Optimum slaughtering time in temporal deer farming in Japan

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23 October 2009

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(Ver. 2009.10.23.)

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Abstract

The purpose of this paper is to examine the most appropriate slaughtering time for deer from an economic perspective under the following conditions: (1) standard deer farming and temporal deer farming; (2) unit price of venison is constant and is a function of age in months (3) grazing and pen feeding. Based on numerical analysis, the optimum slaughtering times are 30 and 31 months when price is constant and 17 and 18 month when price is a function of age in months. Our results suggest that temporal deer farming with pen feeding is not realistic and grazing should be selected.

Key Words

Optimum slaughtering time; Temporal deer farming

JEL

Q20, Q57, Q12

1. Introduction

Deer farming has become increasingly important throughout the world since the 1970s. Chardonnet et al. (2002) state that the number of farmed deer are 62 thousand, 352 thousand, 1,171 thousand, 412.31 thousand and 2,778 thousand heads for Africa, North and South America, Asia, Europe and the Pacific, respectively, among which New Zealand accounts for 54% (2,560 thousand head) (Chardonnet et al. (2002) provide the total number of farmed deer, but the number seems to include rounding error. Here, we provide the summed number of the farmed deer of each country). Although deer have been one of the most utilized animals throughout the world since the dawn of time, domestication has not proceeded successfully. Recently, deer farming has been expanding, and this tendency could possibly continue far into the future.

We can point out the following reasons for the current prosperity of deer farming. First, there has been a reduction in the amount of fertile land. In ancient times, agriculture developed in these fertile lands, which was the dawn of farming and breeding. People increasingly gathered in the fertile lands and urban areas were consequently developed. Ironically, the high level of productivity in these fertile lands led to their complete loss in productivity. In fact, in 1986, the UNDP pointed out that during these 1000 years, human agricultural activity was responsible for changing approximately 2 billion ha of highly fertile land into barren land, which is larger than the total area of cultivated land today (UNEP, 1986; Meadows et al., 2004). In addition, the progression towards a car-oriented society has resulted in an increase in the number of cars by 12 million each year and the alteration of a million ha of land into roads and parking areas, most of which were cultivated land (Brown, 2003). Only the less fertile land has remained. Moreover, even the fertile land has degraded because of its abandonment under the decline of farming as the primary industry.

Given the background mentioned above, it will be increasingly necessary to acquire animals that can be bred in these less fertile lands in the future. In addition, abandoned farmland has soon changed to brushland. To control the alteration into brushland, the breeding of animals, which eat a variety of plants, in abandoned farmland is a promising consideration and there are some examples in the mountainous areas of Japan. Deer seem to adequately satisfy these requirements.

The abovementioned reasoning is why deer farming has received large attention recently. If this reasoning is accurate, deer farming will progress in the future because of the increase in less fertile land and the abandonment of farmland. Consequently, it is essential to examine the optimum slaughtering time in deer farming.

It is true that there are many existing researches that provide the appropriate slaughtering times for domestic animals. However, two things should be considered. First, in the existing researches, slaughtering time is decided based on live weight gain. However, this method does not guarantee economic rationale. In other words, there is a possibility that more profitable slaughtering times exists. This occurs because the costs of breeding and/or slaughtering are not considered in some existing researches. Moreover, if the unit price of meat per kilogram changes according to the age in months, this unit price will influence the optimum slaughtering time. Second, unlike other domestic animals, the extensive domestication of deer has only recently begun. When compared with other domestic animals, the deer has retained many of its attributes as a wild animal. It is necessary to consider these specific attributes when considering the optimum economic slaughtering time of deer.

The purpose of this article is to examine the optimum slaughtering time in deer farming while considering the abovementioned two points. There are a number of deer farming styles among the various species of deer and within the methods of supplying deer. Although we use the Japanese deer as an example, our results can be applied to other types of deer in the Southern Hemisphere where the seasonal differences from the Northern Hemisphere also require calculations adjusted in months. In this paper, we examine not only standard deer farming, which is the typical breeding method in countries such as New Zealand and those in Europe, but also a specific type known as temporal deer farming—in which wild deer are bred for some time before slaughtering—which is the proposed method in Hokkaido, Japan.

Temporal deer farming is a concept, which was first presented on page five of the 'Guidelines for the Efficient Use of Hokkaido Sika Deer' (Hokkaido, 2006) that distinguishes temporal deer farming from standard deer farming (breeding domestic animals in the same manner as pig and cattle), and is used as the term to represent the breeding style of capturing and rearing for some time prior to killing. Since Japan has been suffering from a reduction in and the aging of hunters, temporal deer farming has been seen as a promising solution for these issues: temporal deer farming makes it possible to control the number of deer and efficiently use captured deer because it requires less people to capture a live deer. If deer are captured without being killed, it is possible to satisfy the legal restrictions on selling meat in the market.

2. Empirical Biological Model

2.1. Basic Growth Function

In this paper, we develop an empirical biological model for Japanese deer based on existing researches. We express live-weight-gain curve or growth curve based on two equations. The first equation represents the basic trend of the growth (hereafter referred to as basic growth curve) whereas the second equation represents the seasonal change of growth (hereafter referred to as seasonal growth change curve). We sum up these two equations numerically and use it as the growth curve.

Generally speaking, the following sigmoid curves are used as growth functions: logistic function, Richard's function, generalized logistic functions, among others (Kusec et al., 2008a; Kušec et al., 2008b). In the case of deer farming, because of the influence of seasonal fluctuation on growth, sigmoid curves do not fit well. Therefore, in this paper, we provide the following basic growth curve Eq. (1), which is largely based on the growth curve of male Japanese deer provided in Fig.1 of Uchida et al.(2001).

$$BW = 0.0019X^3 - 0.1536X^2 + 5.3248X + 0.402 \quad (1)$$

where BW and X represent body weight and age in months (initial age in months is set 1), respectively.

2.2. Growth Function with Seasonal Fluctuations

Next, we set the seasonal growth change curve. It is pointed out that the food consumption of wild deer fluctuates seasonally. For example, in the case of the Hokkaido sika deer (Hokkaido sika deer is a subspecies of the Japanese deer living in Hokkaido, the northernmost island of Japan), dry matter intake in the winter season and summer season is 29.8$\pm$6.0g/kg$^{0.75}$ and 43.3$\pm$4.0g/kg$^{0.75}$, respectively (where kg$^{0.7}$ represents metabolic body size), demonstrating that food intake in winter is less than that in summer and significant at the 5% level (Kunishige, 2003a, p. 32). In the case of Japanese deer, Odajima et al. (1991) report that when comparing winter (February) and summer (May, August and November), forage intakes are 55g/kg$^{0.75}$ and 70g/kg$^{0.75}$, respectively, demonstrating a significantly lower winter intake. In the case of group-fed Japanese sika deer, food intake is lowest in February (Odashima et al., 1993). A reduction of food intake in winter is also reported in other researches for Hokkaido sika deer (Souma et al., 1998) and in the case of Kumaizasa (*Sasa senanensis*) intake by Hokkaido sika deer (Masuko et al., 1999).

Wild (non-domesticated) deer have digestive systems that save food intake in winter to adapt to a scarceness of food in their natural environment: the deer endocrine system seems to have something to do with such a seasonal rhythm in high latitudes (Kay, 1985; Barry and Wilson, 1990, p. 1018; Masuko 2008, p. 30).

The reduction of food intake in winter is generally observed in deer (Masuko, 2008, p. 30).

As a result of this reduction of food intake in winter by wild deer, growth per month can show a minus value. For example, Uchida et al. (2001) demonstrate that the growth curves of male and female deer—from birth until the 37th month—demonstrated a decrease in body weight in the 8th and 19th months and for several months after the 32nd, suggesting minus growth. Matsuura (2000) researched fawn (0 years old) at the deer farm and reported that the increase of weight hits a peak in mid-November, which is then followed by a decrease in weigh (Takatsuki, 2006, p. 149).

Based on the above facts, we combine two numerical equations to demonstrate the seasonal fluctuation of deer growth in weight. The first equation is shown above as Eq. (1) and the second equation is shown below as Eq. (2), where Eq. (2) is again largely based on the shape of the growth curve provided by Fig. 1 of Uchida et al. (2001).

$$SF = -192.31M^5 + 1568.33M^4 - 4989.08M^3 + 7720.69M^2 - 5804.22M + 1695.61 \quad (2)$$

where SF is the seasonal fluctuation of weight and M holds values from 1 to 2.1, with increases of 0.1 per month: 1 at January, 1.1 at February, …2.1 at December and on the 13th month (or the first month of year 2), it holds 1 again. We applied the same SF for different ages because it is reported in Yamane, Hayama and Furubayashi (1996, p. 152) that the seasonal fluctuation of weight demonstrated the same pattern each year.

Body weight curve with seasonal fluctuation ($BWSF$) can be depicted by summing up the BW equation and the SF equation numerically, which is illustrated in Fig. 1.

3. Theoretical Economic Model (TEM)

3.1 Total Revenue Function

For the sake of simplicity, we assume the same yield rate for all ages in terms of months. Unit price per kilogram is assumed both as a constant (same for all ages in months) and as a function of age in months. First, let us assume that unit price per kilogram is the constant. We can reduce the following total revenue (TR) function of deer farming (or venison) using the $BWSF$ curve.

$$TR(t) = \alpha \times p \times BWSF(t) \tag{3}$$

where t, α and p are age in months, yield rate, and unit price of venison, respectively.

On the other hand, if unit price per kilogram is the function of age in months t, we assume that $p(t)$ is a quadratic function of t and let $p'(t) < 0$ and $p''(t) < 0$.

3.2 Total Cost Function

We now develop the expression of total cost (TC) in deer farming. It is pointed out that the labour cost of deer farming is relatively low compared with that for domestic animals (Ninomiya, 1989, p. 1094; Jeon and Moon, 2006, p. 39), which implies that the number of manpower required is relatively low in deer farming. Therefore, in this paper, we assume that less staff can manage farmed deer regardless of the number of deer. Thus labour cost is assumed as a fixed cost and we referred to it as C_H.

Jeon and Moon (2006, p. 40) state that there are two types of feeding systems: the first one is a grazing system, which is mainly adopted in New Zealand and Australia, and the second one is a pen feeding system, which is mainly adopted in Japan, Korea and China. Temporal deer farming is specific to Japan, where pen feeding seems to have been selected. One of the main reasons to adopt pen feeding is that it can improve the quality of velvet and venison production through grain feeding (Jeon and Moon, 2006, p. 39). However, there is a possibility that venison provided from deer raised under the grazing system can be better in quality. This is because there seem to be several factors such as longer movement time, which may improve meat quality. Therefore, we will follow with case examinations of grazing and pen feeding.

When the grazing system is adopted, we assume the area to be significantly large and, therefore, although the grazing and roaming by deer may result in its degradation, it will not affect the growth of deer. Thus grazing cost is supposed as a fixed cost and we refer to it as C_P. On the other hand, when pen feeding is adopted, although there is seasonal fluctuation, the amount of grain required will increase as age in months increases. Therefore, pen feeding cost is a variable cost and we refer to it as $C_F(t)$.

Finally, we examine costs concerning slaughtering. Let us assume that the cost required for slaughtering is constant because all carcasses can be treated with the same equipment under similar procedures. Thus slaughtering cost is supposed as a fixed cost and we refer to it as C_S. On the other hand, debris such as gralloch, blood and others increase as the body size increases. Therefore, debris treatment cost is a variable cost and we refer to it as $C_D(t)$.

Now, we can describe the problem in temporal deer farming with pen feeding as follows.

$$\pi = TR - TC = \alpha pBWSF(t) - C_H - C_P - C_F(t) - C_S - C_D(t) \tag{4}$$

As the control variable of our problem is t, Eq. (4) can be reduced to the following equation.

$$\pi(t) = \alpha pBWSF(t) - C_F(t) - C_D(t) \tag{5}$$

Note that in the case of standard deer farming (grazing), $C_F(t)$ = 0 in Eq. (5). In addition, if we assume p is a function of t, p in Eqs. (4) and (5) are replaced by $p(t)$.

4. Optimization of TEM

4.1. Constraints

Here we examine the constraints of our problem before we proceed to the derivation of the optimum slaughtering age in months. In general, there exist upper and lower limits for slaughtering weight in domestic animals. Normally, domestic animals are allowed to grow for a short period of time and slaughtered at a young age because the meat of younger animals is softer and preferred and it is beneficial to raise animals in shorter time spans with a high growth rate. In standard deer farming, the lower limit of body weight is sometimes set. For example, in the main markets of New Zealand, carcass weight is required to be more than 50kg (live body weight should be 93kg) (Barry and Wilson, 1990, p. 1018).

On the other hand, in deer farming, the wild deer caught for deer farming have different attributes than domestic animals. First, the weight growth of farmed deer is inferior to other domestic animals. Second, the age, when rearing starts, differs for each individual deer because they are introduced from nature at different ages and in different months during winter. Therefore, we cannot expect that a farmed deer will reach a substantial amount of weight when they are young and their meat is tender. It will be required to slaughter farmed deer even if their weight is low in order to enjoy the soft meat. On the other hand, if the quality of meat and/or velvet can be improved by grain feeding, deer caught in the wild should be fed for some time even if they have already reached a certain weight. If deer that are caught are too old to merit from the said process and/or improvements, they can be released. In this paper, we will neither set upper nor lower weight limits as constraints.

Next, we examine the constraints concerning velvet. There are two methods to remove velvet. The first method entails cutting velvet at the base of the antlers without killing the deer, and the second method involves removing the velvet with the skull after killing the deer (Tsujii, 1991). In the latter case, the velvet and venison are collected at the same time but in the former case, the timing of the velvet collection will not restrict the slaughtering time (venison collecting timing). In what follows, we assume the former case.

However, wild deer weaken greatly from stress. During the period of time in which deer are captured and subsequently integrated into the breeding farm from the wild, they are frequently injured when they were gathered and/or corralled (Barry and Wilson, 1990, p. 1017) and even died because of stress from transportation to or the time spent in the breeding farm (Suzuki, 1999; Takahashi et al., 2004; Kitahara, 2006, p. 244). Based on the existing research of Onuma et al. (2005) death rates are reported to reach 4–14% if they use *kakoi-wana* (enclosing traps). Therefore, if the collection of velvet places substantial stress on the deer, there is a possibility that the quality of the meat worsens, especially immediately following the collection of the velvet. On the other hand, once deer acclimatize to the rearing process, they mindlessly graze even if other deer are shot to death next to them (Ohtaishi, 1985, p. 1215). Therefore, it is possible to reduce the level of stress in deer and, if so, constraints may not necessary.

4.2. Optimum slaughter age in months

Our problem is to obtain the optimum slaughtering age in months t, which maximizes the value of $\pi(t)$ in Eq. (5). As is mentioned above, we do not apply constraints to weight and velvet collecting. The necessity condition for the optimum slaughtering age in months is that the derivation of $\pi(t)$ equals to zero. Namely,

$$\frac{d\pi(t)}{dt} = \alpha p MR(t) - MC(t) = 0 \tag{6}$$

where $MR(t) = \frac{dBWSF(t)}{dt}$ and $MC(t) = \frac{dC_F(t)}{dt} + \frac{dC_D(t)}{dt}$.

The following can be stated concerning Eq. (6). First, the value of α and p influence the optimum age in months t. However, as is shown in Fig. 1, the $BWSF$ curve fluctuates intricately and t can increase or decrease when α or p increase. The directions of the change are tabulated in Table 1. Suppose Eq. (6) is satisfied. Then if *MR* = *MC* > 0, t increases when *MR* is decreasing and t decreases when *MR* is increasing. If MR = MC = 0, then t will not change. If *MR* = *MC* < 0, t increases when *MR* is increasing and t decreases when *MR* is decreasing.

Second, there exist several solutions for t. Namely, Eq. (6) can be satisfied by several ts. Among them, the most appropriate one exists, which maximizes the value of π. Since Eq. (6) is the first order condition for the optimum, there may exist ts which bring minus values of π; in such cases, these minus πs can not be candidates for the optimum solution (however, in the range of parameter values and t values set in this paper, π is always more than zero).

Third, we must pay some attention to the costs. Generally, in the case of domestic animals, we can apply the same cost curve for all subjects. However, in the case of temporal deer farming, costs start to accrue when deer are caught and costs are differed for each individual deer according to age and other factors. Therefore, the most natural interpretation of Eq. (5) is that it represents net revenue in standard deer farming, where deer are born in captivity. Let us assume the capturing time t_h, then by setting values of zero for $C_F(0)$ and $C_F(t_h - 1)$ and for $C_D(0)$ and $C_D(t_h - 1)$, Eq. (5) represents the net revenue for temporal deer farming. As is discussed above, the cost curves are for the individual (or age-class) deer. In other words, in temporal deer farming, optimum slaughtering times exist for each capturing month and age in months, and we therefore cannot apply the same optimum slaughtering time for all individual deer.

5. Numerical examples

5.1. Parameter settings

In this section, we will examine the optimum slaughtering times in certain cases based on numerical examples. These cases are (a) standard deer farming and temporal deer farming (captured at 6, 18 and 30 months in age), (b) unit price is constant (p) and is a function of t ($p(t)$), and (c) grazing and pen feeding. Let us assume a birth in May and let us set the birth month as 1 age in month, then t = 6, 18 and 30 correspond to ages 0, 1 and 2 for October.

First we set the parameter values of TR. Let us assume the yield rate α is 60%. This is because based on existing researches on young Hokkaido sika deer and Japanese deer, the yield rate is 50% and for deer more than 4 years old, the yield rate is 60–70% (Ishijima et al., 1990, p. 1263). Other existing researches report that the yield rate is 60% (Tsujii, 2007, p. 799); yield rate is 60% and carcass meat rate is 64% (Ishida, 2007, p. 992).

Next, unit price per kilogram is set at 400 yen as a constant. This price is based on the fact that in the town of Ashoro in Hokkaido, Japan, the purchase price of deer loin (or the appropriate part for a roast) and hind legs without damage is 400yen/kg (Ozaki, 2001, p. 54), in the case of gun hunting. For a reference, let us examine other price information. In the town of Ashoro, under controlled killing conditions, the purchase price is 10,000 yen/head; and in the town of Shikaoi in Hokkaido, Japan, the maximum purchase price is 13,000 yen/ head (Ozaki, 2001, p. 55). If members of a hunting club in the town of Ashoro sell meat (boneless) to meat processors, the maximum purchase price is 16,000yen/head (Aoyagi, 2003, p. 56). In of the town of Ashoro, the average weight without gralloch is 45kg/head (Ozaki, 2001, p. 54). Therefore, unit price per kilogram is between 222 yen/kg to 356 yen/kg. Since the main purpose of controlled killing is to remove the animals and its meat is a by-product, 400 yen/kg seems realistic.

When unit price is the function of t, we set the function as in the following procedure. We assume unit prices are approximately 600 yen, 400 yen and 300yen when t = 1, 24 and 30, respectively. This concave function is demonstrated in the following quadratic function.

$$p(t) = -0.265t^2 - 2.1092t + 602.26 \tag{7}$$

Next, we set cost functions. Because of the limitations of the data for deer farming in Japan, we substitute pen feeding costs with fattening cattle (bullock). In 2006, it was approximately 31 yen/kg (MAFF, 2008, p. 44). Let us assume $C_F(t)$ is proportional to $BWSF(t)$ because the growth rate seems to be affected by seasonal fluctuation. We further assume that the cost increases with respect to t and we assume a quadratic function. The pen feeding costs are therefore given as follows.

$$C_F(t) = \gamma \times 31 yen/kg \times BWSF(t) \times t^2 \tag{8}$$

where γ is constant. Note that when grazing is selected, $C_F(t)$ = 0. Ishida (1996, p. 568) states that in the case of Japanese deer, 16 months in age is not enough for meat and recommends raising animals for more than 24. Therefore, we set γ = 0.0025 so that the optimum slaughtering time under grazing is more than 24 months in age.

We suppose 40% of the carcass will be debris because the yield rate is set at 60%. Further, based on Kawata (2006, p. 20) we set debris treatment cost as 1 yen/kg. Debris treatment cost is given by the following equation.

$$C_D(t) = 40\% \times BWSF(t) \times 1 yen/kg \tag{9}$$

Based on the above, we can describe total cost as follows.

$$TC(t) = C_F(t) + C_D(t) = \frac{40\% \times BWSF(t) \times 1yen}{kg} + \frac{0.0025 \times 31yen \times BWSF(t) \times t^2}{kg} \quad (10)$$

This total cost function can be applied to standard deer farming under pen feeding. However, if temporal deer farming is adopted and wild deer are caught at the age in months of t, we adjusted the value of Eq. (10) by setting marginal cost from age in month 0 to $t-1$ equal to zero.

5.2. Optimum slaughter age in months

Figures 2 to 5 illustrate the following cases: pen feeding and price is constant (Case 1; Fig. 2), pen feeding and price is a function of t (Case 2; Fig. 3), grazing and price is constant (Case 3; Fig. 4) and grazing and price is a function of t (Case 4; Fig. 5). As is mentioned above, 6, 18 and 30 months in age correspond to ages 0, 1 and 2 for October. Let us assume the hunting season starts in October and ends in February, then capturing age in months (therefore, breeding start age in months) are t = 6,...,10, 18,..., 22 and 30,..., 34, respectively as is shown in Table 2. In Figures 2 to 5, four cases are illustrated: standard deer farming (t = 0), temporal deer farming (t = 6, 18 and 30). Height of the graphs represent net revenue π ($TR-TC$), and the maximum points of the graph imply the optimum slaughtering times. In what follows, we refer to these 4 cases (graphs of t = 0, 6, 18 and 30) as π_0, π_1, π_2, π_3, respectively.

Table 2, on the other hand, summarizes the optimum slaughtering times and net revenues for standard and temporal deer farming (capturing age in months are t = 6,…,10, 18,…, 22 and 30,…, 34). The shaded regions represent cases in which net revenues are maximized. For example, in Case 1 (pen feeding and price is constant), if wild deer were captured in October at age 1 (t = 18), 14,419 yen will be the maximum net revenue by temporal deer farming fed until t = 28. In Case 1, the highest net revenue is achieved if deer are captured in October at age 2 (t = 30) and sold without feeding. In what follows, we will examine the optimum slaughtering times using Figures 2 to 5 and Table 2.

Case 1 is set as pen feeding and price is constant. As is shown in Figure 2, the line of π_1 (6 months in Figure 2) is located a bit higher than that of π_0 (general in Figure 2), but there is almost no difference. Maximum value is attained at t = 28 for standard and temporal deer farming (t = 6 and 18), and these values are π_0 = 13,080yen, π_1 = 13,142yen and π_2 = 14,419yen, respectively. When t = 18, they are π_0 = 12,778yen, π_1 = 12,840yen and π_2 = 14,117yen, respectively. If deer is captured at t = 30, maximum value is attained at t = 30 and π_3 = 17,682yen. Even if we use Table 2 to search for different ts, it is still optimum to capture and sell meat at t = 30 and obtain π_3 = 17,682yen.

Case 2 is set as pen feeding and price is a function of t. As is shown in Figure 3, the line of π_1 is again located a bit higher than that of π_0, but there is almost no difference. Maximum value is attained at t = 17 for standard and temporal deer farming (t = 6), and these values are π_0 = 15,913yen, π_1 = 15,974yen, respectively. If deer is captured at t = 18, maximum value is attained at t = 18 and π_2 = 16,920yen. If deer is captured at t = 30, maximum value is attained at t = 30 and π_3 = 13,191yen. If we use Table 2 to search for different ts, it is still optimum to capture and sell meat at t = 18 and obtain π_3 = 16,920yen.

Case 3 is set as grazing and price is constant. As is shown in Figure 4, there is a relationship $\pi_0 < \pi_1 < \pi_2 < \pi_3$, but there is almost no difference among them. Optimum slaughtering time is t = 37 if maximum value of t is 37. We can expect that as long as growth continues, optimum slaughtering time will increase as the maximum value of t increases. It is seen from Table 2, that it is optimum to keep deer under temporal deer farming from capture until t = 37. In addition, optimum capturing time is t = 31, which brings in the maximum net revenue of 19,773yen.

Case 4 is set as grazing and price is a function of t. As is shown in Figure 5, there is again a relationship $\pi_0 < \pi_1 < \pi_2 < \pi_3$, but there is almost no difference.

Maximum value is attained at t = 17 for standard deer farming and temporal deer farming (t = 6), and these values are π_0 = 17,228yen and π_1 = 17,238yen, respectively. If deer is captured at t = 18, maximum value is attained at t = 18 and π_2 = 17,102yen. If deer is captured at t = 30, maximum value is attained at t = 30 and π_3 = 13,561yen. If we use Table 2 to search for different ts, it is optimum to capture deer in the ninth month of age and keep deer under temporal deer farming until t = 17, which brings the maximum net revenue of π_1 = 17,241yen.

6. Discussion

In this section, we state several implications based on our results in section 4. In Case 1, (1) temporal deer farming should not be selected because it is most profitable to catch and sell at t = 30; (2) for captured deer under the age of 1 year, it is appropriate to raise them under temporal deer farming until t = 28, which brings the highest net revenue under this condition; (3) the closer the capturing time is to t = 30 (October of age 2), the higher the profits obtained.

In Case 2, (1) temporal deer farming should not be selected because it is most profitable to catch and sell at t = 18; (2) for captured deer at age 0 year, it is appropriate to raise them under temporal deer farming until t = 17, which brings the highest net revenue under this condition; (3) the closer the capturing time is to t = 18 (October of age 1), the higher the profits are obtained; (4) it can be deduced from Fig. 3 that although in this case price is the function of t, if the decrease of the price is low when t is increasing, then there is a possibility that t, other than that mentioned above, can be optimum. Namely, there is a possibility that, as with Fig. 2, t = 30 (October of age 2) can be optimum. On the other hand, if the decrease of the price is high when t is increasing, then there is a possibility that net revenue is maximized when t = 17. In that case, it may be optimum to capture deer at age 0 (t = 6 to 10) and raise them until t = 17. However, although the difference in price between young and old deer is small, there is the limited possibility that temporal deer farming is appropriate.

In the above two cases (pet feeding cases), we can conclude that, in general, temporal deer farming should not be selected to obtain maximum net benefits.

In Case 3, (1) it is most profitable to capture at t = 31 and raise under temporal deer farming until t = 37; (2) if the maximum value of t is set larger, optimum slaughtering time will be larger.

In Case 4, (1) it is appropriate to capture at t = 9 and raise under temporal deer farming until t = 17; (2) for captured deer over 1 year old, it is appropriate to kill them in the place of temporal deer farming. In addition, the following should be noted. In Japan, the hunting season of deer starts around October and ends in February (in Hokkaido) or from November to March (in other districts; hunting season somewhat fluctuates according to the regions and fiscal years) (Dainihon Ryoyukai, 2009). t = 9 corresponds to January, when hunting efficiency decreases because of the decline in the number of deer and the average quality of the remaining deer may be low after intensive gun hunting. Since revenues are almost the same for the case of deer captured at t = 6 and at t = 9, it may be appropriate not to wait until t = 9 and start capturing deer at t = 6.

7. Conclusion

There exists a combination of optimum capturing times and optimum slaughtering times, which result in maximum net revenue. In the case of grazing, it is appropriate to raise deer under temporal deer farming because there is a time lag between optimum capturing time and optimum slaughtering time. However, in the case of pen breeding, because optimum capturing time coincides with optimum slaughtering time, it is appropriate to slaughter captured deer in place of raising them. One of the reasons for these results may be attributed to the fact that temporal deer farming with pen feeding costs substantially compared to the benefit, and it is not feasible therefore from an economic point of view.

In reality, there is much possibility that deer are captured at times other than at their optimum capturing age in months because each deer may be born in a different month or a different year (in addition, hunting season is also from October to February). Therefore, it is necessary to determine the most appropriate slaughtering time for each individual deer based on the information in Table 2 and, if necessary, temporal deer farming should be combined.

In this paper, we gathered existing data and examined the prospects for temporal deer farming in Japan. Temporal deer farming is in its nascent stage and some data are lacking such as the relationship between age in month and unit price per kilogram, and we treat two cases: when price is constant and when price is the function of age in months. Data for the improvement of meat quality and the increase of unit price when deer are raised under pen feeding are also absent. If unit price is substantially increased under temporal deer farming with pen feeding, our conclusion above should be modified and temporal deer farming should be proposed even if pen feeding is selected. These are issues that remain and should be examined in future research so as to make our discussion more accurate.

References

Aagnes, T.H., A.S. Blix and S.D. Mathiesen (1996) Food Intake, Digestibility and Rumen Fermentation in Reindeer Fed Baled Timothy Silage in Summer and Winter, *Journal of Agricultural Science,* 127, 517–523.

Aoyagi, K. (2003) The Wildlife Management of Sika Deer from the Viewpoint of Resource Management: The Case Study of Ashoro-cho in Hokkaido Prefecture, *Journal of Forest Economics*, 49(1), 53–60.

Barry, T.N. and P.R. Wilson (1990) The New Zealand Deer Industry: Development and Progress, *Animal Husbandry*, 44(9) 1015–1021.

Barry, T.N., J.M. Suttie, J.A. Milne, and R.N.B. Kay (1991) Control of Food Intake in Domesticated Deer. In Tsuda, T., Y. Sasaki and R. Kawashima eds. *Physiological Aspects of Digestion and Metabolism in Ruminants*, pp. 385–401, Academic Press Inc.

Brown, L.R. (2003) *Plan B: Rescuing a Planer under Stress and a Civilization in Trouble*, 285 pp, New York, W.W. Norton.

Chardonnet, Ph., B des Clers, J. Fischer, R. Gerhold, F. Jori and F. Lamarque (2002) The Value of Wildlife, *Revue Scientifique et Technique, Off. int. épiz*, 21(1), pp. 15–51.

Dainihon Ryoyukai (March 17, 2009 reffered) http://www.moriniikou.jp/media/Rakude/20080917105654-ryouki20.pdf

Hokkaido (2006) *Guidelines for the Efficient Use of Hokkaido Sika Deer*.

Ishida, M. (2007) Deer Farming in Japan, *Animal Husbandry*, 61(9), pp. 991–996.

Ishida, M., S. Ikeda and T. Takeda (1996) Traits of Carcass and its Chemical Composition and Lipid Characteristics of Japanese Deer, *Animal Science and Technology*, 67(6), pp. 567–573.

Ishijima, Y., M. Yokohama, T. Masuko and Y. Kameyama (1990) Deer in Japan as Resource Animals, *Animal Husbandry*, 44(11), pp. 1261–1265.

Jeon, B. and S. Moon (2006) A Review on Feeding Systems for Deer Production, *Journal of Integrated Field Science* 3, pp. 39–44.

Kawata, Y. (2006) Economic Resource or Mammalian Pest?: A Reconsideration of the Management of Wild Deer, *Japanese Journal of Rural Economics*, 8, pp. 12–25.

Kay, R.N.B. (1985) Body Size, Patterns of Growth, and Efficiency of Production in Red Deer. In Biology of Deer Production. Ed. K.R. Drew and P.E. Fennessy. Royal Society of New Zealand. Bulletin 22. 411–422.

Kitahara, R., T. Masuko, K. Souma and M. Yokohama (2006) Significance and

Possibility of Deer Farming in Hokkaido (2), *Animal Husbandry*, 60(2), pp. 244–248.

Kunishige, K. and T. Tokari (2003) Seasonal Variation in Food Intake, Dry Matter Digestibility and Digestive Tract Retention Time of Timothy Hay Feeding in Yeso Sika Deer, *Bulletin of the Hokkaido Animal Research Center*, No. 25, pp. 31–36.

Kusec, G., G. Kralik, I. Djurkin, U. Baulain and E. Kallweit (2008a) Optimal Slaughter Weight of Pig Assessed by Means of the Asymmetric S-Curve, *Czech Journal of Animal Science*, 53, 98–105.

Kušec, G., G. Kralik, I. Đurkin, D. Vincek, A. Petričević and U. Baulain (2008b) Asymmetric S-function in the Prediction of Growth Characteristics of Hybrid Pigs, *Acta Agriculturae Slovenica*, supplement 2, 173–179.

MAFF (2008) *Syokuniku Benran* 2007 (*Meat Handbook* 2007), Ministry of Agriculture, Forestry and Fisheries (MAFF).

Masuko, T., K. Souma, K. Miyairi, T. Komatsu and Y. Ishijima (1999) Intake, Digestibility and Nitrogen Balance of Sasa (*Sasa senanensis*) in Yeso Sika Deer (*Cervus nippon yesoensis)*, *Animal Science and Agriculture Hokkaido* 41, pp. 72–75.

Masuko, T., K. Souma, M. Okamoto and M. Sekikawa (2008) Effective Utilization of Yeso Sika Deer (*Cervus nippon yesoensis*), *Animal Science and Agriculture*

Hokkaido 50, pp. 29–35.

Matsuura, Y. (2000) Effects of Birth Rate and Growth on the Winter Mortality of Sika Deer Farms, Master Thesis, School of Agricultural and Life Sciences, The University of Tokyo.

Meadows, D., J. Randers, and D. Meadows (2004) *Limits to Growth: The 30-year update*, 338 pp, London, Earthscan.

Ninomiya, K. (1989) The Road to Deer Farming (1), *Animal Husbandry*, 43(9), pp. 1093–1099.

Odajima, M., Y. Kajita, K.T. Nam, S.R. Lee, H. Senge, K. Katoh, Y. Shoji. M. Ohta and Y. Sasaki (1991) Seasonal Changes in Food Passage and Digestibility in Japanese Sika Deer (Cervus nippon) and Sheep under Restricted Feeding Conditions, *Animal Science Journal*, 62(3), pp. 308–313.

Odashima, M., K. Nakajima, Y. Ohtomo, S. Oda, Y. Shoji, K. Katoh, M. Ohta and Y. Sasaki (1993) Year-long changes in food intake and body weight in group-fed Japanese Sika deer (*Cervus nippon*), *Animal Science Journal*, 64(4), pp. p421–423.

Onuma, M., H. Takahashi, M. Asano, M. Ueno, M. Suzuki, K. Kaji (2005) The Capture and Chemical Immobilization of Wild Hokkaido Sika Deer (*Cervus nippon yesoensis*), *Japanese Journal of Zoo and Wildlife Medicine,* 10(1), pp. 19–26.

Ohtaishi, N. (1985) Biology of Deer and Current Condition of Deer Farming in Foreign Countires (2), *Animal Husbandry*, 39(10), pp. 1213–1216.

Ozaki, T. (2001) Efficient Use of Hokkaido Sika Deer, *Dairy Journal*, 54(9), pp. 53–55.

Souma, K., T. Masuko, Y. Kobayashi and Y. Ishijima (1998) Seasonal Alteration of Hay Intake in the Yeso Sika Deer (*Cervus nippon yesoensis*), *Animal Science and Agriculture Hokkaido*, 40, pp. 27–30.

Suzuki, M. (1999) A Review on Capture Myopathy, *Mammalian Science*, 39(1), pp. 1–8.

Takahashi, H., K. Kaji, J. Tanaka, M. Asano, M. Onuma, M. Ueno, H. Hirakawa and R. Akamatsu (2004) Mass Capturing Sika Deer with a Corral Trap, *Mammalian Science*, 44(1), pp. 1–15.

Takatsuki, S (2006) *Ecological History of Sika Deer*, 480pp. Tokyo, University of Tokyo Press.

Tsujii, H. (1991) Rearing Management of Deer in China (6), *Animal Husbandry*, 45(7), pp. 857–863.

Tsujii, H. (2007) Deer farming in Japan, *Animal Husbandry*, 61(7), pp. 799–804.

Uchida, H., S. Ikeda, M. Ishida, T. Inoue and T. Takeda (2001) Growth Characteristics of Artificially Reared Sika Deer (*Cervus nippon*), *Animal Science Journal*, 72(6), pp. 461–466.

UNEP (1986), Farming Systems Principle for Improved Food Production and the Control of Soil Degradation in the Arid, Semi-Arid, and Humid Tropics, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India.

Yamane, M., S. Hayama and K. Furubayashi (1996) Over-Winter Weight Dynamics in Supplementally Fed Free-Ranging Sika Deer (*Cervus nippon*), *Journal of Forest Research,* 1(3), pp. 149–153.

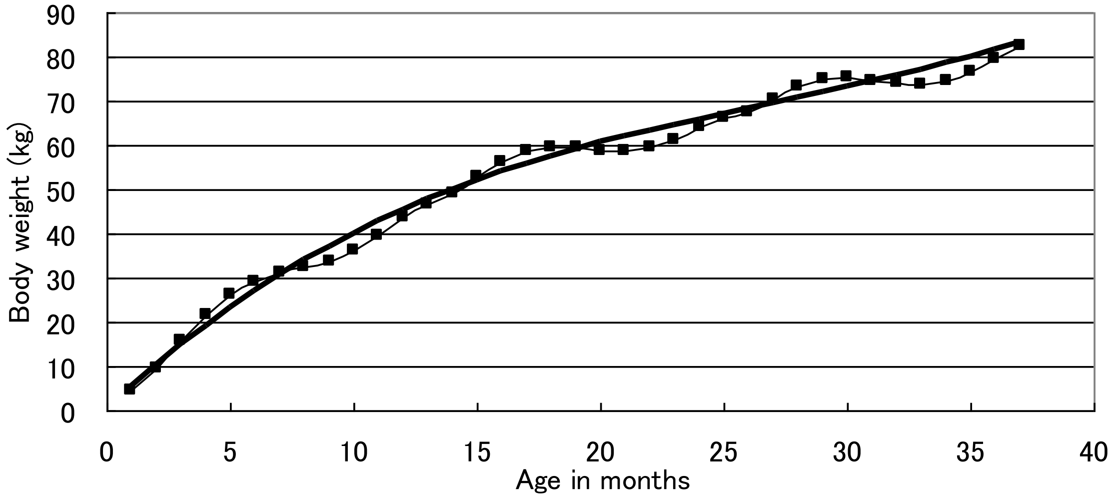

Fig. 1 Hypothetical change in body weight of reared sika deer

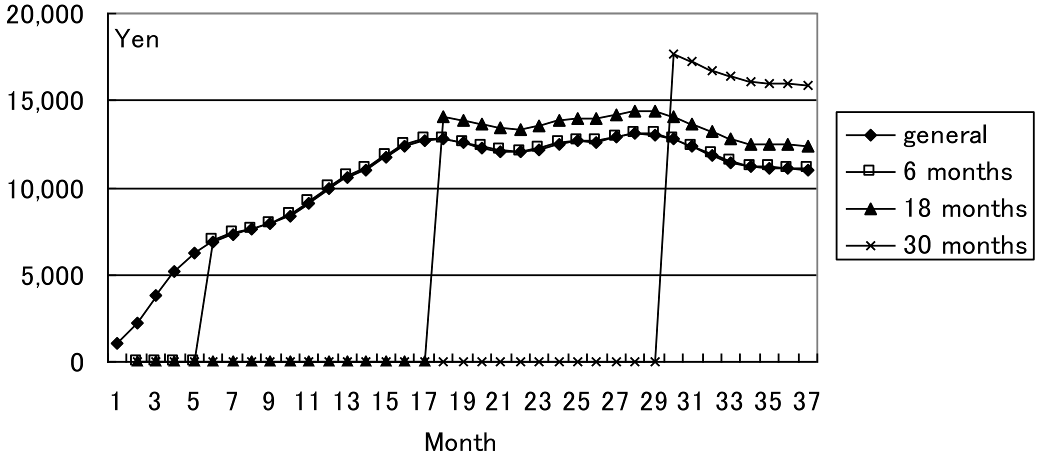

Fig. 2 Pen feeding and price is constant (Case 1)

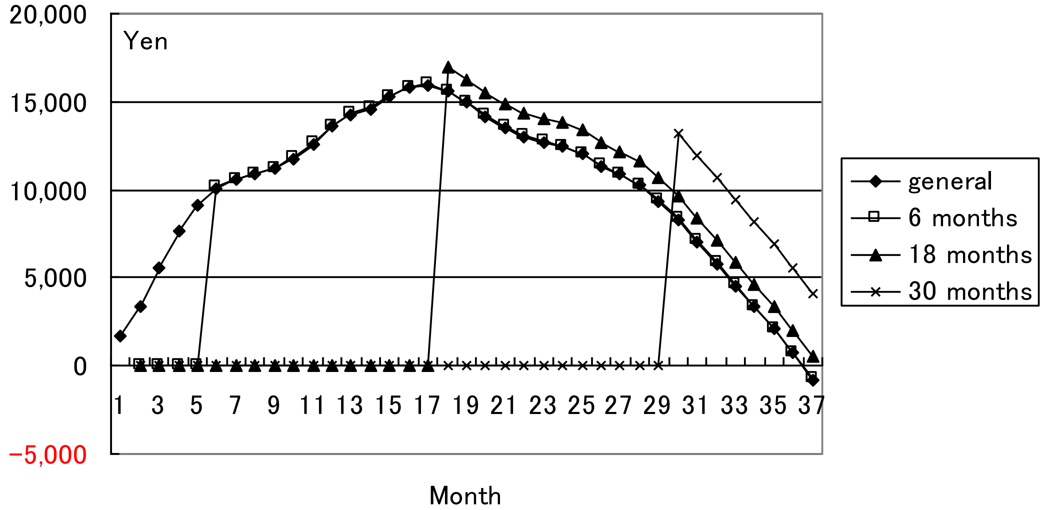

Fig 3 Pen feeding and price is a function of t (Case 2)

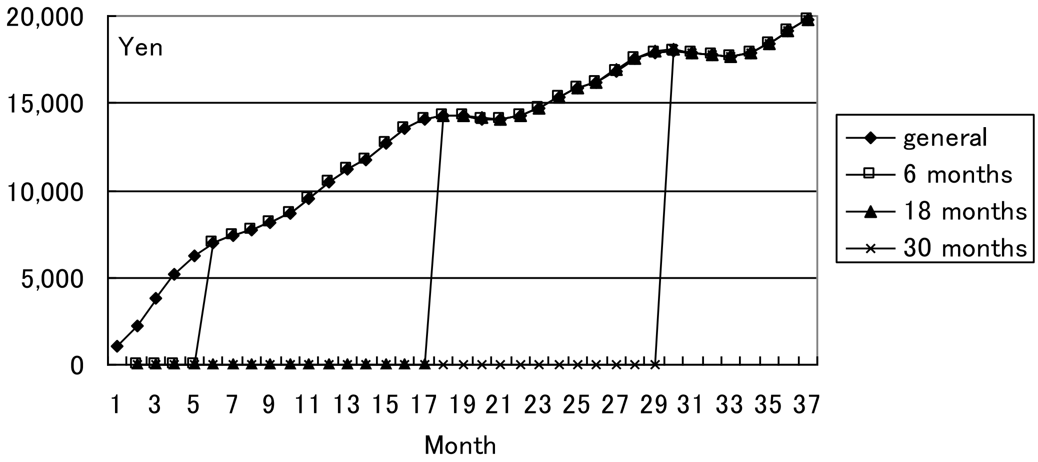

Fig. 4 Grazing and price is constant (Case 3)

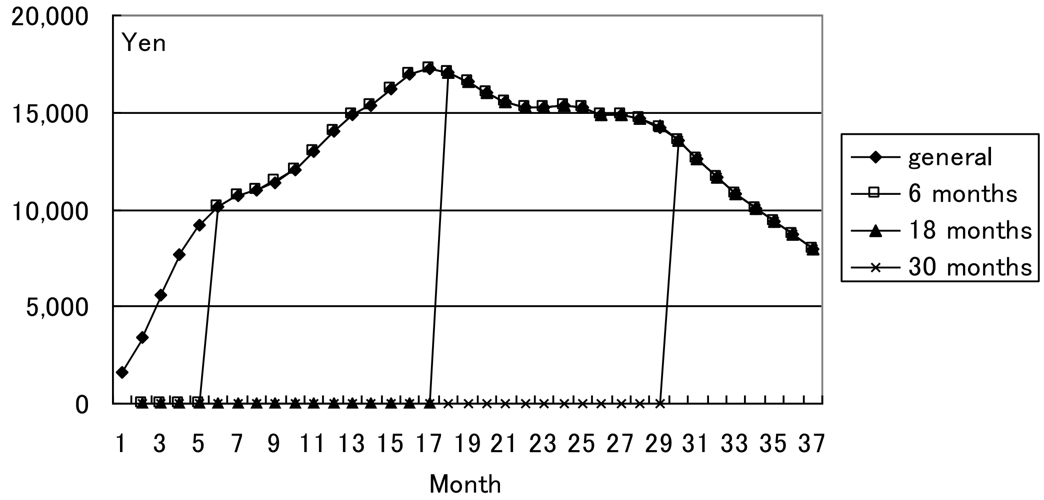

Fig. 5 Grazing and price is function of *t* (Case 4)

Table 1. Change in t when α or p has changed

	MR	t
$MR = MC > 0$	Increasing	Decrease
	Decreasing	Increase
$MR = MC = 0$	Increasing	Unchanged
	Decreasing	Unchanged
$MR = MC < 0$	Increasing	Increase
	Decreasing	Decrease

Table 2 Optimum slaughter age in months

age in months when breeding starts		Optimum slaughtering times and net revenues							
		p				$p(t)$			
		Case 1		Case 3		Case 2		Case 4	
	t	feeding	t	grazing	t	feeding	t	grazing	t
Standard farming	0	13,080	28	19,743	37	15,913	17	17,228	17
October of age 0	6	13,142	28	19,754	37	15,974	17	17,238	17
November	7	13,174	28	19,755	37	16,006	17	17,239	17
December	8	13,211	28	19,756	37	16,043	17	17,240	17
January	9	13,254	28	19,756	37	16,087	17	17,241	17
February	10	13,307	28	19,757	37	16,139	17	17,241	17
October of age 1	18	14,419	28	19,767	37	16,920	18	17,102	18
November	19	14,600	28	19,767	37	16,464	19	16,631	19
December	20	14,766	28	19,767	37	15,879	20	16,042	20
January	21	14,929	28	19,767	37	15,359	21	15,540	21
February	22	15,111	28	19,767	37	15,041	22	15,266	22
October of age 2	30	17,682	30	19,773	37	13,191	30	13,561	30
November	31	17,615	31	19,773	37	12,334	31	12,653	31
December	32	17,451	32	19,773	37	11,387	32	11,694	32
January	33	17,350	33	19,773	37	10,449	33	10,803	33
February	34	17,450	34	19,773	37	9,579	34	10,039	34