Human–Macaque Conflicts in Shrinking Communities: Recent Achievements and Challenges in Problem Solving in Modern Japan

Author: Enari, Hiroto

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Review

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Human–macaque conflicts in shrinking communities: recent achievements and challenges in problem solving in modern Japan

Hiroto Enari*

Yamagata University, 1-23 Wakabamachi, Tsuruoka, Yamagata 997-9555, Japan

Abstract. The populations of the Japanese macaque (*Macaca fuscata*), which were vulnerable until the early 20th century, have recently recovered. However, this recovery process has rarely been hailed as a conservation success, because it has triggered serious conflicts between people and the macaques. The key exacerbating causes of the conflicts have been the drastic changes in the interrelations between the people, forests, and macaques, as well as the unprecedented social changes in modern Japan (i.e., nationwide depopulation). The aim of this review was to illustrate the bigger picture of these conflicts, by untangling the key root causes, and presenting the outcomes of previous macaque management efforts, which have rarely been presented to the global scientific community. Although recently acquired knowledge regarding macaque management has the potential to support the development of future solutions for the human-macaque conflicts, inadequate responses to the key causes of the physical and psychological hollowing-out of communities across Japan, should be understood as a limiting factor for conflict resolution. This review demonstrates the significance of seeking a resolution for this problem under a wider framework, in order to restructure community designs to be appropriate for the new era of shrinking communities.

Key words: community design, damage management, depopulation, habitat manipulation, population regulation.

Globally, a large number of primate species are in danger of extinction (Chapman and Peres 2001; Benchimol and Peres 2014). Furthermore, the loss of primate habitat that is associated with land reclamation, continues to increase, and was approximately 1 500 000 km^2 between 1990 and 2010, leading to > 60% of the primate species from all 16 extant families being threatened with extinction (Estrada et al. 2017). The family Cercopithecidae, Old World monkeys widely distributed in Asia and Africa, are no exception, and 60% of the species belonging to this family are facing an alarming risk of extinction (Estrada et al. 2017). Japanese macaques (*Macaca fuscata*) belong to this family and are the northernmost naturally occurring primate species on the Earth, except for humans. The macaques shared a critical status equivalent to most other Cercopithecidae until the period around World War II (1939–1945; hereafter referred to as WWII) (Mito and Watanabe 1999; Mito and Sprague 2013). The distribution of most populations naturally occurring across Japan had drastically declined and had sometimes, in the worst case, resulted in regional extinctions (Mito and Watanabe 1999; Watanabe 2000; Mito and Sprague 2013). After WWII, the state of affairs with respect to the macaque populations has changed rapidly; the details will be described later in the text, but both the intended national policy for wildlife conservation and the unintended social changes, resulting in the underuse of forest resources, have led to the successful recovery of the macaque populations in their original habitats.

Paradoxically, the recent success in population recovery has provoked and intensified conflicts between people and the macaques, and the residents living in the vicinity of the current macaque distribution areas face serious risks from their invasion into the human habitats (Knight 1999; Sprague and Iwasaki 2006; Enari and Suzuki 2010; Muroyama and Yamada 2010). The seriousness of the

*E-mail: h_enari@hotmail.com

current conflicts is most glaringly apparent in the government statistics, which have estimated the troop numbers of wild Japanese macaques in Japan to be 3025–3149 as of 2011 (90% credible interval; Biodiversity Center of Japan 2011), with > 40% of them already causing visible agricultural damage as of 2017 (Nature Conservation Bureau 2018).

We should recognize that the key causes that exacerbate the conflicts are the drastic changes in people-to-forests, people-to-macaques, and people-to-people relationships, as well as the unprecedented social changes, due to the post-demographic transition (Enari 2010, 2017, 2019), i.e., nationwide aging and depopulation (Hara 2015). To validate this point, I aim to demonstrate: (1) the bigger picture of the human–macaque conflicts in modern Japan, by untangling their root causes, and (2) the recent achievements and remaining challenges for macaque management, including population regulation, habitat manipulation, damage management, and the human dimensions related to conflict resolution. Although these topics have already been covered on an individual basis in several literature sources written in the Japanese language (including the ones published in government and administrative reports), this paper aims to investigate the outcomes of Japan's management efforts, by systematically reorganizing this cumulative information, and to proceed to the next phase of macaque management initiatives by preparing for a new era of shrinking societies. Offering an opportunity for the global audience to understand the outcomes and to learn from the situation in Japan is of critical importance, because the phenomenon of nationwide aging and depopulation is no longer a trend specific only to Japan. It is in fact projected to expand to the international communities, especially in Asia and Latin America (United Nations 2017), where the key habitats of various primate species have been recorded. Thus, the human–macaque conflicts in modern Japan could be the epitome of the upcoming primate issues worldwide, and Japan's initiatives in dealing with the current conflicts are strongly expected to serve as a useful example for those nations.

Chronology of the interrelations among people, forests, and macaques

Before WWII: decline of the macaque populations and the expansion of human activities

The human population explosion in Japan occurred in the mid-19th century. Japan's population at that time was approximately 35 million, and it has grown 2.5 times over the following 100 years (Hara 2015). This population explosion has led to the depletion of natural resources, including the overuse of forest products (Ohta 2012). The late 19th century witnessed the largest extent of natural forest destruction in history, and 30–40% and 40–70% of the natural forests in eastern and western Japan, respectively, were replaced by wasteland (such as grassland and sparse pine forest, typically observed on depleted lands in the warm and humid climate zones), as well as by cypress (Cupressaceae) plantations (Himiyama 1992). This massive deforestation has been recognized as a habitat bottleneck, which led to the reduction or complete extinction of regional macaque populations at the time (Sprague and Iwasaki 2010). At the same time, to the disadvantage of the macaques, game hunting was authorized, and citizens started to acquire modern infantry rifles (called *Murata Jyû*). These social changes might have encouraged people to hunt freely the macaque populations, including the vulnerable populations going through severe habitat bottlenecks. Historical accounts provide evidence that the macaques became commercialized in this period due to their high value as resources, not only as bushmeat, but also as traditional medicinal ingredients (Mito and Watanabe 1999; Mito 2011; Mito and Sprague 2013). In this context, the macaque distributions in the early 20th century were considerably limited and amounted to 2294 cells (approximately 57 000 km^2; Japanese mammal distributions have traditionally been shown by cell count, with cell resolution of 5 × 5 km) (Amagasa and Ito 1978; Koganezawa 1995), which was approximately 60% of the macaque distribution in 2017 (Nature Conservation Bureau 2018).

After WWII: recovering the distribution of macaques and reducing human activities

During the early 20th century, conservation initiatives to protect the declining macaque populations were ignored in Japan, which was at that time ravaged by recurring hostilities. In 1947, the Japanese government eventually reformed the Wildlife Protection and Hunting Law and removed macaques from a list of game species, to prevent their extinction (Mito and Sprague 2013). Moreover, in the 1960s, the outflow of the rural populations to the urban areas— > 30% of rural population left in this period—resulted in the depopulation of rural Japan at the border of the macaque living areas (Ministry of Agriculture, Forestry and Fisheries 2010). In the same period, Japan experienced an energy revolution and became heavily dependent on petroleum and natural gas

as a substitute for coal, charcoal, and firewood, which has led to a decrease in the use of its forest resources (Hein 1990). This revolution has also driven the modernization of agricultural practices, i.e., the expanding use of chemical fertilizers instead of organic composts, including fallen leaves (Hein 1990). All of these factors have resulted in changes in the traditional people-to-forests relationships that once occurred daily, and people have now become distant from the forests both materially and emotionally (Sprague 2002; Muroyama and Yamada 2010; Enari 2019). The unintended attenuation of this relationship has resulted in a recovery of the forest biomass, including natural forests, which grew by 150% from the 1960s to 2010s (Ohta 2012). However, attention should also be paid to the growing demand for timber products during the post-WWII reconstruction era (i.e., in the 1950s), which served as a trigger for planting massive conifer plantations (the details of this silviculture and its influence on macaque habitats will be discussed later in the text).

Both the post-WWII conservation initiatives and the forest underuse, are now commonly accepted as the driving forces for the gradual recovery of the macaque populations. The number of cells with macaque distribution in 1978 was 2288, and it was not very different from the cell number in 1923 (2294 cells), but this number markedly increased by 150% by 2003 (Watanabe 2000). As described above, it is paradoxical that this recovery process has rarely been considered a conservation success, as it has triggered unwanted effects and damaged the people-to-macaque relationships (Sprague and Iwasaki 2006; Enari and Suzuki 2010; Muroyama and Yamada 2010; Mito and Sprague 2013). One of the typical unwanted effects is the agricultural damage by the macaques. The visible damage was first observed in the 1970s in some areas of Japan, and the damaged farmland areas continued to increase thereafter until the mid-1990s (Fig. 1). Because of this, municipal governments have embarked on macaque culling as a stopgap countermeasure against the direct damage. Besides, prefectural governments have also imposed macaque population regulations, aimed at suppressing further population expansions. As a result, the number of killed macaques rapidly increased to above 10 000 in 1998 and above 20 000 in 2011 (Ministry of the Environment 2019a). Considering that the number of killed macaques was < 2000/year during the early 20th century at the time when macaques were considered game mammals (Ministry of the Environment Japan, unpublished data), the recent culling and regulation pressure have increased the number of killed macaques to their highest level in recorded history.

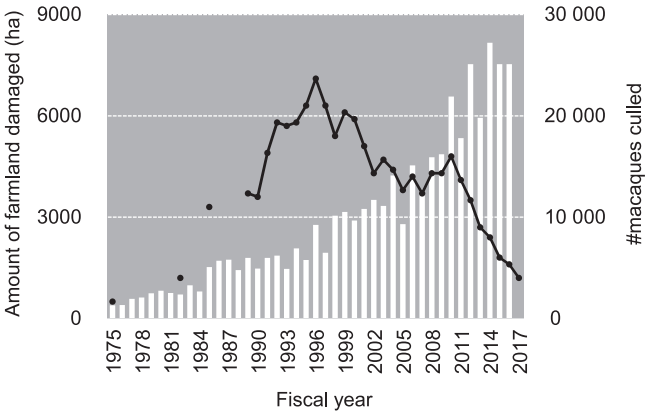

Fig. 1. Yearly changes in the amount of farmland damaged by Japanese macaques (shown as a line graph; Ministry of Agriculture, Forestry and Fisheries 2019) and yearly changes in the number of macaques culled in Japan (shown as bars; Ministry of the Environment 2019a). Only fragmented data were available prior to1989 for the amount of farmland damaged by the macaques.

At the beginning of the 21st century, damaged farmland areas gradually decreased (Fig. 1), giving the impression that conflicts had eased. It is important to note that the decrease in the damaged farmland areas was related to the decline in agricultural industries in rural Japan (Kanzaki et al. 2003; Enari 2019); the more seriously damaged the farmlands were (e.g., farmlands adjacent to forests were directly threatened because of the proximity of macaques that inhabit the forests), the more easily the farmers chose to abandon them (Enari 2017, 2019). Moreover, we cannot ignore the fact that the severity of crop damage in the remaining farmlands has intensified the economic damage in recent years (Fig. 2). This is possibly a result of macaques having a superior ability to intrude into human habitats, even away from forests (Yoshida et al. 2006; see also Enari and Enari 2021 in this special feature), compared with other large mammals.

In addition to the agricultural damage, in some areas it has also been observed that the macaques severely damage the forests by stripping the bark of pine (Pinaceae) and cypress trees (Okada 1996), as it is the case with the well-known cedar bark stripping by Barbary macaques (*M. sylvanus*) (Camperio Ciani et al. 2001). Furthermore, several *Macaca* species have been referred to as '*weed species*' and are able to tolerate and even prosper in conditions of a close association with human settlements (Richard et al. 1989). Japanese macaques often penetrate inside the human habitats, including human residences, to

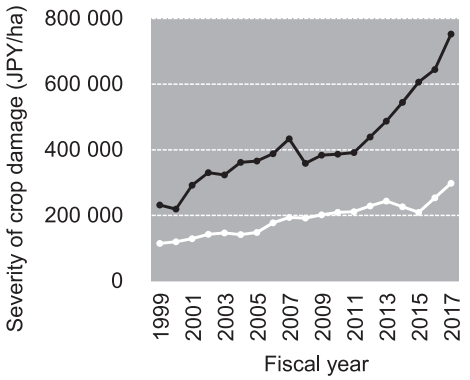

Fig. 2. Yearly changes in the severity of crop damage caused by Japanese macaques (shown as a solid black line) and by all avian and other mammal species combined (shown as a solid white line), calculated as the economic injury per unit area of farmland damaged by each species (Ministry of Agriculture, Forestry and Fisheries 2019).

acquire food. This bold behavior not only arouses a feeling of fear in the residents and worsens people-to-macaque relations, but also increases the risk of zoonotic infections (Enari 2019). The first national-scale questionnaire survey conducted in 2015 revealed that the property damage and physical and psychological harm by the macaques had been observed in 80% of municipalities which are in the vicinity of macaque habitats (Nature Conservation Bureau 2016).

In 2013, the Japanese government developed a drastic management plan designed to halve the number of macaque troops that are inflicting damage on agriculture and affecting the daily lives of residents within a single decade (Ministry of the Environment and Ministry of Agriculture, Forestry and Fisheries 2014). According to this plan, besides culling, the use of non-lethal methods to drive the macaques into the interior forests was recommended (described in detail later in the text). However, a lot of municipalities have now reconsidered this regional plan and have placed greater importance on culling (Enari et al. 2015). Consequently, large-sized box traps and corral traps, which enable culling at a massive scale, have become popular; 174 municipalities out of 411 where macaque culling is being conducted are using large-sized box traps, and 119 municipalities have introduced corral traps as of 2017 (Nature Conservation Bureau 2018)—these numbers are five times higher than those in 2009 (Enari et al. 2015).

In recent years, there have been growing concerns about the disappearance of macaques in several regions because of these culling pressures. There is a significant positive correlation between the total number of killed macaques from 2002 to 2015 and the total macaque distribution areas that were lost during the same period (Spearman's rank-order correlation; $r_s = 0.48$, $P = 0.01$; Fig. 3). Thus, it cannot be denied that the recent intensification of human–macaque conflicts has triggered the second great decline in macaque distribution in history, especially in snowy cold regions with vulnerable isolated habitats (Enari 2013).

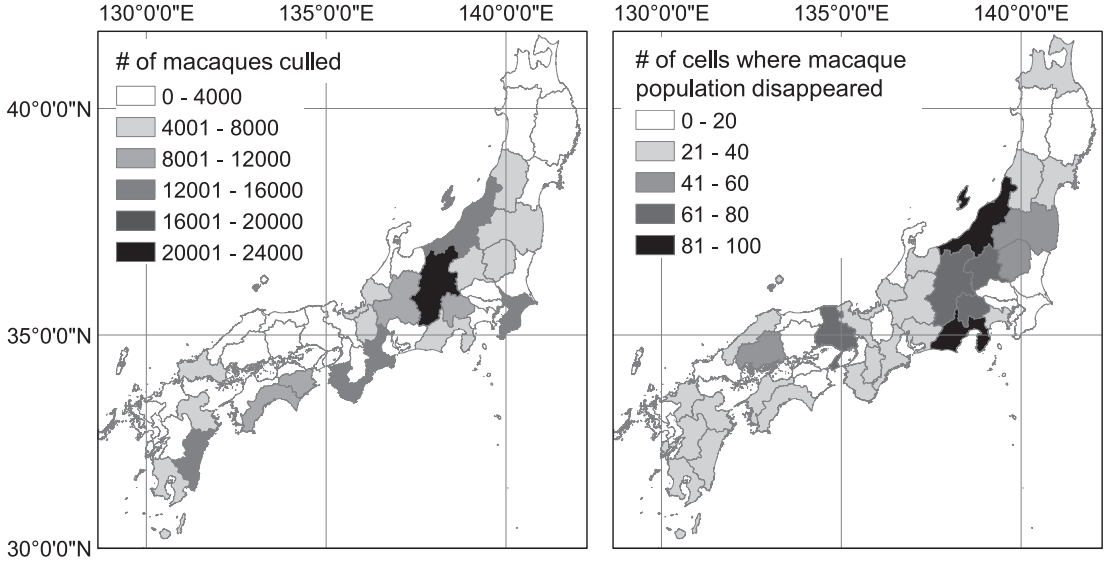

Fig. 3. Total number of Japanese macaques legally culled between 2002 and 2015 (left; Ministry of the Environment 2019a) and total count of cells (5 × 5 km resolution) with no macaque presence from 2003 to 2017 (right). These numbers were calculated for each prefecture by using official statistics (Nature Conservation Bureau 2018).

Verifying possible triggers for modern-day conflicts

The root of these conflicts is most certainly the decreasing spatial distance between people and macaques. At a greater spatiotemporal scale, this closeness should not be understood as unnatural, but as the result of the normal resilience of macaque populations affected by the pre-WWII disturbances (Enari 2017, 2019). It is a well-known historical fact that similar issues between people and macaques were frequently present in early modern Japan (i.e., 16th and 19th centuries) as well (Mito and Watanabe 1999; Mito and Sprague 2013). Although the spatial distance between people and macaques remained the same between the historical and present times, the severity of the conflicts might have increased due to five historical changes in social and environmental dimensions with respect to the people-to-macaque relationships (Fig. 4). In the following paragraphs I determine the triggers that have deepened the conflicts through an overview of those historical changes.

(i) Changes in climate

Though the earth experienced the Little Ice Age from the mid-14th century to the mid-19th century, especially in the northern hemisphere including Japan, the current atmosphere has remained warm due to shifts in the climate that have occurred naturally three times during the 20th century (Minobe 1997). Today, the anthropogenic greenhouse warming effect is accelerating this trend. These climate changes have resulted in warmer winters in Japan and have therefore been considered one of the major triggers for the exceeding growth of the macaque populations (Watanabe 2000). In other words, the recent winter warming has been assumed to alleviate inclement weather conditions in the winter, which could have a bottleneck effect and decrease the maximum sustainable population densities in certain areas (Nakagawa et al. 1996; Hanya 2010). However, we should note that the recent climate changes, besides having positive effects on the population growth, especially in cool-temperate areas, could also have negative effects. For example, they may result in mass mortality of the macaque populations caused by the increasing severity and frequency of extreme climate events (Lee et al. 2018), such as cold spells (Koganezawa and Imaki 1999; Izawa 2009) and heat waves with extraordinary hot and dry conditions (Hanya et al. 2004). Thus, it might be reasonable to conclude that the current winter warming will not cause a dramatic increase in macaque populations, but will rather increase the risk of extinction of regional populations (Enari 2017, 2019).

(ii) Extinction of the apex predator in forests

Aside from large-sized raptors (e.g., the mountain hawk-eagle, *Nisaetus nipalensis*; Iida 1999), wolves (*Canis lupus*) were the potential natural predators of macaques (Mito and Watanabe 1999). Wolves, the apex predators in Japan, were extinct throughout the country until the early 20th century. The imbalance of the ecosystem in the absence of the apex predator has often been singled out as the main factor that allowed the excessive growth of the macaque populations (Wada 1994; Watanabe 2000). However, this notion has yet to be

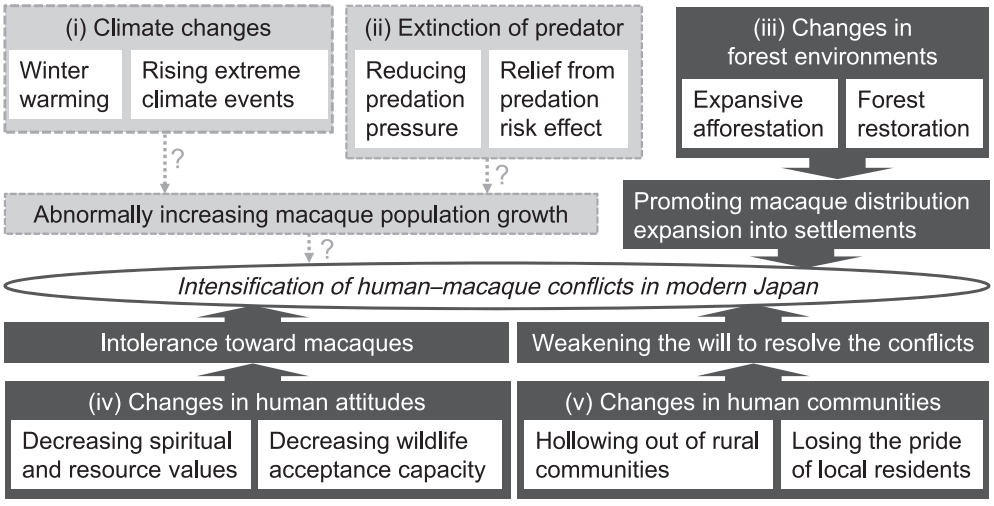

Fig. 4. Five possible causes leading to the intensification of human–macaque conflicts in modern Japan.

empirically validated. Incidentally, long term studies have demonstrated that the general population dynamics of macaques does not always show only increasing trend but fluctuates even in predator-free environments (Hanya 2009). In addition, although it has been widely known that large-sized predators often prey on primate species, certain Felidae species (such as *Panthera pardus* and *P. tigris*, which are not distributed in Japan), not Canidae, are predators on primates in parts of Asia largely covered with forests because of their ability to climb trees (Hart 2007). Given that the presence of wolves as apex predators can influence macaques in different ways, e.g., via nonlethal effects caused by predatory threats that stimulate anti-predator behavior (Lima and Bednekoff 1999), liberation from such effects—by the extinction of wolves—might allow the macaques to spend more time on the ground, which in turn decreases the risk-averse arboreal activities (Mito and Watanabe 1999) and their troop size, and thereby their vigilance cost against predators (Hill and Lee 1998). The influence of these activity changes on macaque population dynamics remains to be investigated.

(iii) Historical changes in forest environments

Historical changes in the distribution of the habitats suitable for macaques have also been widely recognized as one of the leading causes for their relocation from the interior of the forest to the edge of the forest bordering human settlements (Agetsuma 2007a; Muroyama and Yamada 2010; Enari 2017). Two massive landscape changes occurred in Japan during the late 20th century. One was extensive afforestation initiated as a result of a national policy to launch silviculture on a grand scale, mainly by the clear-cutting of the natural forests deep in the mountains and planting conifer trees (mainly Cupressaceae species). This policy was initiated in the late 1950s to meet the growing demand for timber production. The total area of conifer plantations in 2000 amounted to approximately 100 000 km^2 (accounting for approximately 40% of the total forest area or approximately 30% of the total land area of Japan), which was approximately twice the initial area planted in 1950 (Ohta 2012). Monocultural cypress plantations have been considered as unsuitable habitats for macaques due to dwindling food resources as the plantations grow (Hanya et al. 2005; Agetsuma 2007a).

The other massive landscape change, which occurred in parallel to the extensive afforestation, was the forest restoration in wastelands close to human settlements (Yamaura et al. 2012). The forest restoration was a result of the unintended abandonment of the forests by rural residents (mentioned in the previous section) and the intentional afforestation with conifers. This has resulted in a mosaic landscape composed of both secondary broadleaf forests and conifer plantations around human settlements. Conifer plantations function as a valid refuge or safe site for the macaques due to their ability to hide within them and remain undetected, whereas the restored secondary forests with an open canopy produce rich food resources. Therefore, this mixed landscape structure can provide many suitable habitats for the macaques (Imaki et al. 2006). Hence, these contrasting landscape changes occurring simultaneously in inner and marginal forest areas have led us to the hypothesis presented above.

Caution should be exercised when comprehending this hypothesis, which might contain oversimplified interpretations, especially with respect to the influence of monocultural plantations on macaque habitats. Even in mono-species conifer plantations, food biomass could vary widely based on the differences in the afforestation methods. Specifically, the increase in management intensity (e.g., tree thinning) and the increase in stand age (i.e., prolonged rotation cycle from planting to harvesting) may have a positive effect on the species richness of the understory plants; however, the rotation frequency of the plantations and the distances from the seed sources will likely have a negative effect (Nagaike 2012). Moreover, the diversity of plant species in plantations is highly sensitive to the surrounding landscape structure and previous land use (Yamaura et al. 2012). Based on these recent findings, empirical research has been conducted to investigate the influences of the different afforestation methods and the resultant forest conditions on the macaque food resources (Sakamaki et al. 2011), as well as on their habitat quality in cool-temperate forests (Sakamaki and Enari 2012; Enari and Sakamaki-Enari 2013, 2014). Thus, it should be reasonable to conclude that expansive afforestation exerts a non-stationary and inhomogeneous effect on the macaque habitats in both time and space, resulting in a time lag in the conflicts among human settlements around the country (Enari 2019).

(iv) Changes in the attitudes of the Japanese people towards macaques

The worship of nature and the spirit (i.e., animism), along with traditional views of nature based on *Shinrabanshô* (i.e., the Gods exist in all things in nature), had shaped the attitude of the Japanese people

towards macaques, until the rise of premodern Japan (Mito and Watanabe 1999; Maruyama 2006a; Mito 2011). Before premodern times, people in Japan used various body parts of the macaque, including organs and tissues, as both medicines and charms (e.g., *Umayazaru*, the deity protecting horses) to treat numerous diseases, as they believed in a spiritual force that is inherent in animals (Mito and Watanabe 1999; Maruyama 2006a; Mito 2011). In addition, macaques also had indispensable value as an emergency food supply for the people if crops were lost to the cold weather (Mito 2011). Hence, while macaques were viewed as pests even in premodern Japan, just like today, the people of that time had formed an inextricable bond with the animals both spiritually and materially.

This bond was broken once macaques vanished and could not be found around settlements because of their excessive commercial use and habitat bottlenecks observed in the 19th century. The break in this bond lasted for more than 100 years, and has critically influenced the subconscious awareness of modern Japanese people, who today, often instinctively possess three different attitudes towards macaques. The first attitude is intolerance (Suzuki 2008; Enari 2010). This attitude often emerges in vocal rural residents who are in direct conflict with the macaques, as they feel that the macaques should be permitted to inhabit only the deep mountain areas, but not the forests around human settlements (Enari 2010). Incidentally, it was the breaking of the spiritual and material bond with macaques that generated this intolerant attitude, thereby directly leading to the loss of the traditional ecological knowledge about damage management and a lack of self-initiative among farmers to take countermeasures against macaque damage as a part of daily agricultural practice (Enari 2010). The second attitude is radical protection of the macaques. It is formed readily by an urbanized population, whose attitude is highly influenced by secondhand information (such as media), rather than by their own experiences (Kishioka et al. 2010, 2011). These conservation-oriented people do not tolerate macaque killings, and are therefore in frequent disagreements with the people exhibiting the intolerant attitude (Watanabe 2007). The third attitude is indifference to the macaques. This might be a dominant attitude among the Japanese, with the majority being rural populations—excluding stakeholders in the conflict—who rarely develop a cooperative attitude towards the resolution of this issue (Hiroshige et al. 2010; Nakamura et al. 2013; Higashiguchi et al. 2016). The growing number of Japanese people who are indifferent has created the current irrational situation where it is only those rural residents who are directly impacted by the macaque damage, who conduct macaque management.

There was a historical attempt to change the people-to-macaque relationship by adding a touristic value to the animals, e.g., establishing monkey parks, which happened mostly during the 1970s (Mito and Watanabe 1999; Mito and Sprague 2013). These parks were tourist facilities where people could get close to free-range macaques and feed them. These parks have been critically referred to as '*Megazoos*' and their goal was to tame wild animals (Knight 2006). This is why it is reasonable to conclude that these parks have only produced the opposite of the expected effect on people's attitudes towards wild animals—wild mammals were perceived as household pets—rather than restoring favorable people-to-macaque relationships (Setoguchi 2013).

Unfortunately, the intolerant attitude of people facing direct conflicts with macaques has intensified with the recent decline in Japan's agricultural industry, namely, the plunging revenue from agriculture owing to the rise in the amount of financial damage in total agricultural incomes (Enari 2010); this possibly results in reduced wildlife acceptance capacity, i.e., the maximum wildlife population level in an area that is acceptable to people (Decker and Purdy 1988). These historical contexts have instigated the prevalence of a negative attitude toward macaques, identifying them only as pests, and have led to calls for their extermination. We should note the paradoxical consequence that most of the prefectural governments, even in the areas with vulnerable macaque populations that are listed in the domestic Red Lists of threatened species, have adopted a regional plan to shrink their distribution, since the Japanese government presented the drastic population management plan in 2013 (for details of the plan, see the previous section) (Enari and Enari 2016; Enari et al. 2018). Thus, it might be reasonable to conclude that modern Japanese people, directly facing conflicts with macaques are much more likely to regard intensive macaque culling as the only available option for the resolution of the conflict.

(v) Changes in human communities

After the 1960s, the rural population in Japan started to decline rapidly due to migration from rural to urban areas (Ministry of Agriculture, Forestry and Fisheries 2010). Since 2007, Japan has become a country where the population has naturally declined nationwide, and deaths have outnumbered births (Statistics Bureau of Japan 2019).

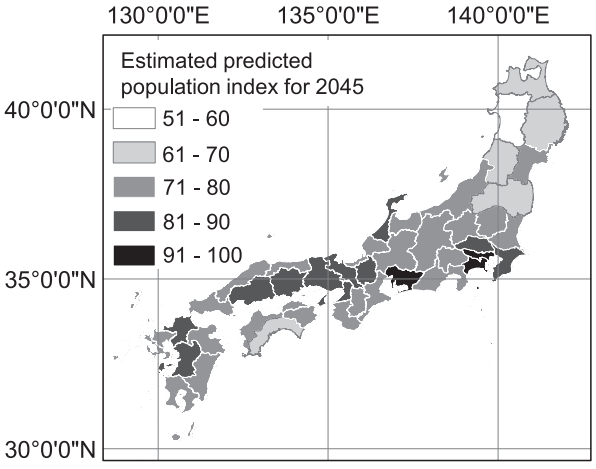

Fig. 5. Estimated population index predicted for 2045, using the population census from 2015 as the base population, in every prefecture of Japan excluding Hokkaido and Okinawa where no macaque populations are naturally distributed (based on data from National Institute of Population and Social Security Research 2018).

According to the National Institute of Population and Social Security Research (2018), Japan's population is estimated to continue to decline in the future, with a 20% reduction by 2045, compared to 2015. None of the prefectures have been excluded from this downward trend (Fig. 5). In addition, official statistics in 2011 provided by Ministry of Land, Infrastructure, Transport and Tourism (2011) have presented grim prospects for sustainability in local communities; the population in > 50% of Japan's settlements will drop by half, and > 20% of the settlements will collapse by 2050.

It is obvious that one of the direct influences on the population decline is the decrease in human activities around the macaque distribution areas, and this decrease is present even during the daytime. This means that the forests adjacent to human settlements, and even the settlements themselves have become safer habitats for diurnal mammals such as macaques. In particular, it is highly likely that the stagnation of community activities, in order to improve damage management around settlements (e.g., psychological attacks on macaques by residents using firecrackers and warning shots), has led directly to the reduction in the '*landscape of fear*' for the macaques. This effect is known as nonlethal risk effect in which hunters constrain habitat use for target mammals (Cromsigt et al. 2013).

Some indirect influences of population decline on the stagnation of damage management activities could be present. A typical example of such influence is the rise in damage management costs that each resident is supposed to pay. This can be explained by the following two reasons. The first reason is the continued extension of the defense lines where each resident is required to conduct some kind of countermeasure against the entrance of the macaques, due to the increase in unplanned and sporadic abandonment of residential and agricultural land spaces in rural regions (Enari 2010; Enari and Suzuki 2010; Tsunoda and Enari 2020). This is because abandoned land adjacent to forests produces convoluted boundaries between the living spaces occupied by people and wildlife, and this has been considered a major hindrance in conducting cost-effective damage management (Conover 2002). Moreover, even if the abandonment occurs in the inner settlements, the abandoned land becomes gradually covered with shrubs serving as temporary shelters for the macaques to hide from the residents, and which often allow macaques to easily enter the settlements (Yamabata 2015; Enari 2017). The second reason is the weakening ability of communities to sustain resident-led public activities and mutual assistance among residents. This has led to the disruption of effective countermeasures that were systematically led by all the residents, such as community-wide activities to push macaque troops out of the settlements (Enari and Maruyama 2005; Yamabata 2011) and the construction and continuous maintenance of macaque-proof fences and strip-shaped clear-cut landscapes, often referred to as *Satoyama* buffer zones, where most trees and every bush are cleared to remove frontline shelters around the entire settlement, which are often used by the macaques to enter the settlement (Takeyama and Kuki 2010). Then, the residents who have enough motivation to manage the damage have no other choice but to individually take stopgap countermeasures with lower cost-effectiveness.

The other indirect effects of the declining population are the loss of pride and affection of the residents for their communities and finally their reduced willingness to remain in the community. This phenomenon could be the final consequence of this negative spiral of events originating in the decline of populations (Fig. 6; Odagiri 2009). Impairment of the residents' ability to think about the future of their communities often disinclines them towards identifying a common goal for problem-solving regarding the macaque issues through raising their own awareness of resignation towards it (Enari 2017). Once communities get into such a state, even help from the local government to support damage management is not enough for residents without their own initiative. Ultimately, physical and psychological hollowing-out of

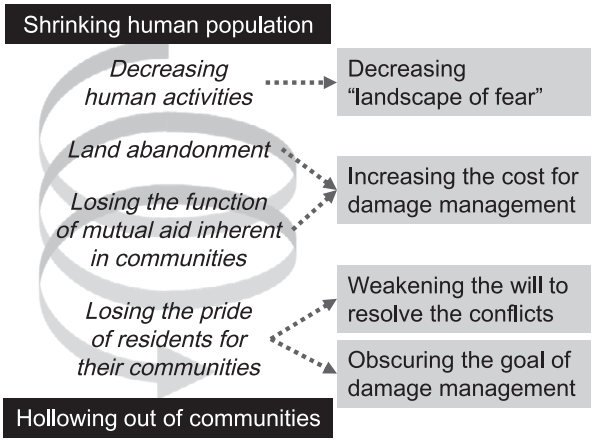

Fig. 6. Negative spiral stemming from declining human populations and its influence on the disruption of macaque damage management.

communities results in the collapse of settlements. Consequently, macaque issues disappear in the areas of collapsed settlements, but are subsequently expanded in other adjacent settlements (Muroyama 2017).

Recent achievements and remaining challenges in macaque management

In this section, I will focus on Japan's past and present efforts to cope with the abovementioned triggers for human–macaque conflicts. Until the 1970s, unlike other large-sized mammals that belong to game category, macaques have been referred to as animals in need of strict conservation, and not as wildlife in need of management that would include population regulation (Watanabe 1995). As a response to the expanding macaque issues across Japan since the 1970s, the expansion of knowledge and techniques to manage their populations, habitats, and the level of damage to human communities, has been strongly encouraged. In particular, technologies for physically preventing macaques from damaging individual farmlands and psychological methods for keeping macaques away from settlements, are already at the completion stages. A typical example of the former is fencing (Muroyama 2003; Honda et al. 2009; Suzuki et al. 2016), and an example of the latter is resident-led activities to diminish the attractiveness of settlements, by removing available resources and refuges within and around the settlements, as well as to create a *landscape of fear* (Enari et al. 2006; Morimitsu and Kawamoto 2015; Muroyama 2017; Yamabata et al. 2018).

Despite the great progress in the development of damage management techniques, there was no interest in investigating management strategies for the macaque populations and habitats, even in the 2000s (Watanabe 2007). One of the opportunities to break through this stagnation was the establishment of the Working Group on the Conservation and Management of Japanese Macaques authorized by The Mammal Society of Japan in 2008 (Enari et al. 2018). The founder and first chairman of the Working Group was Kunio Watanabe, followed by Katsuya Suzuki and then Hiroto Enari (the author of this paper). This working group organized the existing knowledge and techniques (as described below), most of which were accumulated from field research results, but were not necessarily published in academic literature, and the group contributed to the development of a new guideline authorized by the national government in 2016, which today serves as a basis for macaque management policy in each prefecture (Ministry of the Environment 2016). Here, I will discuss the theoretical framework behind the new developments in macaque management from the past decade and explain the remaining challenges.

(1) Population regulation

As described earlier, although the number of killed macaques has been rising steadily, the economic damage done by macaques has further intensified on the remaining farmlands (Fig. 2). The main reason for this is suspected to be the frequent stopgap culling measures that have been implemented in recent years; namely, that macaques have been haphazardly removed without identifying their attributes (Watanabe 2007; Watanabe et al. 2010). Specifically, recent studies have demonstrated a wide difference in the level of addiction to agricultural crops among the macaque troops (Yamabata et al. 2018), and even among members of the same troop (Enari et al. 2006). Hence, effective culling could not be achieved without the appropriate identification of individuals or troops that are strongly drawn to agricultural crops as food (Seino et al. 2018). Moreover, the results of a recent nationwide questionnaire survey have presented the possibility that the current stopgap culling techniques could cause troops to divide into several smaller troops, by upsetting the intra-troop relations. Generally, a smaller troop is less detectable by residents and the damage risk is apt to increase (Enari et al. 2015). Furthermore, it should be noted that, even if an entire harmful troop is successfully culled, the macaque damage will not necessarily decrease in the areas where harmful troops are continuously distributed because neighboring troops

will immediately try to intrude and occupy the open range (Oi 1994; Izumiyama 2010).

In such cases, the current guidelines recommend that population regulation should be considered with respect to each troop, and an optimal option for macaque culling should be selected after evaluating the harmfulness of the troops based on their addiction level to the crops as a food resource and vigilance against residents (Ministry of the Environment 2016; Suzuki et al. 2016). The current available options for culling have become diversified, and they include selective culling of only the harmful individuals, regulation of troop members to a manageable size (30–40 individuals), and corral-trapping to remove an entire harmful troop (Seino et al. 2018).

While the development of the culling options is of growing significance in the advancement of population regulation on the community level, there is an ongoing debate about population regulation strategy aimed to balance population conservation and damage management on a wider scale, which would deal with local populations having some unique ecological and/or genetic properties (Suzuki et al. 2017). Unfortunately, at the present stage, there is no end in sight for this debate not only because of the vague scientific criteria used to determine local populations, but also because of the absence of social arrangements to facilitate consensus-building efforts among multi-stakeholders (Morimitsu and Kawamoto 2015; Suzuki et al. 2016; Enari et al. 2018). Although one previous study tried to estimate the minimum viable population (MVP) for macaques in the light of genetic knowledge (1500 individuals, which is the effective population size, N_e, influencing the loss of genetic variations through genetic drift), no replicative research has been conducted so far (Oi et al. 1996). The minimum area requirements (MAR) to sustain the macaques' MVP has also been calculated once from empirical data on habitat area and population viability (Agetsuma 2007b). That research showed that the estimated habitat surface areas satisfying 95–99% probability of a population persisting for 100–1000 years ranged from 525 to 975 km^2. Given that the average size of a government-designated game reserve (the largest wildlife sanctuaries in Japan; $N = 10$) is approximately 200 km^2 (Ministry of the Environment 2019b), designing a publicly enforced system to conserve the viable population based on this MAR value could be less possible. Hence, enhancing the connectivity of each habitat by constructing ecological corridors would be one of the few feasible solutions (Enari 2007), especially in eastern Japan where the macaque populations are divided (Enari 2013).

Another challenge regarding population regulation on a wider scale, is finding a way to promote the development and utilization of cost-effective population monitoring techniques, to assess the influence of the current policy on the populations (Enari et al. 2015). Macaques, being diurnal and gregarious mammals, are easy to observe directly compared with other middle- and large-sized mammals. For this reason, the number of individuals and troops has most commonly been assessed through direct observations by attaching radio collars to their bodies for troop identification (Watanabe et al. 2010). Using these methods has not only threatened the sustainability of the monitoring due to its high cost but has also caused a delay in developing labor-saving assessment techniques. To respond to such problems, citizens have now been actively incorporated in population monitoring, and a systematic questionnaire survey using routine inspection logbooks has been answered by residents in each settlement to roughly estimate home range, abundance, and harmfulness of the respective troops in a subject area (Morimitsu and Kawamoto 2015). Moreover, another cost-effective monitoring technique for the macaque populations that has recently been developed, is called passive acoustic monitoring. In this technique, macaque calls are used as an efficient cue to automatically detect troops (Enari et al. 2019). Thus, the immediate focus should now be on dispersing these up-to-date labor-saving techniques through more communities.

(2) Habitat manipulation

The basic concept of macaque habitat manipulation follows a rule that states: the value of the habitat unit (= habitat quality × habitat quantity) decreases in settlements and adjacent forests, but increases in interior forests (Muroyama 2003; Muroyama and Yamada 2010; Enari and Sakamaki-Enari 2013). Thus it follows the flow that is reverse of that described in Fig. 4 (iii). As mentioned above, the techniques used to decrease the value of the habitat unit within settlements have already been implemented, e.g., increasing the *landscape of fear*. Today, manipulating forest edges is of particular interest to reduce the frequency of macaque entrances because those areas possibly provide not only preferable food resources for the macaques (shrubs and vines bearing berries), but also frontline shelters for approaching settlements (Imaki et al. 2006; Yamada and Muroyama 2010; Enari and Sakamaki-Enari 2013). Hence, tree thinning in order to reduce the amount of food resources and

enhance the visibility in the forest edges is one of the currently recommended habitat manipulation techniques (Takeyama and Kuki 2010; Enari and Sakamaki-Enari 2013; Ueda et al. 2018).

As for the interior forests, the improvement of the habitat unit has often been considered to be attained by converting monocultural cypress plantations into native forests (Agetsuma 2007a; Muroyama and Yamada 2010). Here we should notice the current inconsistent situation of Japan's forestry: although Japan today has the biggest forestry plantations in history, nearly 70% of the national lumber demand is supplied from foreign countries. Improving the level of self-sufficiency for lumber supply has now been embedded in the national policy. Given this situation, the land sparing strategy (Green et al. 2005; Yamaura et al. 2012) might be a workable alternative. This strategy proposes protecting macaques in part of the land, while continuing with intensive silviculture in other parts. However, it is important to remember that plant species richness in plantations can improve depending on afforestation methods (Nagaike 2012; Yamaura et al. 2012). Namely, in response to a growing public demand for multiple-use forestry, efforts to improve afforestation methods have recently been underway, that contribute to biodiversity conservation based on the land sharing strategy (protecting wildlife in smaller areas while continuing plantation silviculture in the remaining areas, using wildlife-friendly techniques; Yamaura et al. 2012). One such effort is the application of *retention forestry* to create multi-storied forests (Yamaura et al. 2018).

Some recent research has provided concrete evidence that supports the possibility of the land sharing strategy to maintain the balance between forestry and macaque habitat conservation (Sakamaki and Enari 2012; Enari and Sakamaki-Enari 2013). One promising treatment is the long-rotation plantation management, with the rotation period set to 80–100 years, which has been introduced recently with the goal of both improving timber values and avoiding biodiversity loss (Nagaike 2012). According to the scenario analysis, this plantation management method could potentially improve macaque habitat units to levels comparable to those in natural broadleaf forests (Enari and Sakamaki-Enari 2014). Moreover, what should not be forgotten is that most of the tree species used in Japan's plantation silviculture are indigenous species originally observed mainly in the cool-temperate zone (Hayashi 1960), potentially having species-specific functions to sustain native ecosystem processes. For example, cypress species is one of the few evergreen trees in the cool-temperate forests of Japan, and could therefore provide preferable shelters for the macaques to hide from the cold wind and snow (Wada 1994; Wada et al. 2007; Sakamaki and Enari 2012). Considering that the frequency of cold spells is expected to increase in the future, the relative importance of such a function becomes even more significant.

Discussions on the adaptation of habitat manipulation for land sparing and sharing strategies are still in the initial stages (see also Tsunoda and Enari 2020). It is important to note that forests provide habitats not only to the macaques, but also to various other organisms. These discussions should continue, with considerations for a wider-ranging framework, intended for the whole local biodiversity. Today, various spatial statistical techniques for estimating habitat units for all kinds of organisms, including macaques, are relatively easily available (Enari and Sakamaki 2011; Mochizuki and Murakami 2011, 2013; Enari and Sakamaki-Enari 2013, 2014). These techniques would be of help to demonstrate the contributions of different forest planning scenarios to the conservation of macaque habitats, and they could become a powerful tool for facilitating consensus-building efforts among multi-stakeholders.

(3) Human dimensions

As we have seen, although some challenges remain, recently accumulated knowledge offers great potential support to future conflict resolution in the management of the macaque populations, habitats, and the damage they cause. In contrast to these achievements, only a handful of communities have already succeeded in macaque management (Enari et al. 2015). Ultimately, this difficult situation could arise from inadequate responses to the key causes shown in Fig. 4 (iv) and (v), i.e., the limiting factors regarding human dimensions (Manfredo et al. 1995). To respond to the labor shortages in the declining Japanese population, the introduction and development of labor-saving techniques using the information and communication technology (ICT) has become valued and has been generously supported by the national government. For example, ICT-based support systems can be used for sharing information regarding geolocations of troops among residents and for remote-controlled box traps (Enari et al. 2018). It should be noted that the utilization of these techniques is a means, and not an end. If local governments impose these techniques on communities without sufficient initiatives to resolve conflicts in a top-down fashion, local residents can hardly utilize

them effectively and sustainably (Enari and Maruyama 2005). In the worst-case scenario, enforcing such techniques places physical and psychological burdens on already weakened communities (Enari 2017).

Given these situations, the importance of manipulating human factors in wildlife management is now being increasingly recognized (Honda 2007). In summary, the strategy for recommended public help is not to forcibly introduce cutting-edge techniques into the communities, but to promote public involvement, including that of the people with indifferent attitudes toward the macaques, with the goal of encouraging resident-led management activities. This could be attained through community-based approaches, as local governments offer multiple options to cope with the damage, and they generously support the decision-making processes proposed by the multi-stakeholders (Suzuki and Muroyama 2010). This approach is expected to encourage residents to tackle conflict resolution with a positive attitude. Moreover, fostering a positive attitude is an opportunity for improving people-to-macaque relationships, and to break away from people's polarized attitudes (Fig. 4 iv), which can sometimes enhance tolerance towards the animals of local people (Maruyama 2006b; Suzuki 2008). As a case in point, the project for supporting the management of macaque-caused damage with the aid of city dwellers, which was performed as part of agricultural experiences in rural tourism, increased the number of local citizens who acquired a positive attitude towards conflict resolution, as well as decreasing the economic damage caused by macaques (Enari and Maruyama 2004, 2005; Enari et al. 2006).

The process of public engagement became more challenging with the progressive hollowing-out of communities. A strong driving force to reverse this negative spiral (Fig. 6) is required. This reversing process should start by restoring in residents, a sense of pride and affection for their community, before they are then able to share the vision for the reconstruction of a stable community. This approach is no longer an abstract idea for these communities. The idea of reestablishing the socio-economic system to adapt to a new era of declining population has reached the national level. One of the government-led initiatives is the reorganization of national land for use by compact settlements and the promotion of networking among those settlements in order to share the core infrastructure and resources (Ministry of Internal Affairs and Communications 2019). This new initiative officially started in 2014 and has since supported 32 projects across Japan (as of 2019). Although it will take some time to evaluate the effectiveness of each budding project, it is clear that these wider frameworks to restructure the community designs are critical for achieving the feasible and sharable goal of human–macaque conflict resolution. The era of population decline should be understood as a unique opportunity to rethink the distorted interrelations among people, forests, and macaques, as well as to try to finally change them for the better. In conclusion, the key factor to remedy the current conflicts is to find a community design appropriate for this era.

Concluding remarks

The past driving forces of macaque management have been the on-scene practitioners hired by local governments (e.g., the members of hunting associations and consultant firms), rather than members of academia. This is attributed not only to the lack of academic interest, but also to the public belief that only macaque culling is a fast-acting remedy for the macaque-caused damage. This situation has been an obstacle in fostering a valid framework for macaque management through scientific procedures. With the expansion of the macaque issues across Japan, the knowledge and techniques implemented in macaque management that have been discussed above, have gradually been accumulated in each local region; however, the scientific community has failed to validate and disseminate this information through successful collaborations with on-scene practitioners across the regions. This situation also causes a significant loss in knowledge and lessons that could be acquired by sharing information among scientists worldwide, especially regarding the techniques applied to declining communities. Thus, the Working Group on the Conservation and Management of Japanese Macaques has now taken a leading role in strengthening the scientific community, and has accelerated the activities to enhance the accessibility of related knowledge—e.g., feature articles that are published in Primate Research, a journal of Primate Society of Japan (Enari et al. 2018). This special feature in *Mammal Study* is another important example of an activity to enhance the accessibility of this knowledge.

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