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Estimation of the economic value of herd-life length based on simulated changes in survival rate

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Abstract

Functional traits are an important aspect of long-term breeding strategies for dairy cattle. In this regard, it is necessary to develop simple methods for estimating the economic value of herd life. In this study, the economic daily value of herd life was estimated when survival rate varied between −0.05 and 0.05 from the basal survival rate. The extension days per survival rate were 26.5 days in Hokkaido and 20.3 days in other regions. The increases in values of annual income per day of herd life were 95.18 yen in Hokkaido and 101.80 yen in other regions. The relative economic weights of milk yield to herd life per genetic standard deviation were 0.668 in Hokkaido and 1.03 in other regions. Estimated increments in yearly profits based on young sire selection for herd life were 963 yen in Hokkaido and 1,030 yen in other regions. The estimated increments in annual profits based on young sire selection for milk yield were 1,268 yen in Hokkaido and 2,097 yen in other regions. Given that economic value was linearly correlated with herd-life length, the linear regression coefficients between these factors could be used to estimate the economic value of herd-life length.

KEYWORDS

dairy cattle, economic value, herd-life length

1 | INTRODUCTION

Improvements in functional traits are growing in prominence in long-term improvement plans for dairy cattle. Thus, the total selection indices used in many countries now include functional traits (Egger-Danner et al., 2015; Miglior, Muir, & Van Doormaal, 2005; Van Raden, 2004). Bo (2009) showed that the primary aims of dairy cattle breeding for farmers were increasing income (higher milk production), reducing costs (improved fertility and disease resistance), reducing problems (temperament and milking speed), and complying with commercial standards (animal welfare and ethics). Norman, Wright, and Miller (2010) reported that, in contrast to productive traits such as milk yield, the economic weights of health-related and reproductive traits have been increasing in Net Merit, a total selection index used in the United States. Consequently, improvements in milking ability have been slow, although longevity has tended to increase and conception ability has shown a gradual reduction or slight increase. In Japan, the Nippon Total Profit (NTP) index for dairy cattle has been published since February 1996. Following several revisions, the weights of robustness and antiseptic and reproductive functions have been increased. In another Japanese index for longevity and reproductive traits, which has been published since 2011, robustness and health-related and reproductive functions have a weight 30% greater than that attributed to the same traits in the NTP index. Accordingly, the importance of enhancing cow longevity has been increasing recently. However, estimating the economic value of herd life per day is difficult because herd-life length is affected by diverse factors. Thus, it is necessary to develop a simple method for estimating the economic value of herd life per day using published economic data.

If a cow suffers from slight illness, injury, or reproductive problems during lactation, it would be removed from the herd once the lactation period is finished. Byrne et al. (2016) predicted the economic value of herd-life length from changes in profit when the survival rate of each parity was changed by 1%. However, they did not predict the economic daily value of herd life. Because days are used as the unit of the genetic ability for herd-life length, estimates of the economic daily value of herd life are required for inclusion in total indices. This study aimed to estimate the basal survival rate of each parity and the economic daily value of herd life based on changes in herd-life length and economic factors, when the simulated survival rate was changed from −0.05 to +0.05 relative to its basal value.

2 | MATERIALS AND METHODS

Data on Holstein cows until the 10th lactation were obtained from the Livestock Improvement Association of Japan between 2013 and 2015. We obtained 12,760,786 records of test-day milk yield data for 780,139 head of cattle. Calving interval (464,017 records from 359,163 head of cattle), milking length (731,095 records from 469,690 head of cattle), and times of artificial insemination (AI) until pregnancy in each lactation (2,593,077 records from 671,771 head of cattle) were used as reproductivity data. Because there were fewer records of these reproductive traits after the fifth lactation, records obtained after this lactation were treated as the "6th lactation group". The values of selected economic factors were obtained from the Livestock Products Production Cost Statistics (LPCS) from 2013 to 2015 (Statistics Bureau, 2017). Because the parity structure of herds, milk price, and milk production costs in Hokkaido differed from those in other regions of Japan, the economic values of herd life in Hokkaido and in other regions (d = 1 or 2) were estimated separately. The basal survival rate for each parity was calculated based on the number of cows in each parity (Figure 1) using the following equation:

$$s_{di} = 1 - \frac{n_{di} - n_{d(i+1)}}{n_{di}},$$

where s_{di} is the survival rate of the ith lactation in region d, n_{di} is the number of cows of the ith lactation in region d, and $n_{d(i+1)}$ is the number of cows of the (i + 1)th lactation in region d. Because distributions of the calving interval and milking length were right skewed, the medians in the test data of these factors were used as representative values (Table 1). Herd-life length in region d (HL_d) represents the number of days from the parturition day of first parity to the day of removal, and it was calculated by summing the calving intervals and weighted by the number of cows, from the 1st to the 10th lactation (Table 2, eq. 1). Changes in the parity-number structure of cows in a herd are observed when the survival rates of all parities are changed by simulating increments of 0.01 from −0.05 to +0.05 from the basal level. When we estimated the effect of genetic improvement by selection for herd-life length, the effects of involuntary culling related to disease and damage needed to be considered, and the effects of voluntary culling related to low milking ability and sales in terms of dairy purposes were ignored. Therefore, when we

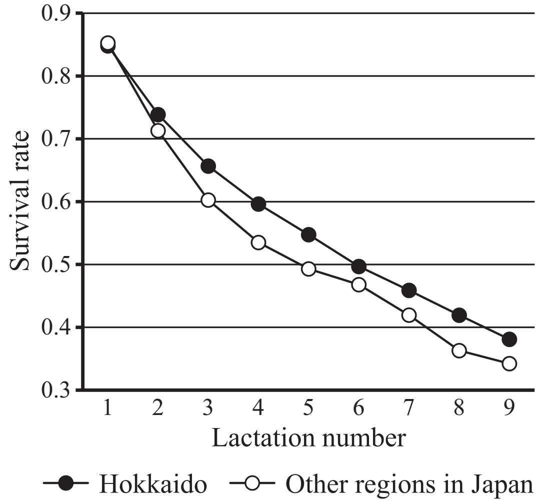

FIGURE 1 Change in survival rate with progression of lactation number. Survival rate was calculated as (1 − hazard), where the hazard is the ratio of the difference in number of cows between the present and next parity to the number of cows in the present parity

performed simulated changes in the survival rate, we assumed that the involuntary culling rate, but not the voluntary culling rate, was changed. Lifetime milk yield in region d (LMY_d) was calculated using the average test-day milk yield, milking length, calving interval, and HL_d (Table 2; eq. 2).

Because the distribution of age at the first parturition was right skewed, the medians in the test data were taken as representative values (Table 3). Revenue from sales of milk and calves was assumed to change according to herd-life length. Depreciation in the cost of cows, AI, and veterinary and medicinal treatment were also assumed to change with herd-life length. Lifetime revenue represents the total revenue from the 1st to the 10th lactation, and lifetime cost represents the total costs from the 1st to the 10th lactation, whereas lifetime income represents lifetime revenue minus lifetime costs. Revenue per lactating cow represents the income per lactating cow minus the revenue from calf sales, plus the costs associated with cow depreciation, AI, and veterinary and medicinal treatment, the values of which were obtained from the LPCS (Statistics Bureau, 2017). We used this calculation to avoid the effects of calf sales and the aforementioned cost factors. Revenue per kg of milk represents the revenue per lactating cow divided by the lactation milk yield. Lifetime revenue of milk sales represents the revenue per milk multiplied by LMY_d. Revenue per calf represents the revenue of calf sales per year divided by the number of calves sold. Lifetime revenue of calf sales represents the calf price multiplied by the number of lifetime calvings. Because the cow depreciation value includes the self-rearing costs for calves, we assumed that all newborn calves were sold and all succeeding heifers were purchased. According to the LPCS data (Statistics Bureau, 2017), the repayment period for depreciation cost of cows is 4 years and, thus, the cow depreciation cost in each region (DC_d) was adjusted by HL_d. Lifetime cow depreciation cost (LDC_d) was calculated as the adjusted cow depreciation

TABLE 1 Median delivery interval, milking length, average number of artificial inseminations (AIs) needed to achieve pregnancy, and annual milk yield in test day data from 2013 to 2015

Lactation number	Hokkaido						Other regions					
	Delivery interval (days)	Milking length (days)	AI (times)	Annual milk yield (kg/year)	Removal ratio		Delivery interval (days)	Milking length (days)	AI (times)	Annual milk yield (kg/year)	Removal ratio	
					Desirable[a]	Undesirable					Desirable	Undesirable
1	393	324	2.38	7,831	0.292	0.708	403	341	2.51	8,205	0.315	0.685
2	401	326	2.49	8,701	0.209	0.791	408	339	2.58	8,932	0.304	0.696
3	402	326	2.49	8,965	0.152	0.848	407	336	2.51	9,202	0.293	0.707
4	405	328	2.50	8,899	0.136	0.864	410	339	2.50	9,215	0.290	0.710
5	410	331	2.53	8,642	0.140	0.860	411	339	2.53	9,013	0.303	0.697
6	414	331	2.58	8,260	0.156	0.844	416	342	2.57	8,740	0.316	0.684
7				7,955	0.155	0.845				8,434	0.337	0.663
8				7,695	0.164	0.836				8,181	0.366	0.634
9				7,479	0.182	0.818				7,928	0.350	0.650
10				7,198	0.194	0.806				7,657	0.358	0.642

Note. Delivery intervals, milking lengths, and AI times after the fifth lactation are represented in the sixth lactation group. The annual milk yield was adjusted by delivery interval and milking length.
[a]Reasons for desirable removal of cows for dairy farmers were sale as dairy cows and low productivity.

cost multiplied by the year of HL_d (Table 2; eq. 3). The cost of each AI in each region (AIC_d) represents the AI cost per cow per year divided by the average number of AIs per year. The average number of AIs per year was 2.24 in Hokkaido and 2.27 in other regions. Annual AI cost per lactation in each region is determined as AIC_d multiplied by the number of AIs per lactation in each region (AIT_{di}). Lifetime AI cost ($LAIC_d$) was calculated by using AIC_d, AIT_d, and HL_d (Table 2; eq. 4). A percentage of the cows that were examined by veterinarians and provided with medication would be culled; we assumed that the rate of such involuntary culling was fixed, even if there was a change in disease rate. Therefore, a change in veterinary and medicinal costs is proportional to a change in the involuntary culling rate. In contrast, the voluntary culling rate does not affect veterinary and medicinal costs. The annual veterinary and medicinal costs in each region represent the veterinary and medicinal costs (VMC_d) adjusted by the change in involuntary culling rate (dCR_d). Lifetime veterinary and medicinal cost ($LVMC_d$) was calculated as the annual veterinary and medicinal costs multiplied by HL_d (Table 2; eq. 5). Annual revenue, cost, and income were calculated from the respective lifetime values divided by HL_d.

3 | RESULTS AND DISCUSSION

3.1 | Changes in economic effects based on simulated changes in survival rate

Because the survival rates in Hokkaido were higher than in other regions, the proportion of younger cows was lower and that of older cows was higher in Hokkaido than in other regions (Figure 2). The rate of involuntary to total culling in herds varied from 0.708 to 0.864 in Hokkaido and from 0.643 to 0.710 in the other regions. These results were based on the analysis of culling reasons (366,477 records). The involuntary culling rate for Hokkaido herds was slightly higher than that for herds in the other regions, and this rate increased with increasing lactation number. When the simulated survival rate was increased, the proportion of young and old cows decreased and increased, respectively. This trend is consistent with that reported by Byrne et al. (2016). When the survival rate was increased by 0.05 from the basal level, the average lactation number at removal increased by 0.35 and 0.26, and the average age at removal increased by 4.7 and 3.5 months in Hokkaido and in the other regions, respectively (Tables 4 and 5). When the survival rate was decreased by 0.05 from the basal level, the averages of lactation number and age at removal decreased by 0.30 and 0.23, and by 4.0 and 3.1 months in Hokkaido and in the other regions, respectively. The annual milk yields peaked at the third lactation, and were higher from the second to seventh lactations than at first lactation. Therefore, when the survival rate was increased, the average milk yield of the herd increased. The lifetime revenue derived from the sale of calves increased concomitantly with the increase in the number of lactations due to an increase in survival rate. However, given that the calving interval was greater than 1 year,

TABLE 2 Equations used for calculating herd-life length, milk yield, cow depreciation cost, artificial insemination (AI) cost, and veterinary and medicinal cost

Equation number	Equation
1	$HL_d = \sum_{i=1}^{10} \left(CI_{di} \times \frac{n_{di}}{n_d} \right)$
2	$LMY_d = \left[\sum_{i=1}^{10} \left\{ \left(DMY_{di} \times \frac{ML_{di}}{CI_{di}} \right) \times \frac{n_{di}}{n_d} \right\} \right] \times HL_d$
3	$LDC_d = (DC_d \times 4) \times \frac{HL_d}{365.25}$
4	$LAIC_d = \left[\sum_{i=1}^{10} \left\{ (AIC_d \times AIT_{di}) \times \frac{n_{di}}{n_d} \right\} \right] \times \frac{HL_d}{365.25}$
5	$LVMC_d = VMC_d \times (1 - dCR_d) \times \frac{HL_d}{365.25}$
Where	AIC_d: AI cost per insemination in region *d*. AIT_{di}: number of AIs during i^{th} lactation in region *d*. CI_{di}: calving interval of the i^{th} lactation in region *d*. DC_d: cow depreciation cost in region *d*. dCR_d: change in involuntary culling rate in region *d*. DMY_{di}: average test day milk yield of the i^{th} lactation in region *d*. HL_d: herd life length in region *d*. $LAIC_d$: lifetime AI cost in region *d*. LDC_d: lifetime cow depreciation cost in region *d*. LMY_d: lifetime milk yield in region *d*.$LVMC_d$: lifetime veterinary and medicinal cost in region *d*. ML_{di}: milking length of the i^{th} lactation in region *d*. n_d: number of cows in region *d*. n_{di}: number of cows of the i^{th} lactation in region *d*. VMC_d: veterinary and medicinal cost in region *d*.

the annual revenue obtained from the sale of calves decreased with the increase in survival rate. The total annual revenue was the sum of the revenues from milk and calf sales. When the survival rate was increased by 0.05 from the basal level, the total annual revenue increased by 39 and 494 yen in Hokkaido and in the other regions, respectively. Conversely, when the survival rate was decreased by 0.05 from the basal level, the total annual revenue decreased by 218 and 597 yen in Hokkaido and in the other regions, respectively. The annual cow depreciation cost decreased in accordance with the increase in survival rate, thereby increasing life length. Because the total AI times during life increased in accordance with an increase in the number of lactations, the lifetime AI cost increased with the increase in the survival rate. In contrast, the annual AI cost decreased because the calving interval was greater than 1 year, and thus, the annual AI time decreased. Although lifetime veterinary and medicinal costs increased with the increase in lifetime length related to the increase in survival rate, the annual veterinary and medicinal costs decreased. When the survival rate was increased by 0.05 from its basal level, the total annual costs decreased by 12,353 yen and 9,679 yen in Hokkaido and in the other regions, respectively. When the survival rate was decreased by 0.05 from its basal level, the total annual costs increased by 12,646 yen and 9,880 yen in Hokkaido and in the other regions, respectively. The annual income increased by 12,392 yen and 10,172 yen in Hokkaido and in the other regions, respectively, when the survival rate was increased by 0.05 from the basal level, whereas when the survival rate was decreased by 0.05 from the basal level, the annual income decreased by 12,864 yen and 10,477 yen in Hokkaido and in the other regions, respectively. The major reason for the change in annual income was the change in costs related to changes in survival rate. However, the effect of the change in revenue on the income was small. The estimated annual income per cow at the basal survival rate assumed in this study was 214,791 yen and 248,654 yen in Hokkaido and in the other

TABLE 3 Average age at first parturition, definitions, and values of prices and costs parameters from Japan cattle from 2013 to 2015

Parameter	Hokkaido	Other regions
Age at first parturition (months)	24.6	24.8
Milk price (yen/kg)	92.72	110.91
Income from milk sales[a] (yen/kg)	32.19	39.34
Calf sale price (yen)	106,158	60,255
Cow depreciation value (yen/year)	112,489	98,507
Artificial insemination (AI) cost (yen/occurrence)	5,296	5,751
Veterinary and medicinal costs (yen/year)	23,732	28,229

[a]This does not include the revenue derived from calf sales, cow depreciation costs, and costs of AI, veterinary, and medicinal treatment.

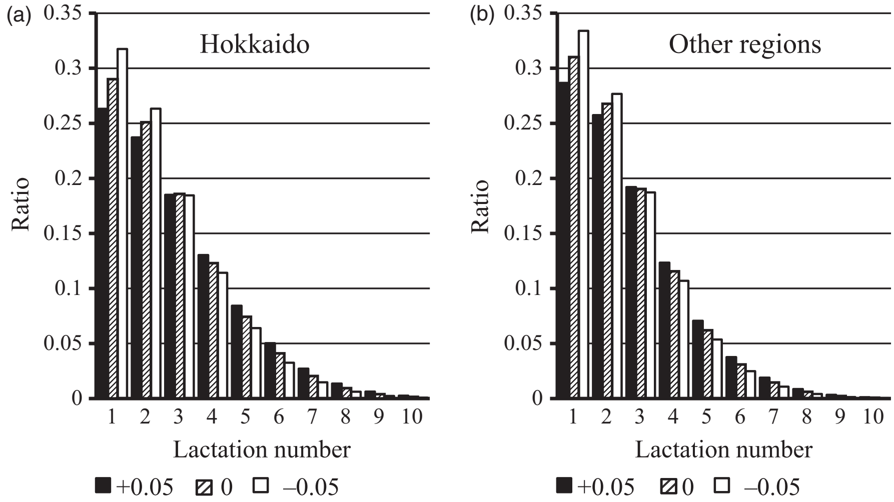

FIGURE 2 Proportion of cows with different survival rates in each lactation in (a) Hokkaido and (b) other regions

regions, respectively. These estimates are consistent with the average incomes from 2013 to 2015 (216,864 yen in Hokkaido and 250,504 yen in the other regions) in the LPCS data (Statistics Bureau, 2017). These results indicate that the economic factors assessed in this study were appropriate for estimating income according to changes in the survival rate.

3.2 | Estimate of economic weights

The regression coefficient of the relationship between annual income and survival rate represents an estimate of the increase in annual income per percentage increase in survival rate. When the survival rate was increased by 1%, the values of annual income were estimated to increase by 2,526.4 yen ($R^2 = 1.00$) in Hokkaido and 2,065.3 yen ($R^2 = 1.00$) in the other regions (Table 6). Therefore, the economic value of survival rate was larger in Hokkaido than in the other regions. The longevity traits for genetic estimation have been shown to be a relative risk, according to survival analysis (Sasaki et al., 2012; Terawaki & Ducrocq, 2009), and a pseudo-survival rate, according to random regression model analysis (Sasaki, Aihara, Nishiura, & Takeda, 2017; Sasaki, Aihara, Nishiura, Takeda, & Satoh, 2015). In these cases, the economic weight of longevity corresponded to the economic value per percentage survival rate. However, in Japan, the trait used to represent longevity is herd-life length. Therefore, we needed to estimate the economic value of longevity per day. When the survival rate was increased by 1%, the herd-life length was extended by 26.5 days in Hokkaido ($R^2 = 0.998$) and by 20.3 days in the other regions ($R^2 = 0.999$). Given that the correlation between herd-life length and annual income was linear, a value for annual income per herd-life day could be obtained from the regression coefficient for the relationship between herd-life length and annual income (Figure 3). When herd-life length was increased by 1 day, the income was increased by 95.18 yen in Hokkaido ($R^2 = 0.997$) and 101.80 yen in the other regions ($R^2 = 0.998$). Because the magnitude of the change in herd-life length according to the change in survival rate was larger in Hokkaido than in the other regions, the economic value of herd-life length was correspondingly smaller in Hokkaido (Table 6). The decrease in cow depreciation value with increasing herd-life length was larger in Hokkaido than in the other regions, but the increment in the revenue of milk sales and the reduction in the veterinary and medicinal costs were small in Hokkaido. Therefore, the total economic value per herd-life length was smaller in Hokkaido than in the other regions.

3.3 | Relative economic weights

The LPCS data (Statistics Bureau, 2017) indicated that the average incomes from milk and calf sales between 2013 and 2015 were 26.62 yen in Hokkaido and 29.10 yen in the other regions. The incomes from milk sales, excluding calf sales, were 13.95 and 23.07 yen in Hokkaido and in the other regions, respectively. Hagiya et al. (2012) reported that the genetic standard deviations of herd-life length (σ_{GL}) and 305-day milk yield (σ_{GM}) were 139.5 days and 635.8 kg, respectively. In this study, the relative economic weights of milk yield to herd life per genetic standard deviation ($a_M\sigma_{GM}/a_L\sigma_{GL}$) were 0.668 in Hokkaido and 1.03 in the other regions, respectively, where a_L and a_M are the economic weights of herd-life length and 305-day milk yield, respectively. Matsuoka and Terawaki (2002) reported that in Hokkaido, in 1998, the $a_M\sigma_{GM}/a_L\sigma_{GL}$ value was 2.41, based on an average 305-day milk yield of 8,000 kg and an average herd-life length of 3 years. Furthermore, Byrne et al. (2016) estimated that the economic value of a 1% increase in survival rate was 8.84 Australian dollars, which was obtained by changing the structure of lactation number in the herd according to a 1% increase in survival rate. They also indicated that the $a_M\sigma_{GM}/a_L\sigma_{GL}$ values of milk yield, fat yield, and protein yield were −0.74, 1.14, and 3.37, respectively. Given that the $a_M\sigma_{GM}/a_L\sigma_{GL}$ values of the milk yield and milk carrier have been reported to range from 1.09 to 3.2 (Alleire & Gibson, 1992; Fuerst-Waltl, Fuerst, Obritzhauser, & Egger-Dannet, 2016; Komlósi et al., 2010), it is assumed that these values are affected by several factors. In this regard, it has been found that the $a_M\sigma_{GM}/a_L\sigma_{GL}$ value is small

TABLE 4 Differences in lifetime and annual reproductive traits, milk yield, income, and costs in relation to those registered at basal survival rate in Hokkaido

	Basal survival rate	Difference from basal survival rate									
		0.05	0.04	0.03	0.02	0.01	−0.01	−0.02	−0.03	−0.04	−0.05
Lactation number at removal	3.45	0.35	0.28	0.20	0.13	0.07	−0.06	−0.13	−0.18	−0.24	−0.30
Herd life (months)	45.4	4.7	3.7	2.7	1.8	0.9	−0.9	−1.7	−2.5	−3.2	−4.0
Lifetime milk yield (kg)	32,059	3,352	2,638	1,946	1,276	628	−608	−1,198	−1,769	−2,323	−2,860
Annual milk yield (kg/year)	8,468	6	5	4	3	2	−2	−4	−6	−9	−11
Revenue from milk sales[a] (yen/year)	272,579	194	170	138	99	53	−60	−126	−199	−278	−304
Revenue from calf sales (yen/year)	96,690	−155	−123	−92	−61	−30	30	59	88	117	145
Total annual revenue[b] (yen/year)	369,268	39	47	46	38	23	−30	−67	−111	−161	−218
Depreciation of cow (yen/year)	118,850	−11,175	−8,966	−6,744	−4,508	−2,260	2,272	4,555	6,849	9,153	11,467
Artificial insemination (AI) cost (yen/year)	11,895	8	7	5	3	2	−2	−3	−5	−7	−8
Veterinary and medicinal costs (yen/year)	23,732	−1,187	−949	−712	−475	−237	237	475	712	949	1187
Total annual cost[c] (yen/year)	154,477	−12,353	−9,909	−7,451	−4,980	−2,496	2,508	5,027	7,556	10,096	12,646
Lifetime income (yen)	813,184	136,177	107,119	79,010	51,811	25,486	−24,681	−48,589	−71,755	−94,208	−115,975
Annual income (yen/year)	214,791	12,392	9,556	7,497	5,018	2,519	−2,538	−5,094	−7,667	−10,257	−12,864

[a]This does not include revenue from calf sales, cow depreciation cost, and the costs of AI and veterinary and medicinal treatments. [b]Total annual revenue corresponds to the sum of the revenues from milk and calf sales. [c]Total annual cost corresponds to the sum of cow depreciation cost, AI cost, and veterinary and medicinal treatment costs.

TABLE 5 Differences in lifetime and annual reproductive traits, milk yield, income, and costs in relation to those registered at basal survival rate in regions other than Hokkaido

	Basal survival rate	Difference from basal survival rate									
		0.05	0.04	0.03	0.02	0.01	−0.01	−0.02	−0.03	−0.04	−0.05
Lactation number at removal	3.23	0.26	0.21	0.15	0.10	0.05	−0.05	−0.10	−0.14	−0.19	−0.23
Herd life (months)	43.3	3.5	2.8	2.1	1.4	0.7	−0.7	−1.3	−1.9	−2.5	−3.1
Lifetime milk yield (kg)	31,665	2,643	2,088	1,546	1,017	502	−490	−967	−1,433	−1,887	−2,331
Annual milk yield (kg/year)	8,775	13	11	8	6	3	−3	−6	−9	−12	−16
Revenue from milk sales[a] (yen/year)	345,228	515	421	322	219	112	−116	−235	−358	−485	−616
Revenue from calf sales (yen/year)	53,854	−22	−17	−13	−8	−4	4	8	12	15	19
Total annual revenue[b] (yen/year)	399,082	494	404	310	211	107	−112	−227	−347	−470	−597
Cow depreciation value (yen/year)	109,195	−8,265	−6,629	−4,985	−3,331	−1,670	1,678	3,364	5,057	6,758	8,466
Artificial insemination (AI) cost (yen/year)	13,005	−3	−2	−2	−1	−1	1	1	2	2	2
Veterinary and medicinal costs (yen/year)	28,229	−1,412	−1,129	−847	−565	−282	282	565	847	1,129	1,411
Total annual cost[c] (yen/year)	150,428	−9,679	−7,760	−5,833	−3,897	−1,953	1,961	3,929	5,905	7,889	9,880
Lifetime income (yen)	897,266	113,185	89,356	66,142	43,524	21,483	−20,943	−41,363	−61,277	−80,701	−99,649
Annual income (yen/year)	248,654	10,172	8,164	6,142	4,108	2,060	−2,072	−4,156	−6,252	−8,359	−10,477

[a]This does not include revenue from calf sales, cow depreciation cost, and the costs of AI and veterinary and medicinal treatments. [b]Total annual revenue corresponds to the sum of the revenues from milk and calf sales. [c]Total annual cost corresponds to the sum of cow depreciation cost, AI cost, and veterinary and medicinal treatment costs.

TABLE 6 Economic weight of survival rate (EWR), economic weight of herd life (EWL), and relative economic weight (REW)

	Hokkaido			Other regions		
	EWR (yen/%)	EWL (yen/day)	REW (%)	EWR (yen/%)	EWL (yen/day)	REW (%)
Income from milk sales[a]	56.0	2.09	2.15	113.2	5.57	5.45
Income from calf sales	−30.0	−1.13	1.16	−4.0	−0.20	0.19
Cow depreciation cost	2,264.8	85.33	87.46	1,673.3	82.48	80.71
Artificial insemination (AI) cost	1.6	−0.06	0.06	0.5	0.03	0.03
Veterinary and medicinal costs	237.3	8.94	9.17	282.3	13.92	13.62
Annual income	2,526.4	95.18	–	2,065.3	101.80	–

[a]This does not include the revenue derived from calf sales, cow depreciation costs, and costs of AI, veterinary, and medicinal treatments.

if milk yield and cow depreciation costs are high, and large if herd-life length is long (Alleire & Gibson, 1992; Matsuoka & Terawaki, 2002). In 1998, the income from milk sales, excluding calf sales, in Hokkaido and in the other regions, was 25.43 and 27.10 yen, respectively (Table 7). These values are higher than those obtained for 2013–2015. All other parameters in 1998 also differed from those in 2013–2015. These differences can be explained in terms of the differences in the economic conditions between 1998 and 2013–2015. When data related to the economic conditions prevailing in 1998 were assessed in this study, we found that the magnitude of the increment in income was 59.79 yen in Hokkaido (R^2 = 0.997) and 77.70 yen in the other regions (R^2 = 0.998). These values are smaller than those obtained in 2013–2015. The $a_M\sigma_{GM}/a_L\sigma_{GL}$ values obtained in 1998 were 1.94 in Hokkaido and 1.59 in the other regions, and the value for Hokkaido was similar to that obtained by Matsuoka and Terawaki (2002). These results indicate that the smaller $a_M\sigma_{GM}/a_L\sigma_{GL}$ values in recent years can be attributed to an increase in the relative economic weight of the survival rate of cows. The depreciation in the cost of cows accounted for 87.5% and 80.7% of the economic value of herd-life length in Hokkaido and in the other regions, respectively (Table 6). Thus, the increment in the economic value of herd-life length is due to an increase in the depreciation of the cost of cows in recent years (Figure 4). However, over the past 6 years, variance in the depreciation of the cost of cows has been small, and thus, the economic value of herd-life length has been stable.

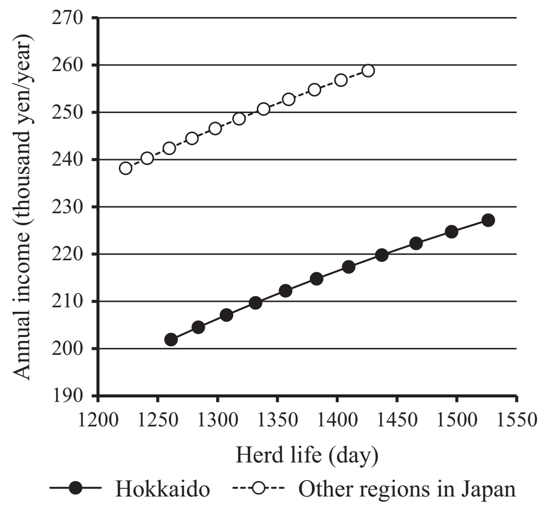

FIGURE 3 Relationships between herd life and annual income

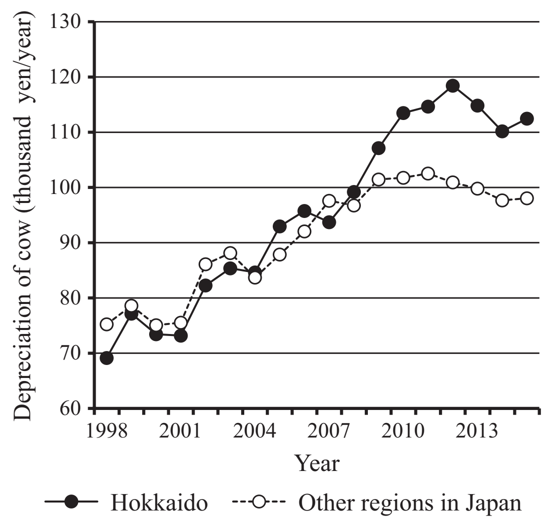

FIGURE 4 Changes in cow depreciation value

3.4 | Economic effect of genetic selection by herd-life length

The genetic gain per generation (ΔG) was calculated using the equation $\Delta G = i\sigma_p h^2$, in which σ_p is the phenotypic standard deviation, h^2 is heritability, and i is selection intensity. When 10% of young sires are selected, i corresponds to 1.755. Hagiya et al. (2012) reported that σ_p and h^2 of herd-life length were 482.2 days and 0.08367, respectively. When the generation interval between sires was 7 years, ΔG/year was estimated as 10.11 days. When young sires were selected according to the genetic ability for herd-life length, the estimated economic values of ΔG/year were 963 yen and 1,030 yen in Hokkaido and in the other regions, respectively. Although the economic value of herd-life length in Hokkaido was smaller than that in the other regions, the difference was small. Hagiya et al. (2012) reported that the σ_p and

TABLE 7 Parameters for estimation of economic weight of herd life (EWL) from Japan cattle in 1998

Parameter	Hokkaido	Other regions
Income from milk sales[a] (yen/kg)	25.43	27.10
Calf sale price (yen)	27,486	37,108
Cow depreciation value (yen/year)	69,135	75,229
Artificial insemination (AI) cost (yen/occurrence)	4,490	4,470
Veterinary and medicinal costs (yen/year)	13,848	18,303
Herd-life length[b] (month)	40.2	50.1
305-day milk yield[b] (kg)	8,457	8,788
EWL (yen/day)	59.79	77.70

[a]This does not include the revenue derived from calf sales, cow depreciation costs, and costs of AI, veterinary, and medicinal treatment. [b]Herd-life length and 305-day milk yield as in Matsuoka and Terawaki (2002).

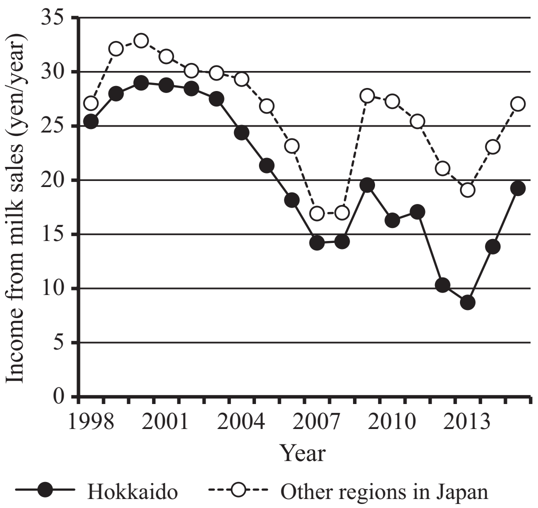

FIGURE 5 Changes in income derived from milk sales. The income does not include the revenue derived from calf sales

h^2 of the 305-day milk yield were 1,115 kg and 0.325, respectively. Therefore, the expected value of ΔG according to selection based on the genetic ability for 305-day milk yield was 636 kg, and thus ΔG/year was 90.9 kg. When the young sires were selected based on the genetic ability for 305-day milk yield, the estimated economic values of ΔG/year were 1,268 yen in Hokkaido and 2,097 yen in the other regions. This difference in the economic values of herd-life length and 305-day milk yield was large in regions other than Hokkaido. After 2003, there was a decrease in the income derived from milk sales, excluding the revenue derived from calf sales, but increased from 2014 onward (Figure 5). In 2015, the incomes derived from milk sales, excluding the revenue derived from calf sales, were 19.25 yen and 27.04 yen, and the economic values by selection based on the genetic ability for 305-day milk yield were 1,750 yen and 2,458 yen in Hokkaido and in the other regions, respectively. The economic weights of herd life were 95.7 and 102.7 yen/day in Hokkaido and in the other regions, respectively, and these were recalculated by using the parameters in 2015. Under these conditions, $a_M\sigma_{GM}/a_L\sigma_{GL}$ values were estimated as 0.92 and 1.20 in Hokkaido and in the other regions, respectively. Because the economic value of herd-life length is assumed to have been stable in recent years, there would have been an increase in the relative economic importance of milk yield.

In this study, it was necessary to consider whether to assess the total index for selection of dairy cattle by region, owing to differences in the $a_M\sigma_{GM}/a_L\sigma_{GL}$ values between Hokkaido and the other regions. In some countries, several types of total indices are used for selection purposes (Byrne et al., 2016; Gay et al., 2014; Miglior et al., 2005). Accordingly, it would be important to consider evaluating the utility of applying different total indices to the various selection targets of farmers. However, we considered that the selection responses determined using different total indices would not differ substantially among the different regions assessed because the economic values of herd-life length were similar between Hokkaido and the other regions. Moreover, we believe that the total selection responses would be restricted because the domestic dairy herd for breeding would be divided into small dairy herd groups according to total index-based selection in each herd. Therefore, in terms of total index selection, the selection response of other traits related to the total index needs to be taken into consideration in further studies.

4 | CONCLUSION

In this study, we detected a linear relationship between herd-life length and economic value in response to simulated changes in survival rate. Accordingly, the economic value per herd-life length could be estimated from the regression coefficients between these factors. The method used to estimate the economic value of herd-life length described in this study will be useful for refining total selection index assessments.

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