DYNAMICS AND VIABILITY OF THE CRITICALLY ENDANGERED CAT BA LANGUR: A NEW PERSPECTIVE FOR CONSERVATION ACTIONS

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ABSTRACT

The golden-headed or Cat Ba Langur (*Trachypithecus poliocephalus poliocephalus)* is an endemic species of Cat Ba Island in northern Vietnam. It is listed as a critically endangered species in the IUCN red list because of its small, isolated sub-populations and low population numbers. This study was undertaken to understand the trend of population development and the risk of extinction of the species in the future. This will help conservationists to minimize the risk of extinction, and develop better conservation strategies for this species. A number of methods were carried out to examine the conservation status and life history of the langurs. This included conducting in-depth interviews with 21 members of forest protection groups and 20 staff of the Cat Ba National Park, gathering secondary data from reports and other publications dating from 1997 onwards, and conducting field surveys. These information and data were then used to construct a simulation model for the dynamics and viability of the langur population. The study found that 12 groups of the langurs consisting of a total of 50 – 60 individuals with an average group size of 4.67 individuals survived on Cat Ba Island. Disturbed social structure is one of the most significant reasons causing the stable population in the past twelve years, and it is predicted to continue to stabilize in the next 10 years, reaching 86 individuals by 2050. The validation tests have confirmed that the model is sufficient to be used as a tool for policy analysis and decision making for conservationists on the island. The effects of reproducing population on birth rate, and birth rate are two factors which have the most influence on the number of langurs. This clearly implies that an increase in the reproducing population numbers and birth rate would have a significant effect on the growth of langur population in the long-term. Relocation of non-reproductive groups to reproductive units, strict protection and management are important strategies to save this critically endangered species from extinction.

Keywords: Cat Ba langur; conservation actions; critically endangered species; system dynamics modeling; extremely isolated population; strategy planning

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Dynamics and viability of the critically endangered Cat Ba langur

1. Introduction

Golden-headed langur or Cat Ba Langur, *Trachypithecus poliocephalus poliocephalus* (Trouessart, 1911) belongs to the subfamily of the leaf-eating monkeys (Colobinae), which occurs only on Cat Ba Island of Vietnam (Schrudde *et al.,* 2009). This subspecies is probably the most endangered species of the Asian colobines and has the smallest distribution among the langur species (Nadler *et al.,* 2007). Cat Ba langurs are classified as Critically Endangered on the IUCN Red List (IUCN, 2012) and listed as the world's 25 most endangered primates from 2000 to 2012. Poaching has been the main cause leading to small, isolated subpopulations and low population numbers. Poaching for traditional medicine and bush meat was the direct cause for the dramatic decline of langur population from approximately 2,400 – 2,700 in the 1960s (Nadler and Ha Thang Long, 2000) to only 52 - 54 individuals in 2001 (Stenke, 2001). As a result of illegal hunting and habitat fragmentation, most of the groups are already in reproductive isolation with no opportunity to exchange group members. The remaining population is now divided into five isolated subpopulations and probably only two of which are reproductive populations as the other three sub-populations either have no males or no females.

The Cat Ba Langur is on the brink of extinction. However, it remains extremely unstudied in comparison with other members of the leaf monkeys. Details of conservation and distribution status, potential habitats, home range and diet remain to be studied. Furthermore, the dynamics and future development of the population are poorly understood, leading to insufficient conservation actions for the species. Understanding the population trend and the risk of extinction or decline of the Cat Ba Langur in the future could minimize these risks and promote chance of recovery for this critically endangered species. In addition, it could help conservationists and managers on Cat Ba Island to have better conservation strategies for the species.

In these circumstances, system dynamics models have proven to be useful in predicting dynamics and future development of population (Faust *et al.,* 2004; Beall and Zeoli, 2008), and they enable conservationists to link observable patterns of behavior of a dynamics population to micro-level structure and decision making processes (Qudrat-Ullah, 2005). The system dynamics models facilitate the understanding of systems behavior, which provides insight as to understand how a system changes over the time (Beall and Zeoli, 2008). Growth, decay and oscillations are the fundamental dynamic patterns of systems, and the methodology is useful for understanding the issues that create limits to growth. This approach provides a set of powerful tools and techniques, such as behavior over the time, causal loop diagrams, stock and flow diagrams and simulation models (Maani and Cavana, 2007). Furthermore, system dynamics models can provide a manageable way of understanding how numbers change over the time or in relation to each other by dealing with internal feedback loops and time delays that affect the behavior of the entire system (Uyenoyama and Singh, 2004). The model also can provide further insights into the behavior of dynamics and viability of the population and gain a better understanding of factors influencing the populations in order to develop better conservation program for endangered species.

This paper applied system dynamics model to analyze the dynamics and future population development of the Critically Endangered Cat Ba Langur. It is expected that an improved understanding of the dynamics and future development of the langur population on Cat Ba Island will attract further interest, research and better actions to conserve this species.

2. Methods

2.1.Study area

The study was conducted on Cat Ba Island (20^{0}42' – 20^{0}54'N and 106^{0}54' – 107^{0}09'E), which is a limestone archipelago with an area of over 240 km^2, consisting of one main island and 266 small islands (Figure 1). The island is about 45 km east of Hai Phong city and 25 km south of Ha Long city. Cat Ba Island is a typical well-developed limestone karts landscape rising abruptly from the sea. The topography is rugged and marked by steep outcrops and areas of bare rock, where much of the elevation is between 50 m and 200 m above the sea level. The main natural vegetation type on the island is limestone forest. However, the forest has been subjected to high levels of disturbance, and large areas have been replaced by limestone shrub or bare rock.

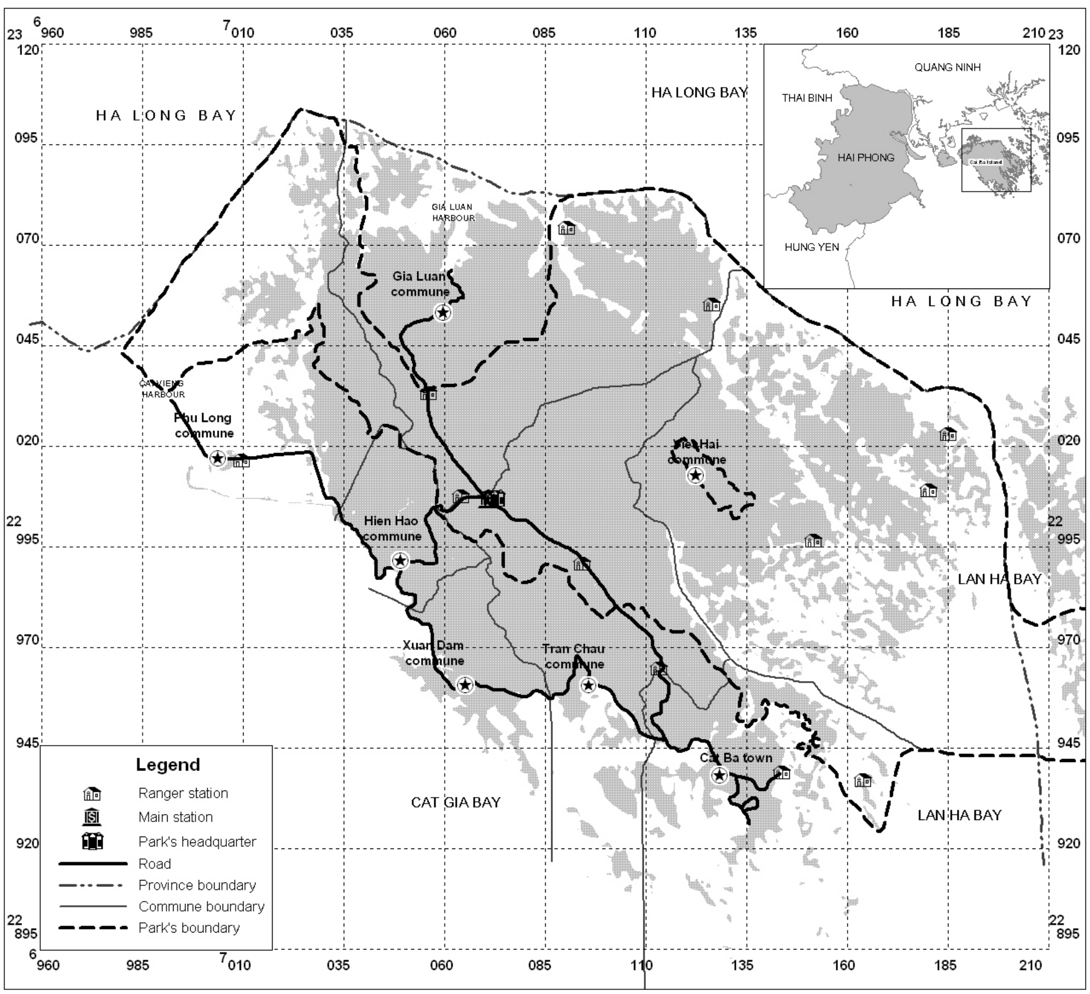


Figure 1: Cat Ba Island

2.2. Dynamics and viability of the langurs

This study applied a systemic approach to assess the conservation status and life history of the langurs, and used system dynamics models to analyze the dynamics and viability of the langurs on Cat Ba Island.

2.2.1. Literature review

Conservation status and life history on previous records of the langurs were gathered from reports and other publications dating from 1997 onwards (Table 1).

Table 1: Previous langur records in the Cat Ba Island

Reference	Population status	Main methods used
Nguyen Phien Ngung, 1997	100 individuals	Secondary data review, field survey
Nadler and Ha Thang Long, 2000	104 – 135 individuals	Secondary data review, field survey
Stenke, 2001	52 – 54 individuals	Secondary data review, field survey

2.2.2. Interviews

A total of 21 members of forest protection groups and 20 rangers and staff of Cat Ba National Park, especially focusing on persons who work in the areas where the presence of the langurs is confirmed, were interviewed for information on the distribution status and life history of the langurs on the island. Information on factors influencing on dynamics population was also collected.

2.2.3. Focus group discussion

The focus group discussion was conducted by having discussion with eight key persons in the Cat Ba National Park and Cat Ba Biosphere Reserve to acquire information on langur conservation, and obtain different views and feedback on the dynamics model of langur population viability, as well as solutions to conserve the langurs on Cat Ba Island.

2.2.4. Field survey

Six localities suggested by the members of forest protection groups and rangers of the Cat Ba National Park, and localities where the presence of the langurs were confirmed by Stenke (2001), were crosschecked during field surveys between November 2012 and May 2013. This aims to confirm whether the species were presence or absent, as well as to identify the numbers and social structure of each group and sub-population. It is the fact that it was unable to follow the langurs because they were not habituated and because of difficult terrain. Therefore, the hilltop positions (providing good overviews of the areas) were chosen for observing the langurs with binoculars 7 x 50. Observations were also made by boats along the coastline to observe the langurs while they were moving and eating. Four out of five sub-populations were observed and taken photos from the coastline, except for the sub-population in Nghia Dia Gia Luan area. Once, langurs were encountered, special effort was made to count all individuals and sex ratio. Social structure of each group such as adult, juvenile and infant was also identified. However, it was quite difficult to do this because they were generally too far away, from 70 to 300 m from the observation posts.

2.2.5. Dynamics model of langur population viability

The dynamics and viability of the langur population simulation model (DVLPSM) was constructed based on the results of literature review, interviews, and focus group discussion and field surveys. Stocks and flows, various parameters were incorporated into Vensim PLE 5.6b software package to simulate the DVLPSM. Langur population and habitat optimal are understood as stocks, and births, deaths, generating and reducing are also understood as flows in the model. Additionally, 16 parameters influencing the births and deaths of the langurs were included during the DVLPSM construction process.

The langur population is influenced by births and deaths. Births are influenced by birth rate and reproducing population (the numbers of langurs could produce in the population). Deaths are influenced by several factors such as life expectancy, carrying capacity, langur crowding, hunting and other reasons. Relationships between stocks, flows and converters in the DVLPSM were established based on historical data, empirical evidence, reasonable assumptions, and theoretical mathematical equations that were referenced from different sources. Some of the relationships were able to be verified using empirical data and literature sources; others were based on experiential knowledge and assumptions.

Dimensionless multipliers were used to represent factors that have the potential to change the value of other components in the model during the course of the simulation (Fisher, 2007). In this study, the dimensionless multipliers were applied to identify the relationships between reproducing population and birth rate, and between langur crowding and death rate. These multipliers are usually defined as graphical functions, of which the vertical axis presents a multiplier or an effect of reproducing population on the birth rate, while the horizontal axis is defined as the ratio of langur population and initial reproducing population as an example. Births are now determined by the product of langur population and actual birth rate. The actual birth rate is the product of the normal birth rate and a multiplier component called the effect of reproducing population on birth rate. These multiplier components produce different values during the simulation. The product of a changing multiplier value and the normal birth rate value generates a new value called the actual birth rate, which also changes during the course of the simulation. Similarly, deaths are now identified by the product of langur population and actual death rate, and illegal hunting and other reasons. The actual death rate is the product of the normal death rate and effect of langur crowding on death rate, which is also a graphical function.

2.2.6. Model validation

Two main types of tests (i) the structure validity test and (ii) the behavioral validity test were used to validate the model (Barlas, 1989).

- ***The structure validity test***

The validity of the structure of the model is the most important principle of system dynamics model (Barlas, 1989). The purpose of this test is to help in establishing confidence in the model (Matis, 2006), and to check whether the structure of the model is an adequate representation of the real structure (Barlas, 1989). The structure validity test includes parameter verification test and dimensional consistency test.

The parameter verification test aims to evaluate the constant parameters against knowledge of the real system, both conceptually and numerically (Forrester and Senge, 1980). Thus, the equations containing in the model correspond to the relationships shown in the causal loop diagram. Especially, the equations and functions in the DVLPSM were carefully checked to ensure that they represent the polarity (+ and -) of relationships represented in the causal loop diagram.

The dimensional consistency test aims to check whether the units of the variables on the left side of equations should be able to be converted to units of the variables on the right hand side of the equations. The dimensional consistency test was checked by using the 'Check Units' facility in Vensim software. When checking, the message "Units are A. O.K..." appears, meaning that units in all equations are dimensionally consistent and valid.

- ***The model behavior test***

The aim of the model behavior test is to check whether the model is capable of producing acceptable output behavior (Barlas, 1989). The model behavior test includes the extreme condition test and the behavior pattern prediction test.

The extreme condition test attempts to determine whether there is a major error in the structure of the model by examining the model behavior under different extreme conditions (Forrester and Senge, 1980; Barlas, 1989). If the model behaves realistically in such conditions (no matter how extreme the inputs or policies imposed on it), it means that the structure of the model reflects the reality it represents. In the DVLPSM, the robustness of the model was tested under several extreme conditions and combinations of these conditions. The test results of key parameters such as normal birth rate and hunting and other reasons by the end of simulation period (2050) under different extreme conditions.

The behavior prediction test aims to compare the behavior that is generated by the model with observed behavior. The data set of observed langur population has only in two years, 2001 and between 2012 and 2013. Thus, the fit level of observed langur population and simulated langur population was not accessed. The observed births and simulated births which have time series data, from 2001 to 2012 are compared to check the behavior pattern. R^2 (coefficient of determination) is used to access the goodness-of-fit between observed births and simulated births by following equation

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})2}{\sum_{i=1}^{n}(Yi - \bar{Y})2} = \frac{ESS}{TSS}$$

$\hat{Y}_i$: Simulated value; Yi: Observed value; $\bar{Y}$: average value; ESS (Explained sum of squares); TSS (Total sum of squares)

R^2 will be in range between 0 and 1, when R is close to 1, the relationships between observed births and simulated births are good fitness.

2.3. Data analysis and sensitive analysis of the model

The comprehensive data related to the langurs collected through the literature reviews, interviews, focus group discussions and field surveys were transcribed into an accessible and understandable transcript form. Then, these transcripts were analyzed and organized into targeted groups on the basic of themes, concepts. Relationships among concepts are identified and examined to understand the cause and effect of langur conservation on Cat Ba Island. The numerical data related to langur conservation status on the island, which were collected and finalized for field surveys and model construction.

Once the model construction was completed, sensitive analysis was conducted to assess model behavior and to identify key leverage points in the system (Maani and Cavana, 2007). A number of langur population dynamics and viability scenarios were populated and tested in search for a plausible scenario for building effective conservation actions in the future. In this study, birth rate, effect of reproducing on birth rate, effect of langur crowding on death rate, and hunting were used as the parameters of which the values were varied to understand the behavior of the model. Langur numbers were used as a dependent variable to assess the results of the sensitivity analysis because the sensitivity of langur numbers to change is crucial for the conservation of the langur population. Langur number prediction was also one of the model outputs that was calibrated against historical langur population records and could therefore be expected to be reasonably valid.

A simple sensitivity analysis of Maani and Cavana (2007) was applied by changing the value of birth rate, effect of langur crowding on death rate, effect of reproducing population on birth rate and hunting at a time (10 % increase and 10% decrease) and holding other remaining input parameters constant at their base case values. The langur numbers at the end of the simulation period (year 2050) were recorded for each variation of the parameters. The percentage change in langur numbers was used to identify those parameters to which the model behavior was most sensitive. The results of sensitivity analysis indicated which factors have the most influence on langur population, and then were used to develop the conservation actions for the langurs on Cat Ba Island.

3. Results

3.1. Conservation status of the langurs

There have been a number of field surveys of conservation status of the Cat Ba langur since 1997. All of these surveys confirmed the status of the langur on the island (Nguyen Phien Ngung, 1997; Nadler and Ha Thang Long, 2000; Stenke, 2001). The results of these surveys are listed in Table 2.

Table 2: Dynamics and previous conservation status of the langurs

Reference	Population status
Nguyen Phien Ngung, 1997	100 individuals
Nadler and Ha Thang Long, 2000	104 – 135 individuals
Stenke, 2001	52 – 54 individuals

Nguyen Phien Ngung (1997) confirmed that there were 100 individuals of the langurs on the island, including 27 adult males, 48 adult females, 15 juveniles and 10 infants. However, Nadler and Ha Thang Long (2000) confirmed that about 104 – 135 individuals of the langur survived on the island. This number was drastically decreased to only 52 – 54 individuals in 2001 (Stenke, 2001). The population was isolated into seven sub-populations, of which three or four sub-populations were all possibly female groups. Only 39 individuals were reproductive units and about nine adult males were confirmed existing in the population in 2001 (Stenke, 2001).

It was notable that the social structure was extremely disturbed, and average group contains only 3.7 individuals, leading to a very low reproductive output (Stenke and Chu Xuan Canh, 2004). The percentage of young groups in the population was very low; both groups of juveniles and infants accounted for only 25% of the population, less than the percentage of adult males and nearly half the percentage of adult females in the population (Nguyen Phien Ngung, 1997). This percentage decreased to 15.25% in 2003 (Stenke and Chu Xuan Canh, 2004).

The results from interviews and field surveys confirmed that 12 groups of the langurs consisting of a total of 50 – 56 individuals survived until May 2013 on Cat Ba Island with an average group size of 4.67 individuals.

Table 3: Current conservation status of the langur on Cat Ba Island

No	Area	Group size	Reproduction between 2010 and May 2013	Remarks
1	Gio Cung 1	15	Yes	Biggest reproductive group on the island; Contact with Gio Cung 2, 3, 4, Van Ta
2	Gio Cung 2	5	Yes	Contact with Gio Cung 1, 3, 4, Van Ta
3	Gio Cung 3	3	No	Contact with Gio Cung 1, 2, 4, Van Ta
4	Gio Cung 4	2	No	Contact with Gio Cung 1, 2, 3, Van Ta
5	Van Ta	3		Contact with Gio Cung 1, 2, 3, and 4 group
6	Cong Ke 1	10	Yes	Reproductive group, contact with Cong Ke 2, Tung Choi and Ang Vem group
7	Cong Ke 2	6	Yes (?)	Unconfirmed
8	Tung Chuoi	2	No	Contact with Cong Ke 1, 2 and Ang Vem group
9	Ang Vem	2	No	Contact with Cong Ke 1, 2 and Tung Chuoi group
10	Hang Cai, Dau Doi, Hang Dinh, Bai Giai	5	No	Five female group, contact with Nghia Dia Gia Luan group probable
11	Cao Vong, Ang De, Thong Cay Nhue, Dop Dan, Nghia Dia Gia Luan	1	No	One male group, contact with Hang Cai group probable
12	Tung Xich, Tung Trang, Cai Lan Ha	2	No	Two isolated female group in a peninsula, contact with other groups and emigration impossible
	Total	**50 - 56**		

Figure 2: Cat Ba langur, *Trachypithecus poliocephalus policocephalus.* Photos by Phan Duy Thuc, 2013

The first sub-population was confirmed to exist in Gio Cung, Van Ta and Tra Bau area, where the highest numbers of the langurs and reproductive units were recorded on the island. This sub-population has five groups with 28 individuals, including five adult males, 12 adult females, one unknown sex adult, five juveniles and four infants. This sub-population also included two females, which were successfully relocated from Dong Cong area by the Cat Ba langur Conservation Project in October 2012. This sub-population started with three groups of about 20 individuals in 2001 (Stenke, 2001). Monitoring records of Gio Cung ranger station confirmed that there were about 24 new born from 2003 to May 2013, of which three infants were disappeared in January 2010 (Table 4). It also was noticed that this sub-population increased 6 individuals from 2001 to May 2013.

The second sub-population was confirmed to survive in Cong Ke, Hang Vem, and Tung Chuoi area. Stenke (2001) confirmed that there were two groups with eight individuals in 2001, and there were two groups with 16 individuals in 2010 (Schneider *et al.,* 2010). The field surveys observed three groups with 14 individuals (Cong Ke 1, Tung Chuoi and Ang Vem group). The group of six individuals observed by Schneider *et al.,* (2010) has four new born in 2013, one was born in January and three were born in April 2013 (Vu Duc Tang. pers.comm.2013). The group of ten individuals was observed in 2010 by Schneider *et al.,* (2010), are now probably fragmented into three groups, one group of two individuals was confirmed to be existing in Ang Vem, another group of two individuals is living in Tung Chuoi, and one group of six individuals was not found. Mr Tang, the langur guard of the Cat Ba Langur Conservation Project stated that this group has not been observed since 2011. However, it is difficult to confirm that this group was lost or not due to difficult terrain and large moving area. Monitoring records of Mr. Tang provided that there were about 12 individuals born from 2001 to May 2013 (Table 4). It was also noticed that this sub-population increased about 6 or 12 individuals from 2001 to May 2013.

Table 4: The infants from 2001 to May 2013

Year	Individuals		Total
	Gio Cung, Van Ta	Cong Ke, Ang Vem	
2001	0	0	0
2002	0	0	0
2003	3	0	3
2004	2	1	3
2005	3	0	3
2006	0	2	2
2007	3	0	3
2008	1	1	2
2009	2	2	4
2010	2	2	4
2011	3	0	3
2012	2	0	2
2013	3	4	7
Total	24	12	36

The third sub-population is now living in Hang Cai, Dau Doi, Hang Dinh and Bai Giai area. This was considered having one or two groups with 10 – 16 individuals by Nadler and Ha Thang Long (2000), and Stenke (2001). However, there are only one group of five females in this area was confirmed by interviews and field surveys.

The fourth sub-population is now living in Tung Trang, Tung Thich and Cai Lan Ha area. This sub-population has had four females in 2001 (Stenke, 2001). During field surveys, this sub-population was confirmed to have only two females in this area. The moving of these two females is quite slow now and probably concluded that these are quite old already.

The fifth sub-population has only one adult male. This individual was firstly observed in December 2012 in Nghia Dia Gia Luan and then this was recorded by local people at many locations, including Ang Di, Thong Cay Nhue, Ang De, Ang Dai, and Ang Dan. The field surveys were carefully checked at Ang De, Doc Dat, Dau Huan, Khe Ta, Ang Dai, Ang Dan, Thong Sau, Thong Dam Thanh and Vuon Chuoi Dung area but without observations. So far, this male has not been confirmed which groups it comes from because there were two groups living in this area, one group of 3 individuals in Ang Ke and other group of 4 – 6 individuals in Ang De – Hien Hao area (Stenke, 2001). However, these groups have not been observed since 2004 (Vu Huu Tinh. pers.comm. 2013).

3.2.Dynamics and viability of the langurs

The DVLPSM consists of 22 parameters, 14 main equations, and 2 graphical functions (Figure 3).

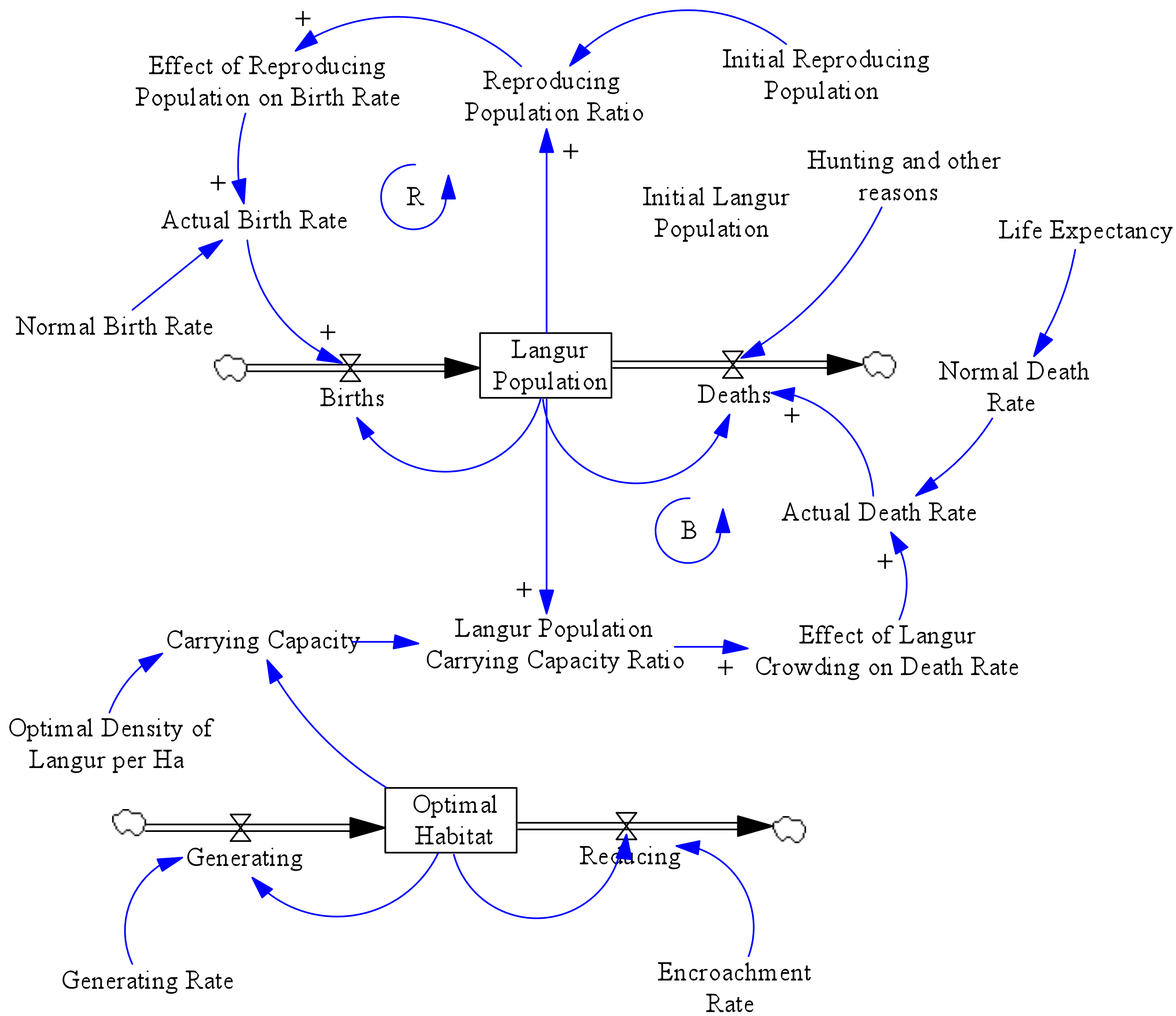


Figure 3: Stock and flow diagram of the langur population viability model

The simulation model interval (time step) is 0.5 years. It means that the Vensim computer simulation software would calculate the values for the stocks, flows and converter every ½ year for the entire simulation run. The model will be simulated from the initial time of 2001 and the final time of 2050. The model uses 2001 data as base year, and the field data between 2012 and 2013 is used to compare and access the simulation result between 2012 and 2013. The relationships between parameters are based on historical data, interviews and field surveys.

The langur population is a function of births and deaths. Births increase the population level, while deaths decrease the population level. Estimation of changes in the langur population is based on the population of the previous year, number of births, and number of deaths as following equation.

$$\text{Langur population} = (\text{Births} - \text{Deaths})\ (\text{langur})$$

The number of births is simply calculated by taking population at time "t" multiplied by the actual birth rate, using the following equations.

Births = langur population*actual birth rate (langur/year)

Actual birth rate = normal birth rate*effect of reproducing population on birth rate (1/year)

The normal birth rate was calculated based on the annual births of the langur in the period from 2001 to 2012. According to the monitoring records of Gio Cung ranger station and Mr. Tang in Cong Ke area, there are about 29 infants born on the island between 2001 and 2012. It means that there are about 2.41 infants born annually or average birth rate for this period is 0.045. Thus, it is hypothesized that the normal birth rate for the initial simulation is 0.045. This number is assumed to be constant over the simulation period.

The effect of reproducing population on actual birth rate was calculated based on the history data of the langur. As mentioned above, the estimated effective population size was only 39 individuals at most and the reproductive rate is very low (Stenke, 2001; Nadler *et al*., 2003). Therefore, the reproducing population ratio was calculated by total langur population/reproducing population in 2001. The relationship between the effect of reproducing population on birth rate and reproducing population ratio was presented in Figure 4.

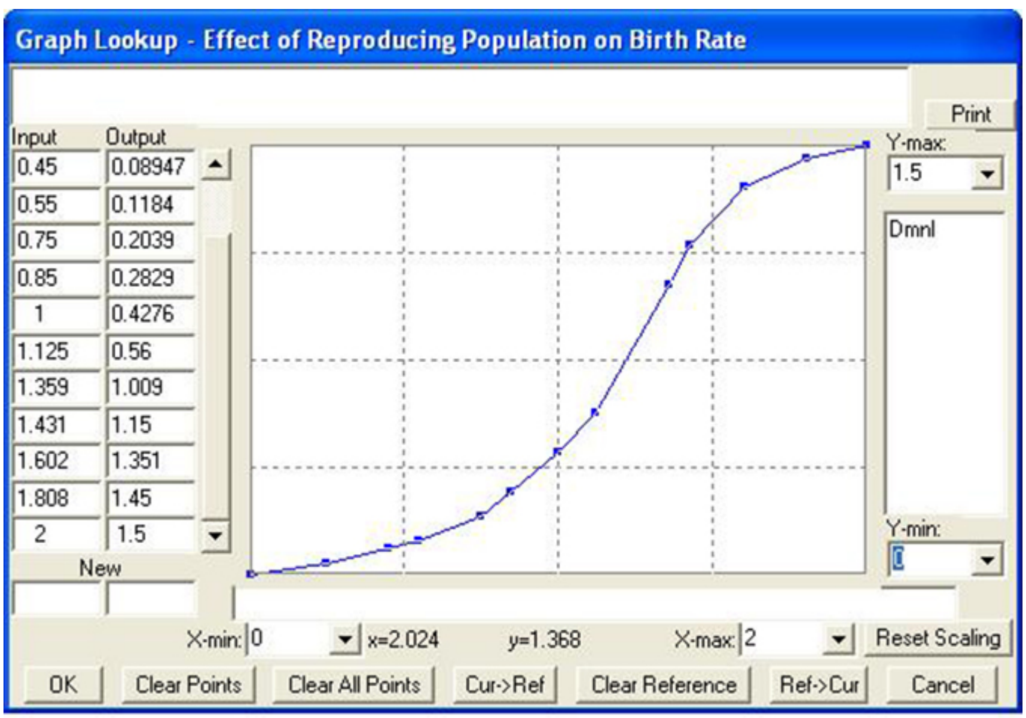


Figure 4: The effect of reproducing population on birth rate

It is assumed that when population is at 2001, the actual birth rate is equal to normal birth rate (multiplier of 1). However, when the reproducing population ratio has an increase, the actual birth rate also increases significantly, and when the reproducing population ratio become 1.5 of the level in 2001 (53/39 = 1.359), the actual birth rate will be 0.0675 (multiplier of 1.5). When reproducing population drops below the 2001 level, the actual birth rate will decline significantly and then slightly (because when the level population is very low, the langurs will stagnate to give births) until the effect of reproducing population on birth rate is zero when the reproducing population ratio is zero.

The isolated population of the langur are identified the main cause affecting significantly to langur population development in the future. Thus, relocation program is one of the priority measures to ensure that the population of the langur is healthy and sustainable in the next decades. As identified the importance of this, in 2012 two isolated females in Dong Cong area were successfully relocated to a sanctuary area, where has the healthiest subpopulation of the langur on the island. We assume that when two isolated females were moved to healthy sub-populations, it will increase the reproductive units and thus reproducing population ratio also increases in 2012. Thus, the curve was adjusted appropriately for increasing birth rate after 2012. The following equation has been used to determine the effect of reproducing population on birth rate.

Reproducing population ratio = langur population/reproducing population (no units)

Similarly, deaths are also influenced by the several factors such as life expectancy, crowding langur, hunting and other reasons. The average life span of the langur population has not been studied but they are similar to other langur species, is estimated about 25 years. Normal death rate of the population will be determined by one divided by the average life expectancy (Fisher 2007, pp 15). Thus, the number of langurs, which die each year, will be determined by calculating 1/25 of the total langur population. This number is assumed to be constant over the simulation period.

Deaths are now determined by the product of langur population, actual death rate, and hunting and other reasons. The actual death rate is the product of the normal death rate and a multiplier component called 'effect of langur crowding on death rate. The following equation is used to calculate deaths.

Deaths = langur population*(actual death rate + hunting and other reasons) (langur/year)
Actual death rate = normal death rate*effect of crowding langur on death rate (1/year)
Hunting and other reasons = 0.0047 (1/year)

The effect of crowding langur on the death rate was identified by the relationship between langur population and carrying capacity. The carrying capacity was calculated by optimal habitat size of the langurs on the island and optimal density of langurs per ha. The optimal habitat size of the langurs on the island is calculated from the vegetation map, which could support for the langurs are about 90 km^2. These areas do not include small islands where the langurs could not move there and other vegetation types which are not suitable for langurs such as areas of headquarter of the national park, ranger stations and plantation forests. The optimal density of the Cat Ba langur was not comprehensively understood. However, by comparing to well studied White headed langur (*Trachypithecus poliocephalus leucocephalus*), which is close relative to the Cat Ba Langur, the density of White-headed langurs in the optimal habitat is about 17.17 individuals per km^2 (Huang Chengming *et al.,* 1998). Thus, it can be assumed that the entire island of optimal habitat could have supported about 1,545 langurs.

Cat Ba Island has been experiencing habitat fragmentation and decline. From 2004 to 2011, the island lost about 4.5 ha annually because of wild fire (Cat Ba National Park, 2012). On the other hand, the massive exploitation of non-timber forest products has been occurring on the island. About 514 households (25.8% of total of households in six communes) on the island were confirmed to regularly collect medicinal herbs (Doan Van Can *et al.,* 2010), and some of these products are food for the langurs (Vu Huu Tinh. pers.comm.2013). Therefore, we assumed that the rate of habitat lost on the island will be about 0.099625 ha per year. However, the generating rate will be very low because of the limestone environment. There have not any studies about the generating rate in the limestone forests but we assumed that it will take more than 20 years for burned forests and 10 years for exploitation to recover back to the original status. Thus, the generating rate of the limestone forests after burning and exploiting was estimated about 0.0071625 ha per year. The following equations are used to calculate the optimal habitat, reducing and generating, and carrying capacity.

Optimal habitat = (generating – reducing) (ha)

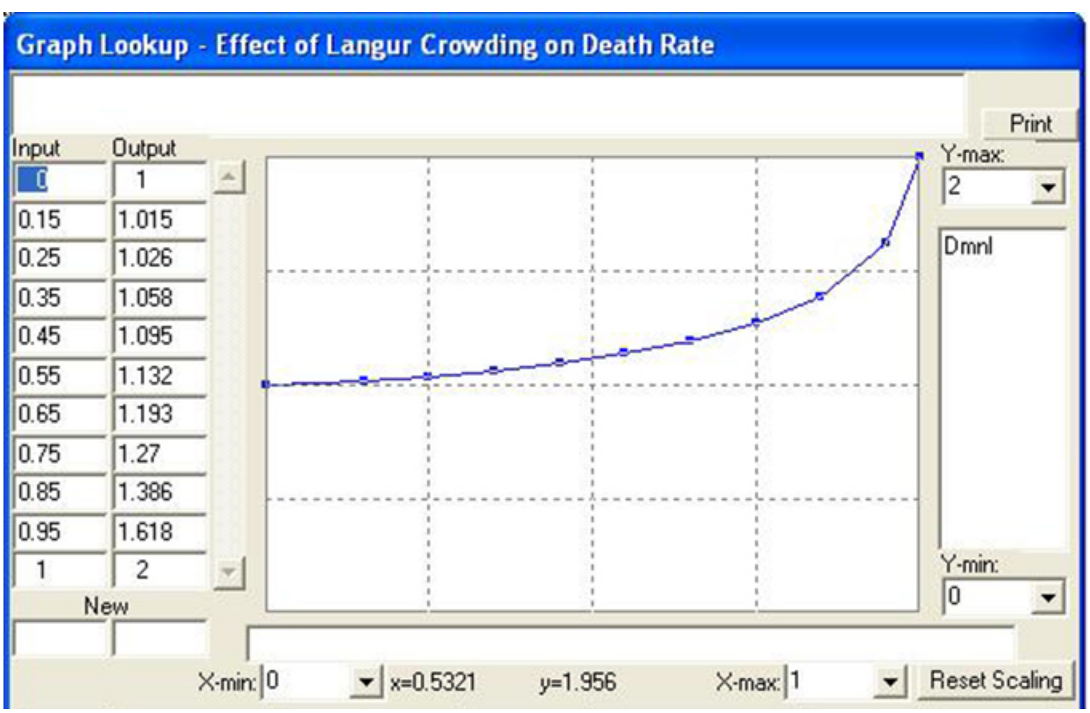
Generating = optimal habitat*generating rate (ha/year)

Reducing = optimal habitat*encroachment rate (ha/year)

Carrying capacity = optimal habitat*optimal density of langur per ha (langur)

The carrying capacity determines the stabilization of a growing population at a level that makes the renewable resource gets consumed and regenerated each year (Fisher, 2007). This means that as the population grows toward the carrying capacity, the death rate would significantly increase. Therefore, we applied this method to identify the effect of carrying capacity on the death rate. The effect of crowding langur on death rate is defined as a graphical function converter. The horizontal axis for the graphical function will be a ratio of langur population and carrying capacity. When the ratio is 0 there is no langur. When the ratio is 1 the langur population is at the carrying capacity. It was assumed that if there are no or very few langurs, the normal death rate for langur will not change since there is no crowding problem that would affect the carrying capacity. So when the horizontal axis value is zero, the vertical axis value will be 1. However, if the langur population is at carrying capacity, the horizontal axis value will be at 1 and the vertical axis value will be 2 because it is expected the population will reach equilibrium when the langur population is at carrying capacity then the death rate must match the birth rate (Figure 5).

Figure 5: The effect of langur crowding on deat



h rate

Hunting and other reasons were direct causes of langur deaths. As mentioned above, hunting has been the major threat causing the dramatic decline of the langur's population on the island. Fortunately, over the last decade, the number of illegal hunting cases has been reduced significantly, and there have been only several illegal hunting cases reported. Langur guards only observed one male killed by illegal hunters in Dong Cong area in the late of December 2001, and two individuals in Ang De was hunted in 2004 (Vu Huu Tinh. pers.comm.2013). Moreover, local people reported that langurs were poached in Gio Cung and Cong Ke areas but this information was not confirmed.

Besides that, infants were often disappeared on the island. For example, in 2010, three infants were born but they were not found by forest rangers working at the Gio Cung station. At that time, the rangers observed two males, which were heads of two groups' fought against each other and the winner probably killed infants of the loser. Additionally, Mr. Tang stated that there was a group of six individuals with two infants but infants have not been observed since 2006. Mr. Tinh provided that that hawks also predated infants. Thus, we assumed that langurs will be lost about 0.25 individuals per year and the lost rate will be 0.047. This number is assumed to be constant over the simulation period.

Model validation

- ***Structure validity test***

+ Parameter verification confirmation test

All equations in the model were carefully checked and found to be corresponded to the relationships shown in the causal loop diagram, and the polarity (+ and -) of relationships was appropriately represented in the causal loop diagram.

+ Dimensional consistency test

The units of each equation were carefully checked to ensure that the units of the variables on the left side are able to be converted to units of the variables on the right side. The 'Check Units' facility in Vensim software was regularly checked the unit consistency in all equations in the DVLPSM to gain the message "Units are A. O.K." These equations were also manually checked and were found to be dimensionally consistent and valid.

- ***Model Behavior Test***

+ The extreme condition test

We used the birth rate, and illegal hunting and other reasons as parameters to examine the behavior of the DVLPSM. The robustness of the model was tested under several extreme conditions and the combinations of these conditions. The test results of key parameters such as normal birth rate, and hunting and other reasons by the end of simulation period (2050) under different extreme conditions are presented in Table 5.

Table 5: Some results by year 2050 at different extreme conditions

Conditions	**Langur population**	**Births**	**Deaths**
Base run	86	5.8	3.87
Extreme conditions			
(1) Birth rate			
Maximum birth rate: 3 individuals per year	551.8	56.3	26.37

Minimum birth rate: 1.5 individuals per year	8.59	0.0085	0.384
(2) Hunting and other reasons			
Maximum: 2 individual per year	1.5	0.000415	0.117
Minimum: 0.2 individual per year	106.2	7.166	4.676
(3) Max birth rate and min hunting	311.43	26.39	13.89
(4) Min birth rate and max hunting	3.64	0.0015	0.214
(5) All set at max value	10.95	0.029	0.645
(6) All set at min value	9.14	0.0096	0.4

a) System behavior at base run

Under normal conditions (base run), the mode reaches an equilibrium state around 2250 where the langur population reaches about 1,432 individuals, both births and deaths reach 97 individuals per year (Figure 6). Births reach a state of equilibrium soonest by 2220 and deaths reach equilibrium state later by 2229. Then the population will slightly decrease because of the fact that the langur population will be affected by several factors, such as insufficient food supplies, habitat destruction and high density of langurs. Also, infants will be killed by males, resulting from intersexual competitions. These balancing loops in the system control the growth of the langur population towards equilibrium and stability. Additionally, the population takes a long period of time to reach the state of equilibrium because the current number of langurs is quite low and the social structure of the species is extremely disturbed.

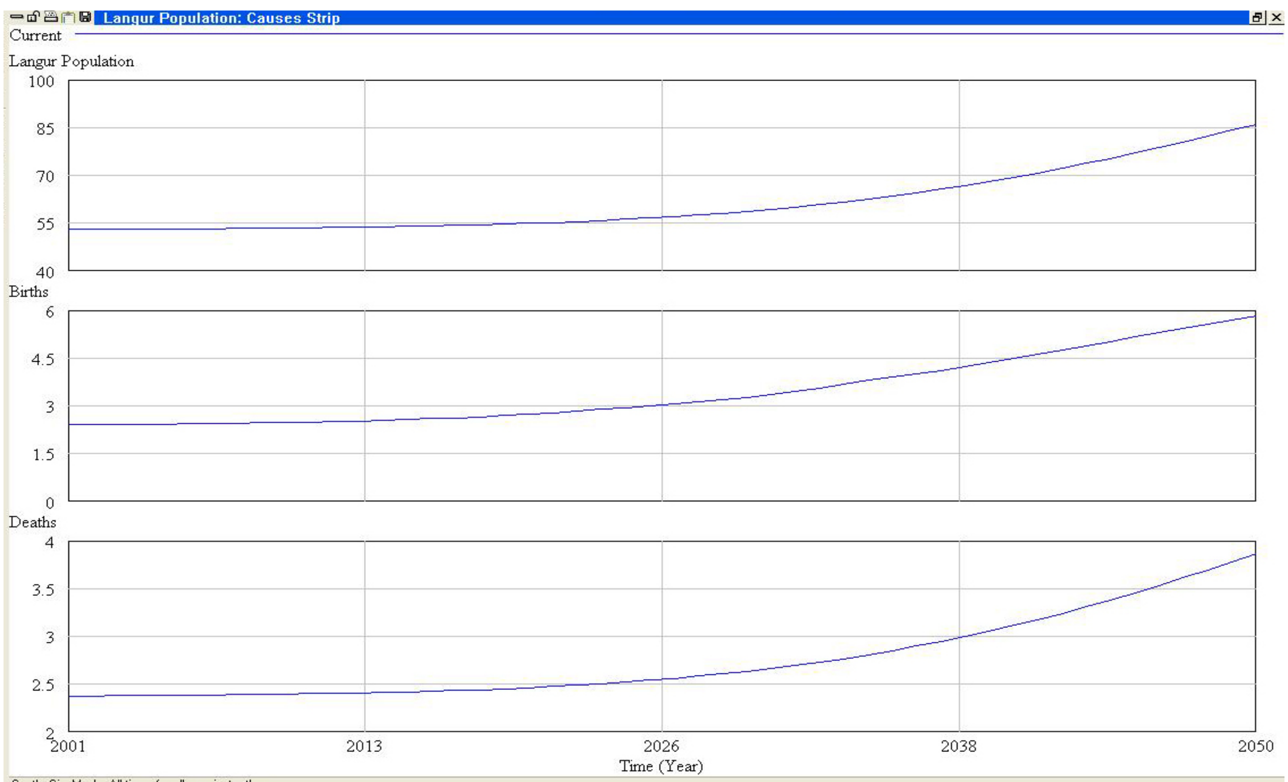


Figure 6: **The system behavior at the base run**

b) System behavior at extreme conditions

The graphs from Figures 7 to 10 illustrate the behavior of the system under different extreme conditions. Under three out of eight conditions (maximum birth rate; minimum hunting; maximum birth rate and minimum hunting), the langur population is observed to develop well until 2050, while others will be extinct after 2050. In the condition of maximum birth rate, the model reaches equilibrium by 2118 when the langur's population reaches about 1,540 individuals. The number of annual births reaches equilibrium state soonest by 2109 with 129 individuals per year, and the number of annual deaths reaches equilibrium state later by 2113 with 129 individuals per year.

Figure 7 shows that the number of births reaches zero quickly when the minimum birth rate undertook, making the species extinct by 2050. In contrast, when the maximum birth rate conducted, the number of births passes over 20 individuals per year by 2040, more than the deaths 10 individuals at the same time. This facilitates the langur population to develop significantly and reaches 300 individuals by 2050.

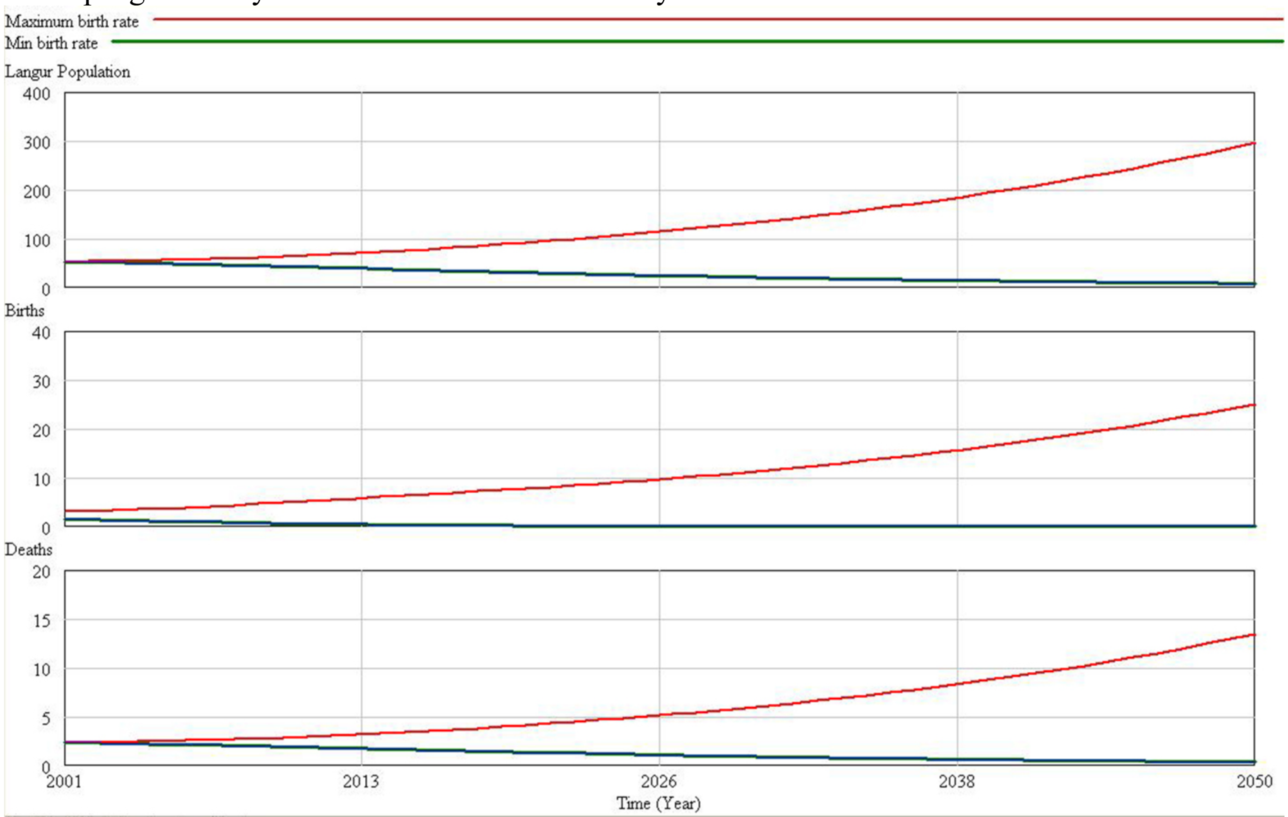


Figure 7: The system behavior at max and min birth rate

It is clear that the trend of maximum and minimum hunting is opposite. Under the maximum hunting condition, the langur's population decreases and will be extinct by 2050, and under the minimum hunting condition, the population increases (Figure 8).

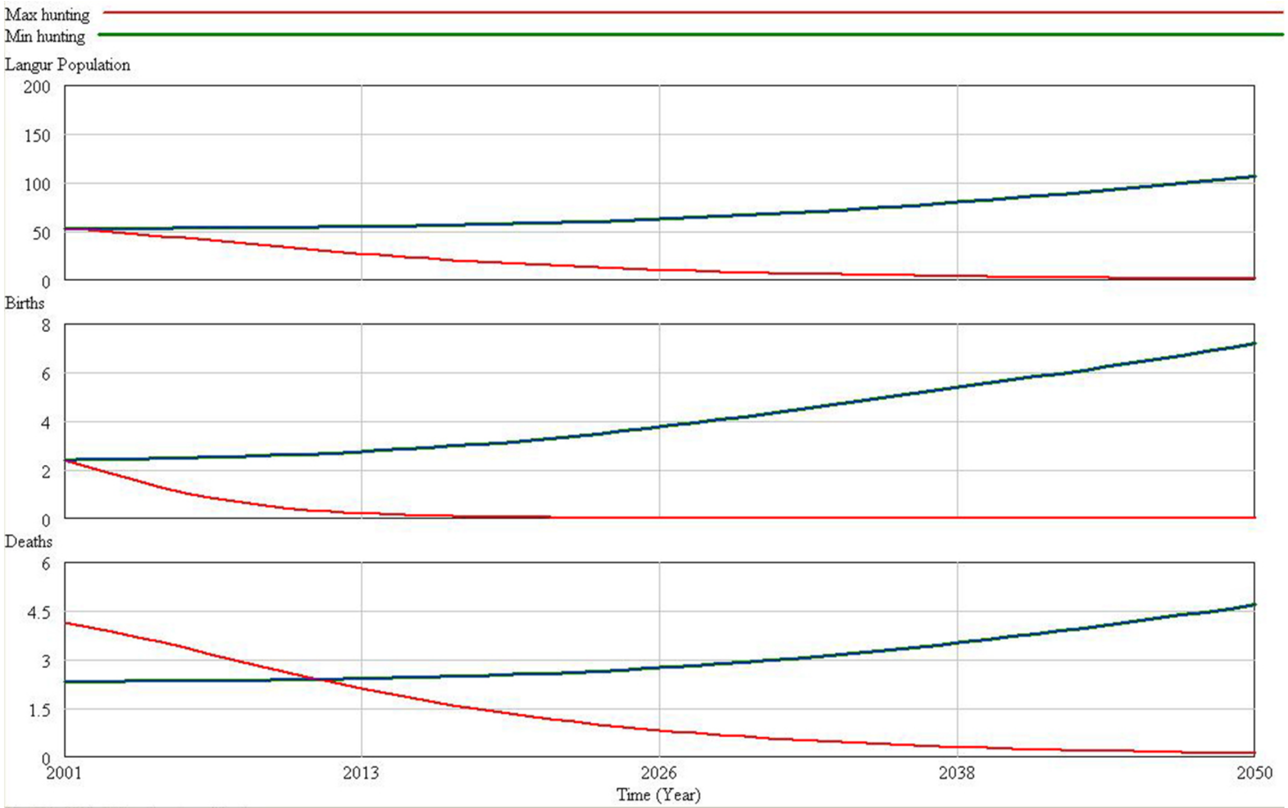


Figure 8: The system behavior at max and min hunting

Figure 9 illustrates the system behavior under two conditions; maximum birth rate and minimum hunting; minimum birth rate and maximum hunting. The condition of minimum birth rate and maximum hunting, the langur will be extinct by 2050, in which the number of births reaches zero in 2004. In contrast, the system behavior under maximum birth rate and minimum hunting, the population increases and reaches 312, 618 individuals by 2050.

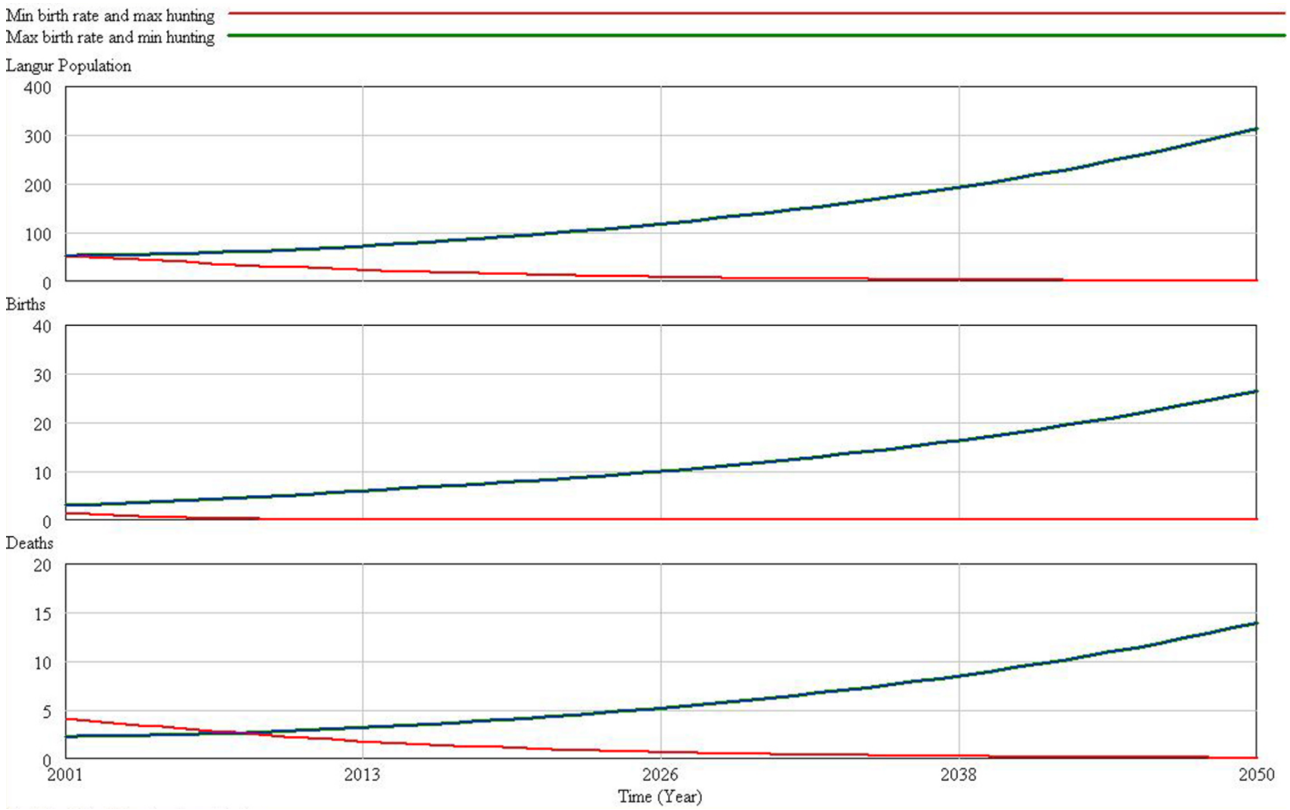


Figure 9: The system behavior at max birth rate and min hunting; min birth rate and max hunting

The system behavior under conditions of all maximum values and all minimum values shows the decreasing trends of the langur population (Figure 10). However, the langur population reaches quickly the extinction state under all maximum values more than all minimum values.

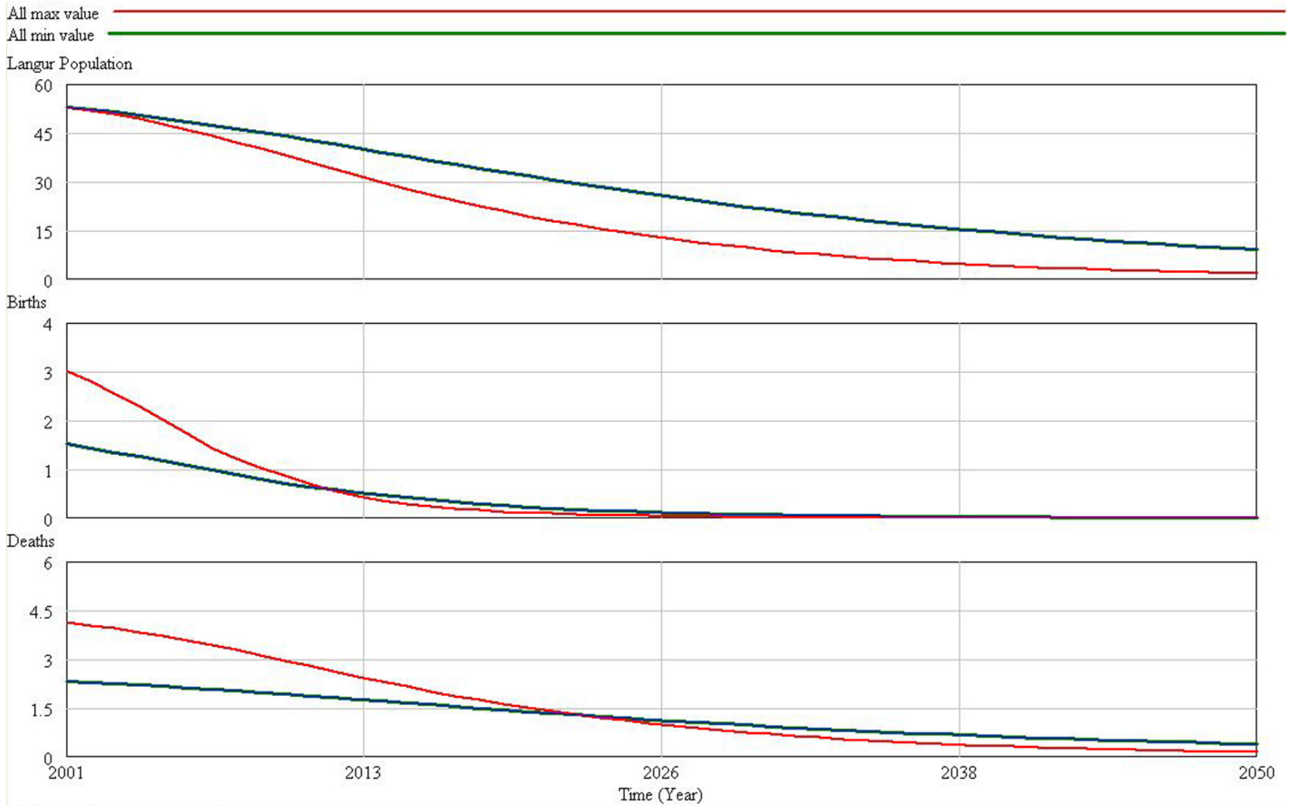


Figure 10: The system behavior at max and min value

c) Behavior prediction test

The historical and simulation of births was presented in Figure 11. It is clear that the pattern estimated by the model forms a slightly different trend in comparison with the historical data. However, the estimation of simulation data for whole period is similar to the observed data. This is confirmed by the calculation of coefficient of determination between simulation results and historical data is = 0.9745 (see Appendix 1), which is good model fitness. Additionally, the population, which was generated by the model, is 53.7 individuals, which is quite similar to the historical data (50 – 56 individuals) between 2012 and 2013.

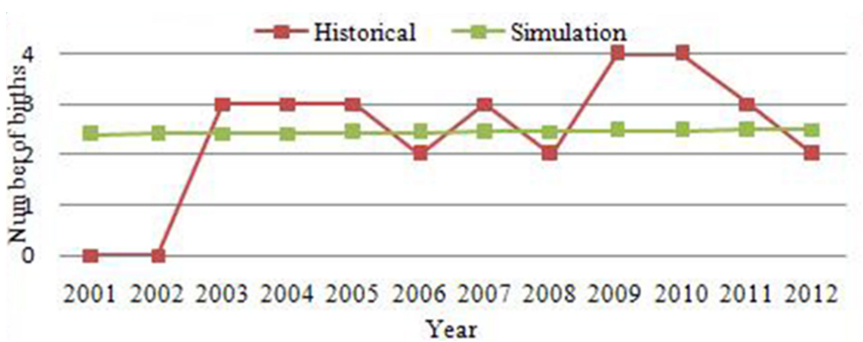


Figure 11: Simulation results and historical data of births

4. Discussion and conclusion

4.1. Dynamics and viability of the langur population

The population of the Cat Ba langurs on Cat Ba Island has stabilized since 2001. Disturbed social structure is one of the most significant reasons causing the stable population in the past twelve years. In 2001, only three groups consisted of 39 individuals with 9 males, were reproductive units in 2001 (Stenke, 2001; Nadler *et al.,* 2003). Over the last twelve years, the langur population has annually stagnated 2 – 4 individuals, leading to very low young generations in the langur population (25% in 1997; 15.25% in 2003; 26% until May 2013). This would have a great influence on the growth of the population of the Cat Ba langur. Thirty-one infants were born and alive between 2001 and May 2013, meaning that these individuals will be reproductive units for langur population in the coming years, replacing sterile individuals in the population. For example, the sub-population in Dau Doi, Hang Cai and Bai Giai areas was observed in 2001 and all of them were adults, meaning that the youngest individual was probably four or five years old in 2001 (Vu Huu Tinh.pers.comm.2013). Thus, this individual could be at least 16 years now. Similarly, the sub-population in Cai Lan Ha area had four females in 2001 (Stenke, 2001) and now two females are confirmed to survive there, and they are old already. This information can be inferred that these individuals will be disappeared from the langur population on the island in the next 5 to 9 years.

Currently, only two sub-populations of the langurs on the island are reproductive units, and they have increased about 12 or 18 individuals since 2001. This suggests that the langur population on Cat Ba Island has increased annually about 1 or 1.5 individuals from 2001 to May 2013. In contrast, other sub-populations are none reproductive groups, decreasing over time. Therefore, the langur population will continue to be listed as critically endangered species in the next 40 years because of low population numbers with less than 100 individuals.

Therefore, these data could suggest that the langur population will stabilize or slightly increase in the next 10 years. It could increase significantly when the isolation of the langur population on the island decreases, meaning that the reproductive population increases. This trend is quite similar to the simulation data in which the langur population stabilizes, and then increases slightly and reaches 86 individuals by 2050. This could conclude that the results of the simulation are quite good fitness in comparison with real condition of the langurs.

The DVLPSM have been through a number of rigorous validity test procedures. The results of the tests show that the DVLPSM is sufficient to be used as a tool for policy analysis and decision making by the Cat Ba Biosphere Reserve, Cat Ba National Park, Cat Ba Langur Conservation Project and other relevant organizations. Furthermore, the results of the model can be used as a good evidence for consensus building, especially on the disagreement on the langur population conservation status over the past period. Many people believe that the number of langurs on Cat Ba Island was about 68 individuals in 2011. However, the dynamics langur population analysis combined with simulation data probably confirmed that the number of langurs on the island could not reach 68 individuals in that year.

4.2.Sensitivity analysis results and implications for conservation actions

Results of the sensitivity analysis are presented in Figure 12 (for details see Appendixes 2 a, b), where input parameters are ranked in the order of their influence on langur population growth or decrease. The hunting parameter has the less influence on the population. However, the effect of reproducing population on birth rate has the most influence on langur numbers, and then the birth rate. A 10% increase in the effect of reproducing population on birth rate resulted in a large increase in langur numbers (nearly 93%). This clearly implies that an increase in the reproducing population numbers would have a significant and far reaching effect on the langur population growth in the long term. This finding reflects the real situation for the langur population in which the social structure is disturbed by very low numbers of males and extremely small and isolated sub-populations.

The level of influence on langur population growth and decrease, and the classification of each parameter are based on criteria proposed by Maani and Cavana (2007): 5 to 14% change in a dependent variable (in this case langur population numbers) is considered a low sensitivity; 15 to 34% change a moderate sensitivity; and > 35% change a high sensitivity. Based on these criteria, three out of four parameters are categorized as high sensitivity (Figure 12). Of the parameters included in the sensitivity analysis, managers and conservationists are only capable to probably control two, namely hunting, and effect of reproducing population on birth rate. These parameters are categorized as internal factors. Remaining parameters are categorized as external factors that are outside the control of langur population managers and conservationists. However, these factors will be influenced by impacting the internal parameters; for example, an increase in the effect of reproducing population on birth rate will increase the birth rate.

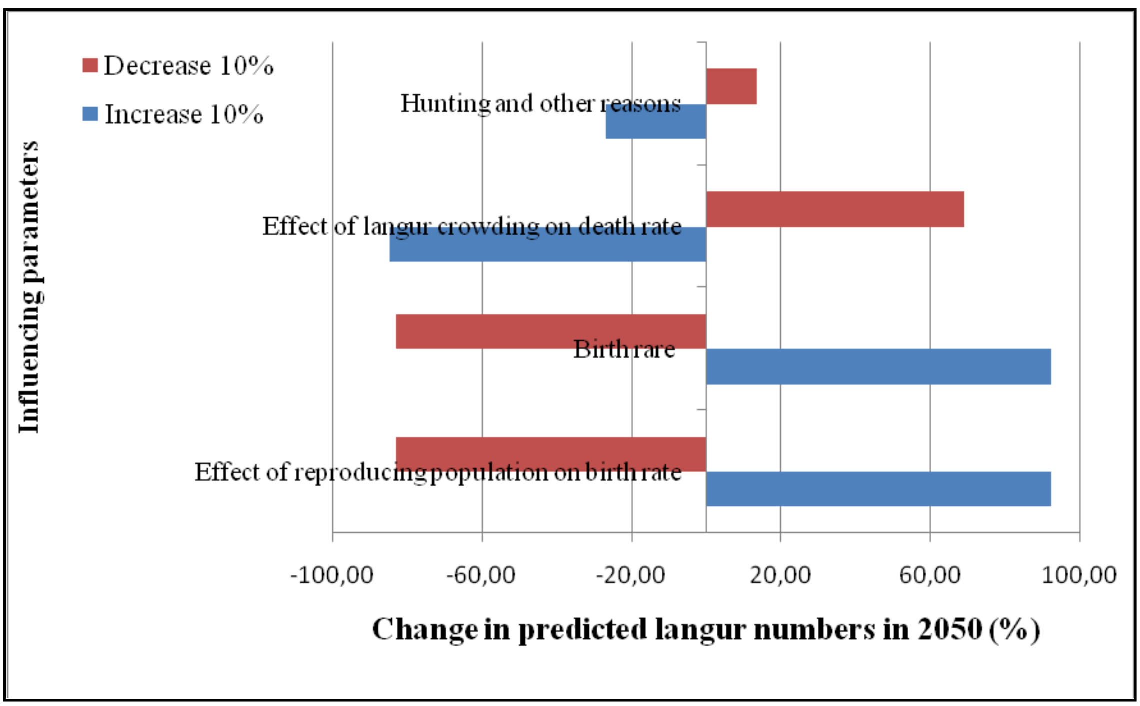


Figure 12: Result of sensitive analysis of langur numbers

Therefore, the increase in reproducing population numbers will play an important role in the long term management for the Cat Ba Langur on Cat Ba Island. This could be facilitated by relocating other isolated non productive sub-populations to productive groups. There are two non reproductive groups which are possibly relocated; five females in Hang Cai, Dau Doi, Bai Giai area, and two females in Cai Lan Ha, Tung Thich, and Tung Trang area. However, these groups are almost old now. There are only one or two individuals which could produce in one or two times. Additionally, the relocation of the langurs will face several difficulties because of limestone forests. Locations enable conservationists to catch the langurs are only in the caves. Thus, it will take a lot of time to monitor the habits of the langurs before relocating. Another action which probably increases the reproducing population numbers is relocating three reproductive individuals from Primate Rescue Centre in Cuc Phuong National Park to the langur population on Cat Ba Island. However, the managers of Cat Ba National need to have an agreement with managers of the Primate Rescue Centre before conducting.

The Cat Ba Langur is at a sensitive level, any ineffective and illegal actions will cause a dramatic decrease in the langur population. This is clearly evidenced by conducting extreme condition tests and sensitivity analysis. Hunting has less influence on langur population numbers in sensitivity analysis, however, if it is not properly controlled, it will cause a dramatic decline in the langur population, which had happened in the past. Therefore, strict protection and management for the langur population are very crucial for the managers of the park to save this species from extinction.

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APPENDIXES

Appendix 1: Summary statistic for coefficient of determination (R^2)

Year	Historical	Simulation	(yi-Y-)^2	(y^-Y-)^2
2001	0	2,4	5,84	5,76
2002	0	2,41	5,84	5,81
2003	3	2,42	0,34	0,34
2004	3	2,42	0,34	0,34
2005	3	2,43	0,34	0,32
2006	2	2,44	0,17	0,19
2007	3	2,45	0,34	0,30
2008	2	2,46	0,17	0,21
2009	4	2,47	2,51	2,34
2010	4	2,48	2,51	2,31
2011	3	2,49	0,34	0,26
2012	2	2,5	0,17	0,25
	2,42	2,45	18,92	18,43
			TSS	ESS
R2 = 0,9745				

Appendix 2a: Sensitive analysis by varying 10% decrease and increase

Influencing parameters	Units	Based case values	Increase 10%	Decrease 10%
Effect of reproducing population on birth rate	dimensionless	0; 0,004; 0,09 0,118; 0,2; 0,283; 0,428; 0,56; 1,009; 1,15; 1,351; 1,45; 1,5	0; 0,004; 0,098; 0,130; 0,224; 0,311; 0,470; 0,616; 1,11; 1,265; 1,486; 1,595; 1,65	0; 0,004; 0,081; 0,107; 0,184; 0,255; 0,385; 0,5; 0,91; 1,035; 1,22; 1,31; 1,35
Birth rare	fraction	0,045	0,0495	0,04
Effect of langur crowding on death rate	dimensionless	1; 1,015; 1,026; 1,058; 1,095; 1,132; 1,193; 1,27; 1,386; 1,618; 2	1,1; 1,117; 1,129; 1,164; 1,205; 1,245; 1,312; 1,4; 1,525; 1,78; 2,2	0,9; 0,914; 0,923; 0,952; 0,986; 1,019; 1,074; 1,143; 1,247; 1,456; 1,8
Hunting and other reasons	fraction	0,0047	0,0052	0,0042

Appendix 2b: Results sensitive analysis by varying 10% increase and decrease

Influencing parameters	**Increase 10%**	**Decrease 10%**	**Different (%)**
Effect of reproducing population on birth rate	92,54	-83,04	9,50
Birth rare	92,53	-82,94	9,59
Effect of langur crowding on death rate	-84,62	69,16	15,45
Hunting and other reasons	-26,81	13,64	13,17