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Release Strategy for the Red Fox (*Vulpes vulpes*) Restoration Project in Korea Based on Population Viability Analysis[1]

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개체군 생존력 분석을 이용한 여우복원사업 방사 전략[1]

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ABSTRACT

The red fox (*Vulpes vulpes*), listed as a Class I endangered species by the Ministry of Environment of Korea, has been considered to be extinct in South Korea since the 1980s, and an intensive restoration project has been underway in Sobaeksan national park. This study was carried out to develop a suitable model for the red fox reintroduction program based on Population viability analysis (PVA) by using the VORTEX program. If 10 animals (5 females and 5 males) were continuously released into the initial zero population every year for 10 years, population growth rate and extinction probability over the next 50 years after the introduction of the population were 0.018±0.204 and 0.354, respectively; the maximum population size was 116.34 at the 16th year after the first release, and a reduction rate of 1.22 every year from the 17th year was inferred. We found that additional releases would be needed from the 17th year after the initial release to maintain a positive growth rate and to prevent the extinction of the released red foxes, and releasing more than 12 individuals every year would be needed for the long-term, continuous existence of red foxes. By contrast, if fewer than 6 red fox individuals were released the extinction probability over the next 50 years was more than 80%. To maintain the minimum population growth rate, the release of more than 8 individuals were needed for positive population growth. The population growth rate was more stable when 10 animals in the change of their sex rate every year from the set value were released as the female-to- male sex ratio of 6:4 rather than 1:1. However, if the female-biased sex ratio was increased by more than 7:3, a negative population growth was expected. The occurrence rate of roadkill and poaching are important factors in the red fox restoration project. The extinction probability was decreased to 30% if each factor was decreased to 3% based on the standard baseline; however, if each factor was increased to more than 3%, an extinction rate of about 90% was reached over the next 50 years.

KEY WORDS: ENDANGERED SPECIES, PVA, REINTRODUCTION PROGRAM, VORTEX

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요 약

여우는 한국에서 1980년대 이후로 절멸된 것으로 취급하고 있으며, 현재는 환경부에서 멸종위기 1급 동물로 지정되어 소백산국립공원에서 복원사업이 이루어지고 있다. 본 연구에서는 여우복원사업에 필요한 적정 모델링과 방사 전략을 수립하기 위하여, VORTEX 프로그램을 이용한 개체군 생존력 분석(Population viability analysis: PVA)을 수행하였다. 초기 개체군 0에서 매년 10개체(암5, 수5)를 향후 10년간 지속적으로 방사할 경우, 개체군의 이입으로 50년간 개체군 성장률은 0.018±0.204였으며, 절멸확률은 0.354로 나타났다. 최초 방사 후 16년차에 116.34로 최대 개체군 크기를 보였으나, 17년차부터 매년 1.22의 감소율을 나타내었다. 방사된 여우의 지속적인 성장과 절멸을 방지하기 위해서는 최초 방사 17년 이후 추가적인 방사가 필요하며, 장기적인 여우 존속을 위해서는 매년 12개체 이상을 방사하는 것이 필요한 것으로 분석되었다. 반면 연간 6개체 이하일 경우 50년 후의 절멸 확률은 80% 이상으로 나타났으며, 최소한의 개체군 성장을 위해서는 8개체 이상의 추가 방사가 필요한 것으로 나타났다. 설정된 조건값에서 매년 10개체씩 암수의 성비를 변화하여 6:4 로 10년간 방사할 경우 1:1 비율보다 안정적인 개체군 성장률을 보였으나, 암컷의 비율이 7:3이상으로 높아질 경우 부정적인 결과를 보였다. 재난요인으로 설정된 road-kill과 밀렵은 여우복원사업의 성패에 중요한 요인으로 확인되었다. 초기 적용값을 기준으로 각각의 요인이 3% 감소할 경우에는 절멸 확률은 30%로 낮아졌으며, 3% 이상 증가할 경우 50년 후의 절멸 확률은 약 90%에 이르는 것으로 분석되었다.

주요어: 멸종위기종, 재도입 프로그램, PVA, VORTEX

INTRODUCTION

The red fox(*Vulpes vulpes*) is a carnivore that belongs to the family Canidae in the order Canivora(Kang and Song, 2010) and is widely distributed in Eurasia, northern Africa, and America(Yu *et al*., 2012). Red foxes were distributed throughout the Korean peninsula in the past but have been considered to be extinct since 1980 because of secondary poisoning from a nationwide rodenticide program as well as habitat loss and fragmentation(Won and Smith, 1999; Shin, 2009; Yu *et al*., 2012). Thus, the Korean red fox has been categorized as and endangered species by the Ministry of Environment, Republic of Korea(Yu *et al*., 2012).

In recent years, numerous efforts to restore endangered species have been initialed around the world, and the number of carnivore reintroductions, in particular, has increased along with a gradually increasing social interest in conservation(Breitenmoser *et al*., 2001; Waters, 2010). The swift fox(*Vulpes velox*) reintroduction program is one example of a successful restoration project worldwide, and around 900 animals have been released in Canada over the past 15 years(Waters, 2010). Another example is the lynx(*Lynx canadensis*) reintroduction program, in which 166 animals were released in Canada from 1999 to 2004 and which continues today(Nova Scotia Department of Natural Resources, 2007). Although restoration projects are occasionally criticized as being too expensive in the initial stages because animals are costly and mortalities can be high, evaluations are often favorable with high survival and reproduction rates(Bremner-Harrison and Cypher, 2007). Furthermore, restoration programs are currently underway for various animals throughout the world: the red wolf(*Canis rufus*), American black bear(*Ursus americanus*), and Louisiana black bear(*Ursus americanus luteolus*) in the USA; the South China tiger(*Panthera tigris*), wild horse(*Equus ferus*) and ibis(*Nipponia nippon*) in China; the otter(*Lutra lutra*) and ibis(*Nipponia nippon*) in Japan; and the brown bear(*Ursus arctos*) in Poland (Ministry of Environment of Korea, 2012).

Red foxes have been studied extensively in a variety of habitats in several countries(Ables, 1975; Lariviere and Pasitschniak-Arts, 1996; Papakosta *et al*., 2010), but in the wild forests of Korea, these animals have been rarely found since the 1960s. Documents show that a male red fox was captured at the Demilitarized Zone(DMZ) in 1976, and another individual was captured in Jirisan national park in southern South Korea in 1987 and in Yang-gu in Gangwon-do in 1980. In relatively recent years, the carcass of what could be a red fox was found in Gangwon-do in 2004, indicating a high possibility that wild red foxes exist in the wild habitats of Gangwon-do.

In South Korea, which consists of 63% forest, carnivores occupy important positions as umbrella species, and the highest classes of consumers or predators have very important positions in the forest ecosystem(Ministry of Environment of Korea, 2006). Mammals such as the Asiatic black bear(*Ursus thibetanus*), Amur goral(*Naemorhedus caudatus*), red fox(*Vulpes vulpes*), and musk deer(*Moschus moschiferus*) have been especially threatened with extinction because of human activities such as overhunting and illegal poaching. Cooperation between relevant agencies and active proliferation and restoration efforts should be required to restore species that lose self-sustainability in the wild and to restore the health of the ecosystem. In addition, methodological approaches such as viability analyses of populations and habitats and selection of release sites that minimize human impacts should be developed(Ministry of Environment of Korea, 2006). An exact assessment analysis should be conducted to determine how much a target species is exposed to the danger of extinction and how many individuals should be released to restore the endangered species. According to the International Union for Conservation of Nature(IUCN) guidelines for reintroductions (IUCN, 1998), the growth of the released population should be modeled under various conditions to determine the optimal number and composition of individuals to be released per year and the number of years necessary to promote establishment of a viable population.

Population viability analysis(PVA) will help identify significant environmental and population variables and assess their potential interactions, and the results can be used as a guideline for the management of long-term populations(IUCN, 1998). Many countries have established conservation strategies for certain species using habitat-suitable models and PVA for the protection and restoration of endangered species(Shin, 2009). VORTEX, one of the most widely used programs for PVA(Lindenmayer *et al*., 1995), would be suitable to model short- and long-term population variables using factors that could affect the reintroduced population. Until now, the VORTEX program was used for PVA in studies of the Przewalski's gazelle (*Procapra przewalskii*)(Li and Jiang, 2002), giant panda (*Ailuropoda melanoleuca*)(Wei *et al*., 1997), spiny rat (*Trinomys eliasi*)(Brito and Figueiredo, 2003), island fox(*Urocyon littoralis*)(Kohlmann *et al*., 2005), and swift fox(*Vulpes velox*)(Moehrenschlager *et al*., 2006). In Korea, the master plan for the red fox program was established by the Ministry of Environment in 2009, and in 2011, facilities were built as part of the restoration program to recover extinct red foxes. In 2012, a restoration project was initiated in Sobaeksan national park using red foxes from the national zoo and red foxes introduced from China.

Since animals of the family Canidae, including the red fox, generally adapt well to various environments and have good fecundity in nature, the red fox restoration project currently in progress would be successful using specific data and long-term release information based on the data. Population growth modeling through PVA can be used to establish detailed plans and methodical bases for red fox restoration, and simulation results can be used to predict restoration project goals. Although various parameters that could affect red fox habitats should be used to assess PVA for red fox restoration, such studies have been poorly conducted in Korea, and ecological data have been collected from only a few red foxes in captivity at the Red Fox Restoration Center. Despite the limited data available for ecological studies, PVA modeling and long-term ecological data collection are needed to minimize errors and to implement the current long-term restoration project.

The purpose of this study was to predict population variation in released foxes in Korea and to determine factors for increasing their survival rate. The results of this study will be used to establish strategies for the initial stage of the current red fox restoration project.

MATERIALS AND METHODS

1. Study area

The study was conducted in Sobaeksan national park (~36° 50' to 37° 4' N, ~128° 21' to 128° 43' E) located between Young-ju City, Gyeongsangbuk-do, and Dan-yang, Chungchungbuk-do(Figure 1). Korea national parks are well-known ecological areas where more than a half of the species found in Korea are protected from human interference and disturbance. In addition, each national park has a management office that manage the park district and protects it from illegal hunting, harvesting of forest products, and degradation of wild animal habitat.

The Ministry of Environment and Korea national park service selected Sobaeksan national park as the most suitable area for red fox restoration, based on risk assessment, abundant food resources, and several other factors(Kang and Song, 2010). Sobaeksan national park(area of 323.383 ㎢) is located in the center of South Korea, and food resources for red foxes are relatively abundant compared with other nearby national parks(Kang and Song, 2010).

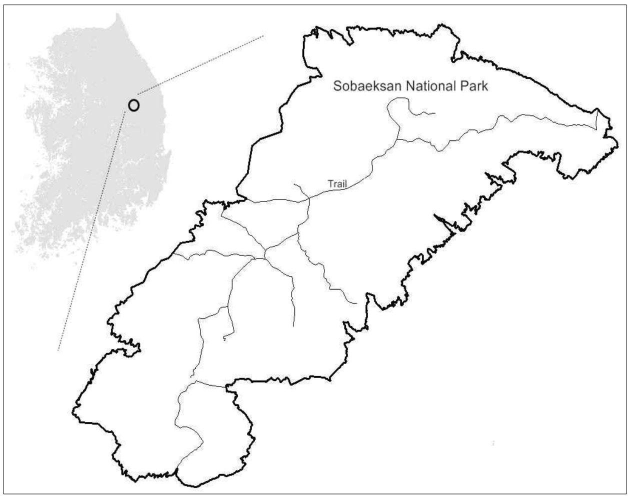

Figure 1. The map of Sobaeksan national park, Korea

2. PVA simulations

The VORTEX(Lacy, 1993, version 9.99) simulation software package was used for the PVA of the fox population in this study. And VORTEX has been used to study random variables influencing the relationships between the life history of target species and their populations and can test the sensitivity of the population by changing statistical and habitat variables(Cheong *et al*., 2009).

Many studies using PVA computer modeling so far have set the simulation period at 100 years(Fuwei *et al*., 1997; Kohlmann *et al*., 2005; Haines *et al*., 2006), possibly because they are based on previous investigations or known minimum parameter factors. However, for this study of red fox extinction in Korea, no established parameters were available. The restoration project began with the reintroduction of red foxes by the Ministry of Environment and Korea national park Service in 2012. Because of the rapidly changing environment in Korea, development of a long-term master project for sustainable restoration of the red fox was based on short-term modeling. We used 1000 iterations to model a 50-year simulation period, with citations related to the input parameter. Restoration policies and release strategies were developed to ensure the viability of the population based on the released animals and sex ratio changes, and extinction of the red fox is defined as when one of both sexes remained. habitats and climates differ regionally, foxes are generally monogamous(Macdonald, 1979), and females are in estrus once a year(McIntosh, 1963; Ryan, 1976). Breeding occurs from December to April, and most mating occurs in January and February(Storm *et al*., 1965; Macdonald, 1979; Allen, 1984). We estimate that female red foxes usually begin breeding as yearlings(Allen, 1984) and can produce up to eight offspring(Weber *et al*., 1999), with a mean litter size of 4.5 offspring(Lariviere and Pasitschniak-Arts, 1996). The mortality rate based on the Canada swift fox as a reference, was set to 55% in first year and to 48% after 1 year(Moehrenschlager *et al*., 2006), and each of the variable changes was simulated to compare with differences in the sex ratios of annually reintroduced foxes or the numbers of released foxes.

Catastrophic factors affecting viability and mortality of the red fox were classified into two groups: roadkill and poaching(illegal traps). Mortality by roadkill was set to 15% by Snow *et al*.(2012), and mortality by poaching was set to 10% based on results of the Asiatic black bear restoration project in Korea. The numbers of red foxes provided yearly were based on the reintroduction of ten animals(five males and five females) in 2012 and five pairs of foxes added every year, for a total of 100 foxes in 10 years. We also calculated results in terms of release condition from a minimum of 4 to a maximum of 14 considering numbers of suitable releases and reintroductions as variables. Based on the extinction of the red fox in the study area, the initial population size of the restoration area was set to zero. Habitat carrying capacity(1.7 fox/㎢) of Sobaeksan national park was determined using calculations described by Voigt(1987)(Table 1).

Table 1. Summary of initial values for population viability analysis for the red fox in Sobaeksan national park, Korea

Parameter	Value	Source
Number of years	50	-
Extinction definition	Only one sex remaining	-
Initial population size	0	Extinction in Korea
Lethal equivalents	3.14	Ralls *et al*., 1988
Percent due to recessive lethals	50%	Ralls *et al*., 1988
Breeding system	Monogamous	Macdomald, 1979
Age of first offspring for female/male	1	Allen, 1984
Maximum age of reproduction	6	Sasmal, 2011
Maximum number of broods per year	1	Ryan, 1976
Maximum number of progeny per broods	8	Weber *et al*., 1999
Specify the distribution of number of offspring per female per brood	4.5	Lariviere and Pasitschniak, 1996
Percent adult females breeding	85%	Moehrenschlager *et al*., 2006
Monopolization of breeding	100%	Sasmal, 2011
Mortality rates from age 0 to 1	55%	Moehrenschlager *et al*., 2006
Mortality rates after age 1	48%	Moehrenschlager *et al*., 2006
Catastrophes	2	Road-kill, Poaching
Harvest	None	-
Supplementation (sex ratio)	100	Each F/M : 5 (Annual)
Carrying capacity (K)	190	Voigt., 1987

3. Sensitivity test

Mortality by artificial catastrophic factors including roadkill and poaching to test sensitivity was set to 15% and 10%, respectively, and population size was expected to vary according to a 1% increase or decrease from the baseline. The range of variability in management strength was calculated by a ±3% standard value, corresponding to the minimum or maximum, and minimum management requirements for policymaking and project establishment were estimated through a correlation analysis of the management strength of roadkill and poaching.

RESULTS

If 10 animals (5 females and 5 males) were continuously released into the initial zero population every year for 10 years, the 50-year period-average population growth rate of released red foxes in Sobaeksan national park was 0.018±0.204, and the extinction rate was 0.354(Table 2).

Population size was stabilized to 116.34, the highest number, 16 years after red foxes were released and then gradually decreased(Figure 2). Survival population size after 50 years decreased 1.22 in average population every year from the start of the decrease to 72.25. The result of the analysis of simulated population growth rate for 100 years with the previous set value was -0.014±0.217 which has a high probability of extinction(0.981), and the remaining population size for 100 years would be 20.42(Table 2). However, if two pairs of red foxes were reintroduced at the site more than twice every 5 years from the 17th year, the year that first showed a decrease, the

Table 2. Parameter estimates from PVA simulation for the mean Stochastic rate(Exponential growth, Mean, Stoc-r),the mean probability of extinction(PE), and the mean number of extant population size (N-ep) as the 50(the 50 year period simulation with the set value), 100(the 100 year period simulation with the set value), and after 17 years(the simulation of additional 2 pair release 2 times after 17th year with the set value). We ran 1000 iterations for all PVA scenarios.

	Stoc-r ± S.D.	PE	N-ep ± S.D.
For 50	0.018 ± 0.204	0.338	72.25 ± 52.19
For 100	-0.014 ± 0.217	0.981	20.42 ± 20.79
After 17	0.004 ± 0.098	0.018	124.04 ± 50.45

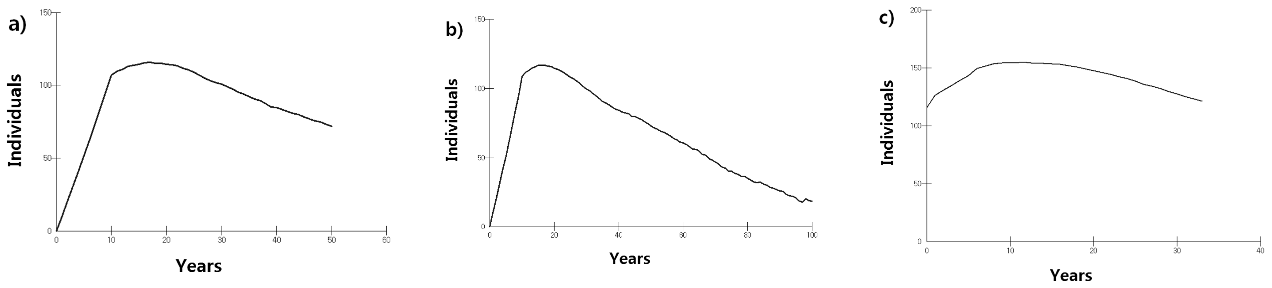

Figure 2. Estimate rates of stochastic rate for the red fox population size in Sobaeksan national park, Korea, using population viability analysis(a: The 50 year period simulation with the set value, b: The 100 year period simulation with the set value, c: The simulation of additional 2 pair release 2 times after 17th year with the set value)

population growth rate was 0.004±0.098, and the maximum number of animals and remaining population size after 50 years were 157 and 124, respectively(Table 2 and Figure 2).

PVA was modeled for 50 years and assessed variation in the released population with the set value to estimate the continued population growth and optimal release number. Release condition was set to a 1:1 sex ratio, and release period was set to continuation for 10 years. Release numbers were set from the minimum of 4 to the maximum of 14 considering the numbers of animals that were reintroduced and that self-proliferated in captivity.

Significant differences were found in the population growth rate($y=0.00048x-0.0286$, $r^2=0.887$, $F=31.60$, $p<0.01$)(Figure 3), extinction rate($y=-0.1003x+1.4108$, $r^2=0.977$, $F=174.36$, $p<0.001$), and remaining population size($y=9.3364x-23.75$, $r^2=0.982$, $F=222.71$, $p<0.001$) according to the numbers of red foxes released yearly (Table 3). If fewer than 6 red foxes were released annually, the population growth rate was zero or negative, the extinction probability after 50 years would be higher than 80%, and the remaining population size was estimated at fewer than 30 individuals. However, if 14 animals were released annually, the growth rate was 0.040±0.170, and the extinction rate was less than 0.066.

Sex ratios as well as release numbers at the release period appeared to be affected by PVA modeling ($F=131.48$, $p<0.001$). For a release under the basic condition, a 1:1 sex ratio, the population growth rate was 0.018, the

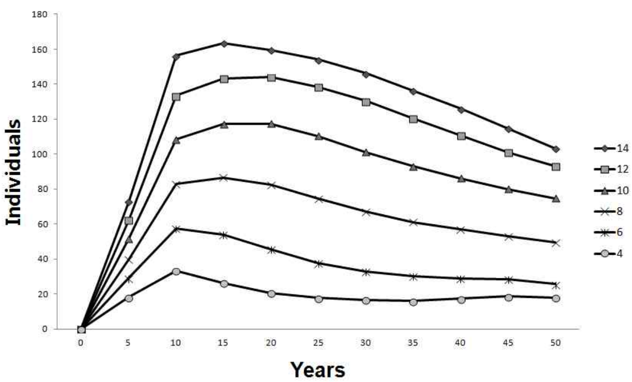

Figure 3. Estimate rates for stochastic rate as the number of supplementation

Table 3. Results of estimate rates for the mean Stochastic rate(Exponential growth, Mean, Stoc-r), mean probability of extinction(PE), and the mean number of extant population size (N-ep) as the released individuals (*p<0.01, **p<0.001)

Individuals	Stoc-r* ± S.D.	PE**	N-ep* ± S.D.
14	0.040 ± 0.170	0.066	103.37 ± 53.33
12	0.032 ± 0.183	0.176	93.23 ± 54.37
10	0.018 ± 0.204	0.338	72.25 ± 52.19
8	0.004 ± 0.232	0.587	49.44 ± 44.46
6	-0.008 ± 0.275	0.887	25.55 ± 28.57
4	0 ± 0.320	0.994	17.83 ± 17.12

Table 4. Results of estimate rate for the mean Stochastic rate(Exponential growth, Mean, Stoc-r), the mean probability of extinction(PE), and the mean number of extant population size (N-ep) as the sex ratio

Scenario	Sex ratio (female/male)	Stoc-r ± S.D.	PE	N-ep ± S.D.
1	1/1(baseline)	0.018 ± 0.204	0.338	72.25 ± 52.19
2	6/4	0.022 ± 0.198	0.281	74.83 ± 53.85
3	7/3	0.015 ± 0.203	0.391	70.08 ± 53.20
4	8/2	-0.001 ± 0.220	0.615	55.78 ± 48.77
5	4/6	0.007 ± 0.215	0.486	63.51 ± 52.71
6	3/7	-0.006 ± 0.230	0.679	52.92 ± 47.91
7	2/8	-0.021 ± 0.249	0.867	35.47 ± 35.14

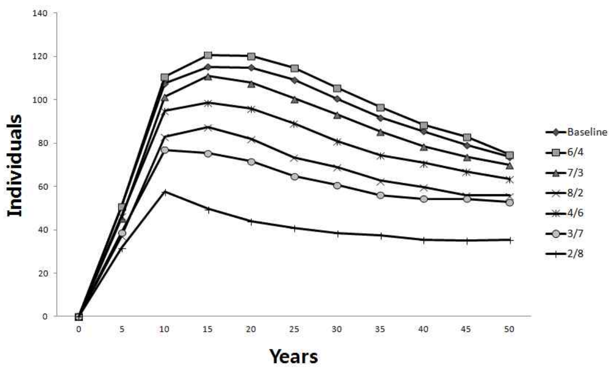

Figure 4. Estimate rates for Stochastic rate as the sex ratio(female/male)

extinction rate was 0.338, and the remaining population size was 52.19. However, if the female-to-male sex ratio was 6:4, the population growth rate was 0.022, the extinction rate was 0.218, and the remaining population size was 74.83, which means a stable population growth rate compared to the 1:1 sex ratio(Table 4). The growth rate and remaining population were decreased and the extinction rate was increased under an increasing sex ratio of 7:3(Figure 4). Conversely, the results were negative when the male-biased ratio was increased. Although the female-to-male sex ratio was set to 4:6, the growth rate was positive but decreased, and the extinction rate was increased in the opposite case. Although the sex ratio was 4:6, the growth rate was low and the extinction rate was

Table 5. Results of sensitivity analysis conducted for catastrophic factors(road kill and poaching /illegal hunting tool) in Sobaeksan national park, Korea, using population viability analysis. The baseline was set by 15% road kill and 10% poaching. The calculated values for the road kill and the poaching variable changes are the fixed condition of 10% and 15%, respectively

Catastrophes (2 Parameters)	H.E.P.	Stoc-r ± S.D.	PE	N-ep ± S.D.
Baseline	-	0.018 ± 0.204	0.338	72.25 ± 52.19
Road kill	12%	0.073 ± 0.157	0.029	160.51 ± 39.51
	13%	0.058 ± 0.167	0.071	138.43 ± 52.12
	14%	0.038 ± 0.185	0.174	105.46 ± 60.18
	16%	0 ± 0.227	0.558	45.55 ± 40.92
	17%	-0.014 ± 0.248	0.764	29.18 ± 30.75
	18%	-0.022 ± 0.262	0.901	18.15 ± 18.45
Poaching	7%	0.069 ± 0.160	0.033	153.80 ± 46.76
	8%	0.056 ± 0.167	0.071	133.75 ± 53.56
	9%	0.037 ± 0.185	0.167	102.12 ± 58.70
	11%	0.003 ± 0.224	0.506	49.05 ± 45.18
	12%	-0.013 ± 0.245	0.747	30.43 ± 30.34
	13%	-0.021 ± 0.261	0.896	19.67 ± 20.92

H.E.P.: Human effect parameter
Stoc-r, PE, and N-ep: $p<0.001$

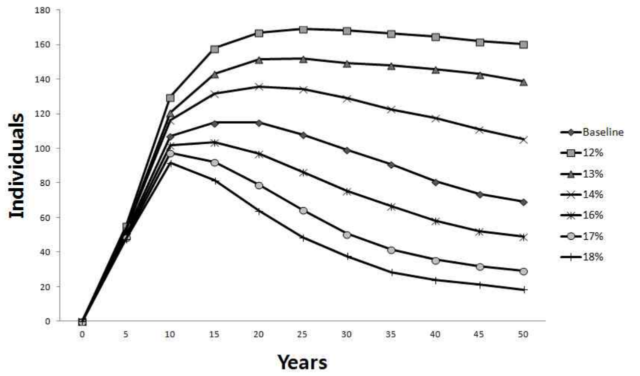

Figure 5. Estimate rates for Stochastic rate as the road kill(12~18%) over 50-year duration

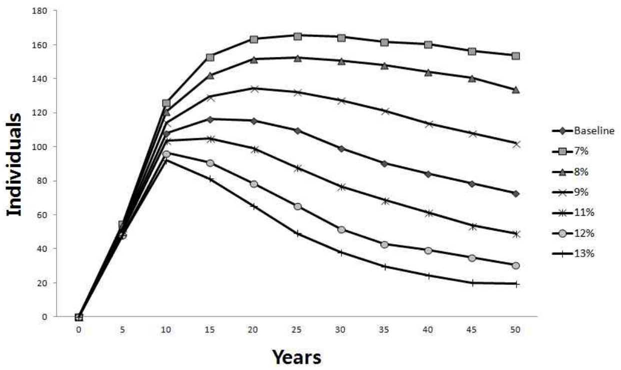

Figure 6. Estimate rates for Stochastic rate as poaching (the illegal hunting tools)(7~13%) over 50-year duration

high compared to the 1:1 sex ratio.

We performed a sensitivity analysis for habitat management using the catastrophic factors of mortality by roadkill and poaching. The results of the analysis showed a significant difference in the PVA modeling value between roadkill ($F=15.12$, $p<0.001$) and poaching($F=12.41$, $p<0.01$) depending on management strength(Table 5). The results

Table 6. Correlation of Stoc-r, PE, and N-ep as a function of catastrophic factors(road kill and poaching/illegal hunting tool) in the sensitivity analysis. Each of values was represented on average

Poaching (%)	Road kill (%)						
	Stoc-r						
	12	13	14	15	16	17	18
7	0.110	0.098	0.086	0.069	0.054	0.035	0.014
8	0.098	0.086	0.072	0.056	0.037	0.015	-0.002
9	0.088	0.072	0.054	0.037	0.017	-0.002	-0.015
10	0.073	0.058	0.038	**0.018**	0	-0.014	-0.022
11	0.057	0.039	0.021	0.003	-0.013	-0.022	-0.027
12	0.040	0.020	0.001	-0.013	-0.021	-0.027	-0.030
13	0.022	0.001	-0.012	-0.021	-0.026	-0.030	-0.032
	PE						
7	0.001	0.002	0.010	0.033	0.080	0.176	0.382
8	0.001	0.007	0.028	0.071	0.178	0.342	0.584
9	0.007	0.025	0.077	0.167	0.330	0.589	0.782
10	0.029	0.071	0.174	**0.338**	0.558	0.764	0.901
11	0.054	0.149	0.307	0.506	0.744	0.899	0.966
12	0.156	0.329	0.522	0.747	0.897	0.969	0.993
13	0.280	0.532	0.744	0.896	0.956	0.994	1.000
	N-ep						
7	184.15	181.05	172.97	153.80	129.13	96.18	64.97
8	180.78	173.55	156.67	133.75	102.79	64.41	44.43
9	173.70	157.35	129.60	102.12	66.66	44.99	28.65
10	160.51	138.43	105.46	**72.25**	45.55	29.18	18.15
11	134.28	103.83	75.11	49.05	30.03	21.89	11.94
12	108.83	77.28	46.38	30.43	19.36	13.23	5.43
13	75.36	46.73	32.84	19.67	14.86	4.83	0

Bold: The calculated for the baseline.

of estimated roadkill mortality by a 1% increase and decrease from the baseline showed that when 12% mortality was decreased to 3%, the population growth rate was increased from 0.018 to 0.073(Figure 5), and the extinction rate was reduced from 0.0338 to 0.029. When a roadkill mortality of 18% was increased to 3%, the growth rate was negative, and the extinction rate was more than 90%(Stoc-r; y=-1.6679x+0.2717, r^2=0.988, F=410.73, p<0.001, PE; y=15.664x-1.9446, r^2=0.968, F=155.77, p<0.001, N-ep; y=-2519.6x+459.3, r^2=0.977, F=216.48, p<0.001). If mortality from poaching was decreased to 7%, the population growth rate and remaining population size were increased from 0.018 to 0.069 and from 72.25 to 153.80, respectively(Figure 6). An extinction probability of approximately 90% occurred at a maximum of 13% in the poaching analysis. As a result, if the mortality rate from roadkill and poaching was increased to 3%, which is higher than the baseline, the extinction rate 50 years later was increased to 90%. However, if the mortality rate was decreased to 3%, which is lower than the baseline, the extinction rate was about 30%(Stoc-r; y=-1.5789x+0.1791, r^2=0.991, F=580.05, p<0.001, PE; y=15.286x-1.1346, r^2=0.964, F=134.92, p<0.001, N-ep; y=-2364.6x+316.62, r^2=0.982, F=276.42, p<0.001).

A correlation analysis of two types of variables was performed to assess minimum management of roadkill and poaching(Table 6). According to the stochastic rate analysis, when roadkill and poaching were increased to 2%, depending on the standard baseline, a negative growth rate appeared, and when roadkill increased to 1% compared to the baseline, the stochastic rate was zero.

DISCUSSION

The study showed that continuous reintroduction or active habitat management is necessary for a successful red fox reintroduction program. The 50-year population growth rate and extinction rate of released foxes in Sobaeksan national park averaged 0.018±0.204 and 0.354, respectively, and the population size was gradually decreased at the 17th year after the first release. Risk of extinction was high(0.981), with a negative growth rate applied to 100 standard years. This result shows that the possibility of extinction occurred eventually if no foxes were introduced because of isolation and fragmentation even though population size was initially kept at more than 100 foxes. However, if fewer than 2 pairs of red foxes were reintroduced at the site more than twice every 5 years from the 17th year, the year that first showed a population decrease, the population growth rate was 0.004±0.098, and the maximum population size and remaining population after 50 years were 157 and 124 animals, respectively. The extinction rate after additional introductions was 0.018, which is less than 2% of the standard baseline for species restoration(Fuwei *et al*., 1997). Our research shows that additional releases should be carried out under continuous population monitoring to ensure continued progress of the red fox reintroduction program.

Because additional release methods should have the same effect as introduction from another population in other areas, the release in Korea where red foxes are extinct must depend on introduction from other countries and self-proliferation in captivity. In addition, because habitats vary, movement and introduction must occur freely by population dispersal to ensure a long and successful red fox reintroduction program. Based on the results of this study, a detailed prediction of release population size and release period should be established through post-population monitoring.

Results of PVA modeling for 50 years showed a significant difference in the population growth rate based on the numbers of animals released annually through the changes in the releasing population. If fewer than 6 foxes were released every year for over 50 years, the extinction probability would be more than 80%, whereas if 14 foxes were released, the extinction rate would be lower. These results indicate that annually released red fox population size is a very important factor for maintaining a stable population growth. Therefore, to maintain a minimum extinction rate of 2%, at least 12 foxes must be released every year, and more than 8 animals must be released for extended population growth.

The result of the PVA showed that the population growth ratio was influenced by a female-biased sex ratio rather than by a male-biased sex ratio. If red foxes were released at a female-to-male sex ratio of 6:4, the growth rate was more stable than the growth rate at a sex ratio of 1:1; when the female-biased sex ratio was increased to 7:3, a negative effect on population growth was found.

If red foxes were released at a male-biased sex ratio of 4:6, the growth rate was positive but could not be compared with a sex ratio of 1:1; when the male-biased sex ratio was increased to 4:6, the growth rate was decreased, and the extinction probability was increased. As a result, in areas of Korea where the red fox has been introduced, the release of animals should be based on a standard female-to-male sex ratio rather than releasing a pair at the initial stage of the release period. When a red fox release strategy is established, the female-to-male sex ratio should be more than 1:1 but not more than 7:3.

The result of the sensitivity test showed that management for artificial threatening factors was closely related to the red fox reintroduction program and requires intensive oversight. With a 3% decrease in mortality by roadkill, the population growth rate was increased from 0.018 to 0.073, and the extinction probability was also decreased, whereas with a 3% increase, population growth rate was negative, and the extinction rate was more than 90%. When mortality by poaching was decreased to 3%, the population growth rate and remaining population increased from 0.018 to 0.069 and from 72.25 to 153.80, respectively, and if mortality by poaching was increased to 3%, about a 90% extinction probability occurred. These results show that when the occurrence probabilities of two catastrophes were decreased to 3% from a standard value, the extinction probability decreased to 30% and that when the occurrence probabilities were increased to 3%, the extinction probability for 50 years reached 90%.

The result of the correlation between two variables showed that there was a negative growth rate if each variable was increased to 2%. For roadkill, the Stoc-r value became zero even though the current baseline was increased to only 1%, and to maintain a 2% minimum extinction rate for species conservation, a decrease of more than 1% of the occurrence rate of each variable is necessary, according to the standard baseline of the catastrophe. When one of the catastrophes was decreased to 1%, the other was decreased to 3%, and a 2% decrease was necessary for each of the factors. For N-ep, to maintain more than 72.25 of an average remaining population after 50 years, each of the catastrophes must not be more than 1%, and a decrease of more than 3% of the occurrence probability of at least one of the two factors is needed to prevent a decrease in population size by one of two intensive factors such as roadkill and poaching.

The swift fox prefers gently rolling habitat with a visible prairie region in a small forest(Russell and Scotter, 1984; Cotterill, 1997). Based on these data, we conducted a red fox restoration program in the lower part of Sobaeksan national park in an area suitable for dens, in grasslands and prairies, in an area adjacent to forests, and in an area of high rodent density. We also considered the road, which is located within 5 km from the release site of the reintroduced foxes, even though there is no vehicle traffic. No scientific evidence or statistical data were available for red fox extinction factors in Korea. However, red foxes have been negativel affected by man-made factors such as traps, guns, and roadkills(Storm *et al*., 1976; Page, 1981; Harris and Smith, 1987; Allen and Sargeant, 1993; Takeuchi and Koganezaw, 1994; Lariviere and Pasitschniak-Arts, 1996), and these factors influence red fox habitat density(Sargeant, 1982; Lariviere and Pasitschniak-Arts, 1996; Alberta Swift Fox Recovery Team, 2007). The red fox survival rate in Japan has been decreased by intensive hunting pressures, which are known to be major factors in the reduction of average survival period(Yoneda and Maekawa, 1982; Lariviere and Pasitschniak-Arts, 1996). Although illegal poaching rarely occurs, poaching and hunting are strictly prohibited in the area of the restoration programs within Korea national parks. Regular patrolling and removal of illegal traps within the national parks districts are currently conducted by park rangers. However, roads outside of the national park are seldom patrolled by park rangers. Therefore, considering the distances of roads as main factors(Waters, 2010), we need to coordinate with local governments and communities to maintain current conditions.

The results of this study show that for species reintroduction and restoration, threatening factors within the habitat should be minimized, and the suitability of the release sites should be assessed before the release. Realistic monitoring is needed to verify the suitability of PVA(Cheong *et al*., 2009), and additional factors should be analyzed in terms of correlations between competition species(Akcakaya and Sjogren-Gulve, 2000). However, because of the lack of red fox studies in Korea, we performed PVA using variables from the results of previous studies in other countries. Thus, the baseline of parameters such as mortality, reproduction rate, and catastrophe could be different from our conditions. PVA simulation will require future monitoring and verification using local data and will result in the prediction and management of long-term population changes.

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