Chapter 10
Adaptive Risk Management of Sika Deer

Hiroyuki Matsuda

Abstract We consider here a management policy for a sika deer (*Cervus nippon*) population on Hokkaido Island and Yakushima Island. Deer populations are characterized by a large intrinsic rate of population increase, no significant density effects on population growth before population crash, and a relatively simple life history. Our goals of management for the deer population are (1) to avoid irruption with severe damage to agriculture and forestry, (2) to avoid the risk of local population extinction, and (3) to maintain a sustainable yield of deer. To make a robust program on the basis of uncertain information about the deer population, we consider three levels of relative population size and four levels of hunting pressures on Hokkaido. We also take into consideration a critical level for extinction, a target level, and an irruption level. We recommend catching males if the population size is between the critical and target levels and catching more females than males if the population size is larger than the target level. The simulation results suggest that management based on sex-specific hunting is effective to diminish the annual variation in hunting yield. We also estimated the population size in Hokkaido. A generalized linear mixed model is used in this estimation. We then estimate the population from the index by evaluating the response of the known amount of harvest. We apply state space modeling to the harvest-based estimation to remove the measurement errors. We propose the use of Bayesian estimation with uniform prior-distributions as an approximation of the maximum likelihood estimation. Simultaneous estimation of absolute population size and the natural population growth rate is difficult. We need the product of these to adequate population control. The biological balance of Yakushima Island is also currently being compromised by the overpopulation of sika deer. To identify the best management practice for future implementation, we evaluated and compared the performances of six different zone-based management strategies. Under the current management scenario, the median population size of the sika deer on the island would temporarily decrease, but it would subsequently rebound. Under a scenario that allows management zones to be prioritized according to the occurrence of threatened plant species and deer

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population size, model simulations suggested that the scenario focusing on the central zone would show the best performance based on the probability of achievement of the management goal.

Keywords Sex-specific hunting · State space modeling · Generalized linear mixed model · Overabundance · Harvest control · Culling · Wildlife management

10.1   History of Overexploitation and Overabundant

It is not only fisheries resources that need population management. The deer has experienced population collapses and outbreaks. In Hokkaido, based on limited information, we started an experiment of population control of deer by hunting. It is considered to use deer as a natural resource.

Japanese sardine is known as organisms whose population fluctuate range is estimated to be >500 times. Mammals such as deer also fluctuate greatly. Yezo deer (*C. nippon yezoensis*) were used as meat (venison) for a short period of time in the Meiji era, and canned venison was exported. Both the horns and the fur had commercial value.

Deer population collapsed due to overexploitation during the Meiji era (Fig. 10.1). The number of catches decreased in geometric progression. On the way, heavy snowfall occurred in 1880 and 1882, and it was hunted from 1884 to 1901. Yezo wolves went extinct probably at the end of the nineteenth century. Deer hunting was once resumed but again banned from 1921 to the mid-1950s.

After the mid-1950s, deer population began to increase in geometric progression. The distribution channel for deer meat had disappeared. Deer devoured farms and
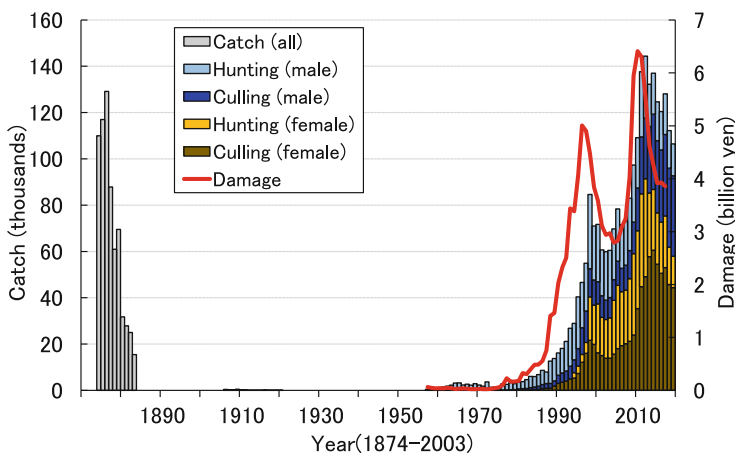

Fig. 10.1 Changes of catch in number of sika deer (drafted from Hokkaido Prefectural Government materials)
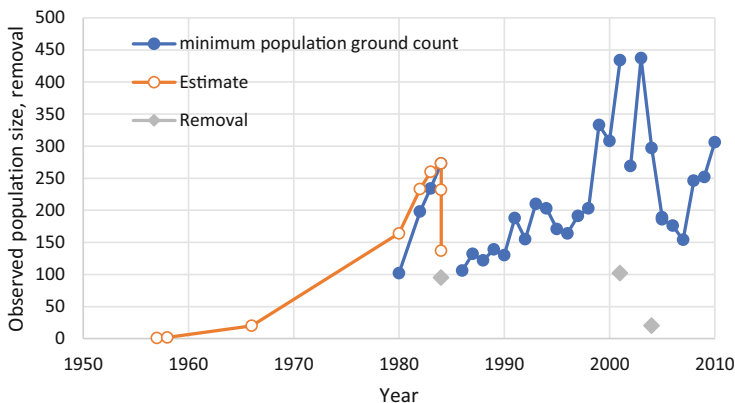
Fig. 10.2 Population changes of sika deer on Nakanoshima Island, Hokkaido, Japan, 1957–2010. Diamonds show the removal in 1983, 2001, and 2004; open circle and black circle shows estimated population size in different ways

pastures, consumed leaves in the plantation and wild plants less than 2 m high including threatened species, and strips bark. The amount of damage to agriculture and forestry, which was 1.4 billion yen in 1988, continued to increase, exceeding 4 billion yen in 1995 (Matsuda et al. 1999).

The population growth of wild animals and plants usually slows down, reaching the carrying capacity. This is called the density effect in population growth. However, the sika deer population often shows an insignificant density effect. The sika deer matures approximately at the age of 2 years and breeds one calf each year. The sex ratio at birth is approximately 1:1. It consumes many species of grass and continues to increase beyond the "carrying capacity." Eventually, a large number of males die of starvation and the population size will decrease sharply. The population collapse has been reported at Cape Shiretoko, Nakanoshima Island with Lake Toya in Hokkaido, and Mt. Kinka in Miyagi Prefecture (Kaji et al. 2005).

Three deer were released on Lake Toya within 10 years from 1957 and continued to increase at a rate of about 15% per year, reaching 299 in the fall of 1983, and 67 natural deaths by May 1984. Then, 95 deer were removed (Fig. 10.2). After the vegetation was once grazed, only grasses such as spurge (*Pachysandra terminalis*) remained on the forest floor (Kaji et al. 2005). In initial peak in autumn of 1983 was followed by a crash in winter of 1983–1984, when 67 carcasses were found and 95 deer were removed. Second irruptive event occurred to a peak in 2000 and declined in winter of 2000–2001, when 40 carcasses were found dead and 102 deer were removed to out of the island. Thereafter the population recovered to 297 deer in 2003, and crashed again (winter of 2003–2004) when 100 deer were found dead.

In the Meiji era, it is said that the sika deer died in large numbers in the heavy snowfall years. The sharp decline in the Meiji era is due to overexploitation and heavy snowfall. When a population management plan based on adaptive management was established in eastern Hokkaido in 1998, we assumed that heavy snowfall

would cause mass mortality once every 20 years on average. In Hokkaido, the average temperature in winter is below freezing even in the warm winter, and it is considered that the amount of snow would not decrease.

In fact, although heavy snowfall years came in 2011, mass mortality did not occur. This is probably because the natural vegetation changed from conifer forest in the Meiji era to deciduous-coniferous mixed forest. Coniferous mixed forests are important wintering sites for sika deer (Sakuragi et al. 2003; Kaji et al. 2005).

A natural enemy, the Japanese wolves (*Canis lupus hodophilax*), have gone extinct, and due to rising hunting and animal welfare movements and the decrease in game hunters, the protection policy is so powerful that there is no threat of deer. Hokkaido has become a suitable habitat for deer due to afforestation and grassland expansion. Even if the sika deer is over-abundant, most of the deer begin to reproduce at 2 years old and breed one calf each year. Not only damage to agriculture and forestry, rail accidents and road accidents, but natural vegetation may also be degraded accross Hokkaido, like Nakanoshima island in Lake Toya.

In 2003, the Japanese Society of Plant Systematics published a statement on "Prevention of Herbivorous for Conserving Endangered Plants in Southern and Western Japan." The impact of sika deer on natural vegetation in Japan is serious (Ministry of the Environment (Japan) 2010). The population control of deer is also enforced in the World Heritage sites of Shiretoko and Yakushima.

10.2 Yezo Deer Conservation Management Policy for Eastern Hokkaido Island

In Hokkaido Prefecture, the management policy was reviewed in 1998, and the "management policy" for eastern Hokkaido population of yezo deer was implemented to keep the number of deer appropriate for humans, avoiding the threat of extinction due to overexploitation. As of 1993, the number of deer in the Eastern Hokkaido area was estimated to be 80,000–160,000. This is the value obtained by multiplying the population density and the total habitat area by counting the number of deer by the areal census. Survival rate, childbirth rate, and maturity age were estimated from a field survey in Nakanoshima Island. In incorporation of about 20% uncertainty percentage in these values, and considering the rate of natural increase as 12–18% per year, and aiming to bring it within the appropriate level after 5 years, we calculated the target number of catches.

To develop a management plan, we consider the life history of deer, mating season, breeding season, migration to a wintering location, return from a wintering location, breastfeeding, and the hunting season (Fig. 10.3). In addition to this, we need to schedule the monitoring of population count, the period for data compilation and analysis to estimate the population size, decision of target number of catch in the next year, and decision of meeting schedule to determine the length of the next hunting season (Matsuda et al. 1999). The earliest and most reliable estimation of the
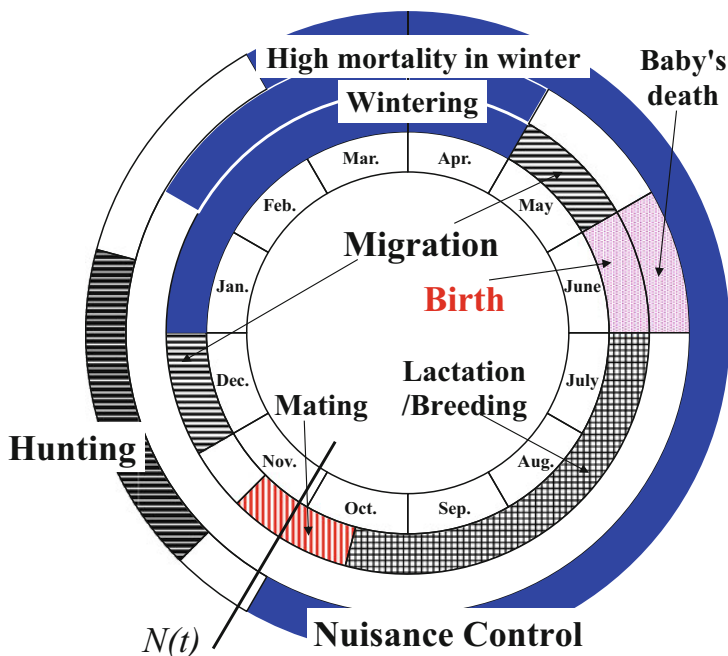
Fig. 10.3 Life history of deer (Matsuda et al. 1999). The number of individuals at the mating period (thick line) is used as the representative value for the year

population in the deer management plan is a spotlight survey conducted in the fall. Municipality staffs drive on fixed roads every year at night and light up to observe deer along the road. We estimate how much the deer is in a range on either side of the road. This is the relative index of population size. About 120 sites are surveyed every year in Hokkaido, and the population trend is read in detail. Since June is the birth period and the visual survey is autumn, the number of individuals aged 0.5 and over 1.5 can be seen. However, we do not know up to age by visual inspection, so we estimate from other data to estimate the age structure.

The management plan was based on the "feedback control" that had been discussed at the International Whaling Commission (Tanaka 1980). Since ecological information such as the population size, survival rate, and reproductive rate is not well understood, the population rends should be repeatedly monitored, protected the population when the number decreases, and removed a lot when the population is overabundant. It can be said to be the first example of adaptive wildlife management in Japan (Matsuda et al. 1999). This management system was the model for the "specific plan" introduced by the Japanese Wildlife Conservation Act, which was revised in 1999. The population dynamics model includes an annual variation of survival rate and reproductive rate, uncertainty of life history parameters (process error), and algorithm for changing hunting pressure policies according to the updated population index. This is called feedback control. Therefore, the numerical

Table 8.1 Measures for the "Conservation and Management Plan for Sika Deer" enforced in 1998

Measures	Implementation conditions	Contents of measures	Hunting female	Hunting male	Culling
Emergency reduction measures	Population index 50%[a] or more	Thorough capture (up to three consecutive years)	5	5	1
Gradual reduction measures	25% or more and less than 50%	Female deer priority capture	1[b]	1	1
Gradual increase measures	5% or more and less than 25%	Male deer priority capture	0	2	0.1
Ban on hunting measuers	less than 5% or after a heavy snowfall	Full hunting ban	0	0	0

[a]Population index means the percentage of population size in 1993
[b]For hunting and culling pressure for females and males, the strength at the gradual reduction measures is set to 1, and that for other measures is the relative value

simulations are repeated, and the risk of management failure will be evaluated. As a result of the examination, we made a management plan as shown in Table 8.1.

Four measures are used according to the population index. The population indices at the boundary are called the outbreak level, the target level, and the lower limit level, which are 50%, 25%, and 5% of the population size as of 1993, respectively.

We planned to take emergent reduction (ER) measures until the population decreased below the outbreak level. After the ER measures end within a few years, ideally we have to continue to take only gradual reduction (GR) measures and gradual increase (GI) measures except for the year following the heavy snowfall year. If it again exceeds the outbreak level or falls below the lower limit level in the future, it means management failure.

However, we cannot say that it will never fail. We cannot say that there is no risk of heavy snowfall coming for three consecutive years. There is a risk of making a large mistake in estimating the number of individuals. Therefore, we have defined that the criterion for judging management failure is once again exceeding the outbreak level or falling below the lower limit. Taking into account uncertainty in mathematical models, the target level, outbreak level, and lower limit level were set so that the risk of management failure within the next 100 years would be below the permissible limit (Matsuda et al. 1999).

In this way, we call "risk assessment" to estimate the risk of failure under a particular situation setting. Risk assessment is necessary not only for wildlife management but also for all systems with uncertainty, from financial investment to nuclear accidents. In addition, management that determine and change policies in terms of risk assessment is called risk management.

Ignoring measurement error of ecological information or assuming that environment is constant (ignoring process error) makes a big mistake. As explained in the

chapter on chub mackerel fisheries, if the fish are caught in constant harvest amounts, the stock size does not stabilize. Uncertainty is inherent in the estimation.

In addition, the fact that changes in catch rates depend on population size means that fluctuations in catches are larger than fluctuations in population size. Hunters will not want a large fluctuation in the harvest. The sika deer management plan recommends catching a large number of females during the ED and GD measures and not the females during the GI measures. Since deer are polygamous, the number of offspring does not significantly depend on the number of males. If the males and females are separately captured in this way, the number of harvests does not vary so much. However, this method is possible because the male horned deer is attractive to a hunter who is aiming for a big game. It will not be possible in the fishing of the mackerel. Hokkaido Government requested the Ministry of the Environment to change the notification, and since 1999 relaxed the catching limit of one deer per day, two females are allowed per day. The hunters are well aware of the significance and goals of the management plan, and they are cooperating to catch a large number of female deer.

Relying on game hunting means using deer as a resource. Currently, various efforts are being made to reestablish the market for deer meat. The Hokkaido conservation and management plan also states that deer sika should be regarded as a common property of the people of Hokkaido.

The Wildlife Protection and Hunting Law (first enforced in 1918) was revised in 1999. There are two major revisions. The first is to transfer the permission rights such as the control of pest animals from the Environment Agency to prefectures in order to be consistent with the Decentralization Act. The other is that deer and serow (*Capricornis crispus*), which have excessively increased, are controlled not by the pest control system but by "Specified Wildlife Conservation Management Plan" that is implemented by a prefectural government. At the same time, the Law, which had been for hunters, should include the purpose of protecting biodiversity. The deer management plan in Hokkaido was recognized as a pioneer of the "Specified Wildlife Conservation Management Plan" of the revised law.

In 2014, the law was again amended into the "Wildlife Conservation and Management Law." At that time, the wildlife management system was introduced by dividing it into three categories: a "protection plan," a "management plan," and a "rare wild animal management plan." Animals with a rare population to be protected and those to be managed in excess were separated in the first and second categories. In addition, even for endangered species, the Ministry of the Environment (Japan) will directly manage animals that require measures against damage caused by wild animals. Also, not only hunters who have been engaged in game hunting, but also wildlife management experts who have acquired population management technology are allowed to manage populations, such as allowing 1 h after sunset.

10.3 Population Estimation by a State Space Model

As mentioned above, Hokkaido estimated the population size of deer in East Hokkaido to be 120,000. Since the discovery rate by areal survey is not 100%, the true population size is not known by this method. IWC (International Whaling Commission) is also trying to estimate the discovery rate by preparing multiple independent observers. For example, suppose two observers A and B. If the numbers of wild animals found by both A and B, found only by A, and found only by B are a, b, and c, respectively, the population size, discover rates of A and B, respectively denoted by n, p, and q, are given by $n = a + b + c + bc/a$, $p = a/(a + c)$, and $q = a/(a + b)$. We can estimate the number of individuals with more detailed data.

However, a more plausible estimate can be made by combining the estimated population number based on an independent population survey each year and the population dynamics model as follows.

$$N_{t+1} = \exp[r + \xi_t - kN_t]N_t - C_{1,t} - C_{2,t} \tag{10.1}$$

Here, t is the number of years from the initial year ($t = 0$); N_t and $C_{1,t}$ and $C_{2,t}$ are non-negative variables which mean the population size, the number of culled deer, the number of hunted deer in year t, respectively; and r and k are non-negative, which mean the intrinsic rate of population increase and the magnitude of density effect, respectively; ξ_t is a normal random variable with mean of 0 and SD of σ_r, which represents the annual fluctuation (process error) of r. The number of catches in year t is set as $C_t = C_{1,t} + C_{2,t}$. In this way, the dynamic model that describes the time change of the state is called the "state model" (Yamamura et al. 2008).

We assume that the estimated population (population index) $\hat{I}_t$ based on population survey and the relative value of the true population N_t have the following relationship:

$$\hat{I}_t = \beta(N_t/N_0)\exp[\zeta_t] \tag{10.2}$$

where β is a positive constant and bias in population estimation, N_0 is the initial population, ζ_t is a normal random variable with mean 0 and SD is σ_N, which represents the estimation error of the number of individuals. This is called an observation model. The set of state model and observation model is called "state space model." When β is unknown, only relative values $I_t = N_t/N_0$ will be used in the end, so here the observed value is $\hat{\mathbf{I}} = \left(\hat{I}_1, \hat{I}_2, \ldots, \hat{I}_T\right)$. In the case of deer management in Hokkaido, the observed value I_t is estimated from the spotlight survey using the generalized linear mixed model (GLMM). From this, the state space model estimate $\hat{I}_t = \tilde{N}_t/\tilde{N}_0$.

From the annual population index estimate $\hat{\mathbf{I}}$ and the number C_t captured, we estimate $\tilde{N}_t$, r, σ_r, σ_N, β. To estimate β, we first assume that each parameter value follows a certain probability distribution. This is called prior distribution. For

example, assume that r is a beta distribution between 0 and 34%, and σ_r is a lognormal distribution with an appropriate geometric mean and standard deviation (Yamamura et al. 2008).

In the case of sika deer, they breed from the age of 2 years and give birth each year, and the sex ratio at birth is 1:1. Therefore, the number of females at the age of 1 is $N_{c,\,t}/2$, and the number of individuals over the age of 2 is $N_{c,\,t}/2$. Putting the number $N_{f,\,t}$, the number of individuals in the next year is

$$
\begin{pmatrix} N_{c,t+1} \\ N_{f,t+1} \end{pmatrix} = \begin{pmatrix} 0 & m \\ S_c/2 & S_f \end{pmatrix} \begin{pmatrix} N_{c,t} \\ N_{f,t} \end{pmatrix}
\tag{10.3}
$$

Where m is the product of reproductive rate and survival rate from birth to 1 year of age, and S_c and S_f are the annual survival rates of 1-year-old calf and female adult, respectively. When $r = S_c = S_f = 1$, the maximum eigenvalue of this right-hand side matrix is $(1 + \sqrt{3})/2 \approx 36\%$, which is the mathematical upper limit of the natural rate of population increase. A higher natural increase rate than this limit is sometimes estimated, but it is probably caused by immigration from the outside or an observation error (Matsuda et al. 1999).

According to the probability distribution, the initial population $\widetilde{N}_0$ and the parameter value are given to repeat the computer simulation, and the time series of population fluctuation $\{N_t\}$ and population index are calculated. We generate the sequence $I_t = N_t/N_0$. Calculate the likelihood that an observation will be observed according to the observation model.

$$
\Pr[\widetilde{N}_t | N_t] = \frac{1}{\sigma_N \sqrt{2\pi}} \exp\left[-\frac{(\widetilde{N}_t - N_t)^2}{2\sigma_N^2} \right]
\tag{10.4}
$$

We calculate the posterior probability distribution for each parameter, using the total log-likelihood in the following, denoted by L (Yamamura et al. 2008):

$$
L = \sum_{t=0}^{T-1} \log\left[\Pr\left[\widetilde{N}_t | N_t \right] \right] = -\frac{T}{2} \log\left[2\pi\sigma_N^2 \right] - \sum_{t=0}^{T-1} \frac{\left(\widetilde{N}_t - N_t \right)^2}{2\sigma_N^2}
\tag{10.5}
$$

In the Bayesian estimation method, each of the above parameters is given as a prior probability distribution, and the posterior distribution is calculated. That is, when the prior distribution of a certain parameter x is $\Pr[x]$, a numerical experiment of population dynamics model is repeated and numerical experiments on population dynamics model are conducted to find the probability that the observed values become $\widetilde{N}_t$ or $\widehat{I}_t$ when the number of individuals is $\{N_t\}$. Therefore the posterior probability distribution is given by
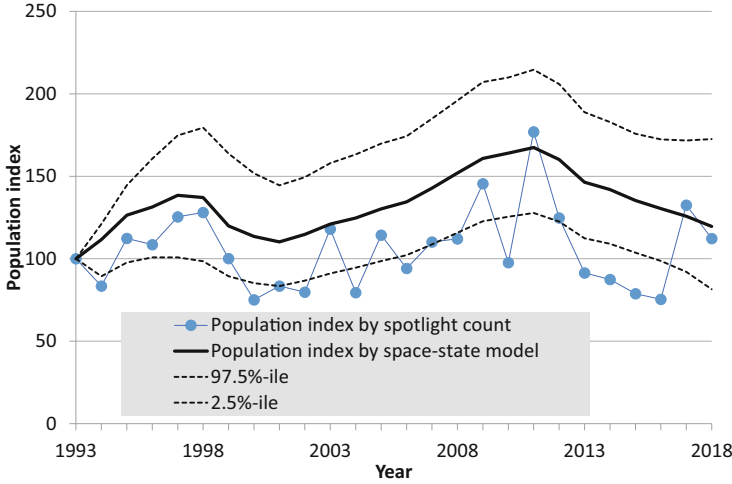
Fig. 10.4 The GLMM population index $\widehat{\mathbf{I}}$ (blue circles) using spotlight survey data and the eastern deer population index $\widetilde{\mathbf{I}}$ using the state space model. Annual changes in median (solid line) and 95% credible interval (upper and lower dashed lines) (redraw from Data by Hokkaido government)

$$\Pr[N_0 \mid \widetilde{N}_t] = \frac{\Pr[\widetilde{N}_t \mid N_0]\Pr[N_0]}{\int \Pr[\widetilde{N}_t \mid x]\Pr[x]dx} \tag{10.6}$$

When this integration is performed, a large number of random numbers are subtracted according to the prior distribution to generate parameter values, the population dynamics model gives the probability, and the posterior distribution is calculated therefrom (Yamamura et al. 2008) (Fig. 10.4).

Although we agreed to catch a large number of deer, we cannot say that population control had been successful. Although it seems to have decreased for 3 years since 1998, it was far behind the goal of leading to an index of 50% within these 3 years. After that, very regrettably, the budget did not continue and the catch in number decreased. We continued emergent reduction measures, but the target number of catches recommended by scientists (Hokkaido Sika Deer Management Plan Experts Council, formerly the Sika Deer Conservation Management Plan Advisory Committee) will not be achieved, and the deer population had increased again. After that, it seems that the management effort increased again and it began to decline again since 2011, but it is still far below the goal of reducing the population index to 50 by 2022.

Population control is a part of the overall management plan, including building fences to protect the agricultural and forestry fields. In Hokkaido, we are also promoting the effective use of deer meat. We have established more than 100 treatment stations based on the Food Sanitation Law, but the utilization rate of captured individuals is about 20%, as of 2019. It is unrealistic to use it 100% because it

includes deer caught in the mountains, but in Hokkaido we aim to make effective use of 30–50%.

In any case, wildlife management and fisheries management, in which management theory is practiced, is a field where scientists are very responsive. It can be seen that the management theory of the two has a lot in common (Shea et al. 1998).

10.4   Yaku Deer is Increasing

Yakushima, inscribed as the Natural World Heritage in 1996, is an island with an area of about 500 km^2. Yaku deer (*Cervus nippon yakushimae*) and Yakushima macaque (*Macaca fuscata yakui*) are endemic subspecies. Population sizes of both subspecies are increasing. Especially in the western part of the protected area, forest floor vegetation has been damaged due to the rapid increase of deer. Fig. 10.5 shows the zoning of the biosphere reserve and density distribution of deer in Yakushima Island. Yakushima World Heritage site is almost the same as the terrestrial core area of the BR. It can be seen that the high-density area of deer overlaps with the western side of the World Heritage area and the western national forest area. There is a national forest area in the south, but there are many orchards on the coast, and it may be that the capture pressure was high to prevent damage to agriculture and forestry (Fujimaki et al. 2016).

There is also a report that the population density is ca. 70 deer/km^2 in the western forest road area, which is particularly dense in the western part (Tsujino et al. 2004), whereas the maximum density of the western area is >100/km^2 in 2018. Usually, when the density of deer reaches >10/km^2, natural vegetation is affected and grasses
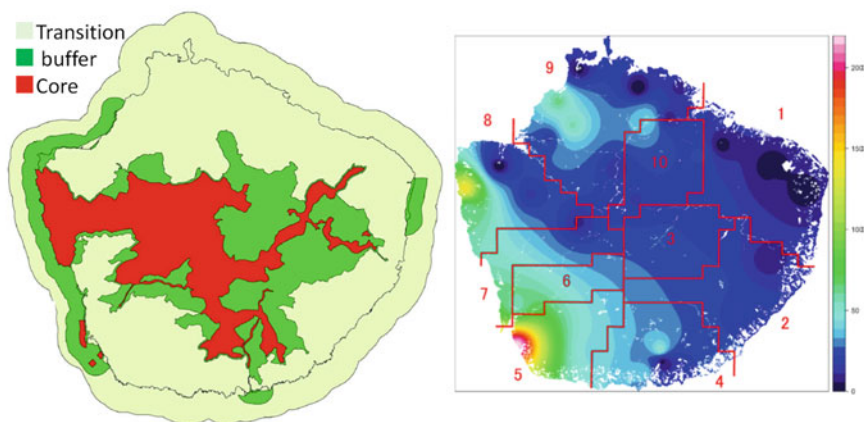

Fig. 10.5   (left) Zoning of Yakushima-Kuchinoerabujima Biosphere Reserve (UNESCO site) and (right) Population density and 10 management units of deer in Yakushima Island, 2018 (Kagoshima Prefecture, Science Council for Yakushima World Heritage, June 25, 2020)

Fig. 10.6 Hananoe-go in Yakushima National Park in 2010 (left) and 2016 (right). The *Sphagnum* moss was peeled off in 2016 due to the trampling of the yaku deer (*Cervus nippon yakushimae*) (Forestry Agency (Japan) 2017 Yakushima World Heritage Science Committee on August 2, 2017)

about 1.5 m tall are cleaned up from the forest floor. This band-shaped space is called a browsing line. Natural vegetation is lost and the ground is exposed in the high-density region as seen in Fig. 10.6(left), but natural vegetation is maintained in the southern part.

Although the number of confirmed species varies among grids, comparing the number of confirmed threatened (sub)species in each of the six areas, the number of threatened species in the western area was small and the numbers in the center and the northeastern were large (Fujimaki et al. 2016). Mt. Miyanoura in Yakushima is the highest peak in the Kyushu region, and it has been registered as a World Natural Heritage site for its diverse biota at various altitudes. The ironic result is that the secluded areas along the coast except the west are more diverse than in World Heritage areas.

The request from the Japanese Society of Plant Systematics (JSPS) in 2003 concerned that many species would become nearly extinct. Most of the surveys by the JSPS are conducted along sidewalks. The topography of Yakushima is extremely steep. Endangered plants could survive in a place where humans and deer cannot access. For example, plants that grow over rocks will avoid feeding damage.

The ecosystem of Yakushima is known to have been devastated by the eruption of a submarine volcano (Kikai Caldera) ca. 40 km northeast ca. 7000 years ago. However, after that, the natural vegetation recovered. However, since we have endured various natural disturbances up to now, there is no guarantee that we will be able to withstand the current human disturbances. At the Shiretoko World Natural Heritage site, a similar controversy was discussed at the Science Council. Although the number of sika deer is still increasing, we have agreed that the impact on natural vegetation such as Japanese elm (*Ulmus davidiana* var. *japonica*) will be the largest ca. 200 years ago, but we could not determine if this was an unprecedented impact in the longer term. There can be both an error of neglecting necessary measures and an error of making unnecessary intervention. These are called type I and II errors in statistics, respectively. In ordinary science, the first priority is to avoid mistakes, or "in dubio pro reo." However, regarding environmental issues, it is recommended

that priority should be given to avoiding type II error when irreversible effects are a concern (Matsuda 2003). This is the precautionary principle described in Chap. 3.

A well-known international agreement stating the precautionary principle is the 15th Principle of the Rio Declaration at the 1992 Earth Summit. The UN Framework Convention on Climate Change, which was adopted in 1992, is also based on this precautionary principle. Countermeasures to climate change were taken based on the precautionary principle until the Intergovernmental Panel on Climate Change (IPCC) determined that climate change was a fact in the fourth report of 2007. Even in Shiretoko World Heritage site, it was agreed that deer population is controlled to avoid concerns of irreversible damage to the natural vegetation. We explained this to the UNESCO and International Union for Conservation of Nature (IUCN) investigative bodies in 2008. They understood the measures conditionally. Permits for human intervention, such as deer capture at natural world heritage sites, are probably rare worldwide.

To reduce the deer population of the whole island, the catch in number must be increased remarkably. A short catch will not reduce the population. To test another hypothesis that the effects on natural vegetation are not serious and are not irreversible, we recommend leaving deer growth uncontrolled. Therefore, on the condition that they are caught in the center of the female deer and the number of catches is increased from 300. We concentrate on catch of deer in the northeast and south if the catch increased to 1000. We could control the deer of the whole island if the catch increases to 4000. We proposed the "three-division management plan" (Fujimaki et al. 2016).

In order to reduce the deer population, we need to significantly increase catches, but there are restrictions on where deer can be caught. Before the hunting season in the autumn of 2007, female deer could only be caught by culling. After that game hunting of female deer became possible. In addition, access to hunters for deer catch is restricted within the national forest. This is due to the accidental death of a forest ranger of the Yakushima Forestry Office in 1988.

However, the catch in number has increased significantly since then, and the Yaku Deer Management Plan by Kagoshima Prefecture has been implemented since 2010, and the catch, which was 325 in 2009, has rapidly increased to 4900 in 2012 (over 2000 female deer). If the population of the whole island is probably <20,000 and the rate of natural increase is 20%/yr., we expect that if the whole population will decrease. However, catch in the western part of the world heritage site that extends to the coast and the central part of the mountainous area was difficult. Population control of yaku deer depends on the consensus of local stakeholders.

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