The Tsushima Leopard Cat (*Prionailurus bengalensis euptilura*): Population Viability Analysis and Conservation Strategy

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science and the Diploma of Imperial College London

September 2008

Acknowledgements

First and foremost, I would like to both acknowledge and sincerely thank my principal supervisor Dr. Tim Coulson and co-supervisor Dr. John Fa, for unwavering support and continued genuine interest in the project. I am also indebted to the Kyusyu Regional Office of the Japanese Ministry of the Environment, the Nature Conservation Department of Nagasaki Prefecture, and the Japan Wildlife Research Centre for allowing me to use previous monitoring data and reports on the Tsushima leopard cat. In particular, I am very grateful to Eri Nakajima, of the Japan Wildlife Research Centre, for providing me with up to date data.

Support from my old colleagues at the Tsushima Wildlife Conservation Centre is deeply appreciated, in particular Shinjiro Sasaki, Tsuyoshi Maeda, Syusaku Moteki, Hanae Yamamoto, and Yuichiro Ohya. I could not complete this project without their understanding and support.

I would also like to express my gratitude to Dr. Shinichi Hayama, Dr. Christopher Spencer, Tadashi Masuzawa, Hajime Ise, Kenichi Cho and Setsuko Nakanishi for valuable advice. In addition to this, support given by friends and family throughout the course of the project is deeply appreciated.

Finally, I am thankful to the people of Tsushima who taught me so much about practicing conservation on the ground and the difficulties associated with it - I cannot think of myself today without them.

Abstract

The Tsushima leopard cat (*Prionailurus bengalensis euptilura*) is a critically endangered species living on Tsushima Island, Japan. As an endangered species, it has been the focus of a conservation program, funded by the Japanese government, since 1995. The aims of this study are to (1) conduct a Population Viability Analysis of the Tsushima leopard cat with data that have already been collected, (2) evaluate the relative impact of current threats including road kill and illegal snare trapping, and (3) compare the performance of a range of scenarios, including reintroductions in the south of the island, to identify the conservation strategies most likely to increase population viability. Previous monitoring data from 1998 to 2006, collected by Nagasaki Prefecture are analyzed to determine the population trend. While the available data are highly fragmented, the research results suggest the population in the northern part of Kamijima is stable or may even be recovering. The trend for populations in the southern part of Kamijima and Shimojima could not be evaluated using existing data. Further research for understanding the population dynamics are needed for directing conservation program appropriately. Population Viability Analysis (PVA) - the use of quantitative methods to predict the likely future status of a population or a collection of populations (Morris and Doak, 2002) - plays an important role in this study.; it is frequently used in conservation biology for different purposes. Because of the uncertainties associated with input values for the required parameters, population viability was not defined. Nevertheless, sensitivity analyses were conducted to identify the most important parameters for population viability. Results suggest that the female mortality rate has the most significant impact on population viability. To conduct a more extensive PVA analysis requires a systematic monitoring program and more focused research. This would have the effect of are required to reducing parameter uncertainties. Based on the findings, it is suggested that even a simple PVA for sensitivity analysis using parameter 'guesstimates' could be of benefit to the leopard cat conservation program, especially during its early stages; however, the results should be carefully handled since their over-interpretation could cause confusion or misdirection of the program. In this respect, PVA users must know the limitations and assumption of their models.

Table of Contents

List of Figures and Tables

1. Introduction

1.1 General introduction to felidae and the conservation

Felidae is a biological family of cats. Out of sixteen mammal families in the order Carnivora, felids are regarded as the most strictly carnivorous. Although there are ongoing debates about how many species are in this family, .recent work suggests a minimum of 36 species (Nowell, 2002) and a maximum of 39 species (Wilson and Reeder, 2005), excluding domestic cats (*Felis catus*).

The IUCN Red List of threatened species is widely recognized as the most comprehensive, apolitical global approach for evaluating the conservation status of plant and animal species (IUCN, 2001). The list for the felidae family was revised for the IUCN Red List in 2004, and all 36 wild species statuses were reviewed (IUCN, 2004). 17 species (47%) of all are classified in the top 3 categories (Nowell, 2002, Table 1). This is much higher than the average of 28% for Carnivora (280 species), suggesting that cats are highly endangered as a taxa.

Table1: Classification of felid species on the 2004 IUCN Red List (Adapted and modified from Nowell, 2002)

Critically Endangered	Endangered	Vulnerable	Near Threatened	Least Concern
Iberian Lynx	Borneo Bay cat	Cheetah	Sand cat	Caracal
	Andean cat	Asiatic Golden cat	Oncilla	Jungle cat
	Tiger	Chinese Mountain cat	Eurasian lynx	Wildcat
	Snow leopard	Black-footed cat	Pampas cat	Jaguarundi
		Clouded leopard	Geoffroy's cat	Ocelot
		Guigna	Manul	Margay
		Lion	Jaguar	Serval
		Marbled cat	Cougar	Canada lynx
		Flat-headed cat		Bobcat
		Rusty-spotted cat		Leopard
		Fishing cat		Leopard cat
		African golden cat		
1	4	12	8	11

Debate over the taxonomy of sub-species is complicated; however, only 23 out of 210 sub-species (Wilson and Reeder, 2005) are assessed for the IUCN Red List. Distributions of each species are wide, and degrees of endangerment at sub-species and regional population levels are not well understood.

Wild cat populations need relatively large blocks of habitat and sufficient quantities of suitable wild prey as predators (Nowell, 2001). Both habitat and prey for cats have declined widely with the increasing pace of human population growth and development over the last century (Nowell, 2001). The big cats have been heavily persecuted because they are a danger to humans and livestock, and furthermore are targeted for their skins: some small cat species have been subject to heavy off-takes for the fur trade (Nowell, 2001).

Cat conservation programs, for example, for tigers and cheetahs, have been a symbol of single species conservation programs because of their charismatic characteristic and their role as top predators for local ecosystem function (e.g. flagship or umbrella species). Felids are typically chosen as priority species for conservation program because of the rarity and strong public interests.

However, there have been a debate on whether single species programs are contributing effectively to the conservation of the biota (e.g., Andelman and Fagan, 2007; Male and Bean, 2005); it is still one of the main policies for biodiversity conservation in many states.

1.2 Tsushima leopard cat

The Tsushima leopard cat (*Prionailurus bengalensis euptilura*, Figure 1), an isolated population of sub-species of the Amur leopard cat, is found on the Tsushima islands, Nagasaki prefecture, Japan. The leopard cat is categorized of least concern in the IUCN Red List (IUCN, 2004) at the species level; however, it is a critically endangered species on the Japanese Red List (Ministry of the Environment, 2007a) and is thus designated as a critically endangered species of Japan (Ministry of the Environment, 2008a).

Figure 3: Tsushima leopard cat (photo: Ministry of the Environment, 2007)

Although local residents knew of the existence of wild cats on Tsushima; the cat was first recorded to science as a distinct species by a British Zoologist, Thomas in 1908. Subsequently, it has been classified as a sub-species of the Amur leopard cat. Results from a genetic study suggests the population is differentiated from the leopard cats of Eurasia and has been isolated for approximately 100,000 years (Masuda, 1995).

The cats' coats are pale brown to tawny yellow, and there are usually four longitudinal dark brown bands and spots running from the forehead to behind the neck. Compared to other sub-species of leopard cat, the spots are not particularly clear and the winter fur coat is noticeably thicker.

Body weight ranges from 2.5 to 5.0 kg; making the leopard cat similar in size to domestic cats (*Felis Catus*) (Kiyonaga et al., 2008).

As with other sub-species, the Tsushima leopard cat is solitary, and the dispersal of juveniles starts at about 6 months of age, until they establish their home range. However, it is still not well understood at exactly what age territories are established.

1.3 Tsushima Island --- The habitat of the Tsushima leopard cat

The island of Tsushima is located about 49.5km from the Korean Peninsula and 138km from Kyusyu Island, Japan (Figure 2).

Figure 2: The Island of Tsushima, Google Earth (2008)

Tsushima has frequently been connected to Eurasia and the Japanese islands during past ice ages. The island finally became separated from the Korean peninsula after the last glacial period which ended between 10,000 and 15,000 years ago.

The Japanese government administers Tsushima Island as a single entity, although it consists of three separate islands divided by two canals; Ohfunakoshi-seto in 1670 and Manzaki-seto in 1900. To the north of Manzeki-seto is Kamijima, and to the south is Shimojima Natural migration between Shimojima and Kamijima has been limited or non-existent since 1670.

The total area of Tsushima is 696 km^2 (Kamijima: 449 km^2, Shimojima: 247 km^2). 89% of the island is privately owned; the remaining 11% has been granted protection, but protected areas are fragmented and scattered over the island.

Approximately 90% of the island is covered by mountainous woodland, with local livelihoods depending on natural recourses (e.g. forestry and Shiitake mushroom farming). The Tsushima leopard cat is primarily found in a patchy environment containing mountainous forest, waterside, seashore, and rice paddies and fields (Tajiri, 1996; Watanabe, 2001). Leopard cats also use the landscape managed by humans including afforested area and agricultural land (Tajiri, 1996; Watanabe, 2001).

1.4 Previous study of the Tsushima leopard cat

The ecology and population status of the Tsushima leopard cat have been studied by scientists from universities and government agencies since 1980's; they were mainly published in form of governmental reports and scientific papers. Sources include the population census conducted and reported by the Ministry of the Environment in 1986, 1997, 2005, rescue and mortality reports collected by the Tsushima Wildlife Conservation Center, annual monitoring program reports conducted by the Nature Conservation Department, Nagasaki Prefecture, and academic research mainly conducted by a Tsushima leopard cat research group of the University of Ryukyus, Kyusyu University, and Nagasaki University.

Data were assembled from previous work to evaluate population trend in recent 10 years.

1.5 Historical change in Population size and distribution

The first large-scale population census was conducted by two high school biology teaches, Yamaguchi and Urata, in the 1960's (1970). Although, this very first population census is ambiguous in some aspects, Yamaguchi and Urata confirmed that leopard cats existed throughout Shimojima and Kamijima. They estimated the population size as being approximately 250 to 300 individuals and concluded that the population would not experience drastic decline as long as habit quality was not substantially altered. Nonetheless the distribution of the cat declined following this initial survey. Three major population censuses were conducted in the 1980's, 1990's, and 2000's by the Ministry of the Environment (promoted from Environmental Agency in 2001), as shown in Table 2.

Table 2: Results from previous population censuses (Ministry of the Environment 2005)

	1980's	1990's	2000's
Population size (N)	98.3-140.5*	91.8-127.7**	83.6-114.5

**, ** The population size in 1980's and 1990's are re-estimated using the same data and analysis for standardizing the result. The population estimate was 88.8 to 126.1 for 1980's, and 65.7 to 85.4 for 1990's.*

These census results suggest that the population could have declined by 10% between the 1980's and the 1990's, and 9% for between the 1990's and the 2000's.

In terms of distribution change, the Shimojima population has shrunk drastically, and, currently, the population is focused nearly entirely in Kamijima (Figure 3).

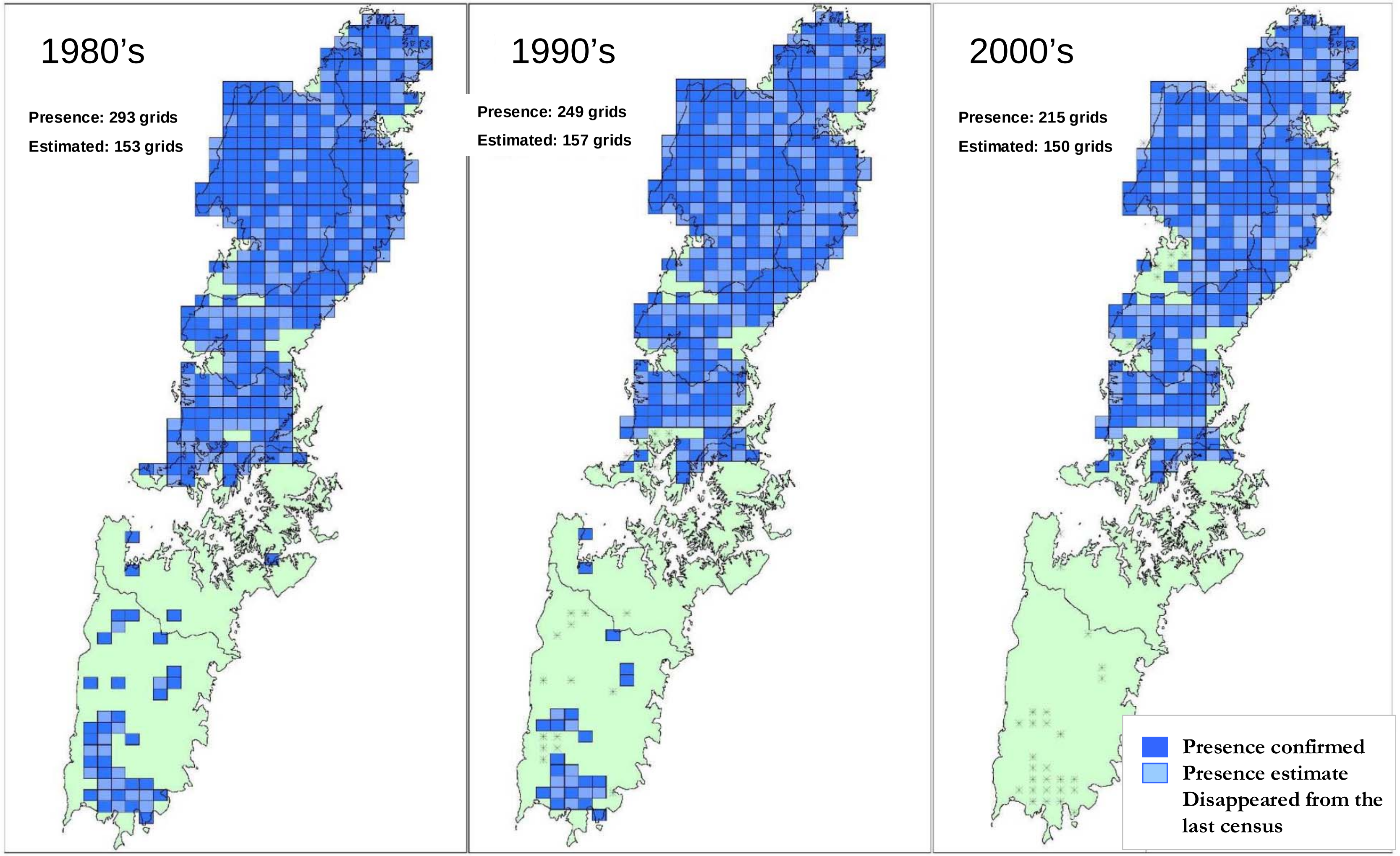


Figure 3: Change in Distribution from 1980's to 2000's (Ministry of the Environment 2005)

Although, some faeces were collected from Shimojima during the 1990's census, there is a possibility that they were from feral cats'. The only reliable evidence of the presence of the leopard cat on Shimojima was a road kill at Se, Izuhara in Shimojima in 1984, and camera traps in March and August 2007, and faeces sampled in May 2007 (Ministry of the Environment, 2007b) and August 2008 (Ministry of the Environment, 2008b). These faeces were confirmed as being from a Tsushima leopard cat using DNA analysis by Nagasaki prefecture. Data from 2007 and 2008 were collected from the same area where the leopard cat was first camera trapped in March 2007, so there is a possibility that they might belong to the same individual. Because the detection rate is very low, the population on Shimojima is likely to be small compared to the population on Kamijima.

1.6 Problem statement, aim and objectives

A population viability analysis (PVA) of the population was conducted as part of the Tsushima Leopard Cat Conservation Planning Workshop in 2006 using VORTEX (Murayama et al., 2006). The baseline model input values and results can be found in the Appendices, Section I. The results suggest that road kill may significantly impact the probability of persistence; however, mortality from foothold traps was not taken into account in this model.

Given concerns about the long-term decline of the population, and the apparent very small population in the south, there is an urgent need to analyze the possibility of reintroducing individuals on Shimojima, as well as running a PVA to help formulate a conservation strategy and identify future research priorities for the population.

The goals of this research are to:

1) Conduct a Population Viability Analysis of the Tsushima leopard cat with data that have already been collected.
2) Evaluate the relative impact of current threats including road kill and illegal snare trapping.
3) Compare the performance of a range of scenarios, including reintroductions in the south of the island, to identify the conservation strategies most likely to increase population viability.

2. Background

2.1 Population Viability Analysis (PVA)

Population Viability Analysis (PVA) was originally defined as any methodology used to determine Minimum Viable Population (Soule, 1987); however, this definition no longer adequately captures the expanding use of PVA in theoretical and the applied work. Based on more recent usage, PVA is arguably better defined as the use of quantitative methods to predict the likely future status of a population or collection of populations (Morris and Doak, 2002). It has been used in a variety of ways to address conservation problems: these uses are defined in part by data availability and theoretical and biological understanding, and in part by social, regulatory and political context (Burgman and Possingham, 2000).

The academic community has debated the predictive accuracy and the practical use of PVA in conservation planning (Brook et al., 2000; Burgman and Possingham, 2000; Coulson et al., 2001). Coulson *et al.* (2001) argues that "PVAs can only be accurate at predicting extinction probability if data are extensive and reliable, and if the distribution of vital rates between individuals and years can be assumed stationary in the future, or if any changes can be accurately predicted". Furthermore, too many factors that are likely to affect population viability are omitted by most PVA analyses (Morris and Doak, 2002). Furthermore, while PVA is increasingly recognized as a potentially powerful tool for comparing alternative conservation plans and relative extinction risks among species, caution in its use has been frequently advocated (Reed, 2002).

An alternative role for PVA is as a support tool for conservation management; this role does not invest so much confidence in the quantitative estimation of extinction risk, but rather focuses on the relative ability of different management decisions to provide acceptable conservation strategies (Possingham et al., 2002).

Reed et al. (1998) suggests PVA may be best used to raise questions and formulate hypothesis for future testing. It is also worth noting that a major reason for the increasing use of PVA is that no attractive alternatives have arisen, despite the criticisms raised (Brook et al., 2002).

2.2 Data assembly from previous Tsushima leopard cat and other small felid study

Nagasaki prefecture has been working on the population monitoring program since 1989. The annual reposts of monitoring program from 1989 to 2006 were the only available continuous data to get a hint of the population trend in yearly base. Research program between 1989 and 1997 were conducted in a very small scale, and the results were not sufficient to analyze the population trend. Data collected between 1998 and 2006 were used for this study.

The major aim of the monitoring program until 2005 was probably to understand the occupancy (Nagasaki prefecture, 2006); so that reason, the total number of census routes and camera trapping cites have been changed almost every year. These data sets were not sufficient to analyze detailed yearly population fluctuation; however, before conducting PVA, it was rather important to understand the rough population trend, whether the population is rapidly declining or relatively stable.

Since direct observation of the species is difficult for small felid, camera trapping and animal tracking on census routes have been the major research methods. Number of the camera trapping sites and census routes and the research period are summarized in Table 3.

Table 3: Number of camera trappings and census routes, research period between 1993 and 2006 (Nagasaki Prefecture).

Financial Year	Number of transect lines	Number of camera trapping sites	Time period
1993	10	2	November - March
1994	10	4	November - March
1995	8	6	October - March
1996	12	8	November - March
1997	9	9	November - March
1998	24	15	September -March
1999	24	20	September -March
2000	24	20	July - March
2001	20	22	April- March
2002	27	7	September - March
2003	30	7	April - March
2004	36	7	April - March
2005	36	6	April - March
2006	26	6	April - March

** Financial year in Japan starts on the 1st April and ends 31st March next year. For example, financial year 2006 starts 1st April 2006 and ends 31st March 2007.*

Although it is likely to be different compared to wild populations, studbook data of the Tsushima leopard cat captive population were used to obtain guess estimates of some parameters. The regional studbook of the Tsushima leopard cat was provided by the Ministry of the Environment for this study. A comprehensive analysis of an international studbook of leopard cat of mortality rata was also available (Kohler et al., 2006).

Demographic study of small felid in wild were not many (e.g. Haines et al, 2004; Haines et al., 2005; Gaona et al., 1998). Available published papers and reports were used to identify the demographic data for PVA model input values.

2.3 Threats

Izawa and Doi (1991) identified current and potential threats for the Tsushima leopard cat as (1) habitat destruction, (2) road kill, (3) introduced disease, (4) inter-specific competition with other carnivores, (5) domestic cats (disease, inter-specific competition, and hybridization), (6) predation from dogs, (7) introduced species, and (8) lack of awareness from local people.

Rescue and death records have been collected since 1992 by the Ministry of the Environment and Nagasaki prefecture. This record could contain biased information; for example road killed individuals are more easily discovered, for example compare to animals killed by disease. In addition to this, the distance of the Tsushima leopard cat from local communities may have an influence on whether mortality is reported by local people or not; nevertheless, rescue and death records do provide some guide to the predominant cause of mortality and injury, revealing that foothold trappings could be another factor to threat the population.

The rapidly growing wild boar population is also a potential concern for the leopard cat by influencing the pray availability. Wild boar lived on Tsushima until 1709, when the population became extinct after 9 years of intensive eradication. About 290 years later, a few wild boars were accidentally reintroduced on Shimojima and Kamijima; they have been expanding their distribution southwards and northwards (Chichibu, 1998); and wild boar are confirmed throughout Tsushima today (Tsushima Wildlife Conservation Centre, personal communication).

2.3.1 Habitat destruction

After the World War II, Tsushima has rapidly urbanized especially around two largest towns on Shimojima, resulting a big change of the lifestyle of local residents. Changes were happening not only in the urbanized area but also in the natural environment. Between the late 1950s and the 1990s, the Forestry Agency implemented a large-scale agro-forestry scheme to convert 41% of the natural forest in Japan into timberland dominated by a few species including Japanese cedar (*Cyrptomeria japonica*) and cypress (*Chamaecyparis obtusa*) (Agency of Forestry, 1995). 32% of the forest on Tsushima had been converted into the timberland by 1995 (Ai-research, 2006).

In general, leopard cats are capable of living near human settlement. Although the cat prefers forests, it is capable of surviving in secondary forest and successional vegetation (Sunquist and Sunquist, 1996). However, broad-scale habitat modification and forest clearance for agriculture, tea plantation, and exotic tree plantations are considered to be major threats to the leopard cat (Sunquist and Sunquist, 1996).

On Shimojima, the sizes of each section of the timberland are larger because the geography is less complex compared to Kamijima. Although it is not possible to attribute the decline of the leopard cat to any single factor in isolation, rapid habitat change due to forestry is suspected to be important factor (Izawa and Doi, 1991).

Agricultural development has increased in recent decades. The number of farmers on the islands has declined from 15,000 (1975) to 5,000 (2000), and the total area of agricultural fields has also been declining from 2900 ha in 1960 to 1000ha in 2000 (Ai-research, 2006). Rice paddies were traditionally built on natural marsh areas and are used as a wintering site and important resting sites during migration by migratory birds. Although the number of farmers and agricultural areas is declining, remaining rice paddies have been reformed, and an irrigation system has been installed for improving the productivity and efficiency. Semi-natural marshlands have been converted into dry fields, and as a result, the number of birds has been reduced significantly. One previous study shows that the Tsushima leopard cat depends on birds, especially in winter (Tatara and Doi, 1994).

2.3.2 Road kill

According to the records of the Tsushima Wildlife Conservation Centre, 41 animals were killed by cars since 1992, representing 61.2% of the total number of the recorded deaths (Figure 4).

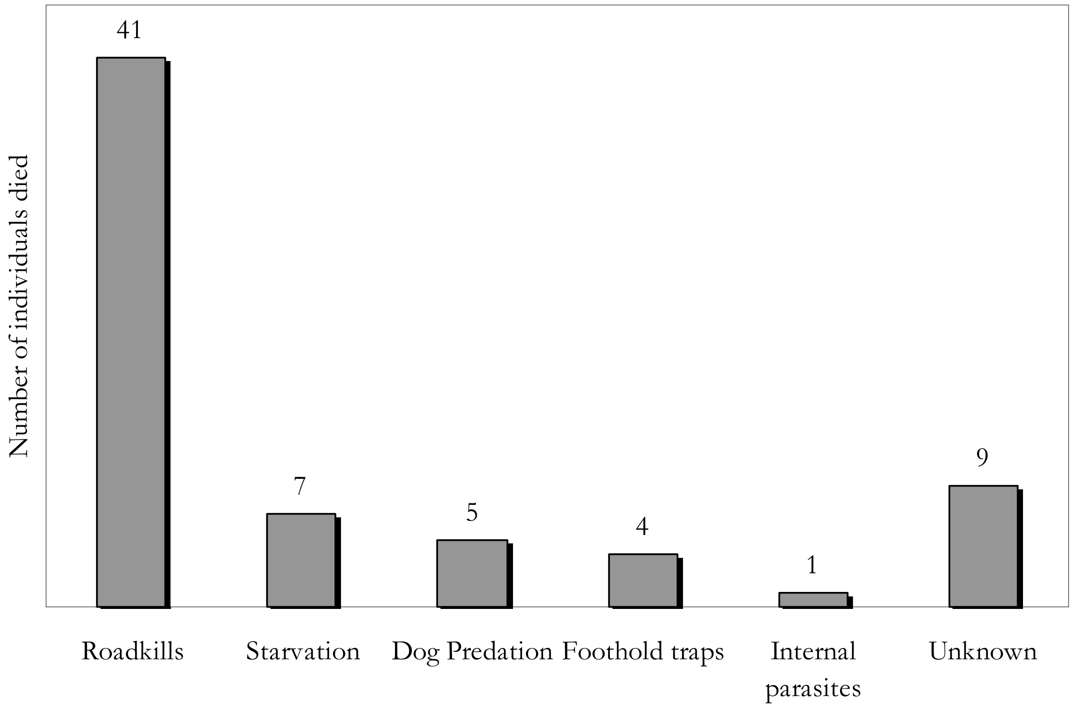


Figure 4: Cause of the mortality from 1992 to April 2008 (Ministry of the Environment, 2008).

As previously mentioned, road kill has been proposed as a major cause of leopard cat mortality. An increase in road kills could be attributed to an increase in the size of the leopard cat population or an increase in the number of cars and journeys.

Leopard cats begin to disperse from their mother's home range after age 6 or 7 months, eventually becoming independent. The number of road kills is highest in November and dispersing individuals have a higher chance of being killed on the roads (Figure 5).

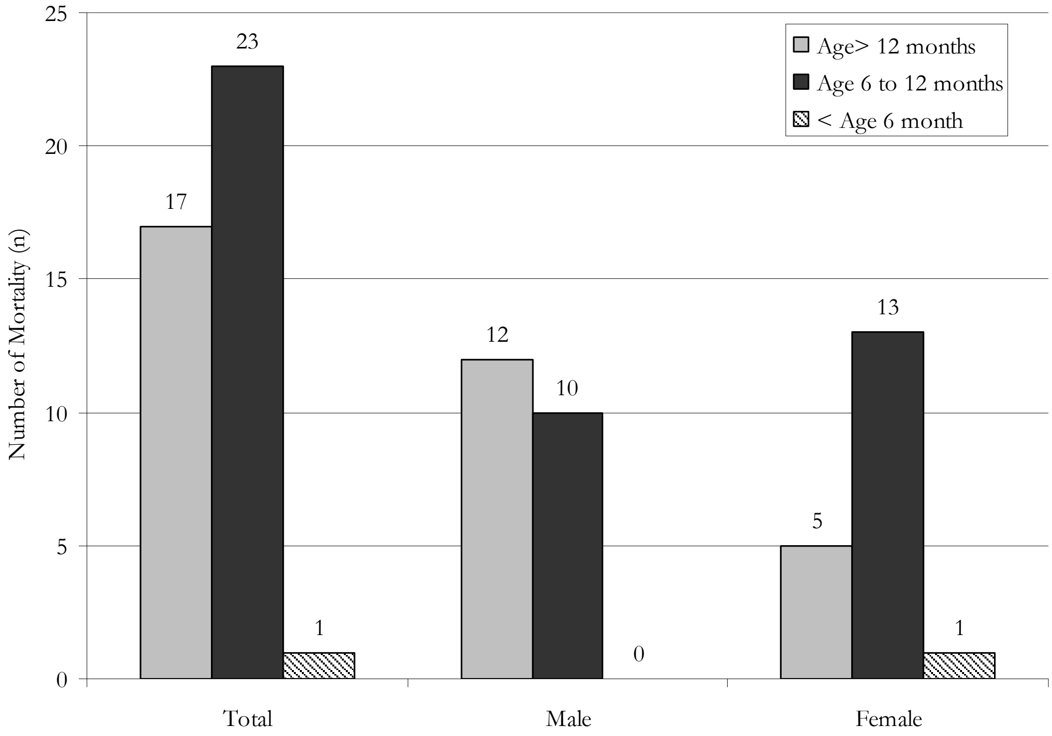


Figure 5: Age class and sex of individuals killed by cars.

** The age class is roughly estimated by the body size and time of the year when they are rescued.*

The average number of roadkills were 2.7 individuals per year (Adult: 0.3 female/0.8 male, Age<1: 0.9 female / 0.7 male) between 1992 and 2007 and been increasing overtime (Figure 6)

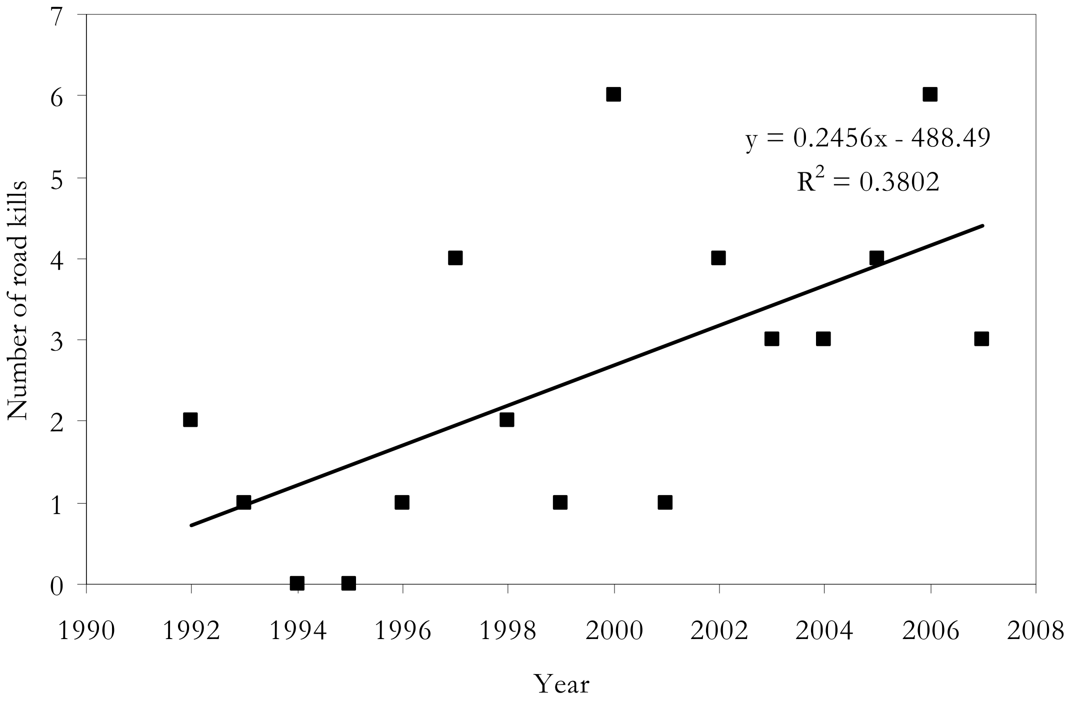


Figure 6: Regression of the number of roadkills reported between 1998 and 2007

This could be partly explained by that the promotion has increased the local awareness toward conservation and reporting rate is improved over time. However, there are more factors which could explain the increasing roadkills.

The human population has declined from approximately 50,000 individuals in 1975 to 38,000 in 2008 (Figure 7). Conversely, the number of cars registered in Tsushima has increased by 46.5 %, (from 17,712 to 25965 between 1990 and 2006), 811.42 cars per year (Figure 8).

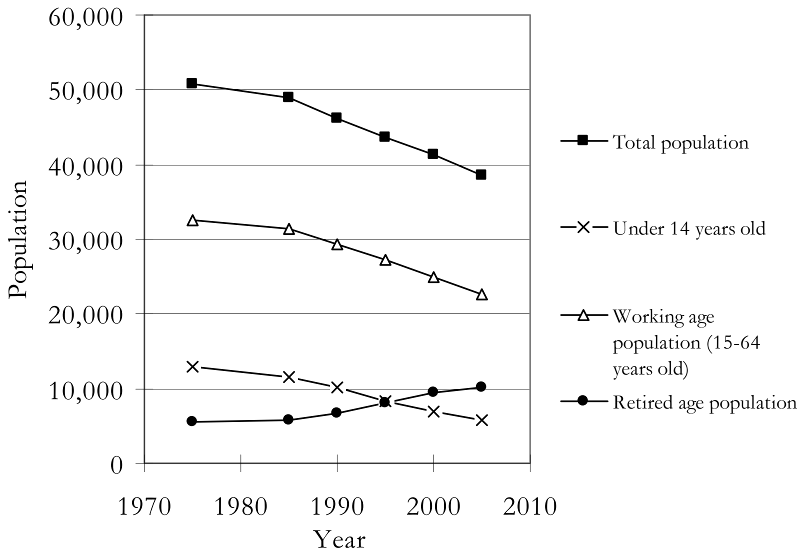


Figure 7: Human population changes in Tsushima (Tsushima City, 2008)

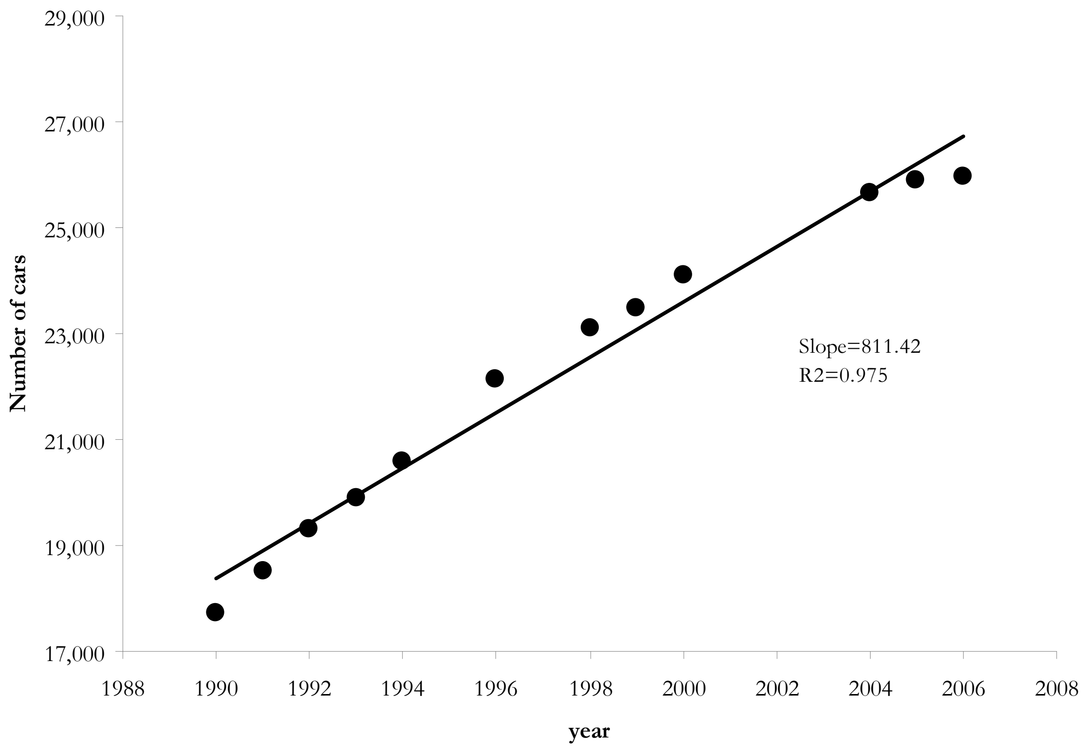


Figure 8: Number of cars registered in Tsushima (Modified from Maeda et al., 2008)

Unsurprisingly the amount of traffic has increased significantly since the 1960s. For example, the number of cars at traffic observation points on Route 283 has increased between 10 and 16 times between 1962 and 2005 (Figure 9).

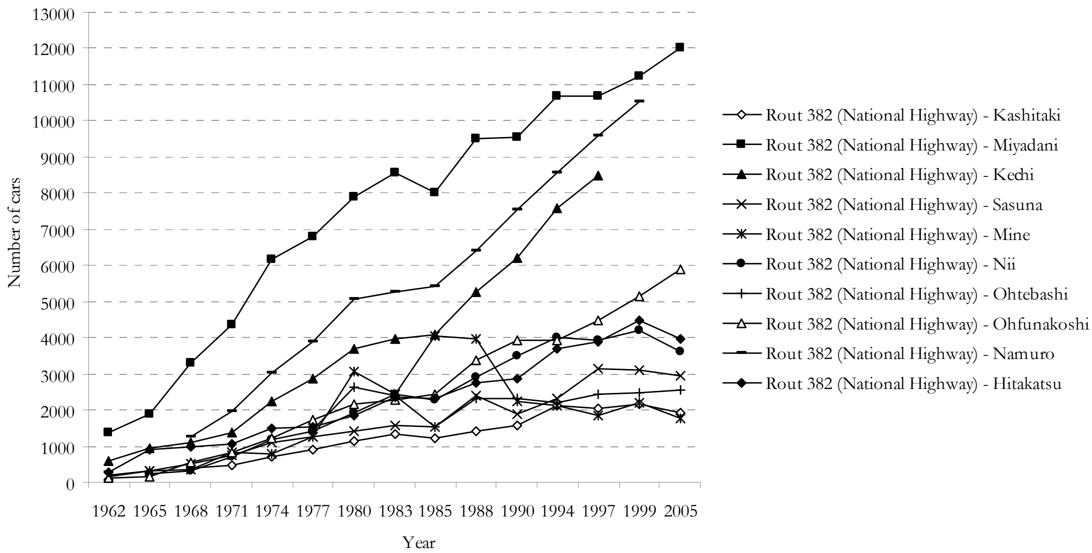


Figure 9: Change in the amount of traffic on National Highway Route 382 between 1962 and 2005 (Data from Tsushima Regional Office, Nagasaki Prefecture, 2007). Each line shows the number of cars passed at each of the observation point in 12 hours.

Izawa has suggested in a report from Nagasaki Prefecture (2006) that the possible factors of road kills are: (1) roads are going through the home ranges of leopard cats, and they must cross the roads to approach hunting sites and to move around in their range, (2) they need to cross road in unfamiliar areas when they expand their range seasonally, for example, for breeding and dispersal, (3) they feed on pray animals, which were squashed by cars.

2.3.3 Trapping

Foothold traps have traditionally been used by locals for chicken predation control. Chickens are commonly farmed by locals for personal consumption; a chicken pot is one of the traditional delicacies of Tsushima to welcome guests. According to the mortality and rescue record, only 4 cases have been reported between 1992 and August 2008; however, this number is potentially an underestimated since people do not necessarily report incidents when they happen because the use of foothold traps to catch leopard cats is illegal. It is worth noting that no organized trappings have been found in Tsushima, although leopard cats are commonly trapped for their skin in Eurasia.

2.3.4 Feral dogs

5 leopard cats were killed by dogs between 1992 to August 2008. Poor dog control is a likely to be a fundamental issue behind this. Groups of feral dogs have been observed in the forest (personal communication). Some trained hunting dogs have also been released into the forest by their owners once the dogs become old and have completed their working life. The number of feral dogs is unknown.

2.3.5 Feral cats (introduced diseases, inter-specific competition, and hybridization)

Feline Immunodeficiency Virus (FIV) was found in a Tsushima leopard cat in 1997 (Nishimura, 1999). Genetic analysis indicated inter-specific transmission from domestic cats. FIV is known from a range of feline species including the African lion (*Panthera leo*) and puma (*Puma concolor*); however, most related viruses are species specific variants, with no significant influence on their survival prospects.

Although species-specific virus type infections are commonly found, inter-specific competition between domestic cats and wildcats has not been reported before the case of Tsushima leopard cat; therefore, there are no study results available on what kind of impact FIV infection might have. Because of the potential impact on the wild population, the Ministry of the Environment keeps infected animals in captivity when FIV infected animals are found. Up to August 2008, three leopard cats have been found to be FIV positive. Two died due to senility; one showed symptoms of immunodeficiency; the impact of FIV is still not well understood.

Feline Leukaemia Virus (FeLV) is another virus disease which might affect the Tsushima leopard cat. FeLV have been found from feral cats in Tsushima (Murayama et al., 2006), and there is a possibility that some leopard cats are already infected; however the impact to the population is not well understood.

Another concern is inter-specific competition with domestic cats. In a local community survey (Tsushima Wildlife Conservation Centre 2006, unbublished data), 24 households out of 92 answered that they owned or looked after cats. The number of domestic cats was at least 52 in this community. The total number of households in Tsushima is 15,652. This suggests a domestic cat population of approximately 8,800 individuals. The majority of these cats roam freely, often in forested areas (Hirakawa, 1999). Analysis of domestic cat faeces from the forest area shows that domestic cats eat the same prey as leopard cats (Tsushima Wildlife Conservation Centre, personal communication).

The Bengal is a hybrid breed of domestic cat and Asian leopard cat (*Prionailurus bengalensis*), bred for its gentle and friendly temperament, while exhibiting the markings (large spots, rosettes, and a light/white belly), and a body structure reminiscent of the wild Asian Leopard Cat (The International Bengal Cat Society, 2008). Asian leopard cats and domestic cats breed in captivity, so there is concern that the Tsushima leopard cat may hybridise with domestic cats. The Scottish wildcat is known to hybridise with the domestic cat, with some scientists seeing it as a possible extinction threat (Nowell and Jackson, 1996).

2.4 Laws and Policies

2.4.1 Legal protection of Tsushima leopard cat

Hunting has been prohibited since 1949 under the Wildlife Protection and Hunting Law, and the Tsushima Leopard Cat was designated as a Natural Monument in 1971 by The Agency for Cultural Affairs. The Tsushima leopard cat is also designated as a National Endangered Species by Wild Fauna and Flora in 1994. A national conservation project plan (formally called "Programmes for Rehabilitation of Natural Habitats and Maintenance of Viable Populations") was established in 1995.

2.4.2 Laws for Endangered Species Conservation in Japan

The Law for the Conservation of Endangered Species of Wild Fauna and Flora was established in 1993 (Ministry of the Environment, 2008b). Before the Law for the Conservation of Endangered Species of Wild Fauna and Flora, there were no comprehensive legislation subjects for the conservation of biodiversity. The Wildlife Protection and Hunting Law, established in 1918, had been the only legislation for regulating hunting for wildlife in Japan. Under the Wildlife Protection and Hunting Law, all birds and mammals are subject to regulation. For plants conservation, the Nature Conservation Law (1972) and Natural Parks Law (1957) had been protecting particular species at particular sites (mainly in protected areas).

The Law for the Conservation of Endangered Species of Wild Fauna and Flora acts as the national law of the Convention of International Trade in Endangered Species of Fauna and Flora (CITES) and four Conventions and Agreements for Protection of Migratory Birds (between U.S, Australia, Russia, and China), as well as an authority of conservation of Japanese endangered species. The Law for the Conservation of Endangered Species of Wild Fauna and Flora Act allows designating the National Endangered Species of Wild Fauna and Flora as a first step to plan conservation programs.

81 species (38 birds, 4 mammals, 1 reptile, 1 amphibian, 4 fish, 10 insects, 23 plants) were listed as the National Endangered Species of Wild Fauna and Flora in August 2008 (Ministry of the Environment, 2008a). Of these 81 species, conservation program plans exist for 38 of them (Ministry of the Environment, 2008a). In contrast, 1002 animals and 2153 plants are listed as endangered (CR, EN, VU in the IUCN Red list category) in the Japanese regional IUCN Red List of threatened species (Ministry of the Environment, 2007b). 200 mammal species were assessed for the Red List, and 43 species are endangered; however only 4 species (Tsushima leopard cat (*Prionailurus bengalensis euptilura*), Iriomote cat (*Prionailurus iriomotensis*), Amami Rabbit (*Pentalagus furnessi*), and Daito flying fox (*Pteropus dasymallus daitoensis*) are designated as the National Endangered Species of Wild Fauna and Flora.

A species (or a sub-species or variation) will be designated as a National Endangered Species of Wild Fauna and Flora when the continuous inhabitancy and breeding of the species is considered to be threatened by anthropologic influences within Japan, and the species fulfils one of the following conditions: (1) population size is smaller than the self-sustainable level, or significantly declining, (2) a substantial proportion of the species habitat in Japan has disappeared or is likely to disappear, (3) the distribution is limited and fragmented, or (4) the habitat is restricted, and the population is over-harvested (Cabinet Office, Government of Japan, 1992). Although not as seen in the Endangered Species Listing Program for the US Endangered Species Act 1973 (Nicholopoulos, 1999), there is not an explicit process for species assessment.

2.5 Conservation and management actions

There are three major foci for conserving both the Kamijima and Shimojima populations: conservation and management of the remaining core population on Kamijima, establishing a captive population as insurance, and research for future reintroduction needs of the declined Shimojima population (Kiyonaga et al., 2008).

2.5.1 *In-situ* Conservation

A local group for Tsushima leopard cat conservation was established in 1993 and initiated conservation actions, mainly supplemental feeding. The Ministry of the Environment initiated their national endangered species conservation program in 1994 and established

Tsushima Wildlife Conservation Centre in Kamiagata Town, Tsushima (Kiyonaga et al., 2008).

A monitoring program was initiated by local and national governments for better understanding of the species; simultaneously, public education and conservation promotion began. Further, a rescue program has been integral for identifying the direct threats to the population as well as releasing recovered individuals back into the wild.

There was no clear and agreed focus of the conservation effort until action plans were formulated during the Conservation Planning Workshop in 2006 (Kiyonaga et al., 2008). Once the conservation actions were prioritized, stakeholders started to take responsibility for the action implementation. For example, comprehensive research for road kill mechanisms and local volunteer activities for preventing road kill started, cat management program became more focused and received continued funding, and national level conservation promotion was implemented by zoos (Kiyonaga et al., 2008). Local awareness increased significantly after the conservation planning workshop; the majority of local children voted to change the name of the local airport from Tsushima Airport to Tsushima "Yamaneko (leopard cat)" airport in February 2008 (Kiyonaga et al., 2008).

2.5.2 *Ex-situ* Conservation

Captive Breeding Program was initiated in 1996, in corroboration with Fukuoka Zoo and the Agency of Environment, as a part of the government conservation program. The first 10 years were an experimental period for developing methodology for captive breeding. The goals of captive breeding were agreed and set by stakeholders in the conservation planning workshop as establishing an insurance population in case of a drastic decline or extinction of the remaining wild population (Murayama et al., 2006). In July 1996 a juvenile male was rescued and sent to Fukuoka, the closest zoo to Tsushima, as a first potential founder. A total of 8 individuals were sent to Fukuoka between 1996 and 1999, and five healthy individuals were chosen for the breeding program (Machii et al., 2002). The first offspring was born in 2001 in Fukuoka; a total of 28 offspring have since been successfully produced (Kiyonaga et al., 2008).

After the conservation planning workshop, four new potential founders (2 female, 2 male) were introduced to the captive population in August 2008 to maintain 90% of the founders' average heterozygosity; this is a commonly used hypothetical target for captive breeding for endangered species (Frankham et al., 2002). Average heterozigocities are the sum of the proportions of heterozygotes at all loci or total loci sampled for captive populations; it is assumed that all founding members have two unique locus when actual data for the species were not available (Ralls et al., 2000).

Among rescued individuals, ones mainly because of starvation and road accident were selected as new founders. As a result, genetic diversity has improved from 81% (2006) to 83% (2008), and has the potential to further increase to 94% of founders' average heterozygosity if newly introduced individuals are successfully bred (Yoneda, 2008).

2.5.3 Government plan for supplementation of Shimojima population

In response to the drastic decline of the population, especially on Shimojima, a reintroduction plan was published by the Ministry of the Environment in 2004. It is a comprehensive plan stating what needs to be studied and prepared before the reintroduction, and draws on IUCN guidelines for re-introductions (IUCN, 1995) albeit with greater local and specific perspectives. A sub-committee for the reintroduction program was formed in 2005 and discussed the feasibility of and more detailed conservation schedules and plans.

3. Research Methods

3.1 Evaluation of population trends from previous monitoring data

Data from a previous monitoring program, conducted by Nagasaki prefecture and the Ministry of the Environment between 1998 and 2006, were assessed to evaluate population trends. Data between 1990 and 1997 were limited making detection of temporal trends difficult – they were consequently not used in this study. Summary tables of the camera trapping and faeces sampling results are provided in Appendices, Section II.

Between financial years 1998 and 2001, data were collected over different periods of time in each year: 1998 and 1999: September to March, 2000: July to March, and 2001: April to March; however, the timeline of data could not be adjusted because the census results were reported as annual total number of field signs (farces and foot prints).

Between financial years 2002 and 2006, data collected between October and March each year were used to compare the proportion of census routes or camera trapping sites where the leopard cat was confirmed present.

Yearly monitoring data from southern part of Kamijima (Toyotama and a part of Mitsushima area) were available from 1998 to 2001; however these data were excluded from the analysis since the protocol for data collection for these areas was changed in 2002, and it was not possible to compare the detection rate between these two time period.

The results were converted into presence/absence data to compare the detection rates of the leopard cat.

3.2 Demographic PVA Model and VORTEX

The demographic model is the most frequently used PVA method. Although there are several approaches to PVA, this type of PVA always requires demographic data, such as survival rates of different sex and age classes, and reproductive rates (Morris and Doak, 2002).

Many PVA packages are available and commonly used either for commercial or non-profit purpose (e.g. GAPPS, INMAT, RAMAS Age, RAMAS Metapop, RAMAS Stage and VORTEX, Brook et al., 1999).

A PVA modelling program, VORTEX, (Lacy et al., 2005) is used for this project to aid comparison with results with the previous PVA model which was also constructed in VORTEX. All simulations were performed using VORTEX version 9.91 (Lacy et al, 2008).

VORTEX is an individual based PVA package which uses simulations of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wild populations (Miller and Lacy, 2005). It simulates a population by stepping through a series of events describe an annual cycle of a typical sexually reproducing, diploid organisms: mate selection, reproduction, mortality, increment of age by one year, migration among populations, removals, supplementation, and truncation (if necessary) to the carrying capacity (Miller and Lacy, 2005).

Since Vortex is the individual base model, it creates a representation of each animal in its memory and follows the destiny of the animal through each year of its lifetime (Miller and Lacy 2005). It keeps track of the sex, age, and percentage of each animal. Demographic events (birth, sex determination, mating, dispersal, and death) are modelled by determining for each animal in each year of the simulation whether any of the events occur (Figure 10).

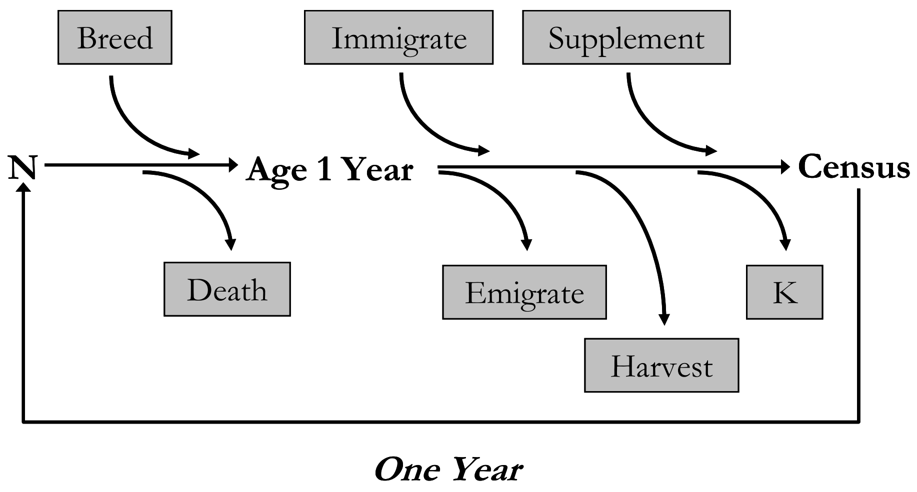


Figure 10: Timeline of the VORTEX (Miller and Lacy, 2005)

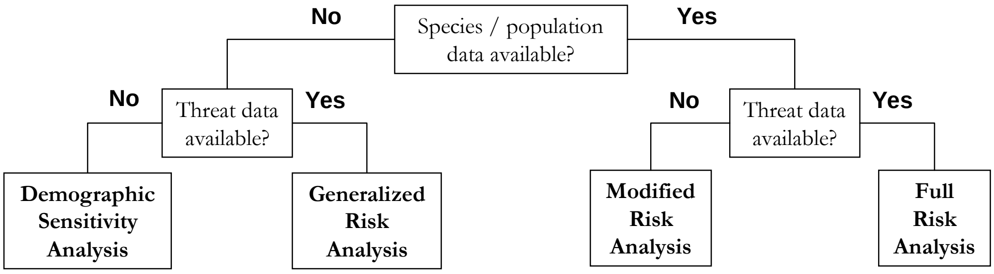
The detailed structure of VORTEX can be found in Lacy (2000) and Miller and Lacy (2005).

VORTEX is one of the most commonly used PVA packages being used in practical conservation; it was used as a decision support tool in the Population and Habitat Viability Assessment (PHVA) Workshop for more than 170 species over 57 countries (CBSG 2008, personal communication). VORTEX was originally designed for mammals and birds (Miller and Lacy, 2005), and it is geared towards quite specific applications (Traylor-Holzer, 2008) (Table 4).

Table 4: Species/population characteristics most desirable for make are VORTEX applications (adapted and modified from Traylor-Holzer, 2008)

Vortex is more appropriate and may be necessary
Low fecundity
Long lifespan
Diploid
Changes in genetic variation of interest
Local population (N) <500
< 20 populations modeled
Age specific fecuidity and survival rates estimable
Age dependent fecundity and survival rates
Fluctuations in rates can be estimated
Catastrophic events modeled
Polygamous or monogamous breeding
Some adults excluded from breeding
Non-random distribution of fecuindity
starting population not at stable age distribution
Unequel sex ratio
Trends projected in habitat quality or area
Managed removal, supplementation, or translocation
Bird, mammal, or reptile

In the workshop process, PVA was used in different ways depending on the availability of data. Figure 11 shows the (simplified) criteria used to decide what type of scenarios are possible based on data availability (Miller, 2008)



Characteristics: • Greater insight into species demography, population trends • Unable to realistically portray underlying causes of demography, population trends • Can identify only general population managament, research priorities **Appropriate scenarios:** • Baseline model using best guess parameters • General sensitivity testing with comparative analysis using arbitrary demographic data where necessary	**Characteristics:** • Unable to accurately predict quantitative impact of threat on underlying population demography • Can more accurately prioritize threat impacts, but cannot set specific management targets based on threat remediation (e.g., reduce hunting intensity from x % to y %) **Appropriate scenarios:** • Baseline model using best guess parameters, generating a reasonable growth rate • Simple risk analysis focusing on relative changes in demographic performance in the face of alternative threats	**Characteristics:** • Can set management thresholds for threat impacts that improve viability, without specific data on the extent of the threat in the field • Valuable opportunity for hypothesis testing in threat assessment (i.e., prioritize data collection on threats) **Appropriate scenarios:** • Baseline model using accurate parameters, generating a population growth rate that describes actual conditions • Exploratory risk analysis models with guess estimates of threat parameters	**Characteristics:** • Opportunity to accurately predict quantitative impact of threat on underlying population demography • Can set specific management targets and /or threshould base on threat remediation **Appropriate scenarios:** • Baseline model using accurate parameters, generating a population growth rate that describes actual conditions • Detailed suite of risk analysis models with direct numerical comparison of populaton response across difficult threats

Figure 11: Flow chart for choosing appropriate scenarios based on data availability (adapted and modified from Miller, 2008).

In the case of Tsushima leopard cat, demographic data are not available and threat data are limited; for this reason, it is arguably more appropriate to conduct sensitivity analysis using arbitrary data for general arbitrary and research priorities based on the criteria (Miller, 2008).

3.3 Review of existing demographic data and Previous PVA modals for small cats

All available data were assessed for deciding the baseline model input values. Baseline models built for the Tsushima leopard cat Conservation Planning Workshop were modified for this analysis. Given some of the data were not available from previous studies, similar information from captive populations from studies focused on other geographic areas, and from other small cat studies were utilized in the modified baseline model inputs.

In addition to being previously used to model the Tsushima leopard cat, VORTEX has been used to model other small cat populations, specifically the Ocelot (*Leopardus pardalis*) (Miller et al., 2005) and Asiatic golden cat (*Pardofelis temminckii*) (Traylor-Holzer et al., 2005). Also, demographic rates for the Iberian lynx (*Lynx pardinus*) were available from the study of Ferreras et al. (2001). A summary table of the demographic data for these species can be found in the Appendices, Section III.

3.3.1 Baseline modal input for demographic PVA and sensitivity test

A baseline model was built to represent the population without any threats. All scenarios were simulated 1,000 times. Each projection lasted for 100 years, with demographic information obtained at annual intervals. In the model, extinction is defined as when only one sex remained. Although, there are two populations of the Tsushima leopard cat, the baseline model was built only for the Kamijima population since there is less likely to be dispersal between the Kamijima and Shimojima populations, and very little information was available for Shimojima population.

Breeding System: Leopard cats are solitary and live within exclusive territories. And males expand their home range during the breeding season (late December to February) to find mates. Once they have established their exclusive territories, they tend to remain at the same place (Ueno, 2004); therefore, their breeding system is best described as long-term polygamy.

Age of First Reproduction: VORTEX considers the age of first reproduction as the age at which the first kittens are born, not simply the onset of sexual maturity (Miller and Lacy, 2005). Leopard cats reach sexual maturity at 18 month of age (Sunquist and Sunquist, 2002). There is no record that the Tsushima leopard cat reproduces in the autumn months. We set the parameter for the Tsushima leopard at 2 years for females and 3 years for males, based on captive breeding data and observation (Yoneda, 2008; Machii, 2001).

Age of Reproductive Senescence: VORTEX in its simplest form assumes that animals can reproduce (at the normal rate) throughout their adult life (Miller and Lacy, 2005). Captive leopard cats are able to live up to 15 years (Kohler et al., 2006), but are unlikely to breed up to this age in the wild population under competitive conditions. The greatest age at which a female in captive population has reproduced is about 10 years old; therefore, it was assumed that leopard cat could reproduce up to 10 years in the wild. In order to test the sensitivity of the model to uncertainty in this parameter, additional models were run with this variable set to either 7 years or 13 years of age.

Offspring Production: There is no data from this particular wild population indicating the average percentage of adult females that successfully bread per year. The average percentage of adult females that successfully bred per year was assumed to be 70%. Previous PVAs for small cats used 50% (Ocelot: Miller et al., 2005) and 76% (Asiatic Golden Cat: Traylor-Holzer, 2005) for this parameter.

This parameter may vary depends on environmental variation. In order to test the sensitivity of our models to uncertainty in this parameter, additional analysis was conducted with this variable set to a range of 40% to 80%.

Annual environmental variation in female reproductive success is modeled in VORTEX by specifying a standard deviation (SD) for the proportion (%) of adult females that successfully produce kittens within a given year (Miller and Lacy, 2005). While no data are available for this parameter, the annual variance is assumed relatively low; therefore, the standard deviation in the percentage of adult females breeding was assumed to be 8%.

Based on the data from captive population, an average Tsushima leopard cat litter size is 1.75 per successful female and the distribution of possible litter sizes for a given successful female is defined as : 1 offspring =35.5%, 2 offspring=53.0%, 3 offspring=11.5%.

The overall population-level sex ratio among newborns is 50%, as seen in captive population data.

Density-Dependent Reproduction: VORTEX is able to model density dependence with an equation (1) that specifies the proportion of adult females that reproduce as a function of the total population size (Miller and Lacy 2005).

(1) $$P(N)=(P(0)-[(P(0)-P(K))(N/K)^{B}])N/(N+A)$$

‘in which, P(N) is the percent of females the breed when the population size is N, P(K) is the percentage that breed when the population is at carrying capacity (K), and P(0) is the percentage of female breeding when population density is low. It is best to derive the values of P(0), P(K), A (=Allie parameter), and B (=steepness of parameter) from a regression analysis of data on the breeding rate of the population’ (Miller and Lacy 2005, p47).

Although, a density dependent reproduction function was used in the previous 2006 model (Murayama et al., 2006), this function was not used this time since there are no data available to support density dependence in reproduction in the Tsushima leopard cat population. Density dependent function was turned off for the baseline model. For sensitivity analysis, additional models were run to see the differences with and without density dependent breeding. $P0$ = 98.4, Pk = 35, A = 0.5, and B = 1 were used for parameters of density dependent breeding.

Male Breeding Pool: In many species, some adult males may be socially restricted from breeding despite being physiologically capable. There is no data available informing this parameter for the Tsushima leopard cat. The first juvenile male rescued and sent to Fukuoka bred at age 6 for the first time (Yoneda, 2008); this observation suggest that males might need a social process to bred successfully. In the previous baseline model, it was assumed that 47.5% adult male leopard cats have chance to breed. This is the same input value as the previous model. Additional models were run to test the sensitivity of the parameter for values of 40 to 100%.

Input values for the baseline model and sensitivity tests for reproductive rats are summarized in Table 5.

Table 5: Parameters for Reproductive rates

	Baseline model	Source	Sensitivity analysis
Reproductive System	Long-term Polygyny		
Age of first offspring for females	2	Sunquist and Sunquist 2002	
Age of first offspring for males	3	Studbook data 2008	
Maximum Age of Breeding	10	Studbook data 2008	Age 7-13
Maximum Number of Broods per year	1	Field observation	
Maximum Number of Progeny per Brood	3	Studbook data, field observation	
Sex Ratio at Birth -- in % Males	50	Studbook data 2008	
Density Dependent Reproduction	No		Yes
% Adult Females Breeding	70		40-80%
EV in % Breeding	8		
Distribution of broods per year			
0 Broods	0		
1 Broods	100		
Distribution of offspring per female per brood		Studbook data 2008	
Distribution		Adapted from 2006 model	
1 Offspring	35.5		
2 Offspring	53		
3 Offspring	11.5		
Meta Monopolization			
% Males in Breeding Pool	47.5		40-100%
% Males Successfully siring offspring	40		
Mean# of mates/successful sire	2.2		

Mortality: Age-sex-specific mortality rates for this particular population in Tsushima were not available. However, the adult mortality rate of the Leopard cat in Thailand has been studied (Haines et al., 2004). A mortality rate of 8% for adult leopard cats was found for an unexploited population in Thailand where anthropologic impact is reportedly small. Data analyzed from the captive population was also available; suggesting the mortality rate between ages 0 to 1 year was 51% (Kohler et al., 2006). Since captive population data were used for litter size and the distribution, the analysis of Kohler et al were employed as the most reasonable data for this analysis. There was no data available for age 1-2 mortality rates either from leopard cat populations in different geographic areas or other small felid, which have similar life history. Haines et al. (2005) suggests the mortality rate of the ocelot in the U.S. during its dispersal period is about 30% higher than when individuals remain within their established territories. However, as no data were available for the Tsushima leopard cat, the mortality rate of sub-adults and dispersing individuals for other small cats was assumed to be greater than the value for adult and smaller than age 0-1 (Miller, 2005; Haines et al.; 2004, Haines et al., 2005; Traylor-Holzer, 2005; Ferreas et al., 2001, for details see Appendices, Section III).

Accordingly a 20% mortality rate was used for the baseline input, and sensitivity tests were conducted for ranges of 20% and 60% for this parameter.

In previous PVA in 2006, probability of extinction at current situation was estimated as 49.7% when adult mortality (both female and male) was 21%. Additional models were run to test the sensitivity of female adult mortality for 2006 model to find out the difference between two models.

Input values and sensitivity analysis of mortality rates for baseline model are summarized in Table 6. Sensitivity tests for males and females are conducted separately.

Table 6: *Input values for Mortality Rates (%)*

Mortality rates	Baseline model	Source	Sensitivity analysis
Female	%		
Mortality from Age 0-1	51	Kohler et al 2006	51-91%
SD in 0 to 1 Mortality due to EV	15		
Mortality from Age 1-2	20		20-60%
SD in 1-2 Mortality due to EV	6		
Mortality from Age 2-	8	Haines et al 2004	4-44%
SD in 2- Mortality due to EV	2		
Male			
Mortality from Age 0-1	51	Kohler et al 2006	51-91%
SD in 0 to 1 Mortality due to EV	15		
Mortality from Age 1-2	20		20-60%
SD in 1-2 Mortality due to EV	6		
Mortality from Age 2-3	8	Haines et al 2004	4-44%
SD in 2-3 Mortality due to EV	2		
Mortality from Age 3	8	Haines et al 2004	4-44%
SD in 3 Mortality due to EV	2		

Harvest: Additional Mortalities, for example due to road kills and foothold trapping, can be regarded as harvest in VORTEX program. Average mortalities due to road kill, foothold trapping, or dog predation between 2000 and 2007 were 1.75 individuals (1 female and 0.75 male) for more than 1 year old, and 2.62 individuals (1.62 female and 1 male) for less than 1 year old.

Additional models were run for a constant harvest of 1 to 10 individuals every year from age 1 and Adult for adults of each sex to test the influence of constant mortality.

Catastrophes: Catastrophes are remarkable environmental events that are outside the limits of normal environmental variation affecting reproduction and/or survival (Miller and Lacy, 2005). Natural catastrophes can be for example, tornadoes, floods, droughts, disease, or similar events. These events are modeled in VORTEX by assigning an annual probability of occurrence and a pair of severity factors describing their impact on mortality (across all age-sex classes) and the proportion of females successfully breeding in a given year (Miller and Lacy, 2005). These factors range from 0.0 (maximum or absolute effect) to 1.0 (no effect), and are foisted during the single year of the catastrophe, after which time the demographic rates bounce back to their baseline values (Miller and Lacy, 2005).

Although, there is a possibility of having some catastrophic events in centuries of time, no catastrophic event was incorporated in the model since the frequency and the impacts were unknown.

A sensitivity test was run to find out the impact of hypothetical catastrophes on the population. Two catastrophes are considered, and the first one is a severe typhoon. It may not have an impact on the leopard cat itself but the rodent population. I have assumed that the typhoon would reduce the female breeding from to 40% and have a survival rate of

75%. The probability of such an event is 2% (once in 50 years). A second catastrophe is a (as yet) unknown disease, which would reduce the reproduction to 30%, with survival rates of 40%. The probability of such an event is assumed 1% (once in 100 years).

<u>Inbreeding Depression:</u> VORTEX includes the ability to model the detrimental effects of inbreeding, most directly through the reduced survival of offspring through their first year (Miller and Lacy, 2005). Specific data on inbreeding depression for captive and wild leopard cat populations was unavailable for this analysis. Estimates of lethal equivalents in 40 population, 38 species of mammals ranged from -1.4 to 30.3 with a mean of 4.6 and median of 3.14 (Ralls et al., 1988). Since the habitat is an isolated island, the Tsushima leopard cat population is naturally small; therefore, a genetic load of 3.14 lethal equivalents and approximately 50% of this load expressed as lethal genes is incorporated in the model as a default.

In order to test the sensitivity of our models to uncertainty in this parameter, additional models without inbreeding depression from the analysis is run.

<u>Initial Population Size:</u> A current estimate of the Tsushima leopard cat population size is approximately 83.6-114.5 individuals (Ministry of the Environment, 2005).For this reason, 95 was used for the baseline input value for the number of individuals. Because of the uncertainty surrounding these estimates, sets of different population size classes are analyzed; the class sizes studied ranged from 10 to 300. A stable age distribution was chosen for this model.

<u>Carrying Capacity:</u> The carrying capacity, K, for a given habitat patch defines a ceiling for the population size, above which additional mortality is imposed randomly across all age classes in order to return the population to the value set for K. Estimating carrying capacity is a very complex process; however, the habitat of the Tsushima leopard cat is geographically limited ($449km^2$), and the ultimate maximum size can be guessed from the home range size. From the previous study, home range size is estimated as The home range sizes are 243.5 ± 397.0 hectares for males, and 101.0 ± 53.1 hectares for females (Moteki 2007). Males are known to expand their home range in winter suggesting the correlation with the breeding season (Ueno, 2004; Hiyama, 2004), and it is suggested that male winter range are overlapped with multiple female ranges (Hiyama, 2004).

However, this is a very rough and optimistic guess, even if leopard cats are capable to live on 90% of the whole area of Kamijima, K is less likely to be more than 400 animals on Kamijima. In this model, carrying capacity is temporarily set as 200 for baseline model, and sensitivity analysis was conducted for between 10 and 300 individuals.

4. Results

4.1 Evidence of population trends from previous monitoring data

In the northern part of Kamijima, where continuous yearly data were available, the population appears to be relatively stable, possibly increasing between 1998 and 2006. No evidence suggesting that the population is rapidly declining was found.

Data were converted into presence / absence data per transect to allow (Appendices, Section IV) me to analyze the percentages of census routes or camera trapping sites that Tsushima leopard cats were confirmed (Table 7). Slope of the regression line for the percentage of camera trapping sites that the Tsushima leopard cat was confirmed presence between 1998 and 2001 were positive (Figure 12).

Table 7: Percentage of Camera Trapping Leopard cat is Presence

Year	Number of sites precence	Number of cameras	% Presence
1998	8	13	61.54
1999	12	16	75.00
2000	12	16	75.00
2001	15	17	88.24

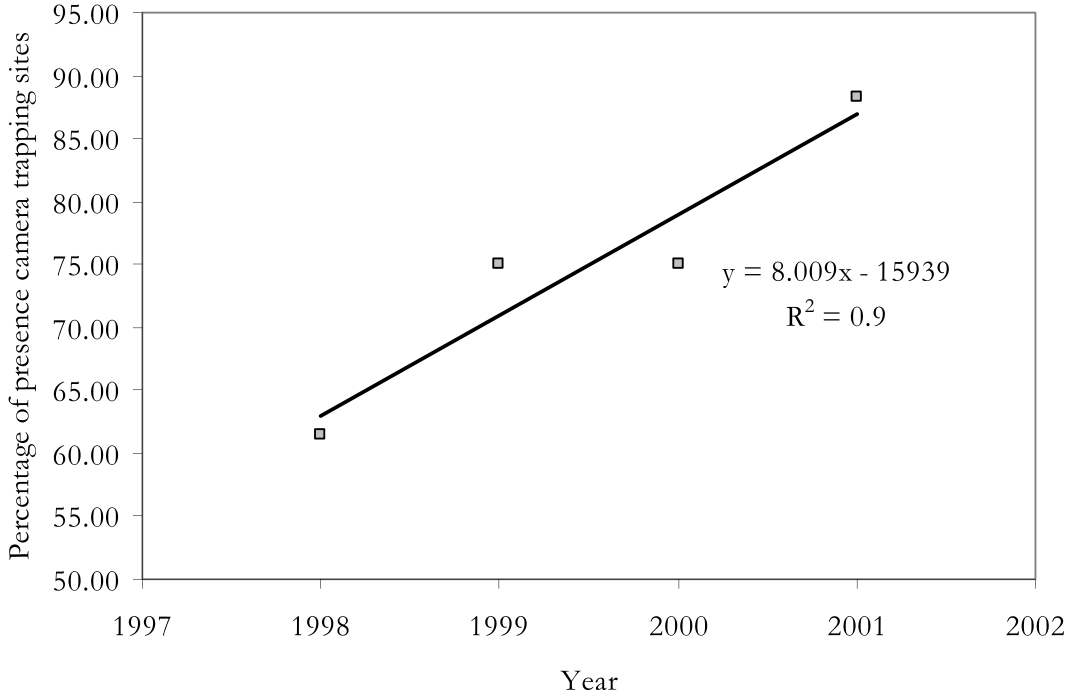


Figure 12: Percentage of camera trapping sites, where leopard cats are confirmed.

Results of faeces census 1998 to 2001 and 2002 to 2006 are treated as two separate data sets since the research protocols were different between these two time periods. Percentage of census routes that the Tsushima leopard cat were confirmed present can be found in Table 8. Slope of the regression lines of data points between 1998 and 2001 were positive, and slightly negative between 2002 and 2006 (Figure 13).

Table 8: Percentage of Census Routes Leopard cat is Presence

Year	Number of Presence Routes	Number of routes	% Presence
1998	11	12	91.67
1999	11	15	73.33
2000	13	15	86.67
2001	13	14	92.86
2002	26	27	96.30
2003	26	30	86.67
2004	35	36	97.22
2005	30	36	83.33
2006	25	26	96.15

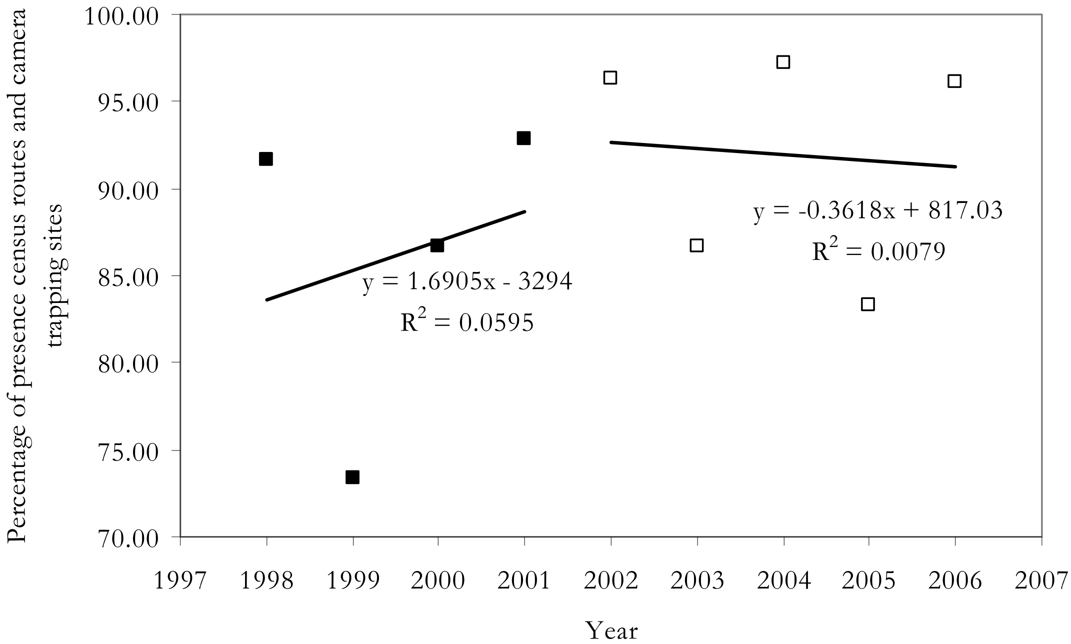


Figure 13: Percentage of census routes or camera trapping sites, where Tsushima leopard cat was confirmed

4.2 Demographic model using VORTEX

Due to the uncertainties surrounding many parameters, the viability of the current population was not defined in this study. Sensitivity analysis was performed for the parameters described in the methods section to explore what parameters would have impacts on population viability.

Modelling result from VORTEX includes (Miller, 2005):

- The average rate of deterministic population growth (r)
- The average rate of stochastic population growth or decline (r_s) demonstrated by the simulated populations, averaged across years and iterations for all simulated populations that are not extinct. This population growth rate is calculated each year of the simulation, prior to any truncation of the population size due to the population exceeding the carrying capacity.
- Probability of population extinction after 100 years, $P(E)_{100}$, determined by the proportion of 1000 iterations within that given scenario that have gone extinct within the given time frame. “Extinction” is defined in this model as the absence of either sex.
- Average population size at the end of the simulation, N_{100}, averaged across all simulated populations, including those that are extinct.
- The gene diversity or expected heterozygosity of the extant populations, GD_{100}, expressed as a percentage of the initial gene diversity of the population. Fitness of individuals usually declines proportionately as gene diversity declines.

- The average time to population extinction, in years, T(E).

The aim of the baseline model is to represent the wild population without any threats. The results of this analysis are presented in Table 9.

Table 9: Results summary for the baseline model

Deterministic population growth rate (*r*)	0.09
Stochastic population growth rate (r_s)	0.075
Standard diviation for *r*	0.114
Probability of Extinction --- $P(E)_{100}$	0
Average population size after 100 years--- N(100)	191.95
Standard diviation for N(100)	14.82

The average deterministic population growth rate was 9%, and the probability of extinction was 0%. This baseline model was used as a default for conducting sensitivity tests.

4.2.1 Sensitivity Analysis

Overall, female mortality rates exert the greatest influence on the population's viability, and it was found that the most sensitive parameter among the three age classes corresponded to female mortality in adults.

The relative magnitude of the impact of different parameters on the deterministic population growth rate is summarized in Figure 14.

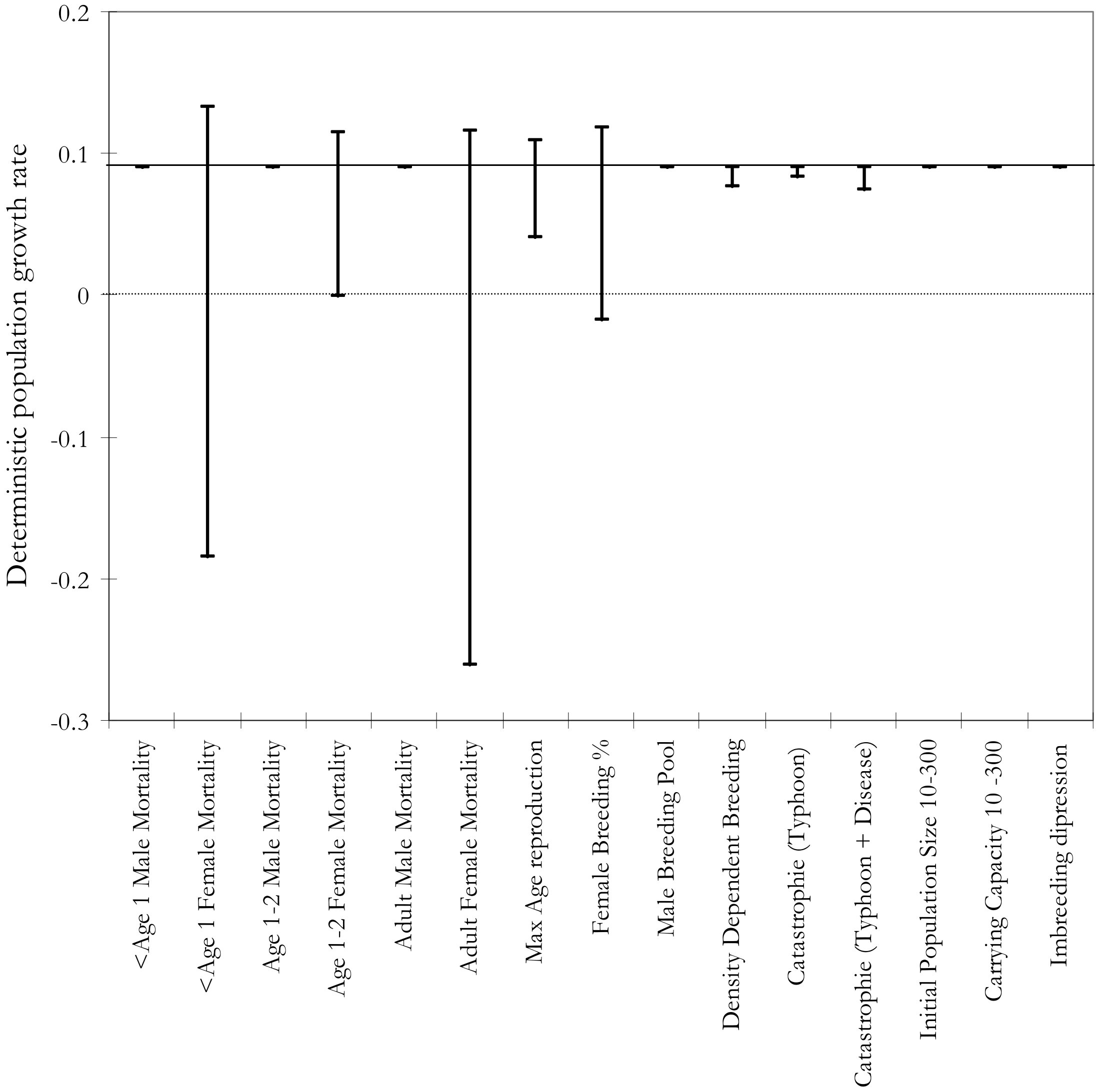


Figure 14: Relative impact of sensitivity analysis on demographic population growth rate (r)

Clearly, the change in the mortality rates of female adults and females age<1 have a strong influence on the deterministic population growth rate (*r*). In contrast, male mortality across all age classifications has little impact on the population growth rate. This can most likely be explained by the polyginous mating system of the Tsushima leopard cat. The proportion of female breeding and maximum ages of reproduction also has an influence on *r*, and the impact of a change in all other parameters was insignificant.

Additionally, female mortality rates were found to have the largest impact on the stochastic growth rate. It was also found that the initial population size and carrying capacity have some influence on r_s (Figure 15).

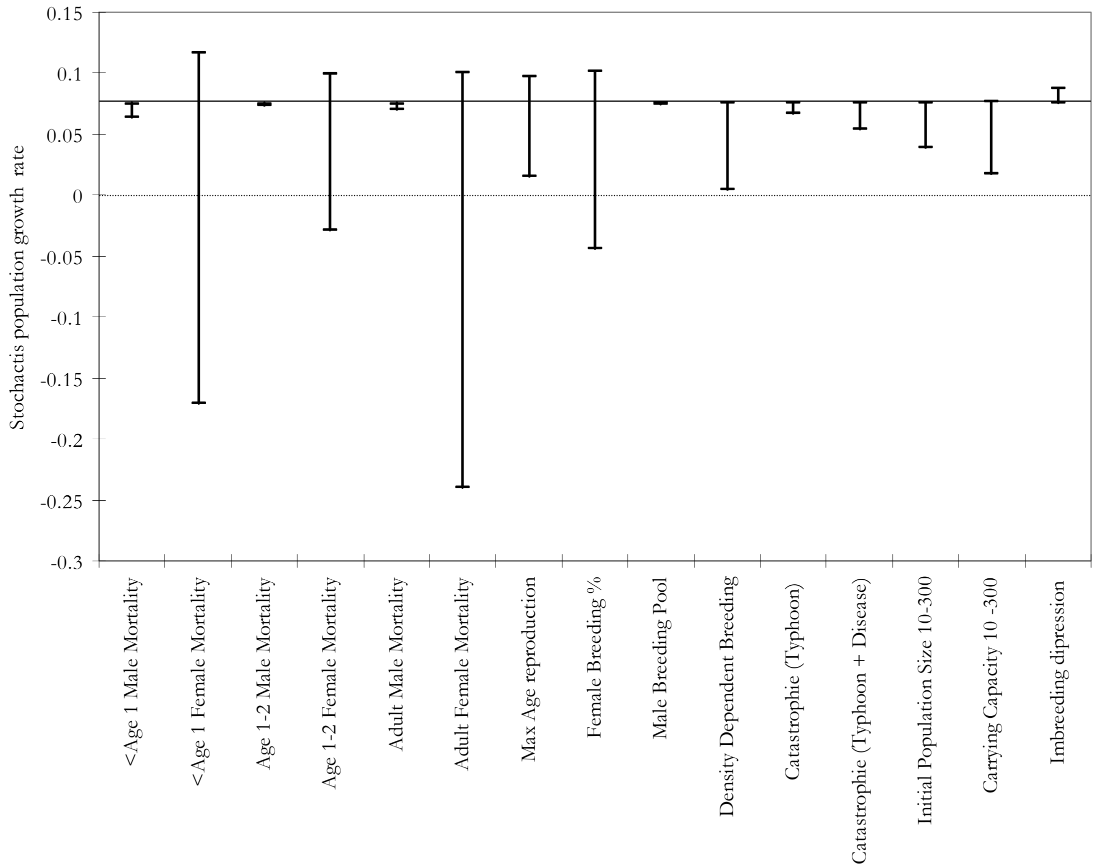


Figure 15: *Impact of sensitivity analysis on the stochastic population growth rate (r_s)*

Figure 16 clearly shows that adult female mortality is the most sensitive parameter. Indeed, for adult females, the stochastic growth rate is characterised not only by negative rates, but rates which are lower than those for other age classes.

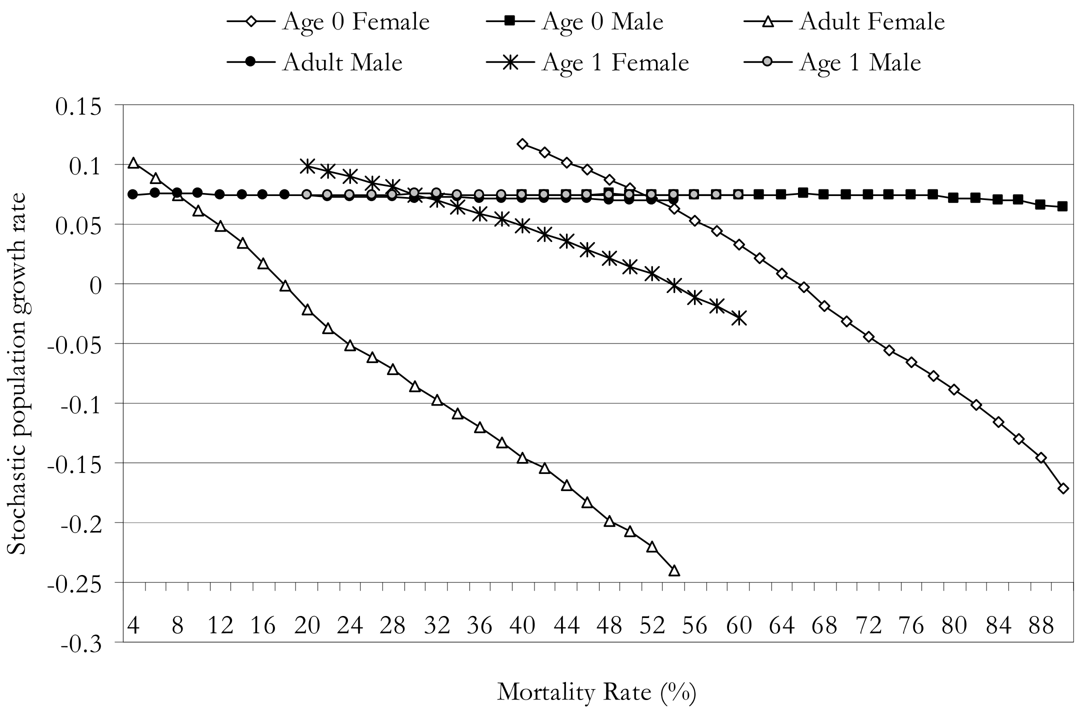


Figure 16: Sensitivity analyses of mortality rates (%) on deterministic growth rate

The results of the baseline model in 2006 also suggested that changes in female mortality significantly affected the viability of the population, whilst male mortality had little effect (Table 10).

Table 10: Probability of extinction for the 2006 model and this study

Model	Parameters chaged	21% Baseline 2006	19%	15%	11%	8% Baseline for this study
2006	Age>2 male and female mortality	0.497	0.277	0.035	0.005	0
	Age>2 female mortality	0.497	0.278	0.034	0.001	0
	Age>2 Male mortality	0.497	0.494	0.446	0.425	0
This study	Age>2 male and female mortality	0.665	0.333	0.019	0	0
	Age>2 female mortality	0.615	0.304	0.016	0	0
	Age>2 Male mortality	0	0	0	0	0

As is already shown in the sensitivity analysis for mortality rates, the harvest of females, either Age 1 or Adult, has a significant impact on population viability. Since many of the parameters are guestimates based on previous research and reports, the relationship between the stochastic population growth rate and harvest in Figure 17 may not represent reality; however, it does suggest that high female mortality in either adult females or Age 1 females could markedly influence the population viability.

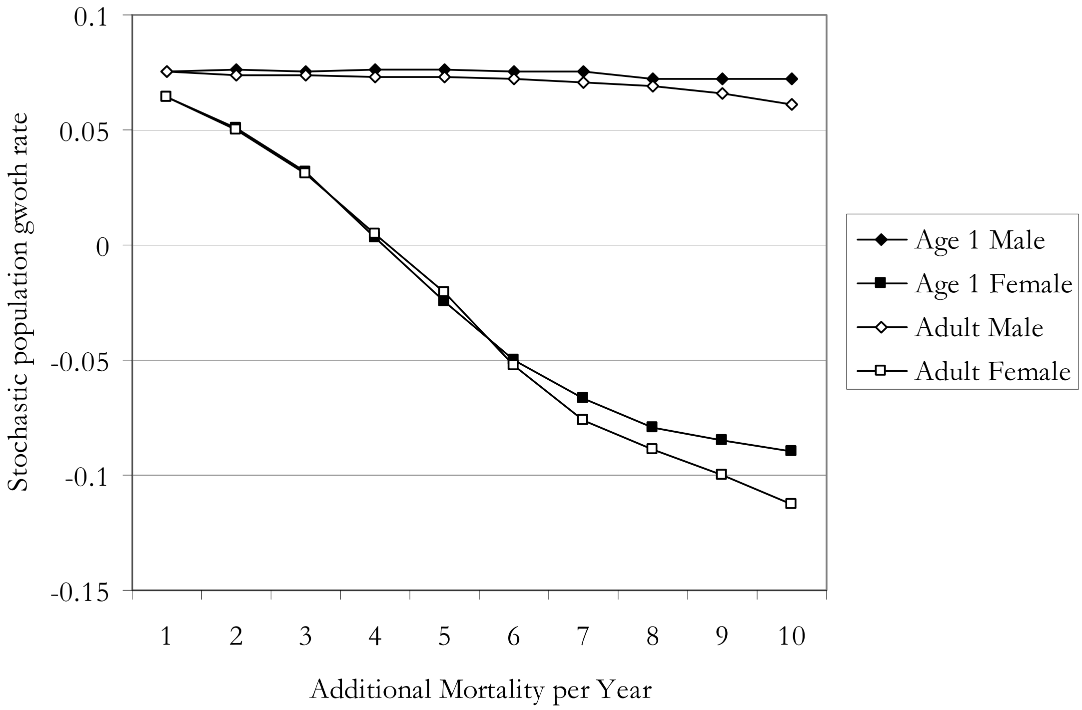


Figure 17: *Sensitivity analysis for additional harvest on the stochastic population growth rate, P(E)*

Female breeding percentages and deterministic population growth rates have a positive near-linear relationship; however the impact is relatively smaller compared to the impact of female mortalities.

While the change in carrying capacity does not have an influence on the deterministic population growth rate, it does exert a significant impact on the average genetic diversity after 100 years. Sensitivity of parameters towards genetic diversity after 100 years is shown in Figure 18.

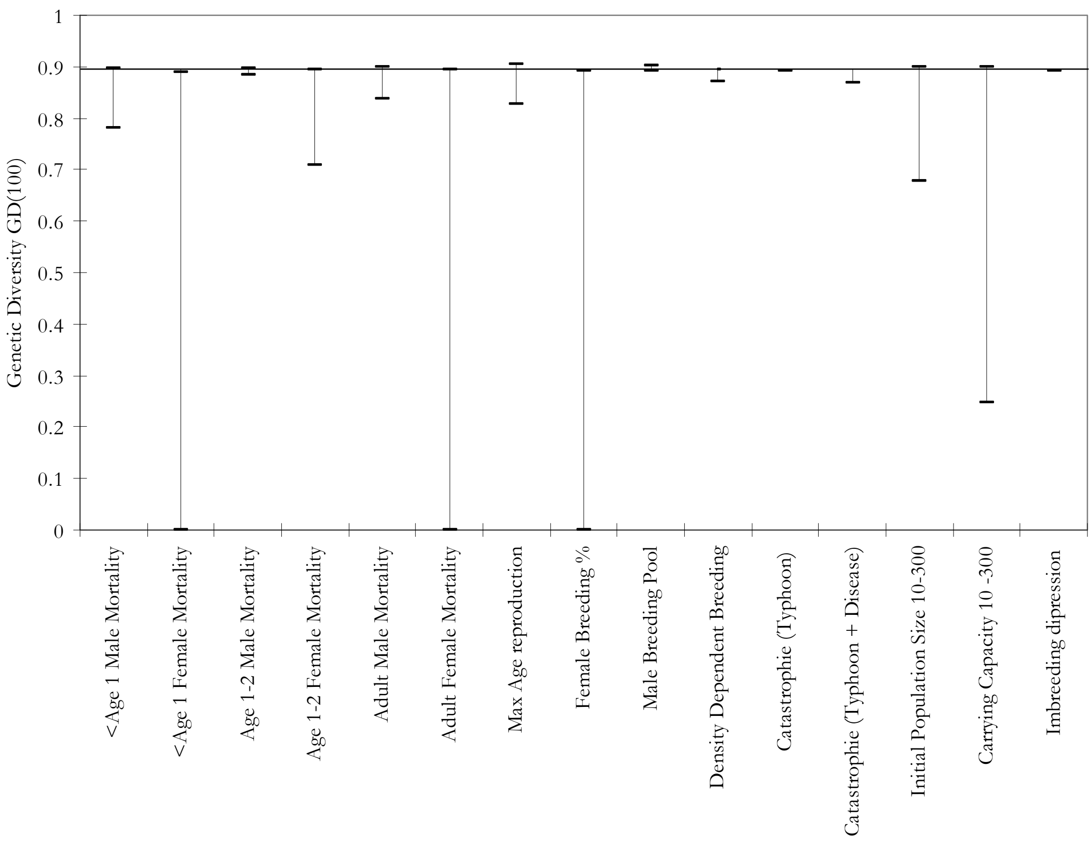


Figure 18: *Relative impact of sensitivity analysis on the Genetic Diversity after 100 years, $GD_{(100)}$.*

The change in initial population size also has some impact on the genetic diversity in 100 years, although the effect is small (Figure 19)

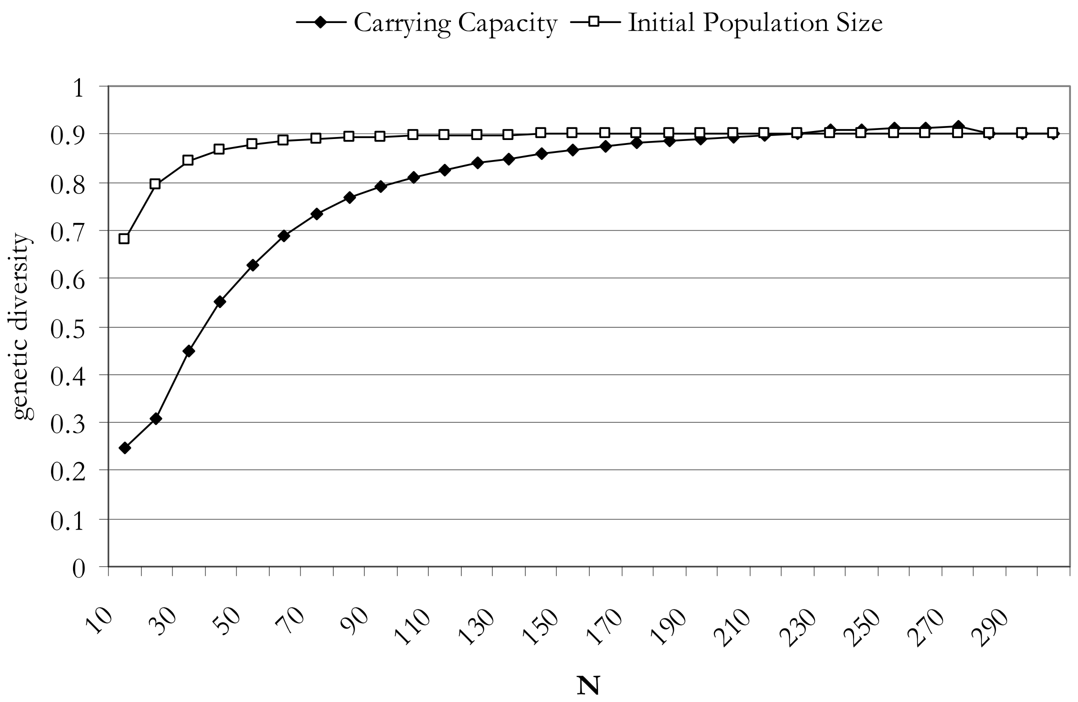


Figure 19: Sensitivity analyses for carrying capacity on the genetic diversity after 100 years

This means that even when the initial population size is small, the genetic diversity of the initial population will be conserved reasonably well, conditional on the population growth rate and the carrying capacity being large enough. There are many studies suggesting that populations with lower genetic diversity have a proportionally higher chance of suffering from inbreeding depression (e.g. Frankham et al., 2002).

For this baseline model, the probability of extinction increases drastically once the carrying capacity falls below certain levels, specifically when carrying capacity was smaller than 60 individuals for this baseline model. However, it should be noted that this finding does not imply population stability when the carrying capacity is over 60, due to the uncertainties of the parameters. Additional model were run to explore the influence if mortality rate on population viability for series of carrying capacity from 10 to 200. The result suggests that when carrying capacity is getting smaller, it is expected to have significant negative influence on population viability even when mortality is slightly increased; this result also have shown the importance of mortality rates on the population viability. (Figure 20).

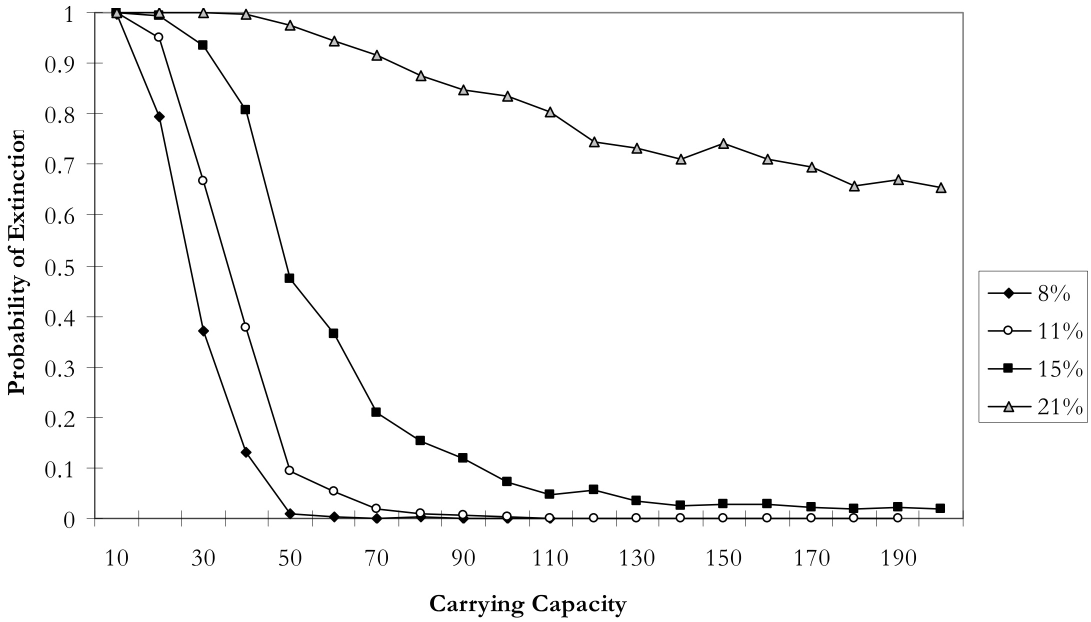


Figure 20: Influence of different mortality (adult mortality rate 8% (baseline), 11%, 15%, and 21%) rate on probability of extinction for series of carrying capacity

5. Discussion

At the outset of this dissertation, I aimed to (1) conduct a Population Viability Analysis of the Tsushima leopard cat with using previously collected data, (2) evaluate the relative impact of current threats including road kill and illegal snare trapping, and (3) compare the performance of a range of scenarios - including reintroductions in the south of the island - to identify the conservation strategies most likely to increase population viability.

To achieve these aims, a thorough analysis of previous monitoring data was undertaken, and a PVA was undertaken using VORTEX. However, for the purposes of conservation strategy and planning, it is necessary to place these quantitative results in context. Therefore, attention now turns to the broader implications of our findings for the conservation of the Tsushima Leopard Cat.

The discussion is structured in three parts. First the results based on monitoring data are examined, after which role of VORTEX, and associated findings are critically assessed. Finally, future directions for conservation strategies, research, and the use of PVA in practical conservation are evaluated.

5.1 Findings of the analysis

Although the quantitative results in Section 4 are informed by a statistical model based on very particular assumptions about model parameters, the analysis has arguably shed some light on issues surrounding the long term population of the Tsushima leopard cat. This in turn may hold implications for Tsushima leopard cat conservation strategies. Of course, it is worth stressing here that given the limitations our population data, the values of many parameters are based on judgement and informed by the results of other published scientific studies.

A key finding based on monitoring data since 1998 to 2006 is that in northern Kamijima, the population is not crashing and may even be recovering. Significantly, this is not consistent with reports from the Ministry of the Environment (2005), which concluded that the population had declined by about 9 % between censuses published in 1997 and 2005, but previous leopard is taking into account of the whole island. Moreover, data limitations severely hampered a more comprehensive analysis of the leopard cat in other parts of Tsushima; it was not possible to understand the yearly population trends corresponding to the southern part of Kamijima and Shimojima, where the population density is lower than northern Kamijima and extirpation is most widespread.

The fact that the northern part of Kamijima population appears relatively stable could be explained as the result of conservation efforts implemented during the last decade. Also, a declining human population on Tsushima (see Figure 7) may be one of the reasons why Tsushima leopard cat population decline has seemingly slowed. However, although roadkills have been reported increasingly since 1992 (Figure 6) in Kamijima, the increase could be attributable to density of the leopard cat remaining unchanged or even increasing during 1990's and 2000's: simply put, the if the population density is greater, the chance of roadkill occurring increases. Saeki and Macdonald (2004) have suggested a positive relationship between the number of the racoon dog (*Nyctereutes procyonoides viverrinus*) road kills and the species density.

Because of the uncertainties of critical parameters, the viability of the current Tsushima leopard cat population on Kamijima could not be determined. As a result of sensitivity analysis, the mortality of females and the proportion of females breeding are the most sensitive parameter affecting population viability. Male mortality, on the other hand, has very little impact on the population viability. This could be explained by their polyginous mating system, whereby males contribute very little to raising cubs. For solitary felids, food availability has a strong influence on the habitat selection of females for raising cubs successfully; on the other hand, maximising breeding opportunities is the most important factor for the habitat selection of males (Sandell, 1989). This habitat selection strategy also can be beneficial to population survival by minimizing female mortality.

Since habitat degradation has been recognized one of the biggest threat, carrying capacity is another big conservation interest. However, sensitivity analysis suggested that the probability of extinction starts to increase rapidly when carrying capacity is falls below a certain size. Unfortunately, the value could not be defined because of the uncertainties in parameters. When adult mortality is changed from the baseline input of 8% to 11%, 15%, and 21%, the threshold dramatically changes Further, in the presence of a very high mortality rate, it was determined that the population would go extinct even when the carrying capacity is reasonably high. Again, because of the parameter uncertainties, it was not possible to define the mortality rate at which extinction would occur; nevertheless, it is important to bear in mind this fundamental biological characteristic of population dynamics for conservation planning.

5.2 Further Direction of Research, Conservation Strategies, and PVA in practical conservation

5.2.1 Further Research Direction

Population Monitoring: The previous three large population censuses were conduced using the best possible methods and best data available for the early stages of a conservation program. They have successfully captured the population decline and the distribution change in the last 3 decades for guiding conservation activities; however, comprehensive population census could be conducted more often if there were an evidence that population is declining. 10 years may be enough for a small vulnerable population to go extinct, if the small island population is crashing with very high speed. The current distribution of the Tsushima leopard cat is reasonably well understood today, and it is critical to keep evaluating the status of whole population correctly and more often. Moreover, since the population distribution is already understood, sampling strategy can be sifted towards a more systematic analysis for the detection of short-term population fluctuations and the effectiveness of conservation activities.

This will help to detect potentially catastrophic population decline and help to verify the effectiveness of conservation actions (Staples et al., 2005). Since the population of the Tsushima leopard cat is naturally small, a slight decline in population size may be critical to the survival, and surveys would need to be sensitive to even the smallest change in numbers (Gese, 2003).

However, whilst raw data were available from previous reports from Nagasaki prefecture , the aims of the monitoring program could not be found, and were not stated. Further population monitoring programs of the Tsushima leopard cat should be rigorously designed and have clearly defined goals. For example, it should be specified whether the monitoring program is aiming to understand change in occupancy and/or relative abundance, and the timelines of the project should be clearly defined. Additionally, the amount of data needed for the any proposed statistical analysis should be considered and decided before further a monitoring program is implemented.

The problem with common abundance-based monitoring strategies is that they usually have low power to detect declines in threatened and endangered species and are largely nonreactive to declines (Staples et al., 2005); it requires intensive manpower and resources.

The census routes for the Tsushima leopard cat were sometimes changed, most probably to confirm their presence around the target area. Yet while changing routes would benefit to increase the chance of detection of leopard cat on different sites, it may cause sampling errors when conducting long-term population monitoring for detecting small population changes. Therefore, once census routes and locations for camera trappings are decided, they should not be changed even no sign is collected from some of the census routes, unless there is an unavoidable reason such as construction work or when the land owner requests it. It is worth noting that in addition to presence data, absence data is also meaningful. It is rather important whether researchers followed survey guidelines and instructions (Karanth and Nichols, 2002).

The sampling should be held during the same month or seasons within a short period of time span (3-15 days), in a standardized manner to make detection probabilities similar, to cover the survey area (Karanth and Nichols, 2002). Large numbers of staff or local volunteers can often be deployed over short periods of time; indeed, such large manpower recourses are necessary for simultaneous landscape-scale surveys of tiger (predator) and prey distribution (Karanth and Nichols, 2002). Karanth and Nichols et al (2002) mentioned that an area of several square kilometres can be covered in a day by 100 teams of three persons each, or alternatively, in 10 days by 10 such teams for the case of tigers in India. The decision has to be made based on a compromise between the quality and numbers of personals, and the time available to complete the survey (Karanth and Nichols, 2002). Large manpower needed for region wide surveys of distribution can be met from a variety of sources (Karanth and Nicholson, 2002) such as conservation centre staff, other government staff, tour guides, local naturalists, biology teachers, college students, and volunteers (local and non-local).

Before the large scale monitoring program is fully implemented, it is recommended to conduct a pilot study where the leopard cats are already confirmed. It will allow us to determine whether the monitoring design provides information of sufficient quality and quantity for management of the species (MacKenzie et al., 2004). However, for the case of the Tsushima leopard cat, a pilot study could be need not be on a large scale if a critical analysis of the data and protocol used in previous monitoring programs is conducted.

As part of the conservation strategy, it is also important to establish a societal role for the leopard cat. The Tsushima leopard cat conservation centre has successfully established their social role in local community, for example, providing environmental education for local schools, training for college students, and becoming one of the popular tourist destinations on the island. The staff members of Tsushima Wildlife Conservation Centre, Nagasaki Prefecture, and Tsushima City have gained an ability to provide appropriate training for potential research assistants as well as to organize this large-scale monitoring program.

However, such an intensive monitoring program could be expensive and time consuming;

additional funding could be minimized if current funding for monitoring program is reallocated based on new strategy. And the monitoring research can be valuable only when the optimal management action would be altered by new findings out from the monitoring program (Hauser et al., 2006).

Intensive traditional population censuses might be too expensive and time consuming. Lack of data and low detection rates of species are fundamental problems with endangered species monitoring, and to deal with the issues, a Bayesian approach has been increasingly used in conservation biology. An interpretation of probability as a conditional measure of uncertainty is the basis of the Bayesian paradigm (Bernardo, 2003). Statistical deduction about a quantity of interest is described as the alteration of the uncertainty about its value in the light of new evidence, and Bayes' theorem identifies how this modification should be made (Bernardo, 2003). Bayesian statistics have been applied to highly complex problems including endangered species conservation, which have been often unmanageable by traditional statistical methods. In a case study of estimating presence of fish when a species is undetected using a Bayesian approach, it is suggested that an approach to estimating detectability and probability of presence can be used with any standardized sampling protocol (Peterson and Bayley, 2004). Reassessment of the date sets used for this study using a Bayesian approach is recommended since they were highly fragmented, and it may provide a different conclusion to this analysis. However, in the case of Japanese species conservation, and thus the Tsushima leopard cat, a key obstacle is whether it is possible to work with a Japanese scientist or statistician skilled in Bayesian techniques, since the school of frequency statistics has been the mainstream (Wikipedia, 2008)

Implications of the Data Analysis for the Shimojima Population: Although, the geographic research area is limited, a very low leopard cat detection rate - namely two camera trapping and two faeces between March 2007 and August 2008 (Ministry of the Environment, 2008)- suggests that the population is probably very small. Understanding a whole picture of remaining population is urgent and should be done as soon as possible. Monitoring of the southern part of Kamijima and Shimojima has not been conducted with the same intensity or the comparable protocol as in the northern part of Kamijima. It is important to choose particular monitoring sites and standardize the research protocol throughout the island even though detection is very little. It would give more objective overview of both the Kamijima and Shimojima populations.

As a result of sensitivity analysis, even when the mortality rate is reasonably low, the population can not be considered viable when carrying capacity is too small. It suggests that the assessment of habitat availability and quality, and the population size and occupancy area estimates, are very important to ascertain population viability to support further decision-making. There is a question of where the camera trapped individuals came from, and more specifically possibility that it might have been captured and moved by someone from Kamijima. However, while the rediscovered individual(s) has survived 1.5 years, that it does not mean that current habitat is sufficient to support a viable population.

Research Priority for Further PVA: One of the criticisms for demographic PVA is that it requires data for many parameters which are not available for many endangered species (Morris and Doak, 2002). Of course, sensitivity analysis might be conducted using data on similar species to find out the most sensitive parameter for the species for the early stage of an endangered species program; however, more detailed PVAs have been used as a tool to evaluate a *priori* the relative effectiveness of management alternatives only when a detailed knowledge of the spatial and demographic structure of the populations, combined with simulations of realistic situations, was available. (Ferreras et al., 2001).

If PVA is to continue to be used to assist further decision making in the Tsushima leopard cat conservation program, mortality rates of this specific population should be studied since they are seemingly the most sensitive parameters. A record of mortalities and rescues are useful to identify the direct threats for the population; however, it does not reflect the reality since many individuals will have died undetected, for example due to disease, are not included. Also, it does not tell the impact of indirect threats such as inter-specific competition with wild boar and cats. Mortality rates of different age classes need to be studied ideally for this particular population; however it is notable that data on the adult mortality rate of leopard cat in Thailand (Haines, 2004) was used to make a judgement what value is reasonable for the species.

Construction of a life table or estimation of survival from radio telemetry data is usually needed to measure the survival rates of carnivores (Gese, 2003). Gese (2003) emphasised that four pertinent questions need to be considered: (1) what is the number of deaths in each age interval?; (2) what is the probability of dying in each age interval?; 3) does mortality vary between seasons?; and (4) what are the causes of mortality? Radio-days and the numbers of deaths during defined time intervals derived from radio-collared animals need to be measured to calculate interval survival rates.

Globally, very little work has been done on the on survival rate of small felids; however there are some notable studies.. Haines et al have estimated the adult mortality from radio-tracking data of 25 adults (17 males, 8 females) of leopard cats in Thailand between 1999 and 2002 (Haines et al., 2004) and 80 individuals (44 male, 36 female) of ocelot in the

United States between 1983 and 2002 (Haines et al., 2005).

The age 1-2 mortality rate of leopard cats was not available at all from studies for any other leopard cat population living in other geographical areas or for species with similar body size and the life-history. Many of the rescued individuals are brought to Tsushima Wildlife Conservation Centre between 6 and 12 months old. If technical issues such as the lifetime of batteries and collar size and design are overcome, radio tracking of released sub-adults will provide valuable data.

Since the demographic rates of such small sized cats (weight 2 to 4 kg) are studied very little, such data would significantly contribution to small cat conservation in general.

For Shimojima, especially for evaluating the habitat availability for reintroduction, spatially explicit PVA model may be an option to support further decision making and planning if data and resources are going to be available. Reintroductions, including supplementation for the declined population, have been frequently used for species recovery programs during the last three decades. Further, PVA and adaptive management have been recognized as useful tools in reintroduction programs (Armstrong and Davidson, 2006). Although a number of programs have succeeded in restoring the local population, reintroduction is not without problems. Many reintroduction projects have failed due to due to poor planning, inappropriate founder animals (confiscations from illegal trade, surplus animals from captive breeding programs, or problem exotic pets), low sample sizes, and lack of resources in the early years (Armstrong et al., 2007). In relation to species reintroduction, a critical analysis of habitat availability must be done but in sensible time scale to maximize the benefit such action.

Geographical Information Systems (GIS) have long been used as a spatial decision support tool; and more recently there has been particular interest in the integration of GIS with simulation modelling (Lethbridge et al., 2001; Seddon et al., 2007). Integrating PVA with GIS will enable us to explore spatially explicit management strategies.

However, some additional population studies are still needed to be done to define the probability of extinction because too little is known for small cat population biology. Indeed, Bayesian PVA could be a possible way to deal with some uncertainties in the parameters. A Bayesian PVA would allow us to move from a statistical calculation to a degree of belief about a future event in the real world (Lee and Riemann, 1997). PVAs often ignore uncertainty in parameters (Wade, 2002). Some PVA packages including VORTEX takes only a single value for each of a large number of parameters (Wade, 2002). Although users can investigate the sensitivity of the PVA results to different parameter values, in a listing decision the user must choose a single distribution to represent the best estimate of risk. The result needs to be interpreted in a particular fashion (Wade, 2002).

Time to extinction has uncertainty both because of the stochastic nature of the extinction process and because our knowledge of the system being modelled is imperfect (Wade, 2002). However, both these both uncertainties can be taken into account in the Bayesian statistics results through probability statements about the possible values of parameters (Wade, 2002).

5.2.2 Conservation and Management Options

Kamijima Population: Conservation of Kamijima population has been recognized as the most priority in the conservation program (Kiyonaga et al., 2008).

Since the population viability could not be decided, it was not possible to compare the performance of a range of scenarios to identify the conservation strategies most likely to increase population viability (e.g. how many road kills should be reduced for the population to be viable).

However, through sensitivity analysis it was identified that reducing the female mortality is clearly the key to conserve the long term population. Any possible activities preventing the anthropologic mortalities of females would be the highest priority certainly for both Kamijima and Shimojima populations. This is basically the same message from the previous model in 2006; however, the relative importance of females was not mentioned. In response to the recommendation made in 2006, research and conservation activities for preventing road kills have stated as being the conservation activities with highest priority (for more details, Maeda et al., 2008; Yamamoto et al., 2008).

There are some concerns which could not be evaluated, such as the impacts of the expanding wild boar population and other introduced species (such as domestic cats and dogs), and the sika deer (*Cervus Nippon*) population, which potentially have a negative impact on the population. However, inter-specific competition between the leopard cat and these species is not well understood and could be complex and difficult to understand: the influence of other species on the Tsushima leopard cat population could not only manifest itself through direct competition, but also indirect competition through reducing the suitable habitat or prey availability. In a study of the European wildcat (*Felis silvestris*) in Spain, the abundance of prey species (rabbits) were negatively associated with the abundance of ungulates wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*) (Lozano et al., 2007). Wild boar control program is implemented by Department of Agriculture as a pest control. As is seen in the Scottish wildcat, hybridization with the domestic cat progress secretly and the difference between pure wildcats and hybrids are not clear for some cases just by the outlook, and DNA analysis is needed for the judgment (Macdonald et al., 2004). It would be too late to take action for conserving the genetic uniqueness as a wild species when it becomes obvious. Genetic analysis to evaluate the possible hybridization of leopard cats and domestic cats is not conducted. With regards to this matter there is a special caution of this issue since leopard cat and domestic cat can naturally bred in captivity, and domestic cats are already abundant throughout the island.

Shimojima Population: Two major strategies have been considered for Shimojima population conservation up to now: (1) maximize the population growth rate by reducing the mortalities through habitat restoration, and (2) supplementation of captive bred individuals for supporting the current population. The strategies are presuming that the habitat on Shimojima still can support a viable population. Another option which has not been considered is triage. The total area of Shimojima is 249 km^2, making it about 55% of the size of Kamijima. This means that simply means the size of the habitat is more limited. Furthermore, human density is higher on Shimojima then on Kamijima. Spatial assessments of the habitat quality and quantity, including the risk assessment of road kills are underway using GIS (Ministry of the Environment, personal communication), and the results should be critically analyzed to see whether the habitat is sufficient to support a completely isolated population for deciding an optimal scenario.

Another felid species of Japan is the Iriomote Cat (*Prionailurus iriomotensis*) of Iriomote island (Okinawa Prefecture, Japan), with a land area of is 284.4 km^2. The Iriomote cat is genetically very closely related to leopard cat (Masuda and Yoshida, 1995); however the habitat is a subtropical island. The Iriomote cat is also a critically endangered species and still surviving on the similar sized island as Shimojima. A key difference with Shimojima is, however, Iriomote's considerably smaller human population (about 2000), and more pristine protected forest (Izawa and Doi, 1999). It could be useful to compare the difference between the two islands to identify the key for population survival.

Intensive conservation activities such as reintroductions require a robust and well structured framework of decision making and an active team with excellent and dedicating personals on the ground for successful adaptive management (Klaiman and Rylands, 2000). Decisions for reintroduction can be made by relatively simple criteria when the population is extirpated from the area since it is more clearly identified in guidelines (e.g. IUCN, 1995); however, decision making is more difficult for the case of supplementation of a declined population, and more data will be required to make a decision whether reintroduction should be implemented or not. PVA has been used as a decision support tool for reintroduction programs such as: whether habitat regeneration has been sufficient to allow population persistence, whether supplementary feeding is needed, and what level of predator control is needed on reintroduced populations; and more recently to assess the growth rate of the population before the reintroduction is implemented to determine optimal reintroduction strategies. (Armstrong and Davidson, 2006)

In the Japanese national species conservation program plan, the conservation goal is defined as establishing "self-sustainable population", though a clear definition is not described. On the other hand, the Japanese Red List, which is one of the important criteria for designating species as being national endangered, has clear qualitative and quantitative threshold (Agency of the Environment, 1997). For example, if the conservation goal is to downlist the population from Critically Endangered to Vulnerable, the recovery of Kamijima population is essential (this would be the best possible status for the Tsushima leopard cat because the habitat is naturally restricted to the Island of Tsushima). To be classified as Vulnerable, the distribution of the population should be greater than 500 km^2, which is only possible if the Shimojima population successfully recovers.

If the population on Kamijima is confirmed stable and the aim of the program is agreed to conserve both the Kamijima and Shimojima populations by stakeholders, the major focus of conservation program may have to shift to Shimojima, especially if a reasonable probability of conservation success was expected.

5.2.3 Further Use of PVA in Practical Conservation

PVA as a Decision Support Tool: Conservation management decision is a social activity and always has to deal with uncertainties - not only biological, but also political and social. Even if the process could be accurately described mathematically, the optimal management for such a spatially complex stochastic population would be impossible to find mathematically in most cases (Burgman and Possingham, 2001). And often, a management decision involves a gamble, such as which patch to purchase first, or which of several populations to target for management (Burgman and Possingham, 2001).

Milner-Gulland (1997), and Possingham and Tuck (1998) cited by Burgman and Possingham (2001) discusses that 'if we recognize that a population management model for a threatened species is inherently stochastic and decision are likely to depend on current circumstances (e.g., the price of timber) then we must accept that stochastic dynamics programming represents the only way to find the precise optimal strategy'. Even a simple model such as a sensitivity analysis from this study or previous PVA model is still helpful for stakeholders to understand the basic biology, stochasticity of the population viability, and the focus of the program especially at early stage of a conservation program. In fact, conservation actions for roadkills have been implemented with stronger emphasis after the conservation planning workshop in 2006 (Maeda, et al., 2008; Yamamoto et al., 2008); and it was because a wide range of stakeholders could finally understand what the critical focus of Tsushima leopard cat conservation are, for the first time in 10 years of conservation program through the simple simulation model (see, Kiyonaga et al., 2008). The finding of a PVA could be simple and obvious for biologists; however, appropriately interpreted PVA results are useful to fill the knowledge and awareness gap among stakeholders such as conservation managers, local residence, and field workers.

At the same time, misuse and misinterpretation of the results can happen very easily because the PVA result would give a definite value of extinction probability even if input data were based on uncertainty or unreliable. However, it could be useful; the data required for sound scientific model are not available through a short term research. Although the interpretation of the results were slightly different, almost the same message were made from the model 2006 and this study since vital rates such as the demographic rates still not well understood from the Tsushima leopard cat. Data were limited for both this dissertation and the previous PVA, a simple sensitivity analysis to model particular model scenarios was arguably the only avenue of research. Moreover, other uses and applications of PVA have here received comparatively little attention, on the basis that our limited data precluded us from undertaking other analytical routes.

This is an important point: for any kind of model, the user must know its limitations and underlying assumptions to prevent over interpretation of the results. Further, it is recommended that a model should be assessed by external scientists and remodelled periodically with updated data (Burgman and Possingham, 2001).

5.2.4 Brief Conclusions and Recommendations

Analysis of the previous monitoring data indicate that the northern Kamijima population is stable or possibly recovering; however, analysis of the population trends in both southern Kamijima and Shimojima was not possible. Further systematically designed population monitoring and focused research is necessary for guiding the program. Sensitivity analysis of the PVA model suggested the importance of female mortality and the habitat size for viable population. However, for further use of more specific PVA models, a different approach for monitoring design and data analysis such as a Bayesian approach and the outcomes from further monitoring and research are needed.

(Total: 14,057 words)

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Appendices

Section I: ***Modeling the Tsushima Leopard Cat Using Vortex***

Murayama et al. (2006; p36-38) states:

Tsushima Leopard Cat PVA Model (Baseline) Input Values

Number of iterations: *1000 per scenario*

Number of years: *100 calendar years*

Extinction definition: *Only one sex remaining*

Number of populations: *1*

Inbreeding depression: *Yes (3.14 lethal equivalents)*

Concordance between environmental variation in reproduction and survival: *Yes.*
It is believed that there is a positive correlation between environmental conditions that affect survival and reproduction (i.e., years that are good for survival tend to also be good for reproduction and vice versa).

Mating system: *Polygynous*

Age of first reproduction: *2 years for females and 3 years for males*

Maximum age of reproduction: *9 years*

Maximum litter size/litter distribution: *3*. This distribution is 35.5%, 53%, and 11.5% for 1 to 3 cubs, respectively, resulting in a mean litter size of 1.76.

Sex ratio at birth: *50% male*

Density-dependent reproduction: *Yes*. Density dependence is defined by specifying parameters of a particular functional shape for the relationship between population density and breeding success. The curve that is often used to represent the functional relationship is:
% breeding = $[(P0-(Po-Pk)*(N/K)^{B})] * (N/(N+A))$. The following parameter values were used in the model:

P0 = 98.4%. This specifies the % of adult females breeding in an average year when population density is very low.

Pk = 35%. This specifies the breeding rate (% females breeding each year) when the population is at its carrying capacity.

A = 0.5. This is a measure of the strength and starting point for Allee effects.

B = 1. This defines the steepness with which breeding decreases as population approaches K.

Environmental variation in breeding (annual variation as a standard deviation): *10.3%.*

Males in the breeding pool: 47.5%.

Mortality: *See below.*

Female		Male		
Age class	% Mortality	SD (%)	% Mortality	SD (%)
0 – 1	44.7	10.3	44.7	10.3
1 – 2	26.2	8.7	26.2	8.7
2 – 3	21.0	7.0	23.1	9.0
3+	21.0	7.0	21.0	7.0

Catastrophes: *2 catastrophes, described as major and minor.*
In the TLC model, major catastrophes have a 0.25% chance of occurring per year, reduce reproduction by 80%, and reduce survival by 40%. Minor catastrophes have a 3% chance of occurring each year, reduce reproduction by 25%, and have no effect on mortality.

Carrying capacity (K): *175 individuals.*
Initial population size (N_0): *95 individuals* (from the latest census)
Harvest: *None.*
Supplementation: *None.*

Model Results
The baseline model predicts a nearly 50% chance of extinction for the Tsushima leopard cat over the next 100 years. More precisely, if nothing is changed, *Vortex* produces an estimated probability of extinction of 49.7% ± 1.6% over the next 100 years. Modeled populations that do remain extant have only 31 individuals left at the end of 100 years and face imminent extinction.

To examine the effects of mortality due to road kills, we examined reducing adult mortality rates from 21% to 19%, 15%, and 11%. This translates to approximately 1, 3, and 5 individuals per year. Adult mortality rates of 15% are typical for leopard cats and other similar-sized felines in populations where they are not persecuted or otherwise facing anthropogenic threats. All three alternative scenarios reduce the probability of extinction significantly. Reducing mortality by three adult individuals per year produces a positive deterministic growth rate and reducing it by five individuals per year produces a stable population (see Table below for details).

	Probability of extinction in 100 yrs	Mean size of surviving populations
Baseline (21%)	0.497	31
19% adult mortality	0.277	40
15% adult mortality	0.035	70
11% adult mortality	0.005	99

The parameter estimates of the model are rough at best. However, it does suggest that stabilizing, or even reversing the decline of the Tsushima leopard cat could be accomplished in large part by lowering mortality rates due to collisions with motor vehicles alone. Estimates from the number of animals brought to the TWCC suggest that mortality due to motor vehicle collisions are probably ≥ 5 individuals per year.

Conclusions

The Tsushima leopard cat (*Felis bengalensis euptilura*) is a critically endangered species that is endemic to Tsushima Island, Nagasaki Prefecture, Japan. A 2004 census estimated that only 80-110 individuals of this species still live in the wild. During at least the past 20 years the population has experienced a slow decline in numbers, and the population on the southern island, Shimoshima, may already be extinct. Population modeling using *Vortex* suggests that the population has a high probability of extinction during this century.

Preliminary data suggests that the Tsushima leopard cat prefers lowland forests with thick and heterogeneous vegetation, the edges of forests and streams, swampy areas such as rice fields, and bamboo thickets (Tajiri *et al.* 1996; Watanabe *et al.* 2003). Preliminary data on their diet suggests that they eat small mammals and birds, as well as fish, frogs, snakes, insects and spiders, and small amounts of plant material (Tatra and Doi 1994).

The preliminary plan emerging from this workshop consists of extensive field research to provide data on the preferred habitats of the Tsushima leopard cat and those habitat types that are rich in preferred prey items, so that habitat protection and restoration can be conducted most efficiently. Further, the data will provide more accurate inputs for modeling the future of the population and allow rigorous prediction of different management outcomes. In addition to further research, the plan calls for improved communication among scientists working on the Tsushima leopard cat, between scientists and government agencies, and greater outreach to the local community and schools.

Positive changes to the mortality rate of adult leopard cats (especially related to motor vehicle collisions) or reintroduction to Shimoshima have the potential to greatly improve the probability of persistence of the only *in-situ* population of the Tsushima leopard cat.

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Section II: Data from previous camera trapping and fasces sampling

Table II-1 Number of leopard cat photos from each camera trapping points (1998 – 2001)

camera point	1998	1999	2000	2001
Nuka	0	0	ND	0
Saho	ND	ND	0	ND
Umugi/Shitaura	0	0	0	1
Nii	ND	5	6	0
Umakokashi	ND	1	0	0
Kisaka A	0	11	1	0
Kisaka B	0	1	1	27
Shitaka A	ND	1	3	12
Shitaka B	ND	0	0	3
Shitaru	ND	16	49	22
Tanohama	5	43	21	8
Sago sarie	10	ND	ND	ND
Sekinosae	6	ND	ND	ND
Ohboke	8	0	4	37
Nakayama	7	12	8	6
Iguchihama	ND	17	20	4
Iguchihama kaigan	ND	3	3	3
Kin A	0	0	0	7
Kin B	0	2	0	66
Syushi	0	8	3	2
Goneo	2	0	0	58
Hamagusu	28	0	1	5
Hamagusu dam	2	13	20	6
Saozaki park	ND	ND	ND	0
Total number of leopard cat photos	68	133	140	267
Total number of lcamera trapping sites	15	20	20	21

Table II-2 Number of leopard cat faeces collected from each census routes (1999-2001).

Camera Trapping Sites	1998	1999	2000	2001
Nakayama	N/D	N/D	3	0
Kyu-Nakayama	7	2	2	N/D
Ohboke	2	4	1	3
Shitaka	2	N/D	N/D	N/D
Shitaka A	N/D	0	3	1
Shitaka B	N/D	1	2	4
Kisaka A	3	6	7	11
Shitaru	29	48	35	25
Tanohama	60	49	42	45
Sago Sarie	4	6	9	5
Sekinosae	0	0	N/D	N/D
Iguchihama	N/D	3	5	5
Iguchihama Kaigan	N/D	2	0	2
Syushi	2	0	0	1
Goneo	4	1	1	1
Hamagusu	2	0	2	2
Hamakusu dam	56	77	53	45
Saho (Nuka)	0	0	0	0
Shitaura	N/D	N/D	N/D	0
Umugi	0	0	0	0
Nii	0	0	1	2
Umakokashi	0	0	0	0
Total number of feces	171	199	166	152
Total number of transect lines	17	20	20	20

Table II-3 Number of leopard cat faeces collected from each census routes (2002 – 2006).

Route	2002	2003	2004	2005	2006
Toyo	N/D	N/D	N/D	N/D	1
Hamakusu (Aza-shimanoura)	N/D	4	16	6	6
Tomigaura (Aza-otokonoura)	N/D	1	5	2	N/D
Izumi (Ohzeki)	N/D	N/D	2	0	N/D
Ohura Akou-Yama	1	0	2	1	N/D
Kusu Yokamichi	1	0	4	0	N/D
Nishitsuya	14	0	1	9	15
Sasuna-Syushi line	2	0	3	11	3
Syushinouchi	N/D	N/D	N/D	N/D	3
Ohmasu A	27	28	10	16	12
Ohmasu B	18	15	20	20	N/D
Tsukumodani	30	21	45	33	17
Kin	8	15	4	7	5
Mogi (Syushi-Mogi line)	12	11	9	9	13
Syushi (Sago-Kawachi line)	15	11	12	1	N/D
Saozaki	N/D	N/D	N/D	N/D	32
Nakayama	19	8	26	16	13
Ohe Rindou	20	43	10	24	13
Ohboke	38	24	21	15	N/D
Ohyadani line	15	3	5	5	1
Nita dam	35	25	27	11	35
Nita dam (kurusu-dani)	5	5	2	5	N/D
Nita dam (oshika-rindou)	43	30	26	23	N/D
Hitoe	N/D	N/D	N/D	N/D	1
Shikoe	N/D	N/D	N/D	N/D	6
Ashimi-kawachi line	11	3	7	0	N/D
Kaidokoro-Saka line A	19	9	9	7	N/D
Kaidokoro-Saka line B	14	7	9	4	N/D
Yanadayana (hitani)	31	26	14	10	5
Shishimi	N/D	N/D	N/D	N/D	5
Shitaka A	4	5	4	12	10
Shitaka B	5	3	3	0	3
Shitaka B betsu (B route shita)	2	1	1	0	N/D
Shitaka C	7	4	5	3	N/D
Machimichi shitaka (Okuyama line)	N/D	3	10	24	N/D
Shikoe	2	3	1	5	N/D
Kisaka	0	3	1	3	6
Shitaru	N/D	N/D	11	3	5
Tanohama	N/D	N/D	7	0	2
Iguchihama	N/D	N/D	6	4	3
Syushi	N/D	N/D	0	0	0
Hamakusu dam	N/D	N/D	30	18	36
Total number of faeces	398	311	368	307	251
Number of Census Routes	27	30	36	36	26

Section III: Summary of the demographic data from other small wildcats

Leopard cat (*Prionailurus bengalensis*)

	Survival rates	source	Factors affecting survival rates
Phu Khieo Wildlife Sanctuary (Thailand)			Pristine forest with wildlife protection
Males-Adults	0.96, Standard Diviation 0.05	Haines et al. 2004	
Females-Adults	0.87, Standard Diviation 0.13	Haines et al. 2004	
Adults (average)	0.92, Standard Diviation 0.06	Haines et al. 2004	
Khao Yai National Park (Malaysia)			Human caused incidents (road kill, poaching etc) presence
Adults (average)	0.53	Haines et al. 2004	

Eurasian lynx (*Lynx lynx*)

	Survival rates	source	Factors affecting survival rates
Juveniles	0.43-0.49	Breitenmoser-Wursten et al 2007	
Adults and sub-adults	0.37 (in protected area)	Jedrzeiewski et al 1996	poaching (71% to the total annual mortality rate)

Ocelot (*Leopardus pardalis*)

	Survival rates	source	Factors affecting survival rates
age 3+	Pooled estimates of annual survival rates differed between resident ((S) over cap = 0.87) and transient ((S) over cap = 0.57) ocelots (P = 0.02)	Hains et al 2005, Haines et al 2006	density dependence, resident or transient
Males			
Age 0-1	0.68 Standard Diviation 0.05	Laack et al 2005, Haines et al 2006	
Age 1-2	0.87 Standard Diviation 0.02	Haines et al 2006	
Age 2-3	0.78 Standard Diviation 0.05	Haines et al 2006	
Adults age 3+	0.87 Standard Diviation 0.02	Haines et al 2007	
Females			
Age 0-1	0.68 Standard Diviation 0.05	Laack et al 2005, Haines et al 2006	
Age 1-2	0.87 Standard Diviation 0.02	Haines et al 2006	
Age 2-3	0.78 Standard Diviation 0.05	Haines et al 2006	
Adults age 3+	0.63 Standard Diviation 0.10	Haines et al 2007	

Iberian lynx (*Lynx pardinus*)

	Survival rates	Source	Factors affecting survival rates
Age 0-1	0.2 (with risk of human caused mortality and starvation) -0.5,	Gaona et al 1998	human caused mortality (road kills, hunting)
Subadults	0.14-0.3 (outside of protected area)	Gaona et al 1998	human caused mortality (road kills, hunting)
Adults	0.7-0.9	Gaona et al 1998	human caused mortality (road kills, hunting)
Males			
Juveniles (Cubs)	0.5 SD0.11	Gaona et al 1998	Environmental variation
Subadults			
(Non-dispersing)	0.7 SD0.04	Gaona et al 1998	
(Dispersing)	0.4 SD0.14	Gaona et al 1998	
Adults			Dispersal
(with territory)	0.9 SD0.06	Gaona et al 1998	
(without territory)	0.7 SD0.19	Gaona et al 1998	
(Old individuals)	0.5-0.6	Gaona et al 1998	
Females			
Juveniles (Cubs)	0.5 SD0.11	Gaona et al 1998	Environmental variation
Subadults			
(Non-dispersing)	0.7 SD0.04	Gaona et al 1998	
(Dispersing)	0.5 SD0.20	Gaona et al 1998	
Adults			Dispersal
(with territory)	0.9 SD0.06	Gaona et al 1998	
(without territory)			
(Old individuals)	0.5-0.5	Gaona et al 1998	

Section IV: Presence /Absence data of previous monitoring

Table IV-1 Camera trapping presence / absence data 1998-2001

camera trapping sites	1998	1999	2000	2001
Kisaka A	0	1	1	0
Kisaka B	0	1	1	1
Shitaka A	ND	1	1	1
Shitaka B	ND	0	0	1
Shitaru	ND	1	1	1
Tanohama	1	1	1	1
Sago sarie	1	ND	ND	ND
Sekinosae	1	ND	ND	ND
Ohboke	1	0	1	1
Nakayama	1	1	1	1
Iguchihama	ND	1	1	1
Iguchihama kaigan	ND	1	1	1
Kin A	0	0	0	1
Kin B	0	2	0	1
Syushi	0	1	1	1
Goneo	1	0	0	1
Hamagusu	1	0	1	1
Hamagusu dam	1	1	1	1
Saozaki park	ND	ND	ND	0
Number of presence sites	8	12	12	15
Total number of sites	13	16	16	17
% of sites Presence	61.54	75.00	75.00	88.24

Table IV-2: Presence/Absence data of feces census in Northern part of Kamijima

1998 - 2001

	Census Route	1998	1999	2000	2001
1	Nakayama	N/D	N/D	1	0
2	Kyu-Nakayama	1	1	1	N/D
3	Ohboke	1	1	1	1
4	Shitaka	1	N/D	N/D	N/D
5	Shitaka A	N/D	0	1	1
6	Shitaka B	N/D	1	1	1
7	Kisaka A	1	1	1	1
8	Shitaru	1	1	1	1
9	Tanohama	1	1	1	1
10	Sago Sarie	1	1	1	1
11	Sekinosae	0	0	N/D	N/D
12	Iguchihama	N/D	1	1	1
13	Iguchihama Kaigan	N/D	1	0	1
14	Syushi	1	0	0	1
15	Goneo	1	1	1	1
16	Hamagusu	1	0	1	1
17	Hamakusu dam	1	1	1	1
	Number of routes TLC confirmed	11	11	13	13
	Number of routes	12	15	15	14
	% Presence	91.67	73.33	86.67	92.86

Table IV-3: Presence/absence data from feces census in northern part of Kamijima, 2002 - 2006.

Route	2002	2003	2004	2005	2006
Toyo	N/D	N/D	N/D	N/D	1
Hamakusu (Aza-shimanoura)	N/D	1	1	1	1
Tomigaura (Aza-otokonoura)	N/D	1	1	1	N/D
Izumi (Ohzeki)	N/D	N/D	1	0	N/D
Ohura Akou-Yama	1	0	1	1	N/D
Kusu Yokamichi	1	0	1	0	N/D
Nishitsuya	1	0	1	1	1
Sasuna-Syushi line	1	0	1	1	1
Syushinouchi	N/D	N/D	N/D	N/D	1
Ohmasu A	1	1	1	1	1
Ohmasu B	1	1	1	1	N/D
Tsukumodani	1	1	1	1	1
Kin	1	1	1	1	1
Mogi (Syushi-Mogi line)	1	1	1	1	1
Syushi (Sago-Kawachi line)	1	1	1	1	N/D
Saozaki	N/D	N/D	N/D	N/D	1
Nakayama	1	1	1	1	1
Ohe Rindou	1	1	1	1	1
Ohboke	1	1	1	1	N/D
Ohyadani line	1	1	1	1	1
Nita dam	1	1	1	1	1
Nita dam (kurusu-dani)	1	1	1	1	N/D
Nita dam (oshika-rindou)	1	1	1	1	N/D
Hitoe	N/D	N/D	N/D	N/D	1
Shikoe	N/D	N/D	N/D	N/D	1
Ashimi-kawachi line	1	1	1	1	N/D
Kaidokoro-Saka line A	1	1	1	1	N/D
Kaidokoro-Saka line B	1	1	1	1	N/D
Yanadayana (hitani)	1	1	1	1	1
Shishimi	N/D	N/D	N/D	N/D	1
Shitaka A	1	1	1	1	1
Shitaka B	1	1	1	0	1
Shitaka B betsu (B route shita)	1	1	1	0	N/D
Shitaka C	1	1	1	1	N/D
Machimichi shitaka (Okuyama line)	N/D	1	1	1	N/D
Shikoe	1	1	1	1	N/D
Kisaka	0	1	1	1	1
Shitaru	N/D	N/D	1	1	1
Tanohama	N/D	N/D	1	0	1
Iguchihama	N/D	N/D	1	1	1
Syushi	N/D	N/D	0	0	0
Hamakusu dam	N/D	N/D	1	1	1
TOTAL	26	26	35	30	25
Number of Census Routes	27	30	36	36	26
% Precence	96.30	86.67	97.22	83.33	96.15