[*Jpn. J. Rural Econ.* Vol. 8, pp. 12-25, 2006]

Economic Resource or Mammalian Pest? : A Reconsideration of the Management of Wild Deer

Yukichika Kawata*

The various kinds of damages currently caused by wildlife throughout Japan can be attributed to the fact that the policies for management and utilization have lacked both a long-term perspective and an examination from the biological and economic points of view. This paper, therefore, addresses the issue of the management of the Yeso deer in Hokkaido and reexamines it. The paper presents three main conclusions. First, when the revenues from forestry products are sufficiently high, it will be appropriate to maintain the wildlife resource level lower than the level corresponding to the maximum sustainable yield (MSY). Second, there is a possibility that certain changes in the discount rate and the price may lead to a substantial alteration of the management criteria. Third, there is little difference between the monopoly case and the socially optimum case under the parameter values set in this paper.

Key words : wildlife management, sustainable resource use, Yeso deer, venison, mammalian pest.

1. Introduction[1)]

All the organisms within an ecosystem have symbiotic, competition, predator-prey or other relationships with one another, and have stabilized their population in the long run by either remaining stationary or following a cycle. Human beings have, as a part of the ecosystem, harvested (hunted, trapped, or both) and utilized wild animals from time immemorial. Until the modern era, human activities do not seem to have severely disrupted the well-established ecosystem since the human population was relatively small and its hunting methods were still undeveloped. However, the situation seems to have changed considerably since around the Meiji era in Japan. The improvements in hunting methods increased the extent to which wildlife could be harvested. In addition, human beings began to exert a considerable indirect influence on other wild animals through the excessive development of the pristine wilderness, which was the habitat of wild animals, as well as the harvesting of a large number of animals that are prey to certain predators such as Japanese wolves. Wolves had been exterminated throughout Japan by around 1890. Down the ages, deer and boars have also been harvested for their meat and leather, which were economically valuable; this in turn has often caused agricultural and forestry damage. Among these wild animals, the Yeso deer appeared to have been hunted to extinction during the Taisho era. Fortunately, some surviving deer were found during the Showa era; hunting of this animal was subsequently prohibited. However, although the prohibition is no longer in force, the number of animals that can be hunted has been restricted until recently. Similarly, hunting of the Japanese serow, which was designated a protected species in 1934, has also been reduced. As a result of improvements in the standard of living, the consumption of meat and leather has decreased; this appears to have accelerated the increase in the population of these protected species. The recent increase in the availability of feeding grounds and the decline in hunting because of the

*Keio University

I am grateful to my thesis advisors, especially Dr. Takashi Takebe at Kyoto University, and to the anonymous referees of the journal for their many valuable comments on earlier drafts.

aging of the hunters has precipitated an increase of the deer population.

On the basis of the brief survey presented above, it is possible to summarize the issues pertaining to wildlife management in Japan and its usage in the past as follows: (1) there has been an extreme policy regarding usage, that is, either extermination or absolute protection, (2) the large-scale exploitation of wild nature in the past and the recent increase of wasteland because of the abandonment of cultivation have caused significant fluctuations in the area of the animals' habitat, (3) hunting activities, which partly assume the role played by wolves, have been decreasing, leading to an increase in the prey population. For natural predators such as wolves, animals such as deer and boars are always prey, while for human beings, these animals are seen as protected wildlife, objects for consumption, or mammalian pests according to changes in the socioeconomic conditions and the attitude of human beings toward wildlife. These alterations have occurred within decades or a century, which are merely fleeting moments in terms of the time scale of the ecosystem. It can be concluded that in the past, wildlife management in Japan lacked a long-range perspective and its goals were ambiguous.

On the basis of the above description, it is evident that economic as well as biological approaches are indispensable for wildlife management. From the biological perspective, it is crucial to maintain individual species while balancing the entire ecosystem. Since human beings have exterminated the wolves in Japan, we are responsible for controlling the population of animals that were formerly prey to wolves. From the economic perspective, it is necessary to judge whether these biological management methods are financially viable and to implement some appropriate measures if required. An assessment of the economic value of wildlife and the implementation of wildlife management is indispensable. This is because the traditional methods of wildlife management and usage were heavily influenced by the social situation; once meat and leather were no longer valuable, human beings considered wild animals as mere pests, and this resulted in a myopic treatment of wildlife.

One of the most well-known and prominent cases that involved confronting and tackling the problems mentioned above is the case of the Yeso deer that occurred in Hokkaido, Japan. The number of the Yeso deer has been drastically increasing in recent times, and agriculture, pasturage, and forestry damages have risen sharply, especially after 1985. The highest damage of more than 5 billion yen was recorded in 1996 (Fig. 1). The damages are particularly severe in eastern Hokkaido,[2] which accounts for nearly 80% of all the (monetary) damages (Hokkaido Government [10]). The Hokkaido government launched the Conservation and Management Plan for Sika Deer in 1998 (Hokkaido Government [9]). While this plan targeted eastern Hokkaido, the area it covered was enlarged in the 2000 plan and revised to include the whole of Hokkaido in the 2002 plan (Hokkaido Government [10]). Such a series of management plans is a progressive approach in Japan and employs what is known as feedback or adaptive management. However, it has been pointed out that there has not been sufficient examination from the economic perspective (HIES [12]).

Therefore, the purpose of this paper is to empirically examine whether the target level of the Conservation and Management Plan for Sika Deer, which is based on ecological studies, is still valid when certain economic aspects are taken into consideration. Since the meat of the Yeso deer (hereafter referred to as venison) has attracted considerable attention from the public because of its potential as a foodstuff, we will examine the management of the Yeso deer by formulating a model that considers the revenue from venison as well as the forest damages. Former studies in resource economics have often examined economically useful wildlife and only a few studies have focused on its attributes as a pest. One such example is the theoretical study conducted by Schulz and Skonhoft [19] and the empirical studies of wild pigs (Zivin, Hueth, and Zilberman [23]) and reindeer (Bostedt, Parks, and Boman [2]).

In the 2nd section of this paper, we will briefly summarize the influence exerted by the Yeso deer on the agriculture, pasturage, and forestry industries and on the venison market. These two areas correspond to the

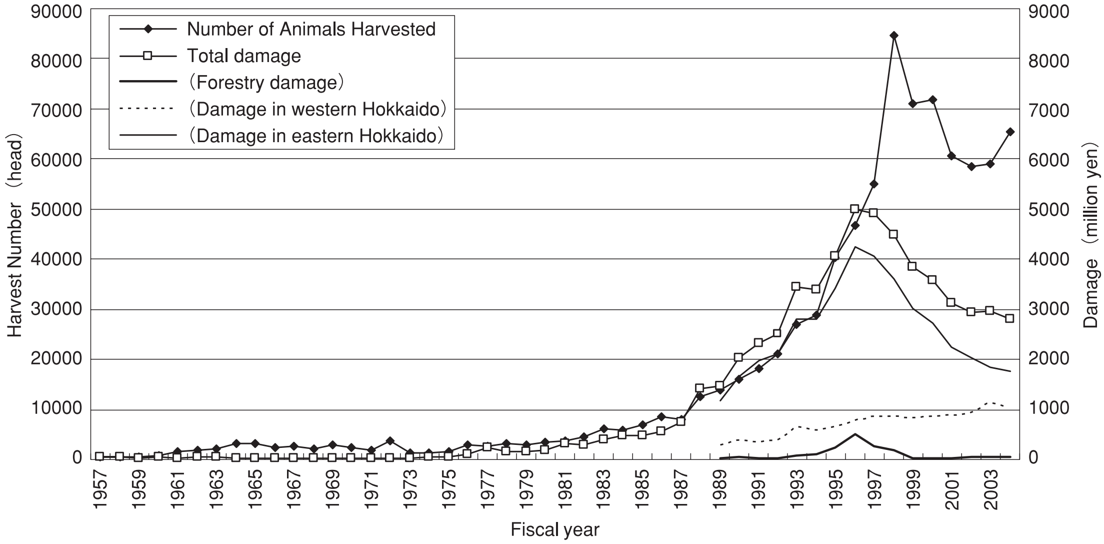

Figure 1. The number of the Yeso deer harvested and the extent of the damage (monetary) from 1957 to 2004

Source: Hokkaido Government [9] and http://www.pref.hokkaido.jp/kseikatu/ks-kskky/sika/data/damage/damage.htm

Note: The number of catches in 2004 is a quick estimation.

two attributes of the Yeso deer, namely, as a pest and as a useful animal. In the 3rd section, we will formulate the model that considers these two aspects. In the 4th section, we present the analytical results, which we then discuss in the 5th section. Finally, we conclude the paper in the 6th section.

2. Impact of the Yeso Deer

1) Agriculture, pasturage, and forestry damages

Japanese deer (of which the Yeso deer is a subspecies) favor and range throughout the borders of the forest—a transitional zone connecting the forests and the grasslands (Miura [17])—and their feeding habits vary (Yokoyama, Kaji and Suzuki [22]). Therefore, they cause extensive damage to agriculture, pasturage, and forestry by browsing, stripping bark, fraying, feeding on agricultural crops, and treading on the crops. On a nationwide scale, forest damages are more serious than agricultural damages (Yamane [21]), whereas in the case of the Yeso deer, a majority of the damage has occurred in agriculture and particularly in pasturage, as seen in Fig. 1. This tendency may persist in the years to come, despite the fact that forest damages (monetary) had increased around 1996 and, on an average, accounted for approximately 3-4% of the total damage. The damage (monetary) in eastern Hokkaido as well as in the whole of Hokkaido has been decreasing since 1996. However, in some subprefectures in western Hokkaido, especially in Hidaka, which borders on eastern Hokkaido, the damage has been increasing since 1998. This may indicate that as a result of excessive hunting, the Yeso deer have fled to neighboring areas. This, in turn, suggests the need for the formulation of a model that not only considers agriculture, pasturage, and forestry damages but also the entire area that suffers significantly on account of the damages caused by the Yeso deer. [3)]

2) The venison market

It is crucial to recognize the economic value of wildlife in order to manage it from a long-range perspective, as discussed earlier. One of these valuable properties is the meat of wild animals. The canned venison of the Yeso deer was exported during the Meiji era and venison was utilized until World War II. After this period, changes in the social and economic conditions took venison outside the sphere of consumption, and its economic value became almost negligible. However, in recent times, the venison of the Yeso deer has attracted public attention because it is low in fat and high in calories and iron,[4] and it has been imported from New Zealand. Therefore, there is a possibility that a large quantity of Yeso deer venison will be traded in domestic and foreign markets. While the available supply of venison amounts to 6-7 thousand head per year,[5] the estimated consumption is approximately 1.2-1.7 thousand head per year.[6] The venison of the Yeso deer has not yet been fully utilized. The reasons for this are as follows: (1) most Japanese are almost completely unaware of the existence of venison and its desirable characteristics and (2) the supply to the markets has been limited because of legal restrictions. With regard to the former, however, the Hokkaido government and the Yeso deer association have offered considerable information about venison and the shops dealing in it on their Web sites, and the amount of information available to the public has improved both qualitatively and quantitatively over the past few years. With regard to the second reason, the legal restrictions may be revised because of the following issues that were raised during the regular assembly of the Hokkaido government held in September 2004. (1) The government is interested in examining the equipment and the institutions necessary for the implementation of venison treatment and (2) The Yeso Sika Efficient Use working group, which is composed of Hokkaido government officials, has discussed the hygienic management of venison. It may be concluded that while there remain some obstacles to the construction of well-functioning markets for Yeso deer venison, these will gradually be realized. Since the deer's value as venison is one of the easiest to accurately evaluate and attracts relatively little criticism, we have focused attention on this characteristic.

3. Model

Zivin, Hueth, and Zilberman [23] developed a resource economic model for feral pigs, which not only cause agricultural damage but also generate economic revenue. The landowners, who are assumed to be decision makers, have the rights (pig hunting permits) to harvest feral pigs on their land and can sell these rights in the hunting-rights market, where the price of permits decreases as the number of kills increases. Landowners select the number of permits sold per period and the number of pigs trapped per period such that they maximize their net revenue while preventing agricultural damages.

This paper examines a situation and a model analogous to the one above; however, there exist certain differences. First, we consider only hunting because traps are seldom used in the case of the Yeso deer. Second, as we will discuss in the next section, a representative forest owner and a public institution are considered as decision makers. We will examine a case in which the price of the deer is given because when the public institution valorizes the purchase price, the price will be given for the hunters. Third, since animal hunting permits have not been introduced and are not under consideration in the case of the Yeso deer, we will not consider the hunting-rights market. Finally, we include the opportunity cost incurred by the forest owner in the harvest cost because the forest owner hunts Yeso deer in order to reduce or prevent damage to standing timbers that have commercial value, and this activity can be regarded as a part of forest management.

1) Assumption of the decision makers

Formerly, some households and restaurants enjoyed venison that was provided directly by the hunters without passing through the market. Recently, some local governments have purchased the carcasses of the hunted Yeso deer, and some of these have been sold as venison in order to facilitate the hunting of the Yeso deer. For example, the town of Ashoro established a plant for the treatment of venison and initiated sales activities; this exerted some influence on other local governments. However, the situation has changed because of the spread of viral hepatitis type E (HEV), which is caused by the consumption of raw meat. For example, on March 31, 2004, the town of Ashoro decided to discontinue the sale of Yeso deer venison. However, as previously mentioned, an increase in the number of venison processing plants is essential in order to expand the use of Yeso deer venison, and at the question-and-answer session of the regular assembly of the Hokkaido government, primary processing using moveable facilities (vehicles) was suggested as one of the promising solutions. Under these conditions, an increase in the number of venison processing plants is expected, although it is unclear whether the majority of these will be built by the private or the public sector.

Forest owners who have suffered forestry damages caused by the Yeso deer will behave so that they maximize their net revenues if they live in an area where the local government has launched a purchasing program for Yeso deer. The net revenue is mainly the difference between the total revenue from the bodies of the hunted Yeso deer and the total agricultural damage cost. On the other hand, if the purchase and utilization of the bodies of the hunted Yeso deer by the local governments and other institutions as well as the quantity of venison traded through the markets is increased in the near future, we can assume a situation in which public institutions will be monopolists in the distribution of venison.

Therefore, we assume the following two decision makers: the forest owner and the public institution. The former represents the situation that was recently prevalent in the town of Ashoro, and we assume that he/she decides the extent of the hunting so that the net revenue is maximized, with the price per head being given by the public institution. The latter represents a future situation in which the sale of venison will yield continuous profits, and in which the public institution purchases the carcasses of the hunted Yeso deer from the forest owners and sells these as venison. The price of the venison will change according to the markets. In the latter case, the public institution will decide the number of carcasses of the hunted Yeso deer to be purchased, and the price per head is assumed to be a function of the extent of hunting. For the sake of simplicity, we assume that the number of hunted deer decided on by the public institution and the actual number of hunted deer will coincide.

2) Derivation of the objective function

In the following section, we will construct a resource economic model that is based, to some extent, on the work of Zivin, Hueth, and Zilberman [23]. Assume that a representative forest owner manages a plot of forest land from which he/she not only procures a forestry income I but also suffers forestry damage caused by the Yeso deer, which accounts for $\alpha(X)$ proportion of the total forest. Then, the forestry income when damage is considered is given by

$$R_f = I[1-\alpha X(t)] \tag{1}$$

where $X(t)$ is the number of Yeso deer per km^2 and is a function of time per year t, which, for the sake of simplicity, is hereafter denoted by X. The forestry income I is expressed more precisely, that is, $I = F \times A$, where F and A represent the per km^2 income from forest management and the total area of the forest, respectively.

The forest owner also earns R_d by hunting and selling Yeso deer. If the total hunting cost increases as the resource level of the Yeso deer declines, it can be expressed as

$$C(X) = c_1(X)h(t) \tag{2}$$

where $c_1(X)$ and $h(t)$ represent the hunting cost per head and the number of Yeso deer hunted, respectively.

As is seen in several cases, even-toed ungulates such as deer often display a sudden and sharp decline in their population (known as a crash) after a period of exponential growth (Caughley [3], Takatsuki [20]). Since it is expected that under appropriate management, the resource level X will be maintained safely below the carrying capacity K, we will assume $X \leq K$. Then, the natural growth function of the Yeso deer $G(X)$ may be described by a logistic equation, which is often used to describe wildlife growth. The dynamics of the Yeso deer are given as follows:

$$\frac{dX}{dt} = G(X) - h(t) = r\left(1-\frac{X}{K}\right)X - h(t) \tag{3}$$

where r is the instantaneous growth rate. The carrying capacity K has displayed an upward fluctuation in the long run. Although this may continue in future decades, it is expected to be a token degree. Therefore, we assume K to be a constant. [7)]

Now, the forest owner selects $h(t)$ to maximize the following objective function:

$$\int_0^{\infty} e^{-\delta t}[R_f + R_d - C(X)]dt \tag{4}$$

under the constraint expressed by eq. (3). In eq. (4), δ denotes the discount rate.

3) When the price per head is given[8)]

In this subsection, we assume that the forest owner will maximize the net revenue, with the price per head being given by the public institution. Let p be the selling price per head. The total revenue generated by the hunting and sale of Yeso deer will be specified as follows:

$$R_d = ph(t) \tag{5}$$

The Lagrangian and the current-value Hamiltonian corresponding to the problem given by eqs. (3) and (4) are as follows:

$$L = \int_0^\infty \left\{ e^{-\delta t}[(1-\alpha(X))I + (p-c_1(X))h(t)] + \lambda\left[G(X) - h(t) - \frac{dX}{dt}\right]\right\} dt \tag{6}$$

$$Hc = [1-\alpha(X)]I + [p-c_1(X)]h(t) + \mu[G(X) - h(t)] \tag{7}$$

where λ is the Lagrange multiplier and μ equals $\exp(\delta t)\lambda$. The multiplier μ can be interpreted as the shadow price of hunting additional Yeso deer at time t. If we assume an interior solution, the conditions for optimality are given by the following partial derivatives:

$$\frac{\partial Hc}{\partial h(t)} = p - c_1(X) - \mu = 0 \tag{8}$$

$$-\alpha'(X)I - c'_1(X)h(t) + \mu G'(X) = -\dot{\mu} + \delta\mu \tag{9}$$

where $\dot{\mu}$ denotes the partial differential of time t. Since the shadow price and the resource level will not change at the steady state, $\dot{\mu}$ and $G(X^*) - h^*$ will equal zero, where * indicates the steady state equilibrium. By substituting these conditions in eqs. (8) and (9), and after certain calculations, we have the following equation:

$$\delta = -\frac{\alpha'(X^*)I + c'_1(X^*)G(X^*)}{p - c_1(X^*)} + G'(X^*) \tag{10}$$

This is the modified version of the golden rule equilibrium equation, which was first given by Clark and Munro [6]. Following the publication of this work, the r. h. s. of eq. (10) is often referred to as the "own rate of interest," which expresses the extent of the increase in the harvest during subsequent periods by preventing the additional hunting of Yeso deer during the current period. The pair of variables X^* and h^* (equal to $G(X^*)$), which satisfy eq. (10), denote the dynamic sustainable resource level and the dynamic sustainable yield, respectively.

To calculate X^* and h^* numerically and plot the supply curve, we will specify the functional forms of $\alpha(X)$ and $c_1(X)$. On the basis of Zivin, Hueth, and Zilberman [23], we assume that the forestry damage is directly proportional to the resource level of the Yeso deer, that is, $\alpha(X) = nX$, where n is a constant of proportion. We also assume that the hunting cost per head is given by $c_1(X) = M/X$, where M denotes the harvest cost of the Yeso deer. By substituting these in eq. (10), if $0 \leq \delta < \infty$, we get an explicit solution as follows:

$$X^* = \frac{1}{4}\left\{\left(1 - \frac{\delta p + nI}{pr}\right)K + \frac{M}{p} + \sqrt{\left[\left(1 - \frac{\delta p + nI}{pr}\right)K + \frac{M}{p}\right]^2 + \frac{8MK\delta}{pr}}\right\} \tag{11}$$

where δ, as is well known, plays a crucial role. As the value of δ increases, the future value of the Yeso deer will be discounted further. An extreme case is one in which $\delta = 0$; here, the present and future values of the Yeso deer will be the same. Then, eq. (11) is reduced to the following:

$$X^* = \frac{1}{2}\left\{\left(1 - \frac{nI}{pr}\right)K + \frac{M}{p}\right\} \tag{12}$$

The dynamic sustainable resource level given by eq. (12) is often compared with the static rent-maximizing equilibrium—they are identical. The other extreme case is one in which $\delta = \infty$; here, the future value of the Yeso deer is no longer recognized. On solving eq. (10) for p and allowing δ to increase infinitely, p will be equal to $c_1(X^*)$. Therefore, we have

$$X^* = \frac{M}{p} \tag{13}$$

Essentially, this equation is identical to the open access equilibrium (Conrad [7]), where the static rent has diminished.

Usually, the dynamic sustainable resource level X^* and the corresponding sustainable yield h^* are not attained under unregulated forestry. Therefore, some policy will be launched in order to realize the optimal steady state represented by X^* and h^*. Since the current-value Hamiltonian of this problem is linear in the control variable $h(t)$, the optimal approach path will be a bang-bang approach path (Clark and Munro [6]) if the current resource level diverges from X^*. That is,

$$h^*(t) = \begin{cases} 0 & \text{if} \quad X(t) < X^* \\ h_{\max} & \text{if} \quad X(t) > X^* \end{cases} \tag{14}$$

Equation (14) implies that if the resource level of the Yeso deer at time t is below X^*, the maximum investment is optimal, which means that there exists a moratorium policy (no deer are harvested). Conversely, if the resource level of the Yeso deer at time t is above X^*, the maximum disinvestment is optimal, which implies harvesting at the maximum effort (harvesting as many deer as possible, which is represented by $h_{\max}$). In a theoretical deterministic setting, the steady state resource level will persist once it has been achieved.

Finally, we summarize the supply curves. As seen in Fig. 2, these have unique shapes. If $\delta=0$ or close to zero, the supply curves will be upwardly concave when the price is sufficiently low. When the value of δ is close to 0, these curves appear as sigmoid curves. For high values of δ, they appear as backward-bending curves. At a certain intermediate value of δ, the supply curve is perpendicular. As the price increases, the upwardly concave supply curves are asymptotically close to the sustainable resource level corresponding to the Maximum Sustainable Yield (MSY), while the backward-bending curves attain this resource level at a lower price level. In this context, both curves may have a somewhat similar shape. However, they have a different correspondence to the sustainable resource level, which we will discuss later.

4) When the price per head is a function of the catch[9)]

In this subsection, we assume that the public institution purchases Yeso deer as a distribution monopolist.[10)] The price per head will be a function of the number of animals harvested. Let $p(h(t))$ be the inverse demand function; then, the total revenue will be specified as follows:

$$R_d = p(h(t))h(t) \tag{15}$$

We specified the inverse demand function as in Zivin, Hueth, and Zilberman [23], that is,

$$p(h(t)) = b - ah(t) \tag{16}$$

The current-value Hamiltonian is given by

$$\begin{aligned} Hc = {} & [1-\alpha(X)]I + [p(h(t)) - c_1(X) - c_2]h(t) \\ & + \mu[G(X) - h(t)] \end{aligned} \tag{17}$$

where the meat packing cost per head, c_2, is added. The golden rule for the monopoly case is modified as follows:

$$\delta = -\frac{\alpha'(X^*)I + c'_1(X^*)G(X^*)}{MR - [c_1(X^*) + c_2]} + G'(X^*) \tag{18}$$

where the marginal cost MR is given by

$$p(G(X^*)) + \frac{\partial p(G(X^*))}{\partial h} G(X^*).$$

As is generally known, in a normal monopoly market, a monopolist will utilize resources more slowly than in a competitive industry. As a result, there will be greater conservation of resources. However, in the natural resource market, this is not always the case because of the following reasons: (1) as Clark [5] pointed out, the private discount rates tend to be higher than the social discount rate, and in this case, the magnitude relation of the resource use by a monopolist and the competitive industry will not be found a priori. (2) Since the supply curve of the venison can take the form of a backward-bending curve, a monopolist may utilize more resources depending on the shape and position of the supply and demand curves of the venison. Since this paper considers the public institution as a monopolist, there will be no difference between the discount rates in the monopoly case and those in the socially optimum case. Therefore, we will analyze only the latter case, in which the current-value Hamiltonian is given by

$$\begin{aligned} Hc = {} & [1-\alpha(X)]I + U(h(t)) - [c_1(X) + c_2]h(t) \\ & + \mu[G(X) - h(t)] \end{aligned} \tag{19}$$

where $U(h(t)) = \int p(h(t))dh$ denotes the gross social utility of the consumption of venison. Then, the golden rule will be modified as follows:

$$\delta = -\frac{\alpha'(X^*)I + c'_1(X^*)G(X^*)}{p(G(X^*)) - [c_1(X^*) + c_2]} + G'(X^*) \tag{20}$$

Equation (20) can also be derived by substituting $\partial p/\partial h=0$ in eq. (18).

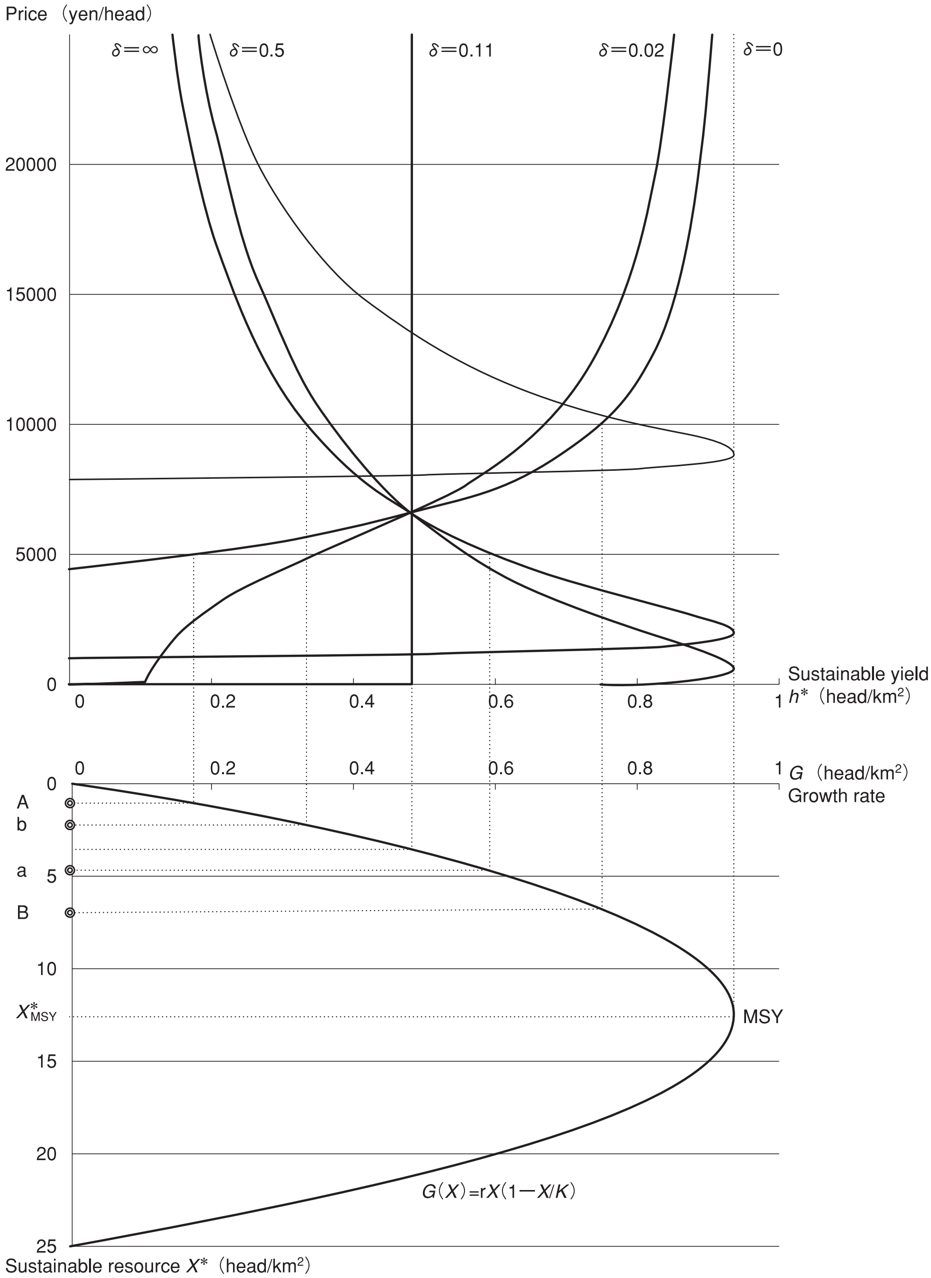

Figure 2. The supply curves of the Yeso deer and the corresponding growth curve

Since it is difficult to solve eqs. (18) and (20) for X^*, we will arrive at it by determining the value of X^* that equalizes these equations at a certain value of δ. However, when $\delta=\infty$, eq. (18) is reduced as follows:

$$X^*=\frac{M}{p-c_2-a} \tag{21}$$

4. Data

In this section, we will set the following parameters: the intrinsic growth rate r, the carrying capacity K, the discount rate δ, the forestry income I, the price per head p, the harvest cost M, the processing and residue disposal cost c_2, the slope a and the intercept b of the inverse demand function, and the proportionality constant n. We assume these parameters because p can be regarded as a policy variable for the public institution, which uses it to control the number of Yeso deer. The other factors, which may change according to the economic and social conditions and whose values cannot be determined accurately, are assumed as parameters in order to conduct a sensitivity analysis. These values are set as follows:

The intrinsic growth rate r : We set this at 0.15 per year, depending on the Hokkaido Government [10] and the HIES [11].

The carrying capacity K : The population of the Yeso deer depends on the biomass of the bamboo shrub *Sasa senanensis*. Therefore, when setting K, the sustainability of the bamboo shrub should be taken into consideration. According to a study conducted at Nakanoshima Island in Lake Toya, in which the ecological carrying capacity proposed by McCullough [15] and deCalesta and Stout [8] was applied, the bamboo shrub begins to decrease at approximately 30 deer per km^2 and disappears at 45 deer per km^2 (HIES [12]). Moreover, the density of Yeso deer in eastern Hokkaido, the most seriously damaged area, is 11.5 deer per km^2 (Yokoyama, Kaji, and Suzuki [22]). Taking into account the above values, we set the number of deer per km^2 at 25.

The discount rate δ : When the Yeso deer are not fully recognized as an economic resource, the subjective discount rate of the decision makers may exceed the market interest rate. Therefore, we include the case in which $\delta=\infty$.

The forestry income I : We assume it to be the expected gross forestry revenue per forest owner (deflated) ÷ the land area per forest owner, where the former is calculated as the gross forestry revenue in Hokkaido (the average value during the period 1989-2000) + the average forestry damage (in eastern Hokkaido during the same period) (SID [18]). The latter is calculated as the area of other private forests and of the communal forest ÷ the number of forest owners (in eastern Hokkaido).

The price per head p : We can set this to a maximum of 24 thousand head per year. This is because meat traders purchase dressed carcasses of Yeso deer at the rate of 3 to 16 thousand yen per head and slaughtered Yeso deer at the rate of 1 to 3 thousand yen per kg (Aoyagi [1]).

The harvest cost M : We assume it to be the opportunity cost of the forest owner × the hunting time per day × the average number of hunting days per year ÷ the land area per forest owner. The first 3 terms are set at 2,000 yen per hour (calculated from MHLW [16]), 8 hours, and 23.6 days (Aoyagi [1]), respectively. The harvest cost M is, therefore, 24 thousand yen per km^2. The cost to hunters from outside Hokkaido for their lodging as well as for hunting Yeso deer amounts to 300 thousand yen per week (Aoyagi [1]); this can be regarded as almost equivalent to the expenditure set for the forest owner.

The processing and residue disposal cost c_2: We assume that it comprises the processing cost + the residue disposal cost, which amount to 4,000 yen per head (depending on the meat processing plants) and 1 yen per kg (based on the planned amount of tax in Hokkaido), respectively. Thus, it amounts to approximately 4,100 yen per head.

The slope a and the intercept b of the inverse demand function: They are assumed to be 2,000 yen per head and 24 thousand yen, respectively.

The proportionality constant n: We assume it to be approximately 0.028, which corresponds to the case in which the resource level is 20 head per km^2 and the (monetary) extent of the forest damage is approximately 57%.

The above values are summarized in Table 1.

5. Results

Figure 2 depicts 6 supply curves: 5 for the case in which the price of the deer is given according to eqs. (11)-(13), and the other for the case in which the price of the deer is a function of the number of animals hunted according to eq. (21). Since the model presented in this paper considers the contrasting attributes of the Yeso deer, that is, as objects for consumption and as mammalian pests, the supply curve will, over a certain range of

Table 1. Assumption of parameters

Notation	Value	Unit	Exposition
r	0.15	/year	Intrinsic growth rate
K	25	head/km^2	Carrying capacity
δ	$\leq\infty$	/year	Discount rate
p	$\leq$ 24,000	yen/head	Price per head
M	24,319	yen/km^2	Harvest cost
c_2	4,072	yen/head	Processing and residue disposal cost
n	0.028	—	Proportionality constant
I	29,229	yen/km^2	Forestry income
a	2,000	yen	Slope of the inverse demand function
b	24,000	yen	Intercept of the inverse demand function

discount rates, differ from those usually derived. In the following section, we will enumerate the characteristics of the supply curve for the cases in which the price is given; these always have analytic solutions irrespective of the discount rates. Usually, when the discount rate is zero, the supply curve will have a upwardly concave form and will be asymptotically close to the sustainable yield level corresponding to the MSY. As the value of the discount rate increases, the usual supply curves attain this sustainable yield level at lower prices and turn backward at this point. Therefore, the usual supply curves will be what are known as backward-bending supply curves over a certain range of discount rates. Further, the supply curves presented in this paper have the same shapes when the discount rates are zero and when they are sufficiently large (for example, when $\delta=0.5$ and ∞, as seen in Fig. 2). However, there are some differences between these two cases. In the lower chart of Fig. 2, the highest sustainable resource level of the growth function, K, corresponds to the point where the usual supply curves intersect the vertical (price) axis, and as the price increases, the corresponding sustainable resource level decreases. However, in the context of this paper, when the discount rates are sufficiently low (less than 0.11), the relationship between the price and the sustainable resource level will be reversed.

In Fig. 2, we illustrate the above by examining the changes in the sustainable resource levels for two cases, $\delta<0.11$ (set as $\delta=0$), and $\delta>0.11$ (set as $\delta=\infty$), when the price per head (set at 5 thousand yen and 10 thousand yen) is changed. As is depicted in the lower chart of Fig. 2, if the prices are set at 5 and 20 thousand yen when $\delta=0$, the sustainable resource levels will be $A=1.29$ head per km^2 and $B=6.9$ head per km^2, respectively, and the usual relationship is reversed. On the other hand, if the prices are set at 5 and 20 thousand yen when $\delta=\infty$, the sustainable resource levels will be $a=4.86$ head per km^2 and $b=2.43$ head per km^2, respectively. This is the usual relationship (Table 2).

Because of the reversal of the relationship between the price and the sustainable resource level, the supply curves in this model will be sigmoid curves at around $\delta=0.11$. When $\delta=0.11$, certain sustainable resource levels and a sustainable yield will be realized independently of the price, and all the supply curves will intersect at one point on the vertical supply curve (in Fig. 2, this corresponds to 6,500 yen).

We have examined the relationship between the shapes of the supply curves and the sustainable resource levels. We now examine the reasons why these unique supply curves exist. The forest owner expects revenues from the sale of both timber and venison. The weighting for these revenues changes with the discount rate. For instance, if $\delta<0.11$, future revenues from the management of the forest will be discounted to a lesser extent since the value of the discount rate is relatively low. If the price per head is low, it is reasonable for the forest managers to reduce the number of Yeso deer in their forest areas so as to maintain their forestry income, since they cannot expect a significant income from the Yeso deer because of its low price. As the price per

Table 2. Numerical examples of X^* and h^*

(Unit: head/km^2)

Discount rate	Price (yen)				Relationships
	5, 000		10, 000		
	X^*	h^*	X^*	h^*	
0	1. 29 (point A)	0. 18	6. 90 (point B)	0. 75	ps and their corresponding X^*s have the reverse of the usual relationship
∞	4. 86 (point a)	0. 59	2. 43 (point b)	0. 33	ps and their corresponding X^*s have the usual relationship

Note : The points correspond to the lower chart of Fig. 2.

head increases, the forest owners will conserve the Yeso deer because the revenue they generates will increase.

Next, we examine the cases in which the price of the deer is a function of the extent of hunting. For the sake of simplicity, we assume the same reverse demand functions for the monopoly case and the socially optimum case. Since the relationship between the price and the sustainable resource level given above is still effective in these cases, the discount rate will determine which of the two cases is more resource-conservative. For some values of $\delta > 0.11$, the monopoly case will be more resource-conservative than the socially optimum case (which is the same as the usual case), whereas for some values of $\delta < 0.11$, the monopoly case will be less resource-conservative than the socially optimum case.

6. Discussion

Several features of the supply curves discussed above have a bearing on the management of the Yeso deer. We will now discuss the following using the case in which the price is given as an example: (1) the relationship between the change in the discount rate and the management criteria and (2) the relationship between the optimum sustainable resource level (hereafter referred to as X^*_{MSY}) and the sustainable yield corresponding to the MSY level.

With regard to the first issue, it should be noted that the management criteria will be reversed depending on whether the discount rate is below or above 0. 11. As we have already noted, when $\delta = 0.11$, the sustainable resource level is approximately 3. 8 deer per km^2, and this resource level remains unchanged when the price changes. However, if the Yeso deer are managed at a level other than this sustainable resource level, the maximum or minimum prices should be set according to the combination of the price and the discount rate. Figures 3 and 4 present the maximum/minimum prices in the cases in which the resource level of the Yeso deer is maintained at more than or equal to 3 head per km^2 and 4 head per km^2, respectively. As indicated by Fig. 4, the maximum and minimum prices must be reset below and above $\delta = 0.11$ in order to maintain the resource level of the Yeso deer at more than 3. 8 head per km^2.

With regard to the second issue, it will be unrealistic to maintain the resource level of the Yeso deer at more than X^*_{MSY} in our model. As is easily seen from Fig. 2, when $\delta < 0.11$, the supply curves will be asymptotically close to the sustainable yield level corresponding to the MSY, and resource levels higher than X^*_{MSY} will not be attained. When δ

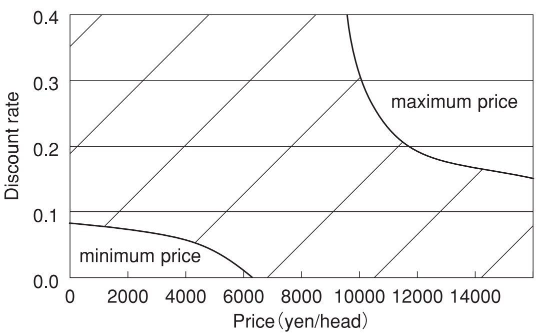

Figure 3. The maximum/minimum price required to maintain the sustainable resource level at more than or equal to 3 head/km^2

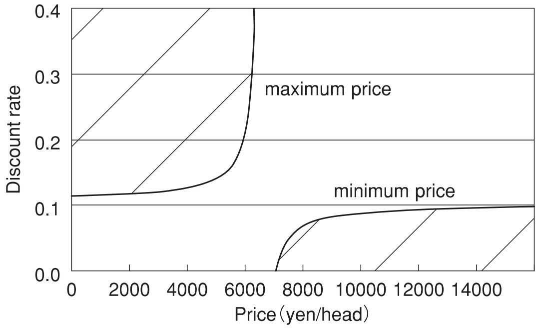

Figure 4. The maximum/minimum price required to maintain the sustainable resource level at more than or equal to 4 head/km²

>0.11, the price will be low despite the possibility that a resource level higher than X^*_{MSY} may be attained. X^*_{MSY} is achieved at 600 yen when $\delta=0.5$ and at 0 yen when $0.11<\delta<0.33$. The present management plan launched by the Hokkaido government focuses on the reduction of agriculture, pasturage, and forestry damages for the first issue, the number of Yeso deer has controlled at the low level. We can conclude that our results support this policy.

However, the methods for the management of deer implemented in Western countries aim to maintain the resource level higher than X^*_{MSY} so as to retain the maximum yield and the sustainability of the utilized wildlife (Kaji [13]). Therefore, we will now examine whether our result is unique or is the same as that obtained from the policies of Western countries when the parameter values are changed. Here, each parameter value will independently be varied by 20%. As is shown in Table 3, the result indicating that the sustainable resource level is maintained below X^*_{MSY} will remain unchanged. This result may reflect the fact that the forestry income is relatively high as compared with the harvest cost. Unlike in this case, if the forestry income I is less than 4,700 yen and $\delta=0.02$, the supply curves will bear the usual relationship and it will be appropriate to maintain the resource level higher than or equal to X^*_{MSY} .

Finally, we compare the monopoly case and the socially optimum case. The values a and b of the inverse demand function (eq. (16)) are assumed to be 2,000 yen per head and 24 thousand yen, respectively. The value of a reflects the fact that, in general, venison is classified as a luxury item and has some substitutes. As shown in Fig. 5, the difference between the optimum sustainable resource levels in the two cases is zero at $\delta=0.11$ and changes as δ increases or decreases; however, the difference remains small. For example, when $\delta=0.02$, the optimum sustainable resource level of the socially optimum case is approximately 0.25 head per km²—larger than that of the monopoly case. When δ is less than 0.11, the optimum sustainable resource level of the socially optimum case is smaller than that of the monopoly case.

7. Concluding Remarks

Traditional wildlife management and usage in Japan has been deeply influenced by socioeconomic conditions; however, this was

Table 3. Sensitivity analysis of the supply curves

Parameters	The discount rates at which the supply curves become vertical (/year)	Prices at which the supply curves intersect (yen)	Sustainable resource levels (head/km²)
(Intact values)	(0.105)	(6,600)	(3.8)
I	0.111	7,600	3.2
n	0.111	7,600	3.2
M	0.097	6,800	4.4
r	0.116	5,600	4.4
K	0.111	6,400	3.9

Note : 1) When $\delta=\infty$, changes in values other than M will not influence the supply curves.
2) Every parameter is increased by 20%.

undesirable from both the biological and economic perspectives and resulted in many wildlife-related problems throughout the country. One of the most significant and advanced plans to tackle these problems was the one formulated by the Hokkaido government, in which the appropriate resource levels were determined on the basis of the biological perspective. In addition, the Hokkaido government recognized the value of the Yeso deer and the need to realize this value through the utilization of the carcasses of the hunted deer. Since the plan for the management of the Yeso deer did not sufficiently take into account the economic aspects, we re-examined this plan and arrived at the following conclusions.

First, when the revenues from forestry products are sufficiently high, it will be appropriate to maintain the wildlife resource level lower than the level corresponding to the MSY. We can conclude that the resource level targeted in the current plan formulated by the Hokkaido government can be justified from the economic perspective.

Second, there is a possibility that certain changes in the discount rate and the price will result in a substantial alteration of the management criteria. In order to avoid such alterations, the Yeso deer should be maintained at a level lower than X^*_{MSY}, a level at which the resource is kept higher than the minimum viable population.

Third, there is little difference between the monopoly case and the socially optimum case

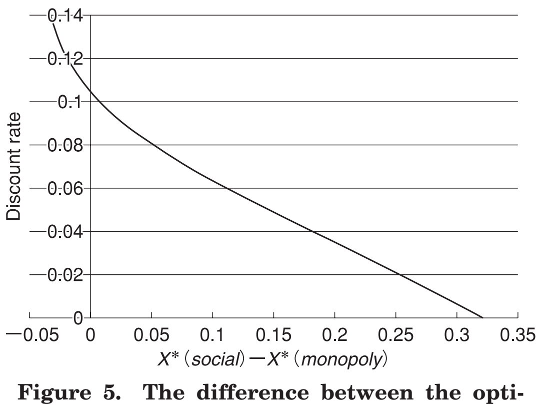

Figure 5. The difference between the optimal sustainable resource levels in the monopoly case and the socially optimum case

under the parameter values set in this paper. Therefore, the resource level of the Yeso deer will be almost the same in both cases.

In this paper, we do not incorporate several components such as traffic and/or vegetation damages caused by the Yeso deer as well as their non-use values. A modification of the model in order to incorporate these costs and/or benefits is a pending issue.

1) This paper is largely based on Kawata [14].
2) In the 2000 plan, the subprefectures of Abashiri, Tokachi, Kushiro, and Nemuro are classified as eastern Hokkaido ; Sorachi, Kamikawa, Soya, Hidaka, and Iburi constitute central Hokkaido; and Ishikari, Oshima, Hiyama, Shiribeshi, and Rumoi constitute southwestern Hokkaido. The 2002 plan refers to the central and southwestern regions as western Hokkaido.
3) In this paper, we apply the model to forest management because of the limited data on agriculture and pasturage. However, by replacing, for example, the forest land A and the forestry income I with the agricultural land and the agricultural income, respectively, and by changing the values of the harvest cost and the proportionality constant, the model presented in this paper can be applied to agriculture, pasturage, and to a combination of several industries.
4) Web site of the Yeso deer association: http://www.yezodeer.com/taberuno.html
5) Web site of the Yeso Sika Efficient Use exploratory committee : http://www.pref.hokkaido.jp/kseikatu/ks-kskky/sika/katuyo/kento/ken1.htm
6) For the calculation process, see Kawata [14].
7) With regard to the area covered in the analysis, this article considers the areas of other private forests and that of the communal forest in the same subprefectures referred to in the 2000 plan (Hokkaido Government[10]). This amounts to approximately 10 thousand km^2.
8) Although this paper assumes a representative forest owner, in actuality, forest owners may decide on and change the extent of their hunting according to the behavior of other forest owners. This issue is not discussed in this paper and the game theoretic situation as mentioned above should be examined in future studies.
9) The derivations of the monopoly case and the socially optimum case in this subsection are mainly based on Clark [4] [5].
10) The monopoly of natural resources is different from an ordinary monopoly in that there is a maximum limit to its supply.

References

[1] Aoyagi, K. "*Shigen Riyo karamita Ezo Sika no Hogo Kanri* (The Wildlife Management of Sika Deer from the Viewpoint of Resource Management: The Case Study of Asyoro-cho in Hokkaido Prefecture)," *Journal of Forest Economics*, Vol. 49, No. 1, 2003, pp. 53-60.

[2] Bostedt, G., P. J. Parks, and M. Boman. "Integrated Natural Resource Management in Northern Sweden: An Application to Forestry and Reindeer Husbandry," *Land Economics*, Vol. 79, Issue 2, 2003, pp. 149-160.

[3] Caughley, G. "Eruption of Ungulate Populations, with Emphasis on Himalayan Thar in New Zealand," *Ecology*, Vol. 51, No. 1, 1969, pp. 53-72.

[4] Clark, C. W. *Mathematical Bioeconomics*. John Wiley and Sons, 1976.

[5] Clark, C. W. *Bioeconomic Modelling and Fisheries Management*. Wiley, 1985.

[6] Clark, C. W. and G. R. Munro. "The Economics of Fishing and Modern Capital Theory: A Simplified Approach," *Journal of Environmental Economics and Management*, Vol. 2, 1975, pp. 92-106.

[7] Conrad, J. M. *Resource Economics*. Cambridge University Press, 1999.

[8] deCalesta, D. S. and S. L. Stout. "Relative Deer Density and Sustainability: A Conceptual Framework for Integrating Deer Management with Ecosystem Management," *Wildlife Society Bulletin*, Vol. 25, No. 2, 1997, pp. 252-258.

[9] Hokkaido Government. *Conservation and Management Plan for Sika Deer* (*Cervus Nippon*) *in Eastern Hokkaido*, 1998.

[10] Hokkaido Government. *Ezo Sika Hogo Kanri Keikaku*, 2000, 2002.

[11] Hokkaido Institute of Environmental Sciences (HIES). *Higuma Yeso Sika Seisoku Zittai Chousa Houkokusyo III*, 1997.

[12] Hokkaido Institute of Environmental Sciences (HIES). *Ezo Sika no Hozen to Kanri ni Kansuru Kenkyu* (*Study on Conservation and Management of Sika Deer in Hokkaido 1996-2000*), 2001.

[13] Kaji, K. "Yesozika to Tokutei Chouzyu no Kagakuteki Keikakuteki Kanri nituite (The Management Policy of Hokkaido Sika Deer and Special Game Animals Based on Sound Science)," *Seibutu Kagaku*, Vol. 52, No. 3, 2001, pp. 150-158.

[14] Kawata, Y. "Chiiki Shigen tositeno Yesosika no Saitekikanri (Optimal Management of Hokkaido Sika Deer as a Regional Resource)," *Nogyo Keizai Kenkyu* (*Journal of Rural Economics*), Vol. 76, No. 3, 2004, pp. 186-196.

[15] McCullough, D. R. "Lessons from the George Reserve, Michigan," in L. K. Halls, ed., *White-tailed Deer Ecology and Management*. Stackpole Books, 1984, pp. 211-242.

[16] Ministry of Health, Labour and Welfare (MHLW). *Chingin Kouzou Kihon Tokei Chosa*, 2002.

[17] Miura, S. *Yasei Dobutu no Seitai to Noringyo Higai*, National Forestry Extension Association in Japan, 1999.

[18] Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries (SID). *Rinka Keizai Cyousa Houkoku*, 1991-2002.

[19] Schulz, C.-E. and A. Skonhoft. "On the Economics of Ecological Nuisance," Paper to the 7th Ulvön Conference on Environmental Economics, 2000.

[20] Takatsuki, S. "Sika ga Oyobosu Seitaigakuteki Eikyo (Effects of Sika Deer on Ecosystem)," *Seibutu Kagaku*, Vol. 52, No. 1, 2000, pp. 29-36.

[21] Yamane, A. "Sanson niokeru Yasei Dobutsu niyoru Higai Bozyo to Kyosei," in T. Tabuchi and M. Shiyomi, eds., *Cyusankanchi to Tamenteki Kinou*. Norin Tokei Kyokai, 2002.

[22] Yokoyama, M., K. Kaji and M. Suzuki. "Food Habits of Sika Deer and Nutritional Value of Sika Deer Diets in Eastern Hokkaido, Japan," *Ecological Research*, Vol. 15, Issue 3, 2000, pp. 345-355.

[23] Zivin, J., B. M. Hueth, and D. Zilberman. "Managing a Multiple-use Resources: The Case of Feral Pig Management in California Rangeland," *Journal of Environmental Economics and Management*, Vol. 39, Issue 2, 2000, pp. 189-204.

(Received October 25, 2005; accepted December 9, 2005)