, Japan
*Corresponding author : Makoto Asano, Laboratory of Wildlife Biology, Department of Environmental Veterinary Sciences, Graduate School of Veterinary Medicine, Hokkaido University, Sapporo, 060-0818, Japan
Phone : +81-11-706-7188, Fax : +81-11-706-5569
E-mail : asano-jr@vetmed.hokudai.ac.jp

been imported into Japan as pets[13,17]. In Hokkaido, the northernmost island of Japan, the population has been distributed over the west-central area in the last 20 years because of the intentional release and escape of pet raccoons[13,17]. The control actions for naturalized raccoons in Hokkaido commenced in 1997, and the annual control kill of raccoons averaged 700 between 1999 and 2001[12].

Asano *et al*.[1] reported that the mean litter size and pregnancy rate of yearling raccoons in west-central Hokkaido were similar to those of the highest levels reported for populations at the northern parts in the United States[5,26]. The main human-related causes of mortality among the feral raccoon populations in Hokkaido would be the control and research kills during summer. A lower trapping success for juvenile raccoons (young of the year) in Hokkaido was suggested by Asano *et al*.[1] Therefore, improvement and monitoring of the trapping success for juveniles are required for an eradication program of the feral raccoon populations in Hokkaido. However, the harvest record of raccoons killed for nuisance control could not be utilized for population analysis because of the lack of data on sex and age. In Hokkaido, some efficient techniques for separating juveniles from the older animals should be exhibited, especially in consideration of applying for carcasses in nuisance control.

In North America, some external metric characters for separating juvenile raccoons from the older animals include the lengths of the ear, hind foot and tooth[30], but these criteria can be just used for a short period, by late summer or early fall[30]. Body weight is also a reliable criterion for the classification of juveniles and the older animals during fall[30]. However, a second estrus or late litters have been observed in raccoons[1,4,6,29,31], therefore juveniles potentially have much variation in their weights even if they are harvested at the same period. Thus, in order to apply body weight or body length as a criterion for separating juveniles, it is necessary to clarify the neonatal growth and seasonal weight fluctuations in respective study area.

However, little was known about the growth and weight fluctuations of feral raccoons in Hokkaido. The objectives of this study were to show the growth patterns in body length and total body weight of feral raccoons, and to evaluate the seasonal weight fluctuations between sexes, age classes and reproductive statuses.

Materials and Methods

The study site was located in west-central Hokkaido, which was confirmed the earliest establishment of feral raccoons in Hokkaido[13] (Fig. 1). In the study area, the differences in the mean monthly temperatures between summer and winter were approximately 30℃. The minimum daily temperature was below −20℃ in February and the greatest accumulative depth of snow was about 85 cm in winter during the study period. Snow remained in the forests until late April. These climatic data were obtained from the Sapporo District Meteorological Observatory.

We collected a total of 684 raccoons between May 1999 and October 2001. Most of the animals were caught using box traps and euthanized for research or nuisance control between June and October[2]. Raccoons were measured for their body length (straight line length from the tip of the nose to the base of tail) to the nearest 0.5 cm, and for their total body weight to the nearest 100 g. Females were examined for their reproductive status, parous or nulliparous, by evidence of placental scars, fetuses and uterine swellings[1,14,29]. Fetuses were weighed and measured for their crown-rump lengths.

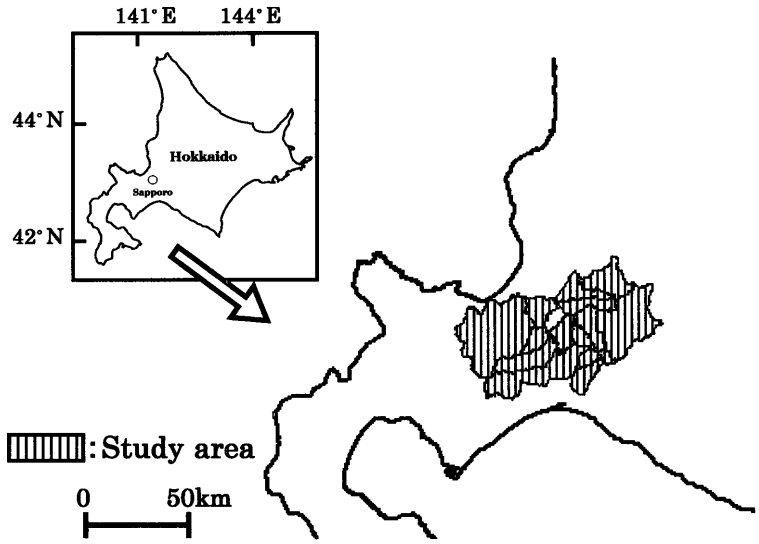

Fig. 1 The study area where feral raccoons were collected in west-central Hokkaido, Japan during 1999-2001.

Juveniles (young of the year) were distinguished from yearlings (animals born in the previous season) or adults (animals ≥ 2 -year -old) by the root foramina closure of canines[9], then aged in months from tooth eruption[21] and/or cranial suture obliteration[15]. Yearlings and adults were aged according to the annual incremental lines in the tooth cementum of the canines and / or incisors[9]. In Hokkaido, most of the litters were born between March and May[1], and we assumed a mean birth date to be 15 April. The ages of yearlings were converted into months relative to 15 April in the year of their birth.

The growth rates in the body size, body length and total body weight, were described for juveniles and yearlings using the Gompertz growth model[7,25,33] :

$$M(t) = A \times e^{-e^{-k(t-I)}},$$

where M(t) = body size at age t (months), A = asymptotic body size, k = a growth rate constant (per month), and I = the age at the inflection point (months). The growth curves were fitted by nonlinear regression with the Base System and Regression Models of SPSS 10.0 J for Windows (SPSS Japan Inc., Tokyo, Japan).

Due to the small sample size, we pooled all the data over the years. The sample sizes varied among the months because the trapping effort for feral raccoons was not constant between seasons. Statistical differences between the regression parameters were tested with a t-test. We used Mann-Whitney U-test to compare the monthly measurements between sexes and age classes or reproductive statuses. The seasonal fluctuations of weight were tested using analysis of variance. We considered $p < 0.05$ as significant for all statistical tests.

Results

Of the total of 684 raccoons, 250 were juveniles (132 males and 118 females), 223 were yearlings (101 males and 122 females) and 211 were adults (69 males and 142 females). The average proportion of parous females was 68% in yearlings and 96% in adults for the females collected during the study period.

Growth rates for body length and weight

We obtained two litters near their full term of gestation, according to the criteria reported by Hamilton[10] and Llewellyn[18]. The mean crown-rump length and weight of these five fetuses were 97.6 cm (SD=3.7) and 83.8 g(SD=9.6), respectively.

The body length and total body weight for juveniles of both sexes increased rapidly (Fig. 2). The parameters of the fitted Gompertz curves are listed in Table 1. Both the asymptotic length ($t=121.7$, $df=471$, $p<0.05$) and asymptotic weight ($t=135.1$, $df=471$, $p<0.05$) for males were greater than those for females. Males and females reached 90% of their asymptotic body length at 4.6 and 4.2 months old, respectively. The asymptotic lengths of both sexes were 96% of their mean adult body length, 61.3 cm (SD=3.0) for adult males and 57.9 cm (SD=2.9) for adult females. For the body weight, males and females reached 90% of their asymptotic value at 6.6 and 6.7 months of age, respectively. Significant differences between the sexes for juveniles in body length ($U=8.0$, $p<0.01$) and body weight ($U=6.4$, $p<0.01$) were detected after the age of 6 months. Juveniles less than 4 months old did not weigh beyond 5.0 kg for male ($n=119$) and 4.0 kg for females ($n=108$) during the study period. Discriminant body weights which differentiate yearlings trapped during October and juveniles at 6 months were estimated to be 7.1 kg for males and 5.4 kg for females using logistic regression. Mean weight of juveniles at 8 months (6.4 kg, $n=3$) tended to decrease during winter at the degree of 36% (4.1 kg, $n=8$), though the difference was not significant ($U=20$, $p=0.10$).

Seasonal weight changes

Adult raccoons had seasonal variations in the mean monthly weights for both males (May-October, $F=4.28$, $df=5,64$, $p<0.01$) and females (June-October, $F=6.87$, $df=4,134$, $p<0.01$) (Fig. 3). Mean monthly weights of adults varied 25% for males (March-October) and 28% for females (March-October) between maximum and minimum value.

The mean monthly weights of yearlings were significantly smaller than those of adults for males until at least October, and for females until August. Nulliparous yearlings had relatively smaller mean weights than those of parous yearlings until the middle of summer. From June to August, nulliparous yearlings gained weight at 17%, though mean weights for adult females and parous yearlings did not gain.

Discussion

Table 1. Growth parameters of the Gompertz model fitted to growth in body length (cm) and body weight (kg) for feral raccoons collected in west-central Hokkaido, Japan, during 1999-2001

	Body length		Body weight	
	Males	Females	Males	Females
A	59.0 (0.32)	55.7 (0.28)	6.26 (0.08)	5.36 (0.06)
k	0.556 (0.031)	0.630 (0.032)	0.556 (0.056)	0.523 (0.058)
I	0.540 (0.104)	0.577 (0.093)	2.515 (0.068)	2.350 (0.081)
R^2	0.88	0.87	0.85	0.84

Abbreviations. A: asymptotic body size, k: growth rate constant per month, I: age at inflection points (months), R^2: coefficient of determination.
Numerals in parentheses are SD.

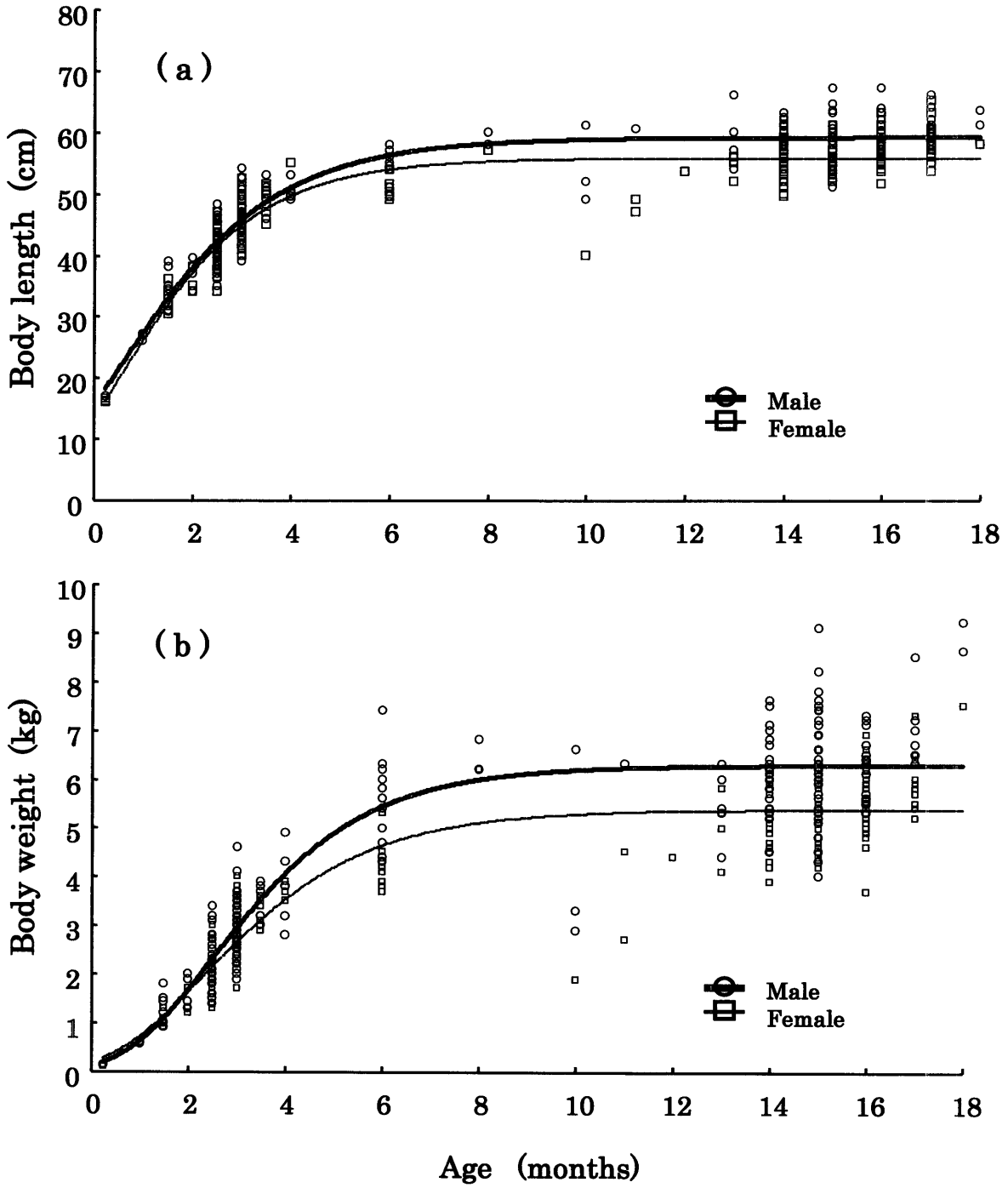

Fig. 2 The relationships of age to body length (a), and body weight (b) for feral raccoons collected in west-central Hokkaido, Japan, during 1999-2001. The growth curves were drawn according to the Gompertz growth model.

Growth pattern of young raccoons

The average weight of 83.8 g for the five full term fetuses in this study was relatively heavier compared to newborn weights of 60-75 g reported in North America[10,30-32]. Ritke[26] showed that the geographic variation in litter sizes of the raccoon was positively correlated with female body size and latitude, but little

is known about the geographic variation in fetus weights for raccoons. More data sets need to be collected in order to examine the intraspecific variation in newborn weights and the relationship between litter mass and litter size in raccoons.

Raccoons in Hokkaido had a larger growth rate constant and an earlier inflection point for body length compared to those for body weight. Then, growth in length attained earlier at 90% of the asymptotic value than in weight for 2.0 (for males) and 2.5 months (for females). Because the total body weight increases as a power function of linear measurements[25], the growth in the body length was not isometric with the body weight in raccoons.

The growth curve showed that young raccoons born during spring in Hokkaido could grow potentially up to their asymptotic size at the beginning of their first winter. Raccoons in the study area had relatively larger growth rate constant and smaller asymptotic body weights compared with those of raccoons in subtropical climate area, South Texas, reported by Gehrt and Fritzell[7]. In raccoons in South Texas, the growth rate constant (per month) of body weight were 0.264 for males and 0.200 for females, and asymptotic body weights were 6.606 kg for males and 6.382 kg for females, respectively. There are few studies on the growth rate of raccoons in introduced areas and in northern parts of original range. The rapid growth of raccoons in Hokkaido compared with that in subtropical climate area, South Texas, was consistent with Case[3] that species in highly seasonal environments would have a high growth rate. But smaller asymptotic weights in Hokkaido than subtropical area were conflicting Bergman's rule that geographic variation in body size of raccoons was correlated with latitude[27]. It would be conceivable that the sufficient food availability contributed to the rapid growth for juveniles in the study area, and then resulted in the average 68% of females to be sexually mature before one year of age. Since reproduction is energy expensive[8,11], the energetic cost of reproduction highly influenced the weight of parous yearlings nursing their litters. The cessation of weight gain was observed in parous yearlings and adult females during the summer in this study. Not only reproduction but also variable factors would have an effect on area-depended variations in body sizes[16,27].

Seasonal weight fluctuations of yearlings and adults

Adult raccoons had seasonal weight fluctuations with weight loss of 25% to 28% of mean maximum weights in west-central Hokkaido. This result would be an underestimate of the degree of annual weight fluctuations because we could not obtain data on the adult weights during late fall to winter. Northern raccoon populations in North America lose as much as 50% of their maximum weights during winter to spring[20,30]. The magnitudes of seasonal weight change for northern populations were relatively larger than those for southern populations due to the winter dormancy[23]. The rapid increases in the mean weights after September observed in this study suggested that raccoons stored energy for the winter period by depositing body fat during fall in Hokkaido, as that was reported in North America[20,22-24,30]. The snowy and severe winter in Hokkaido would be a critical period for raccoons that could not deposit enough fat reserves in fall.

The significant differences in the mean monthly weights between yearlings and adults suggested that the raccoons in Hokkaido did not reach fully their adult sizes until at least fall for males and summer for fe-

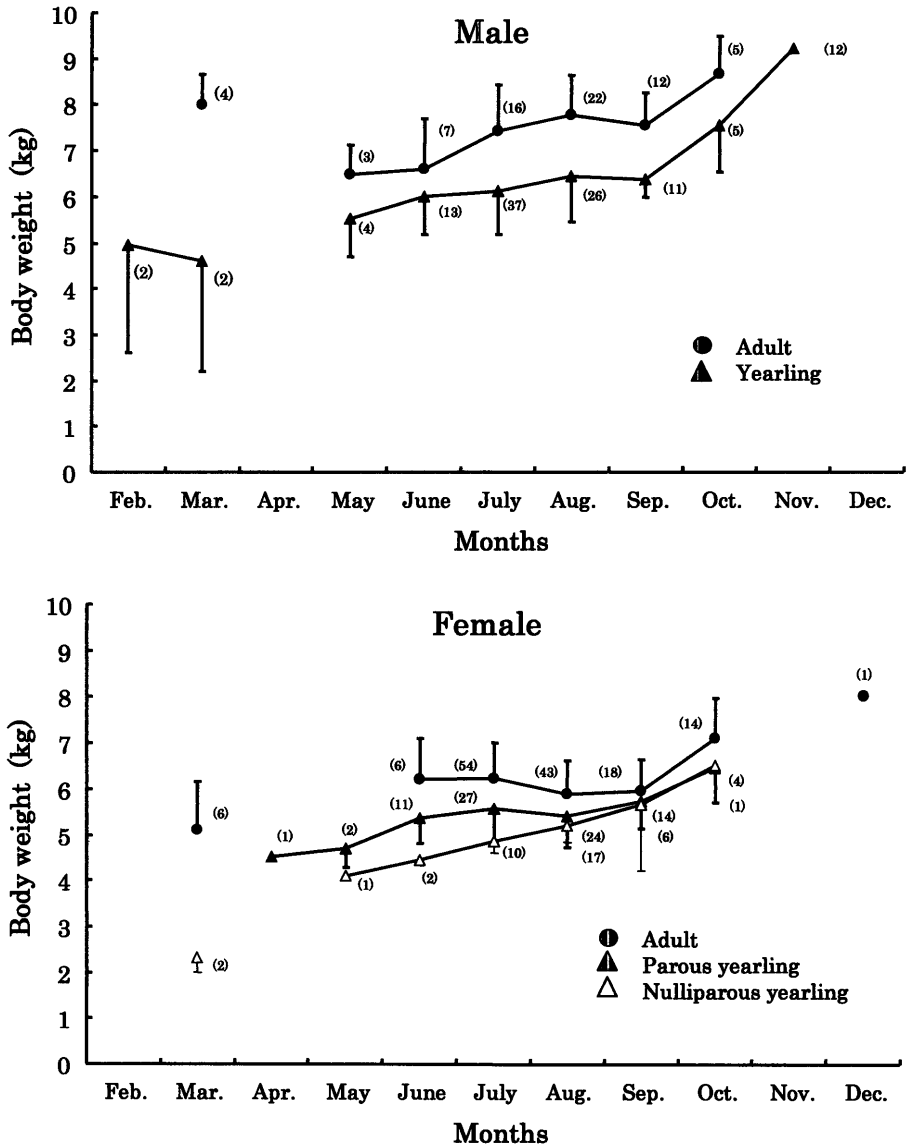

Fig. 3 Seasonal changes in body weight for adult and yearling feral raccoons collected in west-central Hokkaido, Japan, during1999-2001. The vertical bars represent the standard deviations and the numerals in parentheses are the sample sizes.

males. In North America, raccoons at northern latitudes may attain their adult weights later than those in southern populations[7,30], due to the weight loss during the severe winter[20,30]. Our limited data suggested that juvenile raccoons in Hokkaido would lose their weights about 36% during the first winter, and then yearlings would attain their adult weights after the fall of their second year, similar to the raccoons at northern latitudes in North America[30]. The differences in mean body weights of yearlings between parous and nulliparous females until fall suggested that nulliparous raccoons did not attain their mature body sizes for mating.

Management implications

Juvenile raccoons can be distinguished from the older animals by measuring body length or body weight during fall in Hokkaido. Judging from the delay in age that attained the asymptotic values, body weight can be used for long period than body length as an external criterion to separate juvenile raccoons from the older animals. In addition, weight data could be obtained from carcasses with rigor mortis. The results from a logistic regression, weights of less than about 7.0 kg for males and 5.5 kg for females in fall would be reliable criteria for separating juvenile raccoons in Hokkaido. The lack of sexual differences in body sizes for juveniles younger than 6 months suggested that sex determination is imperative by checking the external reproductive organs.

Acknowledgements

We wish to thank the many trappers and farmers who helped us collect the raccoons. We are also grateful to local government offices, EnVision, Hokkaido Forest Management Corporation and Nopporo Natural Forest Park Office who 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 partly funded by the Nature Preservation Division of the Hokkaido Government.

References

1) Asano, M., Matoba, Y., Ikeda, T., Suzuki, M., Asakawa, M. and Ohtaishi, N. Reproductive characteristics of the feral raccoon (*Procyon lotor*) in Hokkaido, Japan. *J. Vet. Med. Sci*. (in press)

2) Beaver, B. V., Reed, W., Leary, S., McKiernan, B., Bain, F., Schultz, R., Bennett, B. T., Pascoe, P., Shull, E., Cork, L. C., Francis-Floyd, R., Amass, K. D., Johnson, R., Schmidt, R. H., Underwood, W., Thornton, G. W. and Kohn, B. 2001. 2000 Report of the AVMA panel on euthanasia. *J. Am. Vet. Med. Assoc*., 218 : 669-696.

3) Case, T. J. 1978. On the evolution and adaptive significance of postnatal growth rates in the terrestrial vertebrates. *Quart. Rev. Biol*., 53 : 243-282.

4) Fritzell, E. K. 1978. Reproduction of raccoons (*Procyon lotor*) in North Dakota. *Am. Midl. Nat*., 100 : 253-256.

5) Fritzell, E. K., Hubert, G. F. Jr., Meyen, B. E. and Sanderson, G. C. 1985. Age-specific reproduction in Illinois and Missouri raccoons. *J. Wildl. Manage*., 49 : 901-905.

6) Gehrt, S. D. and Fritzell, E. K. 1996. Second estrus and late litters in raccoons. *J. Mammal*., 77 : 388-393.

7) Gehrt, S. D. and Fritzell, E. K. 1999. Growth rates and intraspecific variation in body weights of raccoons (*Procyon lotor*) in Southern Texas. *Am. Midl. Nat*., 141 : 19-27.

8) Gittleman, J. L. and Thompson, S. D. 1988. Energy allocation in mammalian reproduction. *Amer. Zool*., 28 : 863-875.

9) Grau, G. A., Sanderson, G. C. and Rogers, J. P. 1970. Age determination of raccoons. *J. Wildl. Manage*., 34 : 364-372.

10) Hamilton, W. J. Jr. 1936. The food and breeding habits of the raccoon. *Ohio J. Sci*., 36 : 131-140.

11) Harvey P. H. 1986. Energetic costs of reproduction. *Nature*, 321 : 648-649.

12) Hokkaido Government. 2001. *White Book on Environmental in Hokkaido*, Hokkaido Environmental Policy Planning Div., Sapporo. (in Japanese)

13) Ikeda, T. 1999. Progress of Naturalization of Raccoons and Related Problems in Hokkaido. *The Annual Report on Cultural Science, Faculty of Letters, Hokkaido*

University, 47 : 149-175. (in Japanese)

14) Junge, R. E. and Sanderson, G. C. 1982. Age related reproductive success of female raccoons. *J. Wildl. Manage.*, 46 : 527-529.

15) Junge, R. E. and Hoffmeister, D. F. 1980. Age determination in raccoons from cranial suture obliteration. *J. Wildl. Manage.*, 44 : 725-729.

16) Kennedy, M. L. and Lindsay, S. L. 1984. Morphologic variation in the raccoon, Procyon lotor, and its relationship to genetic and environmental variation. *J. Mammal.*, 65 : 195-205.

17) Kurashima, O. and Niwase, N. 1998. Spacing pattern of feral raccoons (*Procyon lotor*) in Eniwa, Hokkaido. *Honyurui Kagaku* (Mammalian Science), 38 : 9-12. (in Japanese with English abstract)

18) Llewellyn, L. M. 1953. Growth rate of the raccoon fetus. *J. Wildl. Manage.*, 17 : 320-321.

19) Lotze, J. -H. and Anderson, S. 1979. *Procyon lotor. Mammalian Species*, 119 : 1-8.

20) Mech, L. D., Barnes, D. M. and Tester J. R. 1968. Seasonal weight changes, mortality, and population structure of raccoons in Minnesota. *J. Mammal.*, 49 : 63-73.

21) Montgomery, G. C. 1964. Tooth eruption in preweaned raccoons. *J. Wildl. Manage.*, 28 : 582-584.

22) Moore, D. W. and Kennedy, M. L. 1985. Weight changes and population structure of raccoons in Western Tennessee. *J. Wildl. Manage.*, 49 : 906-909.

23) Mugaas, J. N. and Seidensticker, J. 1993. Geographic variation of lean body mass and a model of its effect on the capacity of the raccoon to fatten and fast. *Bull. Florida Mus. Nat. Hist.*, 36 : 85-107.

24) Mugaas, J. N., Seidensticker, J. and Mahlke-Johnson, K. P. 1993. Metabolic adaptation to climate and distribution of the raccoon *Procyon lotor* and other Procyonidae. *Smithsonian Contrib. Zool.*, 542 : 1-34.

25) Prestrud, P. and Nilssen, K. 1995. Growth, size, and sexual dimorphism in Arctic Fox. *J. Mammal.*, 76 : 522-530.

26) Ritke, M. E. 1990. Quantitative assessment of variation in litter size of the raccoon Procyon lotor. *Am. Midl. Nat.*, 123 : 390-398.

27) Ritke, M. E. and Kennedy, M. K. 1988. Intraspecific morphological variation in the raccoon (*Procyon lotor*) and its relationship to selected environmental variables. *Southwestern Nat.*, 33 : 295-314.

28) Sanderson, G. C. 1987. Raccoon, In : *Wild Furbearer Management and Conservation in North America*, pp487-499, Novak, M., Baker, J. A., Obbard, M. E. and Malloch, B. eds., Ontario Trappers Assoc. Publ., Ontario.

29) Sanderson, G. C. and Nalbandov, A. V. 1973. The reproductive cycle of the raccoon in Illinois. *Ill. Nat. Hist. Survey. Bull.*, 31 : 29-85.

30) Stuewer, F. W. 1943. Raccoons : their habits and management in Michigan. *Ecol. Monogr.*, 13 : 203-257.

31) Stuewer, F. W. 1943. Reproduction of raccoons in Michigan. *J. Wildl. Manage.*, 7 : 60-73.

32) Zeveloff, S. I. 2002. *Raccoons : a natural history.*, Bolen, E. A. eds., The Smithsonian Institution, Washington, D.C.

33) Zullinger, E. M., Ricklefs, R. E., Redford, K. H. and Mace, G. M. 1984. Fitting sigmoidal equations to mammalian growth curves. *J. Mammal.*, 65 : 607-636.