Comparison of Food Availability and the Density of Japanese Macaques in Primary, Naturally Regenerated, and Plantation Forests

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Introduction

Japanese forests have changed considerably since the 1960s through ‘expansive afforestation,’ that is, through deforestation and replacement of broad-leaved trees with conifers, such as Japanese cedar *Cryptomeria japonica* and hinoki cypress *Chamaecyparis obtusa*. As a result, about 40% of Japanese forests have been converted to artificial coniferous forests. These tree species do not provide food for most indigenous vertebrate species, and are therefore believed to significantly affect Japanese wildlife. For example, crop raiding by Japanese macaques *Macaca fuscata* rapidly increased in the 1980s, and the area of damaged farmland has now reached 6000 ha. Agetsuma (1998) speculated that for about 10 yr after logging, food availability for the macaques did not decline because they foraged the grass vegetation in logged patches. However, as planted conifer stands developed, the grass was gradually replaced by tree plantations. In the 10–20 yr after logging, the planted forest became an artificial coniferous forest that provided little food for the macaques, leading them to raid crops. Damage to crops and forestry products by black bears (*Ursus thibetanus*), sika deer (*Cervus nippon*), Japanese serow (*Capricornis crispus*), Japanese hares (*Lepus brachyurus*), and wild boars (*Sus scrofa*) are also serious problems, which are suspected to be caused directly or indirectly by expansive afforestation (Takatsuki, 1996). In the 1990s, about 8000 Japanese macaques, 1200 Japanese serow, and 1500 black bears were killed annually as pests in Japan, even though some of these populations were endangered. Thus, to reduce damage to crops and to conserve wildlife, it is important to clarify and quantify the effects of expansive afforestation. In recent years, large-scale expansive afforestation has rarely been practiced due to the lack of adequate labor, and logged broad-leaved forests have often regenerated naturally with minimal human management. However, little empirical data exist on the disparate effects of these two regeneration systems on large, forest-dwelling mammals in Japan.

We compared food availability and group density of Japanese macaques on Yakushima Island, Japan, in three different forest types: primary forest, naturally regenerating forest, and artificially regenerating forest planted with *Cryptomeria japonica*. On this island, as in other parts of Japan, large-scale expansive afforestation was conducted in the 1960s and 1970s, and crop raiding by Japanese macaques became a serious problem in the 1980s. Now the annual cost of damage to crops is 10–40 million yen and more than 400 macaques are killed annually on Yakushima for pest control (Agetsuma, 1998). The goal of this study was to clarify differences among these forests types with respect to food availability and the density of Japanese macaques.

Methods

The study site was located in the western part of Yakushima at 700–1200 m above sea level. The primary vegetation here is transitional between a higher elevation coniferous forest and a lower elevation warm–temperate broad-leaved evergreen forest. The study area included both primary forest protected as national park and disturbed forest outside the park (Fig. 1a). The study in 2003 was conducted 7–27 yr after logging. For simplicity, we hereafter refer to the age of the regenerating forests in relation to the year 2003. The regeneration system changed in 1984. Before 1984, expansive afforestation was conducted: the forest was clear-cut, the felled areas were cleared, and 1000–2000 conifer saplings (*Cryptomeria japonica*) about 60 cm tall were planted per hectare. Weeding was conducted once a year for a few years after logging. Since 1984, no afforestation has occurred and clear-cut forests have been left to regenerate with little human management. We refer to the former stands as ‘plantation’ and the latter as ‘naturally regenerated.’

We established 5 × 5-m plots in primary and logged forests. In the primary forest, plots were randomly selected within a larger (0.75 ha) plot established in 1999. In the logged forest, we set each plot at the approximate center of each logged patch in 2002. We established 30 plots in primary forest, 10 in plantation forest (five in 19–22-yr-old and five in 23–27-yr-old forests) and 17 in naturally regenerated forest (seven in 7–10-yr-old, five in 11–13-yr-old, and five in 14–18-yr-old forests). In each plot, we recorded the species and diameter at breast height (DBH) of all trees taller than 1 m.

In early September of 2002 and 2003, we studied the fruit production of species eaten by macaques. This was carried out by a single observer counting the number of fleshy fruits on marked branches of each tree in each plot. The number of fruits in the tree was estimated by dividing the number of fruits on marked branches by the proportion of the branch relative to the total crown.

We censused Japanese macaques in August 2000, 2001, 2002, and 2003 using a point census with group follows (Hanya et al., 2003). We divided the 7.5-km^2 census area into 30 500 × 500-m grid squares (Fig. 1b). One observer was positioned in each grid square at a fixed point. Observers stayed at the points from 06:00 to 16:00. When they detected macaques by direct observation or vocalization, they recorded the time and approximate location, regardless of whether the animals were within or outside of the grid square. Whenever possible, 10–14 researchers followed groups that appeared in the census area. Group followers recorded the location of the center of the group every hour. Each point was censused for 6 days in 2000, 9 days in 2001, 7 days in 2002, and 5 days in 2003.

To estimate group density, we defined a group as a cluster of macaques whose spread was 500 m at maximum. At each point, we counted the number of groups detected each hour (e.g., 06:00–06:59) as follows. The number of groups detected each hour was averaged for each day, and then the day’s average value was averaged across all census days of the year for each point. We refer to this value, n, as the number of groups detected at a point. Because we followed some groups, it was possible to calculate the proportion of groups detected by point observers (detectability) at a given distance. We regressed the relationship between point-group distance *y* and detectability g(*y*) on a half-normal model: $g(y) = e^{-\lambda y^2}$ and calculated λ as the 'detectability constant.' Then, group density *D* was calculated as $D = \frac{\lambda n}{\pi}$ (Hanya et al., 2003).

Results

Fruit production was higher in young naturally regenerated forests than in primary forests (Fig. 2). However, the pattern varied among the four main fleshy-fruited species (Fig. 3), which comprised more than 95% of the fruit production. Fruit production was highest in 11–13-yr-old forests for *Eurya japonica* and 11–13-yr-old forests for *Symplocos myrtacea*. In the case of *Symplocos tanakae*, fruit production did not vary between primary and naturally regenerated forests in 2002 and was largely restricted to the 11–13-yr-old naturally regenerated forest in 2003. In contrast, *Cleyera japonica* fruited only in primary forest.

The density of macaque groups was higher in the youngest (7–10-yr-old) naturally generated forest than in the oldest (23–27-yr-old) plantation forest (Fig. 4).

Discussion

Food availability and group density of Japanese macaques were quite different between younger naturally regenerated forests and older plantation forests. In plantation forests 19 yr after logging, fruit production was negligible. The forest was composed mostly of *Cryptomeria japonica*, which offers male pollen cones as food only during the winter (Hanya, 2004). In contrast, in naturally regenerated forests, fruit availability was higher than in either primary or plantation forests for at least 7–18 yr after logging. Fruit availability is important because macaques in this region prefer fruits over other foods (Hanya, 2004), fruit availability is the principal determinant of the altitudinal variation in macaque density on Yakushima (Hanya et al., 2004), fruit production is known to affect reproduction in female Japanese macaques (Suzuki et al., 1998), fruit is high-quality food because of its high energy and low fiber content (Iwamoto, 1982), and fruit is generally a limited resource, whereas other foods, leaves in particular, are often superabundant (Janson & Chapman, 1999). Variation in the density of Japanese macaques was consistent with variation in food availability, at least for the plantation forest; macaque density was lowest in old plantation forests, where food availability was lowest.

In plantation forests, the macaques' food trees were cleared during logging. Even if they appear after logging, they are often cut to enhance the growth of *Cryptomeria japonica*. Once *Cryptomeria japonica* trees become large enough, short trees cannot reproduce under their shade. Our data indicate that these undesirable changes for frugivores, such as Japanese macaques, take place within 19 yr.

In young naturally regenerated forests, availability of food, and of fruit in particular, is higher than in primary and old plantation forests. Large fruiting trees are usually killed by clear-cutting, but this was not the case for the main sources of fruit for the macaques in this forest, as they are small trees. In cases of natural regeneration, felled areas are not cleared, and some small trees survive. When tall trees are cut, small trees receive more sunlight, which enhances their reproduction (Guariguata & Saenz, 2002). However, *Cleyera japonica* did not fruit in logged forest. The minimum DBH at which *Cleyera japonica* reproduced was 10 cm. This suggests that small *Cleyera japonica* in logged forests cannot reproduce like other species, even when light conditions are enhanced. Considering the observed interspecies variation in responses to logging, we propose that the effect of logging on frugivores varies with the flora. When large trees are the main source of fruit foods for frugivorous primates, their density and fruit availability are reduced by logging (Felton et al., 2003). When small trees offer a considerable amount of fruit, food availability for frugivores can be increased by logging (this study; Ganzhorn, 1995).

In conclusion, conversion of natural broad-leaved forest into monocultural *Cryptomeria japonica* forest is detrimental to the conservation of Japanese macaques. When small trees provide fruit for macaques, natural regeneration offers habitats of high fruit availability in the initial stage of regeneration, which lasts at least 7–19 yr after logging, and macaque density there is as high as in the primary forest.

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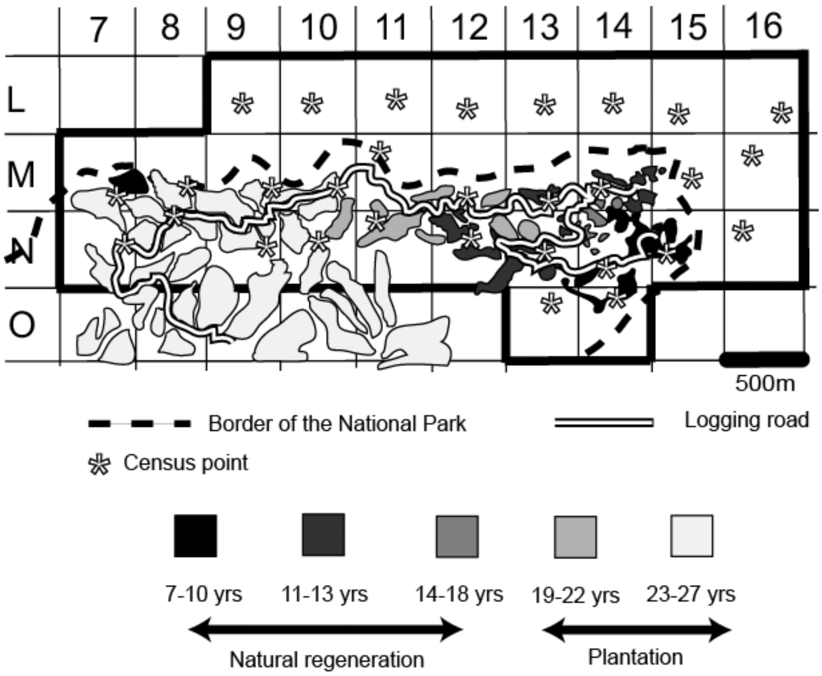

Fig. 1. Vegetation and the distribution of points where macaque groups were censused.
Thick lines indicate the census area.

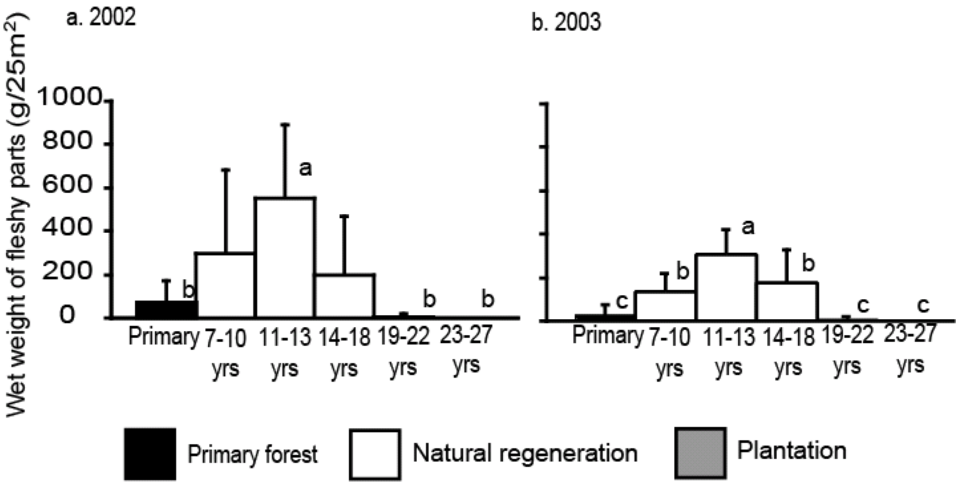

Fig. 2. Total annual fruit production. Means and standard deviations are shown.
Letters above the bars indicate significant differences between bars with different characters (in the order a > b > c).

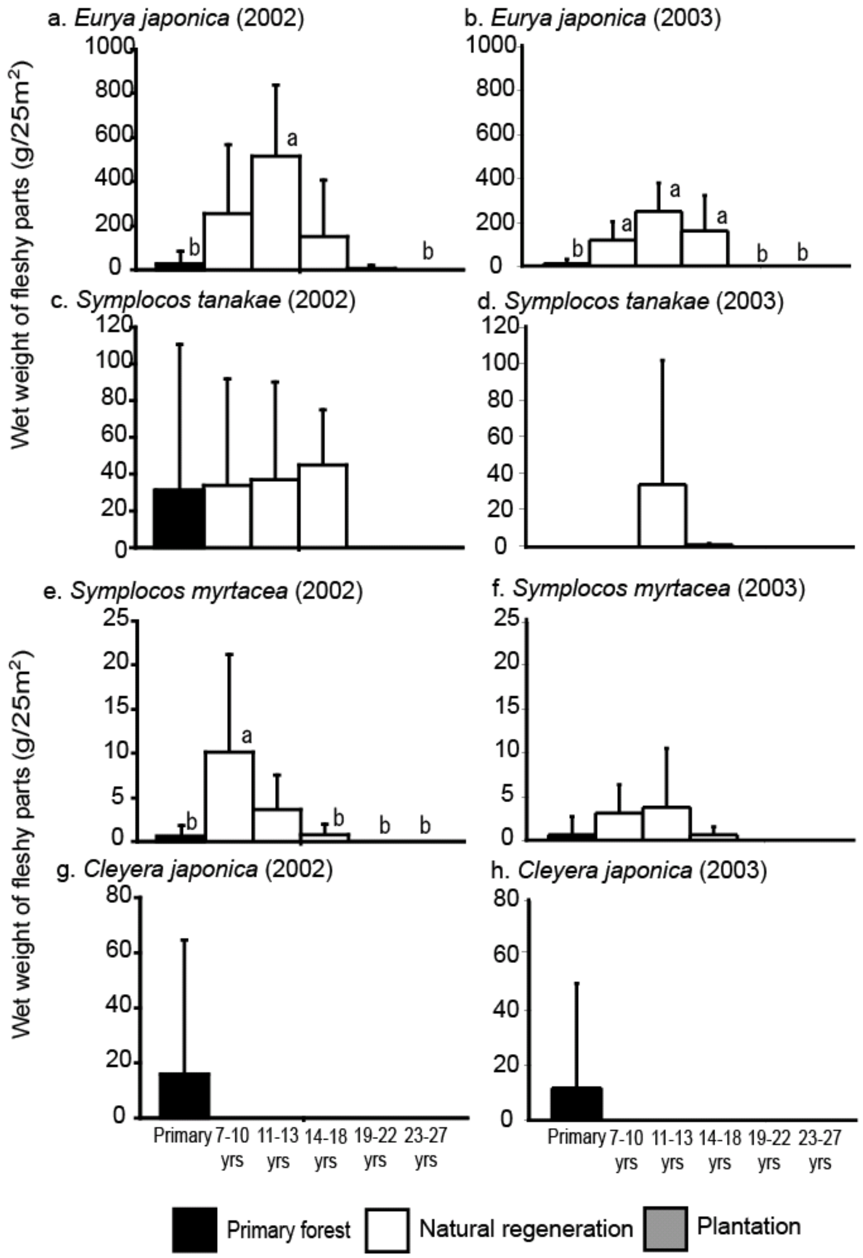

Fig. 3. Fruit production of the main species. Means and standard deviations are shown. Letters above the bars indicate significant differences between bars with different characters (in the order a > b > c).

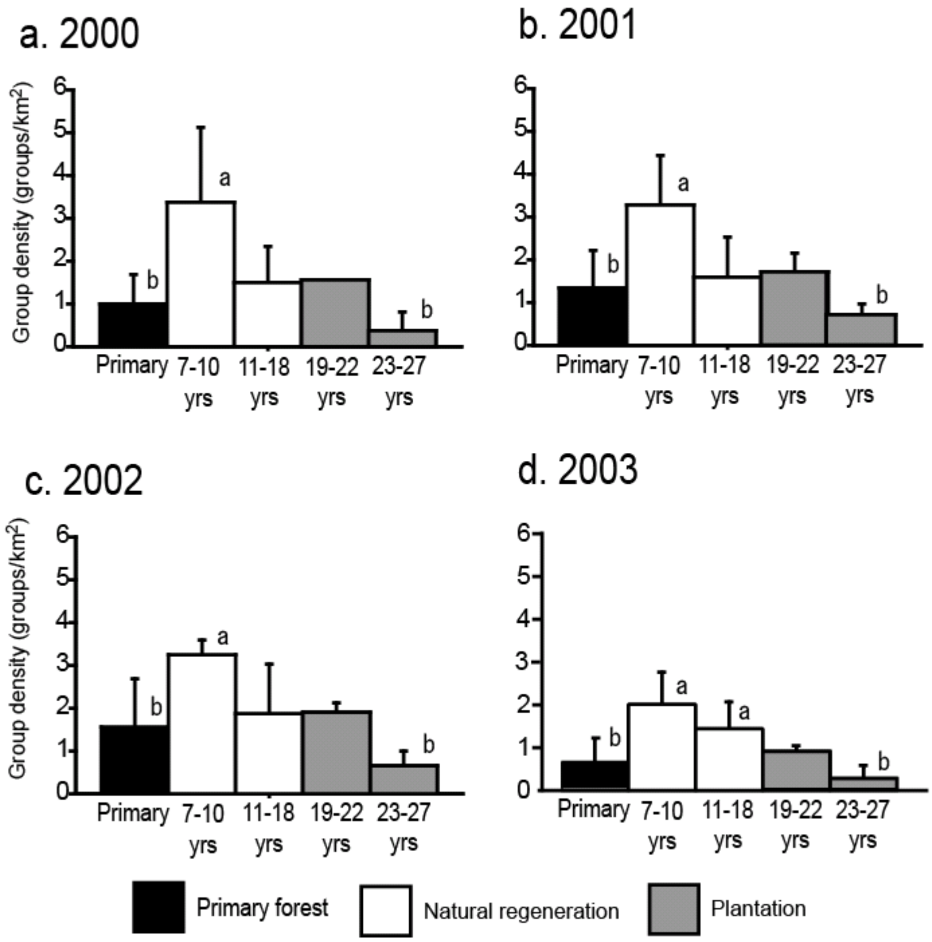

Fig. 4. Group density of Japanese macaques. Means and standard deviations are shown. Letters above the bars indicate that there are significant differences between bars with different characters, in the order of a>b>c