

Studies on male reproductive characteristics of feral raccoons  
(*Procyon lotor*) in Kanagawa Prefecture, Japan

Summary

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In Japan, the raccoon (*Procyon lotor*), an omnivorous medium-sized member of the Carnivora, was imported from North America as a pet and had naturalized throughout the country. Therefore, feral raccoons are becoming a problematic invasive species by law that was enforced in 2005 and are being commonly captured. An annual damage amount of agricultural crops and number of the capture is increasing year by year. Until now, feral raccoons were captured a lot at Kinki, Hokkaido and Kanto, but in late years the number of the capture is increasing at Kyushu quickly.

In Hokkaido, it has been proposed that feral raccoons could be effectively captured by shifting capture efforts to spring, which is when the animals are caring for their offspring. However, there are regional differences in the parturition periods of feral raccoons. Because in Kamakura, Kanagawa Prefecture, the parturition periods of raccoons is thought to be from February to October and shows a bimodal distribution, capture efforts cannot be concentrated. In North America, the parturition periods of feral raccoons tend to be longer at more southern latitudes. Therefore, the parturition periods of raccoons in Kyushu where the number of the capture is increasing were expected like Kamakura, so management plan like Hokkaido cannot be adopted simply at Kyushu.

As the cause of the bimodal distribution of parturition period of feral raccoons, the factor of the female side was considered until now, but a study is not performed about the factor of the male side. To assess the cause of the bimodal distribution, the present study proposes following two hypotheses: 1) The yearling males reach sexual maturity after spring and produce offspring; 2) Because the number of adult male raccoons being sexually inactive in summer excessively increased, a part of the original peak became dented.

The objective of this study was to study the reproductive characteristics of male raccoons to understand the role of the male for distribution of parturition periods of raccoons and test the above two hypotheses.

First, the parturition periods of raccoons at Kanagawa and Kyoto was estimated in Chapter 2. Then for testing of hypothesis 1, the age when feral raccoons start spermatogenesis and the growth of male sexual organs, such as baculum and prostate, was studied in Chapter 3. Furthermore, it was inspected whether the reproductive characteristics, such as spermatogenesis, and the growth of male sexual organs, such as testis and prostate were different between early litters and late litters in Chapter 4. And for testing of hypothesis 2, the seasonal change of reproductive characteristics was studied in Chapter 5. In addition, the simple evaluation methods to assess reproductive characteristics of male raccoons were developed to make it easy to introduce the study of that for the management plan.

## **1. Estimation of the parturition period of feral raccoons in Kanagawa and Kyoto (Chapter 2)**

2,673 raccoon carcasses were collected by raccoon control programs in Kanagawa Prefecture from November 2005 to October 2014 and 738 raccoon carcasses were collected by raccoon control programs in Kyoto Prefecture from March 2009 to February 2014. To estimate birth month, the crown-rump length of fetuses was measured and age determination was performed by their tooth eruption. In this study, there were significant differences between the parturition period of feral raccoons in Kanagawa and that in Kyoto ( $\chi^2=40.44$ , d.f.=2,  $p<0.01$ ). That in Kanagawa were estimated to range from February to December with two peaks, that big in May and small in August, and the amount decreased in the latter half of that were gradual. In contrast, the parturition period of feral raccoons in Kyoto were estimated to range from January to November with one big peak in May and the amount decreased after May were sudden.

## **2. Estimation of the age of sexual maturity of male raccoons in Kanagawa and Kyoto (Chapter 3)**

### **1) Estimation of the time of commencing spermatogenesis of feral raccoons in Kanagawa and Kyoto (Chapter 3 section 1)**

359 raccoon carcasses were collected by raccoon control programs in Kanagawa from July 2005 to January 2014 and 33 raccoon carcasses were collected by raccoon control programs in Kyoto from December 2007 to December 2013. The ages of the raccoons were determined by the cranial suture obliteration method. Then for estimating the age when feral raccoons start spermatogenesis, the testis and the tail of the epididymis was studied by histologically. The male raccoon in Kanagawa started spermatogenesis at six months of age. In contrast, most male raccoons in Kyoto started spermatogenesis over twenty months of age, except one that started spermatogenesis at eight months of age. Therefore, it was expected that yearling male breed in Kanagawa at their first mating season and that breed in Kyoto at their second mating season.

### **2) Growth of the baculum of male raccoons in Kanagawa and Kyoto (Chapter 3 section 2)**

189 raccoon carcasses were collected by raccoon control programs in Kanagawa from September 2005 to January 2014 and 31 raccoon carcasses were collected by raccoon control programs in Kyoto from July 2011 to December

2013. The ages of the raccoons were determined by the cranial suture obliteration method. After the baculum was removed, boiled and dried, then was measured and weighed. By calculation of using the expression of the growth curve of Gompertz, the growth of the baculum of raccoons at Kanagawa and Kyoto were similar to North America, thus it was expected that the baculum of raccoons at Kanagawa and Kyoto matured at seven months of age.

### **3) Development of the male reproductive organs of feral raccoons in Kanagawa and Kyoto (Chapter 3 section 3)**

359 raccoon carcasses were collected by raccoon control programs in Kanagawa from July 2005 to January 2014 and 33 raccoon carcasses were collected by raccoon control programs in Kyoto from December 2007 to December 2013. The testis, the epididymis and the prostate were analyzed by histologically. Growth rates of various parameters, such as the testicular weight, were calculated using the expression of the growth curve of Gompertz. Because of high growth rate of Kanagawa and high asymptotic value of Kyoto, feral raccoons at Kanagawa were precocious and that at Kyoto were large-sized. Then, the prostate of feral raccoons matured at six months of age in synchrony with spermatogenesis.

### **3. Difference in reproductive characteristics for birth time (Chapter 4)**

To estimate the birth months of feral raccoons at Kanagawa (n=323), specimens of two months of age were analyzed by the cranial suture obliteration methods. Although the parturition season of feral raccoons in Kamakura occurs between February and October, it was considered that feral raccoons born by May represented early litters, whereas those born from June were late litters. There was no difference about the age that started spermatogenesis and growth rates of various parameters, such as the testicular weight, between early litters and late litters. By analysis according to the capture time, it was expected that the yearling males of the early born group in Kanagawa are a father of early litters, and that of late born group is a father of late litters.

### **4. Seasonal changes in spermatogenesis of feral raccoons in Kanagawa and Kyoto (Chapter 5)**

309 raccoon carcasses were collected by raccoon control programs in Kanagawa from July 2005 to January 2014 and 77 raccoon carcasses were

collected by raccoon control programs in Kyoto from December 2007 to December 2013. The testis, the epididymis and the prostate were analyzed histologically. Growth rates of various parameters, such as the testicular weight, were considered about seasonal change. The greatest percentage of adult male raccoons was sexually inactive in summer (spring: 100%; summer: 50%; autumn: 86%; winter: 100%). In contrast, the ratio of male raccoons being sexually active was constant in 50% throughout the year. Because the ratio of juvenile males being sexually active was increased in summer, it was expected that the juvenile males mated in summer and the late litters was born.

## **5. Methods of evaluating the spermatogenic ability of male raccoons (Chapter 6)**

Generally, spermatogenesis is studied histologically. At present, male spermatogenic ability is not well understood in Japan, unlike female reproductivity, because the histological method to evaluate it is both more difficult and more expensive than macroscopic observation. So, 182 raccoon carcasses were collected by raccoon control programs in Kanagawa from March 2005 to September 2008. In this study, the spermatogenesis of feral male raccoons was evaluated by histologically examining the testis and the tail of the epididymis to establish a simple method of estimating spermatogenesis from external measurements. GSI that is frequently used to monitor breeding activities in fish and body weight were chosen as criteria of spermatogenesis and the judgment rate was 97%, and GSI was chosen as criterion for presence of spermatozoa in the tail of the epididymis and the judgment rate was 98%.

## **6. Summary and conclusion (Chapter 7)**

In Chapter 2, there were significant differences between the parturition period of feral raccoons in Kanagawa and that in Kyoto, and there were more late litters in Kanagawa than Kyoto.

In Chapter 3, the male raccoon in Kanagawa started spermatogenesis at six months of age, and the baculum and the prostate of feral raccoons matured in synchrony with spermatogenesis. From the comparison with other studies, there are regional differences in the sexual maturity of feral male raccoons. Therefore, it was expected that yearling male breed in Kanagawa at their first mating season and that breed in Kyoto and Hokkaido at their second mating season.

In Chapter 4, late litters in Kanagawa were matured at the latter half of their

first mating season. Hence, it was expected that the yearling males of the late born group in Kanagawa are a father of late litters.

In Chapter 5, the greatest percentage of male raccoons over twelve months of age were sexually inactive in summer. In contrast, the ratio of male raccoons being sexually active was constant in 50% throughout the year. Because the ratio of juvenile males being sexually active was increased in summer, it was expected that feral raccoons in Kanagawa could mate throughout the year though the raccoon was seasonally breeding mammals.

In Chapter 6, a simple method that was useful for analysis about reproductive characteristics of male raccoons was developed, and it was clarified that GSI that had not been used for mammals very much until now was useful in order to estimate the reproductive characteristics of male raccoons.

First hypothesis was accepted, because male raccoons started spermatogenesis at their first mating season, the ratio of male raccoons being sexually active in Kanagawa was constant in 50% throughout the year, toward that in Kyoto was 20% and the yearling males of the late born group in Kanagawa are a father of late litters. Then, second hypothesis was accepted, because the greatest percentage of adult male raccoons was sexually inactive in summer. However, there was seasonal change in parturition period of feral raccoons in Kanagawa though the ratio of male raccoons being sexually active in Kanagawa was constant in 50% throughout the year. Therefore, it was expected that the factor of female was important for distribution of parturition periods of raccoons. It was thought that new approach such as the histological analysis of the ovary was necessary in future.

As the suggestion of management, I recommend that feral raccoons should be captured at mating season, which is when activity of animal increase to look for a partner, and dispersal season of juveniles. Not usual management of harmful birds and animal that the capture is carried out only at the affected areas, making low density of feral raccoons at establishment areas and prevention of the distributional expansion are important and necessary for management of feral raccoons. So, it is necessary to understand the reproductive characteristics, such as parturition period, thus it is necessary to develop the simple method that was useful for analysis about reproductive characteristics, such as the methods that this study provided. And continuous capture without analysis is not

recommended. Local management plans should be formulated with an understanding of local raccoon situation by continuous monitoring. Therefore, it is important to develop the simple method that was useful for analysis about reproductive characteristics for continuous monitoring.