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ORIGINAL ARTICLE

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Evaluation of relative density indices for sika deer in eastern Hokkaido, Japan

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Abstract We evaluated relative density indices of sika deer (*Cervus nippon*) to aid in population management. We monitored sika deer population trends from 1992 to 2002 in the eastern part of Hokkaido Island, northern Japan, using spotlight surveys, aerial surveys, catch per unit effort (CPUE), sighting per unit effort (SPUE), and cost of damage to agriculture and forestry. We assumed that the artificial bias in the spotlight index would be lower than in other indices, and compared temporal patterns of other indices to those produced using spotlight surveys using model II regression. There was a significant correlation between the damage cost index and the spotlight index, and both indices indicated consistent population trends. Managers used CPUE as a tool to determine hunting quota efficiency. The SPUE index had the smallest standard error among the indices, and the spotlight survey index had the second smallest standard error. Overall, the spotlight survey was the most useful index because its estimate error was small and it was precise in showing population trends; however, spotlight surveys did lead to underestimation once in 1994. The SPUE index seems to be effective in checking the validity of the spotlight index, but there are so many environmental and demographic uncertainties that several independent indices should be used and crosschecked for accurate evaluation of population trends.

Keywords CPUE · Relative density index · Sika deer · Spotlight survey · SPUE

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Introduction

The estimation and evaluation of population sizes and trends is essential for conserving and managing wildlife populations (Begon et al. 1996; Thompson et al. 1998). However, the real absolute size of wildlife populations is often unknown. Since complete counts across entire study areas are rarely possible, incomplete counts such as index methods can be useful (Thompson et al. 1998). Indices of relative density, such as track counts, pellet group counts, spotlight surveys, and catch per unit effort (CPUE), have often been used to evaluate the status or trends of large mammal populations (Caughley 1977).

A lack of rigor and validity in the use of index methods has led to many problems (White 2001). Anderson (2001) emphasized that investigators should evaluate the variation in detection probability when using population indices. Engeman (2003) pointed out that population changes may be successfully monitored if sufficiently rigorous procedures are employed to provide an index. He also stressed that investigators must be clear about monitoring objectives when they decide whether to estimate a population size, or to produce an index to detect population changes (Engeman 2003).

There are at least three populations of sika deer on Hokkaido Island (Akan, Hidaka, and Taisetsu), all of which have different haplotype compositions (Nagata et al. 1998). The Akan population in eastern Hokkaido has irrupted over the last 20 years (Kaji 1995), causing severe damage to agriculture and forestry. In 1998, the Hokkaido Government implemented the "Conservation and management plan for sika deer (*Cervus nippon*) in Hokkaido" (CMP) and began substantial population control based on feedback management (Hokkaido Government 1998; Matsuda et al. 1999). Its goals are to prevent population irruption and related severe damage to agriculture and forestry, to avoid the risk of deer extinction, and to maintain a sustainable yield of deer.

The Hokkaido Government has been using five indices of relative density based on spotlight counts, aerial surveys, CPUE, SPUE, and damage to agriculture and forestry (Kaji et al. 1998). Relative density indices are obtained through comparison to 1993 indices; the absolute population size of sika deer in eastern Hokkaido at that time was estimated at 120,000 ± 46,000 individuals (Hokkaido Institute of Environmental Sciences 1995), and this is assumed to have been the entire population. The government considered three levels of relative population size and four levels of hunting pressure, and chose one of four possible actions, based on estimates (i.e., indices) of relative density (Matsuda et al. 1999). This shows how important the evaluation of indices and their estimate errors is in feedback management.

The estimate error of an index includes some bias and measurement variance. The spotlight index was considered suitable as a standard against which we could evaluate other indices because its artificial bias was probably lower than in any other index. Because hunter activity affects CPUE and SPUE indices, the bias in these indices may be higher than in spotlight and aerial surveys. While other surveys were conducted over 11 years, aerial surveys were only performed over 7 years (see Methods), so the aerial index seemed insufficient for comparing with others. The cost of damage can be influenced by local economics and damage controls, and researchers consider it a sociological index (Kaji et al. 1998).

This study focused on the Akan population because of the severe damage it has caused, and because it has been monitored by the Hokkaido Government since 1992. We evaluated relative density indices by comparing measurement variance and performing a regression analysis using the criterion index (i.e., the spotlight index). The objectives were to evaluate the precision and consistency of relative density indices for the Akan sika deer population in eastern Hokkaido, and to clarify which characteristics of relative density indices are useful for large mammal population management.

Methods

Study area

Hokkaido Island is divided into 12 management units (Hokkaido Institute of Environmental Sciences 1994). The Akan population ranges over units 9, 10, 11, and 12 in eastern Hokkaido (Fig. 1) (Nagata et al. 1998). The study area, from 42°43′ to 44°21′N and from 143°00′ to 145°48′E, includes 40 municipalities, and occupies 19,726 km^2. The study area has an average annual temperature of 4–6°C. It has a cool climate in summer and little snow in winter; the maximum snow depth is less than 100 cm, except in mountainous areas (Akitaya et al. 1994). The average annual precipitation is approximately 815 mm in Abashiri and 1,043 mm in Kushiro (Japan Weather Association, Hokkaido Regional Head Office 1991).

At altitudes in the range 300–800 m, the major vegetation includes coniferous forest and a mix of coniferous and deciduous broadleaf forest. Dominant species include the Yezo spruce (*Picea jezoensis*), Sakhalin fir (*Abies sachalinensis*), maple (*Acer mono*), linden (*Tilia japonica*), and oak (*Quercus crispula*), with an understory of Sasa bamboo (*Sasa senanensis*) (Igarashi 1986). In higher mountainous areas, *Betula ermanii* forest and *Pinus pumila* forest dominate. In lower areas, deciduous broadleaf forest composed of maple, linden, oak, and white birch (*B. platyphylla*) dominates. Riparian vegetation includes Japanese elm (*Ulmus davidiana*), *Fraxinus mandshurica*, and *Salix* spp. Plantations of Sakhalin fir

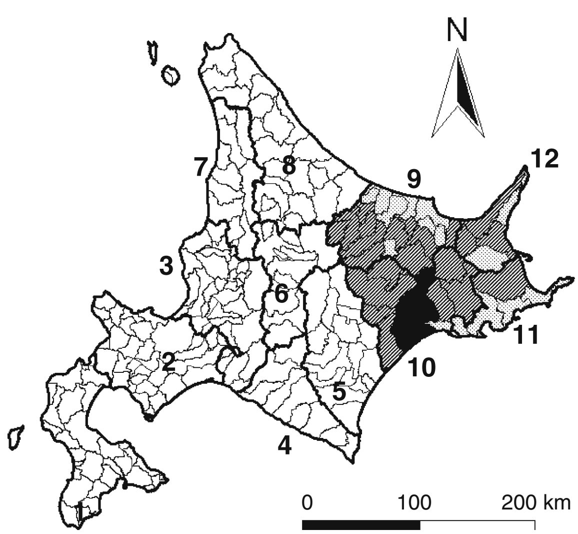

Fig. 1 Study area. *Numbers* indicate the sika deer management units (Hokkaido Institute of Environmental Sciences 1994). The study area comprised units 9–12 (40 municipalities). In the *black* and *hatched* areas we were able to use the spotlight counts, CPUE, and SPUE data (25 municipalities, The data from two spotlight counts were excluded from the analysis because of net fences). In the *dotted* areas, we were able to use only data from spotlight counts (15 municipalities). In the *black* area we also carried out an aerial survey (3 municipalities)

and Japanese larch (*Larix leptolepis*), pastureland, and cropland are mainly distributed in areas of low elevation.

Spotlight survey

From the 61 fixed survey routes in farmland that were established throughout eastern Hokkaido in 1992 (Kaji and Tomizawa 1993), we collected data from the 40 that were within the range of the Akan population (units 9–12). Because two survey routes had been enclosed with deer fence in both 1999 and in 2002, we excluded these data; data from a total of 38 routes were used in estimating the index (Table 1). We conducted annual deer spotlight counts from 1992 to 2002 between late October and early November, before the start of the hunting season. We used a vehicle driven at 20–40 km h^{-1} on each fixed route; routes were each about 10 km long. Two observers used hand-held spotlights (Q-Beam 160,000 candle-power, Brinkmann, Tx.) to search both sides of the survey route; we calculated the number of deer observed per 10 km.

Although line transect methods of estimating population density, such as distance sampling, require the measurement of perpendicular distances between animals and observers (Buckland et al. 2001; Koganezawa and Li 2002), we did not measure this distance because our objective was to estimate the relative population index (Kaji and Tomizawa 1993).

We assigned $u_{i,t}$ to be the number of deer observed per 10 km in year t along route i (Table 2). Using the ratio estimator method (Cochran 1977; Matsuda et al. 2002), we obtained the average, bias, and variance of the relative density index, denoted by P_t, b_t, and s_t^2, respectively:

$$P_t = \frac{\bar{u}_t}{\bar{u}_{1993}}, \quad (1a)$$

$$b_t = \frac{\bar{u}_t \sigma_{1993}^2}{n_t \bar{u}_{1993}^3} - \frac{\mathrm{Cov}_t}{n_t \bar{u}_{1993}^2}, \quad (1b)$$

$$s_t^2 = \frac{\sigma_t^2}{\bar{u}_{1993}^2 n_t} + \frac{\bar{u}_t^2 \sigma_{1993}^2}{\bar{u}_{1993}^4 n_t} - 2\frac{\bar{u}_t \mathrm{Cov}_t}{\bar{u}_{1993}^3 n_t} \quad (1c)$$

where $\bar{u}_t$ is the average of $u_{i,t}$, and Cov_t represents the covariance between $u_{i,t}$ and $u_{i,1993}$. The bias (b_t) was so small ($b_t < 0.011\%$) for all years that we ignored it in all later calculations (Table 2).

Aerial survey

Aerial surveys from a helicopter (Aerospacial AS-350B) were conducted in Akan National Park and the Shiranuka Hills area in February–March 1993, 1994,

Table 1 Comparisons of sampling methods among five relative density indices

	Spotlight survey	Aerial survey	CPUE	SPUE	Damage cost
Method	Individual counts	Individual counts	Questionnaire	Questionnaire	Questionnaire
Period	Late October–early November	Late February–early March	November–January (November–February[a])	November–January (November–February[a])	April–March
Sample size	38	24	25	25	40
Type	Fixed survey route	Fixed survey plot	Municipality	Municipality	Municipality
Unit	Individuals/10 km	Individuals/km^2	Individuals/hunter-day	Individuals/hunter-day	Yen

[a]The hunting period in fiscal year 2000 was from November to February

Table 2 Mean, standard error, and sample size of sika deer individuals per 10 km observed by spotlight survey in eastern Hokkaido, Japan, from 1992 to 2002, and point (P_t) and interval estimates of the relative density index, estimated using Eq. 1 (adapted from Matsuda et al. 2002)

Year	Observed number of individuals per 10 km			Ratio estimated using spotlight survey (%)				
	n	Mean	SE	P_t	Bias b_t	95% CI		s_t
1992	38	43.3	6.9	101	0.007	74	127	14
1993	38	43.1	6.3	100				
1994	38	33.5	5.1	78	0.004	60	95	9
1995	38	46.2	7.1	107	0.004	84	130	12
1996	38	45.9	7.6	107	0.005	78	135	14
1997	38	47.2	6.8	110	0.011	80	139	15
1998	38	47.4	6.5	110	0.010	83	137	14
1999	38	37.5	5.6	87	0.005	67	106	10
2000	38	31.0	4.8	72	0.006	52	91	10
2001	38	34.2	5.3	79	0.006	59	100	11
2002	38	31.0	5.5	72	0.005	50	94	11

and 1997–2002 (Fig. 1; Table 1). We divided the study area (224.2 km^2) into 24 survey plots ranging from 6.3 to 12.7 km^2, and estimated the average density per plot as the relative index (Hokkaido Institute of Environmental Sciences 1995). Because we surveyed only 9 plots in 1993 and another 15 plots in 1994, we pooled the data from the two years as 1993/94. It is unlikely that this treatment produced significant bias, because snow depth is the most important factor affecting deer distribution (Sakuragi et al. 2003), and 1993 and 1994 had very similar average snow depth and duration of snow cover.

Sightability is defined as the percentage of deer seen in a searched area (Caughley 1977). Gasaway et al. (1986) proposed the sightability correction factor (SCF) as the product of an observed correction factor (SCF_o) and a correction factor constant (SCF_c). The SCF_c is a constant under a given set of conditions (e.g., location, habitat); it was negligible in estimating the relative index, since surveys were conducted in the same areas every year. The SCF_o varied with snow cover and researcher experience. It was calculated as follows:

SCF_o = (number of animals seen during an intensive search)/(number of animals seen during a standard search) + correction for small sample bias (Gasaway et al. 1986).

In the standard search (SS), we flew 100 m above the ground at 80 km h^{-1} and spent about 30 min over every plot (search effort was about 3 min km^{-2}). We recorded the number of observed males, females, and fawns in each herd. In the intensive search (IS) used to estimate SCF_o, we flew at 40 km h^{-1} and counted the number of deer in half or one-third of the plot's area. The IS search effort was about 6 min km^{-2}.

We searched five to nine units using an IS every year, and used a formula to estimate SCF_o (Gasaway et al. 1986) as follows:

$$SCF_o = \frac{\sum_k w_k}{\sum_k v_k} + \frac{n_0 s_{wv}^2}{\left(\sum_k v_k\right)^2} - \frac{n_0\left(\sum_k w_k\right) s_v^2}{\left(\sum_k v_k\right)^3} \tag{2a}$$

$$s_{wv}^2 = \frac{\sum_k w_k v_k}{n_0 - 1} - \frac{\sum_k w_k \left(\sum_k v_k\right)}{n_0(n_0 - 1)} \tag{2b}$$

$$s_v^2 = \frac{\sum_k v_k^2}{n_0 - 1} - \frac{\left(\sum_k v_k\right)^2}{n_0(n_0 - 1)} \tag{2c}$$

where n_0 is the number of intensive survey plots, and w_k and v_k are the number of deer observed during an IS and a SS of the kth plot, respectively. We calculated the average density corrected by SCF_o for the 24 plots each year and estimated the average, bias, and variance of the population index using Eq. 1.

Catch per unit effort and sighting per unit effort

To analyze hunting activity, we requested that hunters report the date and place of hunting, the number of each sex of deer harvested, and the total number of deer observed. The ratio of the number of harvested deer reported by questionnaire surveys to the whole number of deer harvested ranged from 29% to 84% (Table 3). We used these data to calculate CPUE (number of deer harvested per hunter-day) and SPUE (number of deer sighted per hunter-day) in 40 municipalities. Since 15 municipalities lacked data for several years because of a hunting ban, we used data from 25 municipalities to estimate the indices (Table 1). We used Eq. 1 to estimate their error.

Cost of damage to agriculture and forestry

We acquired the costs of damage to agriculture and forestry caused by deer from statistics presented by the Hokkaido Government (2002). These values had been collected from reports by farmers and forestry workers in each 40 municipalities (Table 1).

Hunting data

Statistics for the annual number of deer harvested were based on reports from hunters at the close of each hunting season (Hokkaido Government 2002). We estimated the number of deer harvested in the study area (units 9–12) from that in the whole area of Hokkaido using the results of questionnaire surveys. From 1994 hunting of female deer was legal; hunting seasons for female deer were from 6 to 15 January in the fiscal years 1994–1996, from 15 November to 15 December in the fiscal year 1997, from 1 November to 31 January in the fiscal years 1998, 1999, 2001, and 2002, and from 1 November to 28 February in the fiscal year 2000 (fiscal year indicates the period from April to March). Hunting seasons for males were from 15 November to 15 January in the fiscal years 1990–1997, from 1 November to 31 January in the fiscal years 1998, 1999, 2001, and 2002,

Table 3 The number of deer harvested from 1992 to 2002, as reported by questionnaire survey in eastern Hokkaido, Japan

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Number of deer harvested (A)	12,758	16,402	17,995	25,566	22,922	25,345	50,829	40,317	45,912	36,252	37,134
Number of harvested deer reported by questionnaire surveys (B)	7,728	4,721	7,230	14,585	12,711	15,148	39,087	32,219	34,950	29,360	31,169
B/A (%)	61	29	40	57	55	60	77	80	76	81	84

and from 1 November to 28 February in the fiscal year 2000.

We analyzed relationships using a model II regression analysis using spotlight count data as the independent variable, and data from aerial surveys, CPUE, SPUE, and cost of damage as dependent variables (Sokal and Rohlf 1995). We used the major axis method and estimated the slope of dependent variables on the independent variable using JMP 5.1.1 (SAS Institute, Cary, N.C.).

Results

Relative density indices

Table 2 shows statistics of spotlight surveys including relative density index (P_t), 95% confidence interval (CI), and standard error (s_t). The relative density index calculated using spotlight counts increased from 1992 to 1998, and decreased thereafter (Fig. 2). Indices compared to the 1993 index were 110% (CI 83–137%) in 1998 and 72% (CI 50–94%) in 2002 (Table 2). Standard errors in the spotlight index varied from 9.0 to 15.3%.

Table 4 shows the number of deer observed during IS and SS by aerial survey, with estimated sightability correction factors (SCF_o) that varied from 1.3952 to 1.9628. The average density corrected by SCF_o was 26.6 ± 6.1 ($\pm$SE) deer per km^2 in the fiscal year 1996 (February–March 1997), and 13.2 ± 2.1 deer per km^2 in the fiscal year 2001. The index estimated using aerial surveys was 134% (CI 79–189%) in the former and 63% in the latter (CI 15–111%; Fig. 2). The variance of the aerial index for the fiscal years 1996, 1997, and 1999–2002 was greater than that of the spotlight index (F-test, $P < 0.05$; Table 5).

The CPUE index in 1998 (285 ± 51%, average $\pm$CI) increased to twice the index in 1997 (138 ± 24%; Fig. 3). The CPUE values in 1998 were significantly different from those in 1997 (Wilcoxon's signed-ranks test, $z = -4.372$, $P < 0.0001$). The variance of the CPUE index for 1994 and 1998–2002 was greater than that of the spotlight index (F-test, $P < 0.01$; Table 5).

The SPUE index in 1998 was 118 ± 18%, and then decreased; by 2002 it was 84 ± 14% (Fig. 3). The variances of the SPUE index for 1994, 1996–1998, and 2001–2002 were lower than those of the spotlight index (F-test, $P < 0.05$; Table 5).

Damage to agriculture and forestry in the 1990 fiscal year cost 1.525 billion yen, and increased markedly (Fig. 4); in the 1996 fiscal year it reached 3.727 billion yen. The damage index in 1996 was 151% and decreased until 2002, when the index was 66% (Fig. 4).

Table 6 shows the slopes, Y-intercepts, and coefficients of determination of the dependent variables (aerial surveys, CPUE, SPUE, and damage costs) for spotlight surveys. Spotlight survey results were significantly related to damage costs ($R^2 = 0.517$, $P = 0.013$). There were no significant relationships between the results of spotlight surveys and aerial surveys, CPUE, and SPUE ($P > 0.05$).

Numbers of deer harvested

Figure 4 shows changes in the number of deer harvested in units 9–12. In 1990, 11,932 (9,695 males and 2,237 females) were harvested. In 1994, when hunting for females was legalized, the number was 21,787 (15,460 males and 6,327 females). The maximum number of deer harvested was in 1998: 60,438 deer (28,511 males and 31,927 females) were killed when the Hokkaido Government began aggressive population control based on the CMP. From 1999 to 2002, the number of deer harvested gradually decreased. In the period of male-only hunting from 1990 to 1993, 48,475 males and 11,622 females were killed. During the period of a hunting quota of one deer per hunter-day from 1994 to 1997, 83,194 males and 43,561 females were culled, and during the period of a hunting quota of two deer per hunter-day from 1998 to 2001, 89,586 males and 107,731 females were culled. There was a significant difference in the sex

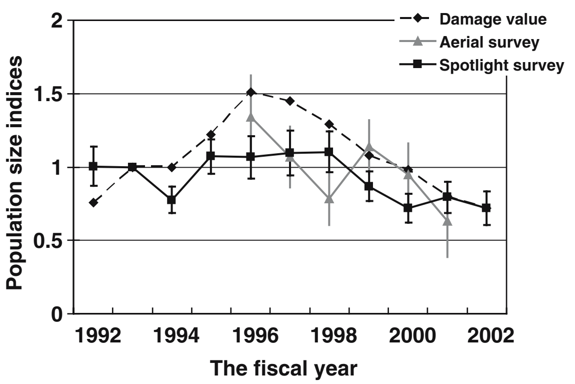

Fig. 2 Changes in the spotlight survey, aerial survey, and cost of damage to agriculture and forestry population indices for the Akan population of sika deer on Hokkaido. *Error bars* indicate standard error

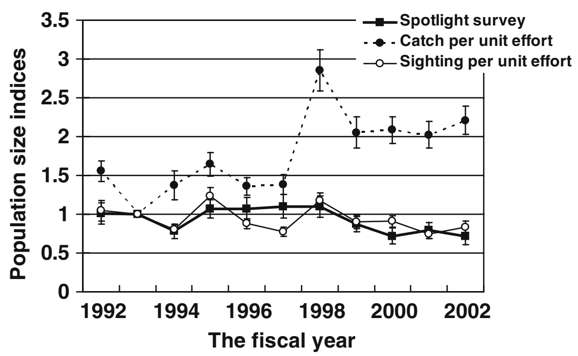

Fig. 3 Changes in the spotlight survey, CPUE, and SPUE population indices for the Akan population of sika deer on Hokkaido. *Error bars* indicate standard error

Table 4 Number of deer observed during intensive search (*IS*) and standard search (*SS*), aerial survey, and the sightability correction factor calculated from Eq. 2

Fiscal year	Number of units surveyed during IS (n_0)	Sightability correction factor (SCF_o)	Number of deer observed during SS (v_k)									Number of deer observed during IS (w_k)								
			$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$	$k=8$	$k=9$	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$	$k=8$	$k=9$
1992/93	5	1.3952	49	22	59	80	111					66	40	81	140	126				
1996	0	–																		
1997	2	–	34	38								71	95							
1998	5	1.7733	8	60	45	25	13					10	128	59	42	25				
1999	7	1.7632	54	26	56	53	35	23	18			75	26	122	96	67	55	25		
2000	9	1.9628	43	40	28	37	44	55	41	21	26	91	91	72	70	114	76	77	48	40
2001	8	1.6570	60	15	24	32	36	22	32	46		93	27	53	48	74	56	44	51	

Table 5 Point (P_t) and standard error (s_t) of the relative density index, CPUE, SPUE, and aerial survey, for sika deer in eastern Hokkaido, Japan, from 1992 to 2002. P_t and s_t were estimated from Eq. 1

Fiscal year	CPUE		SPUE		Aerial survey	
	P_t (%)	s_t (%)	P_t (%)	s_t (%)	P_t (%)	s_t (%)
1992	156	13	105	13		
1993	100		100		100	
1994	137	19	81	6		
1995	164	15	123	11		
1996	136	11	88	6	134	28
1997	138	12	77	6	107	21
1998	285	26	118	9	79	18
1999	205	20	90	9	114	18
2000	209	17	91	8	95	21
2001	202	17	75	6	63	24
2002	221	18	84	7		

ratio of deer harvested between these three periods (G-test, $G=29{,}664.0$, df$=2$, $P<0.0001$).

Discussion

Evaluation of relative density indices

Feedback management requires indices of relative density to monitor population changes in a target area accurately, and to evaluate errors in measurement estimation. CMP management programs for sika deer are implemented according to relative density indices (Hokkaido Government 1998). For example, if a recent index is more than 50% of the 1993 index, the Hokkaido Government applies population control in the form of hunting and controlled kills, especially of females.

Measurement errors in the SPUE index were smaller than errors in the spotlight index, while errors in the CPUE index were larger than both. The variance of the aerial index was also greater than that of the spotlight index. It was not possible to estimate the error of the damage index. Among the four indices for which error was measured, the SPUE index had the least error in its estimates of relative density.

Sampling methods and periods were different among the five indices (Table 1). It was difficult to distinguish the measurement error from the bias of sampling localities strictly. We assume the standard errors of indices indicate the measurement errors. Since we do not know how spatial and temporal variations in deer distributions affect the bias in estimates of the relative density indices, further study is required.

There was no relationship between the temporal patterns of the SPUE index and the spotlight index (Fig. 3). The SPUE index decreased over the period 1995 to 1997, while the spotlight index gradually increased. The number of deer harvested increased over the period 1995 to 1997 (Fig. 4), even though the hunting quota and hunting effort were unchanged (K. Kaji et al., unpublished data). We do not have any idea why the SPUE index showed such a temporal decrease. Mass mortality of calf deer was reported by Uno et al. (1998) in the spring of 1996 in Akan National Park area. However, mass mortality was not seen during 1995 and 1997 in the other area of eastern Hokkaido, for example Shiretoko National Park (Kaji et al. 2004). This evidences does not support a decrease in the population size during that period. Thus, the SPUE index was not effective in evaluating the population trend.

There was also no significant relationship between temporal patterns in the CPUE index and the spotlight index. The CPUE index in 1998 was double that in 1997 because the 1998 hunting quota (deer per hunter-day) was double the 1997 quota. Changing the hunting quota inevitably affects the CPUE index. Novak et al. (1991) suggested that CPUE is influenced by hunting pressure and method. Thus, the CPUE index is not useful for revealing population trends when hunting quotas regulate hunter activity. However, as a tool for population control, the CPUE index does indicate changes in the hunting quota. This index may be useful for wildlife managers to evaluate the efficiency of hunting regulation. For example, using the CPUE index, managers may be able to determine whether a hunting quota regulates the number of deer harvested if the quota is changed from two to three deer per hunter-day.

The aerial survey index was not related to the spotlight index. The 1998 aerial index seems to be an underestimate compared to trends obtained with the spotlight index (Fig. 2). According to Gasaway et al. (1986), SCF_c is a constant value for a particular habitat

Fig. 4 Changes in the numbers of sika deer of the Akan population on Hokkaido killed from 1990 to 2002 for nuisance control and by hunting, and the cost of damage

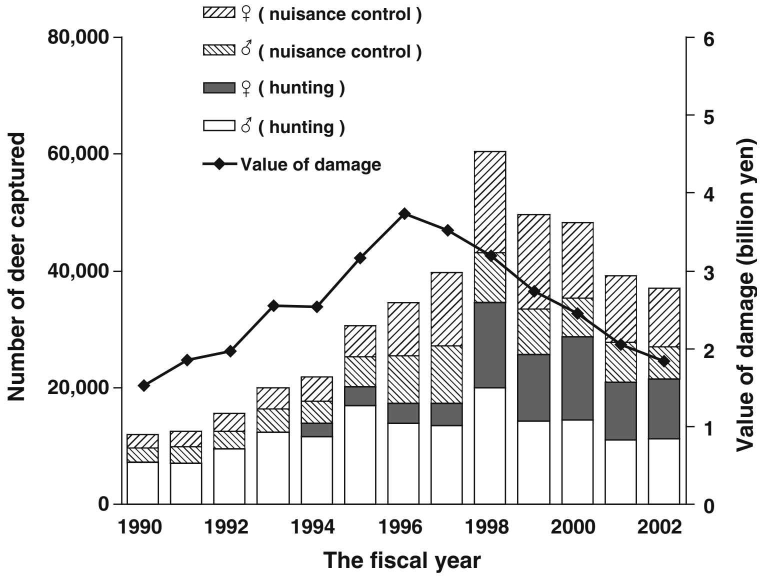

Table 6 Results of model II regression. The independent variable is spotlight survey data, dependent variables are aerial survey, CPUE and SPUE data, and damage cost to agriculture and forestry (billion yen)

Variables	Slope of major axis (*b*)	*Y*-intercept (*a*)	Coefficient of determination (R^2)	Probability (*P*)
Aerial survey	0.384	3.750	0.122	0.443
CPUE	−0.005	0.750	0.046	0.529
SPUE	2.148	0.071	0.302	0.080
Damage cost	0.068	−0.033	0.517	0.013

condition, and SCF_o is a variable. Since there were no large land-use developments in our study area during the study period, the assumption of a constant SCF_c is correct. If it were not possible to estimate annual variation in sightability using SCF_o, this method would not be able to provide sufficient population trend results. The probability of detecting a group of deer is usually proportional to group size (Samuel et al. 1987; Ooi et al. 1993). The relationship between sika deer sightability and group size should be examined when evaluating the aerial survey index.

The index of damage to agriculture and forestry showed a consistent trend (Fig. 2). The ratio of the damage in year $t+1$ to that in year t was negatively related to the number of deer harvested in year t (linear regression, $R^2=0.431$, $P=0.020$). Thus, the damage index appeared to reflect the change in population size during the study period. A significant relationship between the spotlight and damage indices supports this conclusion.

The cost of damage, however, was affected by damage control measures (Muroyama 2003). To reduce crop damage, 2.5-m high net fences intended to exclude sika deer were established along farmland edges. By 2001, there was a total of 2,500 km of net fence in eastern Hokkaido (Hokkaido Government 2001). In the future, damage control such as net fencing may cause the damage index to be less reliable for estimating population trends.

The spotlight survey index appeared to track actual population changes because the decline in the index from 1998 to 2000 (Fig. 2) coincided with a period of aggressive CMP culling during which more than 27,000 female deer were killed annually (Fig. 4). Researchers consider that these efforts resulted in the removal of more individuals than were recruited into the population (Matsuda et al. 2002). A telemetry study estimated that hunting and culling were the major causes of increased rates of mortality in adult females (Igota 2004; Uno and Kaji 2006) . These results support the population trend shown in Fig. 2.

Among the five indices, the spotlight index appeared to be the most useful for evaluating population trends because it had a small estimate error and showed a consistent trend. The coefficients of variation for spotlight counts were between 84% and 109%, and did not show great annual variation from 1992 to 2002. Results suggest that the precision of observations using spotlight surveys is comparatively constant among years, supporting the usefulness of this index.

However, there was an unexplained temporal decrease in the spotlight index from 1993 to 1994. Visibility during spotlight counts is affected by vegetation density (Whipple et al. 1994); thus, the effects of annual variation in vegetation density need to be examined. There are a large number of environmental and demographic uncertainties, and the use of several relative density indices may be required for accurate evaluation of population trends. The SPUE index is useful for checking the validity of the spotlight index because its estimate error is small, and the index is not relatively affected by changes in hunting quotas. Investigators should monitor population trends by cross-checking several independent relative density indices to confirm their consistency.

An estimate of absolute population size is required for managers to determine the necessary number of deer to be harvested when implementing the CMP. Matsuda et al. (2002) examined a stage-structured population dynamics model and estimated the absolute population size of sika deer in 1993 using a ratio estimator of spotlight survey data and number of deer harvested. They estimated the 1993 population size to be between 160,000 and 330,000 individuals using feasible computer simulations (Matsuda et al. 2002). We were able to estimate a reliable index interval using spotlight count data and to correct the estimator, resulting in a small sampling bias (Cochran 1977).

Useful indices for population management

Relative density indices do not always accurately reflect population trends. We can improve the index accuracy by considering hunting as an experiment to manipulate a wild population, and monitoring the index as a result of these manipulations. Adaptive resource management is needed to manage wild populations. Walters (1986) pointed out the importance of acknowledging the uncertainties of population parameters when implementing an action plan, and to improve the plan using new information to reduce uncertainty.

For actual management, it is important to discuss the characteristics of a useful relative density index. Evaluation of population indices should include: whether confidence intervals can be estimated and whether the estimate error is sufficiently small; how quickly data can be obtained to allow management decisions; and whether the same method can be sustained for a long period with regard to costs.

First, the estimation of the measurement error of an index allows precise knowledge of population trends. The error estimates for SPUE and spotlight survey indices in this study were small. We were also able to estimate absolute population size with confidence intervals using the population dynamics model.

Second, the speed in obtaining index estimates is important because the government must regulate hunting (i.e., the hunting quota and duration) according to the available information. We could perform spotlight counts in November of year $t-1$, allowing the Hokkaido Government to use this information to determine hunting quotas and durations for June of year t. On the other hand, for CPUE, SPUE, and damage indices, only year $t-2$ data would be available at this time. Delays in the availability of these data make them less useful for practical management.

Third, long-term monitoring is an essential component of population management. Managers must use a consistent method or a method by which they can obtain comparative data. Spotlights and hunting questionnaire surveys cost less than aerial surveys, and so are more suitable for long-term sustainability.

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