

Some population characteristics and viability of captive Asian elephant (*Elephas maximus*) in Thailand

MANANYA PLA-ARD, RONGLARP SUKMASUANG*, SUWIMOL UTHAIRASMEE

Department of Forest Biology, Faculty of Forestry, Kasetsart University, 50 Phahonyothin Road, Chatuchak District, Bangkok 10900, Thailand.

Tel. +66-2-579-0176, fax. +66-2-942-8107, *email: mronglar@gmail.com

Manuscript received: 17 January 2022. Revision accepted: 27 January 2022.

Abstract. Pla-ard M, Sukmasuang R, Uthairasmee S. 2022. Some population characteristics and viability of captive Asian elephant (*Elephas maximus*) in Thailand. *Biodiversitas* 23: 1072-1081. Sustaining long-term viable populations of captive Asian elephants poses a challenge in managing the existing populations. Therefore, studies of the characterization and long-term persistence of the population are an important aspect of the action. The results of long-term population analysis of captive Asian elephants (*Elephas maximus* Linnaeus, 1758) using Population Viability Analysis (PVA) from the demography information showed that the birth and reproductive rate of the captive elephants in Thailand are declining significantly while the mortality rate trends are stable. Analysis results of the population's ability to persist in the long term from the initial population of 4,252 elephants, it was found that extinction of the population if the percentage adult female breeding is 80%, which is the best-case scenario, if the mortality rate increases by 6% from the present, the population will start going into extinction. If the percentage adult female breeding is set to 2.3%, which is the lowest breeding condition in captive Asian elephants, the population will become extinct in every scenario. Therefore, the most important method in maintaining the captive Asian elephant population is to increase the birth rate improve the well-being, health, nutrition, environment, and welfare of elephants in captivity are important factors that would reduce deaths and are very important for the long-term survival of the population in Thailand.

Keywords: Captive elephant, probability of extinction, time of extinction

INTRODUCTION

The Asian elephant (*Elephas maximus* Linnaeus, 1758) was once very abundant in the wild and widely distributed throughout its range from the Tigris-Euphrates River basin in Iraq, Syria, Turkey, the areas near the Persian Gulf in Iran, Gulf of Oman, to the countries in Southern Asia, Southern China to the Yangtze River Basin, as well as covering the countries in Southeast Asia including Java, Sumatra and Borneo islands (Williams et al. 2020). However, the Asian elephant population has decreased, with only 48,323-51,680 elephants left within the 13 range countries (Menon and Tiwari 2019), with its conservation status classified as Endangered (IUCN 2022). For captive elephants, evidence shows that human society's domestication of wild elephants started in the Indian region and has been conducted for approximately 4,000 years (Clutton-Brock 2012).

In 1997, the world captive elephant population was approximately 19,500 elephants (Vanitha et al. 2010). Later Sakamoto (2017) and CITES (2021) reported the number of captive elephants to be approximately 14,000-15,000 elephants or about one-third of the current population of Asian elephants, with approximately 1,000 elephants kept in zoos worldwide. Jerang et al. (2020) found that Burma has the largest number of elephants in captivity, reaching between 6,000-7,000 elephants, followed by India with 3,600 elephants, Thailand with 3,500-4,000 elephants,

Indonesia with 498 elephants, Lao PDR 446 elephants, Sri Lanka with 253 elephants and so on (CITES 2021).

In Thailand, wild elephants are present in natural areas in almost every region (Pla-ard et al. 2019; 2022). The population is between 3,000-3,700 elephants, distributed in 69 protected areas throughout the country (IUCN 2017). The main reasons for the decline of the wild elephant population are the loss of natural forest areas, forest fragmentation, habitat degradation, disturbance, and becoming subpopulations susceptible to threats, especially from human activities in wild elephant habitats (Menkham et al. 2019). The conflicts between humans and wild elephants have increased due to the overlap between human and wild elephant habitats, resulting in an acceleration of the mortality rate within the elephant population to increase exponentially (Shaffer et al. 2019). Elephants have been brought into captivity in Thailand for hundreds of years. Before the 19th century, it was reported that the number of captive elephants in Thailand was more than 100,000 elephants (Schliesinger 2015). Thitaram (2012) reported that the captive Asian elephant population in Thailand has declined from 13,397 elephants in 1952 to 2,681 elephants in 2001. The main cause of the decline in the captive elephant population is lower than the optimum birth rate. It is also found that the proportion of older elephants is large in the total captive elephant population and an increasing number of adult female elephants that are not reproductive (Thitaram 2012). A study of the reproductive rates of captive elephants in seven elephant camps in Northern

Thailand found between 0.03 young elephants per year and 3.5 young elephants per year (Toin et al. 2020), while mortality in the elephant population was high in particular, male elephants (Thitaram 2012). Elephants in captivity also suffer from physical inappropriateness for work, rest, natural malnutrition, bathing, exercise and proper social interaction (Schmidt-Burbach et al. 2015).

After the logging ban in 1989, the use of captive elephants in Thailand had to be modified from the former used primarily in the logging industry, causing many captive elephants to disappear and some were used to make money by roaming the big cities to sell food. Pimmanrojngool and Wanghongsa (2002) found that there were 41 captive elephants brought to walk the streets in Bangkok in October 2000, which was before the ban on bringing captive elephants into the city. Later, the raising of captive elephants was developed into tourist attractions providing elephant rides and tours of the forest in the country's tourist area (Schliesinger 2015), an important activity that affects the conservation of the captive elephants. Captive elephants have always been affected by the changes in social and economic conditions and the relations with the spread of various disease epidemics (Songthammanuphap et al. 2020).

The current condition of captive elephants reported in Thailand is that they are scattered across different regions, either under governmental or private ownership, held in 153 places in 56 provinces (Sukmasuang et al. 2013), each elephant holding contains between 1-195 elephants (Pintavongs et al. 2014). Some of the captive elephants also face nutritional or health problems (Bansiddhi et al. 2018; 2019), accidents (Bansiddhi et al. 2020), risk of contracting and spreading diseases (Puyati et al. 2015) and lack of chance for reproduction (Thitaram 2012). Furthermore, the nature of male elephants that tend to go into musth during the rutting season makes them difficult to control and have a high risk of being injured or killed (Lohanan 2002). Therefore, it is doubtful that if the activities of raising captive elephants in Thailand are carried out as they have been in the past until present, how long will the existing captive elephant population be able to maintain the population with normal mechanisms in the future? Although the population of captive elephants in Thailand seems to be quite large. However, various conditions that may affect the extinction of captive elephants, especially the mortality rate and birth rate, are important factors that managers should use as information for mutual understanding and long-term management.

Population Viability Analysis (PVA) estimates based on available data as well as concepts and calculations are a tool used for understanding the risk of extinction of low-population species. Anticipating the future of the increase or reduce the population in various aspects for planning alternatives for further management in the future is an important tool in conservation biology (Radchuk et al. 2016) for management planning to reduce the likelihood of species extinction based on population variables as well as creating hypothetical events in various aspects including defining conditions for variation in population and environment. The selection of the VORTEX program is

appropriate for low fertility species with long life spans, as well as having unequal sex ratios in the population (Lacy 2019). The VORTEX program was used to analyze the persistence of domesticated elephant populations in Burma (Leimgruber et al. 2008) and Laos (Suter et al. 2014), as well as in wild elephants on Sumatra, Indonesia (Mossbrucker et al. 2016), Sri Lanka (de Silva and Leimgruber 2019), Yunnan Province, China (He et al. 2020). A study by Prado-Oviedo et al. (2016) found that captive Asian elephants kept in zoo conditions in North America cannot survive on their own in the long term, while the results of the study on the ability to sustain the captive elephant population of the European Association of Zoos and Aquaria Ex-situ Program (EEP) found that it can be sustained over the long term. There are 15 baby elephants born per year out of 307 elephants or 4.89% of the total number of domesticated elephants/year. This is a result of the development of husbandry care systems, population structure management, health, environmental management, and the genetics of the elephants, as well as increasing knowledge of the reproductive biology of elephants, especially in females (Schmidt and Kappelhof 2019). The results of the existing analysis of the population of captive elephants in Laos with an initial population of 480 captive elephants revealed that the population of the elephants in Laos had a negative growth rate ($r = -0.099$), having a higher mortality rate than the birth rate. Results of the study show that the captive elephant population in Laos is likely to become extinct within 112 years (Suter et al. 2014). While Leimgruber et al. (2008) reported that although the number of captive elephants in Myanmar is the highest within the Asian elephant range countries, with a population of approximately 6,000 captive elephants, however, the long-term viability analysis shows that the captive elephant population in Myanmar is unable to sustain itself long term. To maintain the captive elephant population in Myanmar, wild elephants have to be caught and added to the captive elephant population. This method affected the wild population characteristics and raised questions concerning the conservation process (Jackson et al. 2019).

A study of the viability of the captive elephant population is therefore essential for the long-term management of the captive elephant population. In this study, 7 scenarios were formulated, including 1) the preservation of Thailand's captive elephant population if carried out under current conditions; and, where specified that the mortality rate of young elephants is reduced by 2% from the current number, to test the sensitivity of the equations that satisfy the program conditions. 2) the mortality rate in the population is specified to increase by 2, 4, 6, 8 and 10% from the present, to consider the possibility of extinction of the country's elephant population in the future. The expected benefits of this study are to know the population status of captive elephants in Thailand to be able to formulate guidelines for their management in various population aspects, for the long-term preservation of the captive elephant population of Thailand, as well as to increase understanding of activities that affect treatment and management to reduce mortality,

increase births in the captive elephant population to be able to sustain the population.

MATERIALS AND METHODS

Study area

The study was conducted on captive elephant populations from all regions of Thailand that were reported of ownership and microchipped for the identification ticket registration with the National Institute of Elephant Research and Health Service (2013) and the final technical report of Sukmasuang et al. (2013).

Procedures

The information on captive elephants in different regions of Thailand was obtained from the study on the population status and distribution of elephants in Thailand by Sukmasuang et al. (2013), which is based on the information from the National Institute of Elephant Research and Health Service (2013), who reported the number of captive elephants in the southern region, from a total of 14 provinces, to be 402 males and 658 females, adding to a total of 1,060 elephants; from the 10 provinces in the Northeast include 408 males and 982 females, adding to 1,390 elephants; from 10 provinces in the North include 442 males and 836 females, a total of 1,278 elephants; and the 17 provinces in central Thailand including 156 males and 442 females, adding to a total of 597 elephants. The total number of captive elephants found in 56 provinces throughout Thailand was 4,325 elephants which were 1,407 males and 2,918 females (Sukmasuang et al. 2013). However, the number of captive elephants reported to be possessed by captive elephant owners varies between provincial authorities and central authorities. The study, therefore, used numbers registered with the central authorities, a total of 4,252 captive elephants, for this analysis.

Age structure

The age structure of the elephant population was divided into 4 major age classes, including young and juvenile with age between 0-5 years old, subadult from 5-15 years old, sexually mature adult from 15-55 years old and senescent over 55 years old based on biological condition according to Sukumar (1989) and Arivazhagan and Sukumar (2008).

Birth and deaths

The fecundity of the elephant population is determined by the number of births in the population. Therefore, the percentage of calving was divided by the total number of sexually mature females during the study period, known as the percentage reproductive rate, and the percentage of elephant calves born in that year for the total elephant population that year is called the percentage of birth in a population (Mar 2013).

Mortality rates were calculated using the number of elephants found dead divided by the total number of elephants during that period (Mumby et al. 2013). Since the

age of the elephants that died could not be distinguished from the data. Therefore, the calculation was made by combining the data. The trend of the birth rate, reproductive rate and mortality in the captive elephant population between 2005 and 2010, a total of 6 years, was tested using a linear regression model. In the F test, the coefficient of determination was considered with the significance level at $P < 0.05$.

Modelling, baseline parameters for PVA scenarios and sensitivity testing

The probability of extinction of captive elephants was assessed by PVA using VORTEX 10.5.0.0 program (Lacy and Pollak 2021), a method used to calculate minimum population numbers to maintain the populations not to face extinction (Lacy 2019). In general, PVA modeling by the VORTEX program can be integrated with measures for conservation planning because the program can accept parameters hypothetically and the variability of a given environment that can be adjusted for management benefits (Lacy 2019). Therefore, the VORTEX program was chosen for the analysis of this study, as it is a simulation program suitable for low fertility, long life span, and uneven age and sex ratio (Lacy 2019).

The study specified a time frame for the 500-year analysis and baseline parameters, as did Leimgruber et al. (2008), Suter et al. (2014), and He et al. (2020), by setting a variable to test the baseline scenario. Only the death variable was tested by assuming the situation on both sides increases and a decrease in population mortality in the current fertility situation of the herd elephant population how it affects the long-term treatment of the population.

Parameters for the six scenarios were determined from the Thailand Captive Elephant Registration Database conducted by the National Institute of Elephant Research and Health Service (2013) (Sukmasuang et al. 2013), as well as the relevant elephant population data to be able to determine the parameters of the analysis accurately. Important parameters were elephant age, sex and initial population size, defined as 4,252 elephants. The carrying capacity was 20% of the current population (Leimgruber et al. 2008). This study used the number of mortalities in domesticated elephants reported by the National Institute of Elephant Research and Health Service (2013) (Sukmasuang et al. 2013).

The parameters used in the analysis could be precisely configured. Important parameters include the elephant's age, sex and initial population size. The population was considered a closed population trait because there is no immigration or movement. This study used the number of deaths in captive elephants that were reported by the National Institute of Elephant Research and Services (2013) (Sukmasuang et al. 2013) and from the report of Leimgruber et al. (2008) because we did not want the extinction results to be exaggerated if the mortality rate in captive elephant calves was set to be as high as in wild elephants, because, in captivity, baby elephants are cared for by an advanced veterinary system of Thailand. Furthermore, the sex ratio of the captive elephant calves was set to be the same between the sexes. The percentage

of sexually mature females in the captive elephant population was based on data collected from the National Institute of Elephant Health Research and Service (2013) from 1998 to 2010 (Sukmasuang et al. 2013). The baseline values of this study were an age of first offspring for females (years), age of first offspring for males (years), maximum age of reproduction (years), maximum number of progeny per year, according to Suter et al. (2014). Mortality in each age class classified into four age classes ($>0-1$, $>1-5$, $>5-15$ and >15) according to Arivazhagan and Sukumar (2008) in sex users according to Leimgruber et al. (2008), while the female mortality based on documents by Mar et al. (2012) and Suter et al. (2014).

This study used the percentage of fertile females and males according to Suter et al. (2014), who analyzed the percentage of breeding females in the Lao captive elephant population and reported it to be relatively low, with a value of 2.3%. In comparison, the proportion of the male breeding population was proposed to be 80%, following Leimgruber et al. (2008). This is consistent with the reality that most reproductive male elephants in captivity do not have the opportunity to mate (Toin et al. 2020). Therefore, in this study, a total of 7 scenarios were formulated: 1) Preserving Thailand's captive elephant population if carried out under current conditions and if it is specified that the mortality rate of young elephants can be reduced by 2% from the present as a to test the susceptibility and the program's response. 2) The mortality in the population was set to increase by 2,4,6,8, and 10% from the present, together with the assigned of % adult breeding female in two situations, which is 80%, the same as the recommended for males by Leimgruber et al. (2008) and set at 2.3% (Suter et al. 2014), which is considered the best event to increase fertility in the population and the lowest for this study.

RESULTS AND DISCUSSION

Population structure and sex ratio

The results of the population structure analysis of 4,252 captive elephants in Thailand showed 1,473 males and 2,779 females, as shown in Figure 1 and Table 1. However, when considering the captive elephant number from the microchip identification and captive Asian elephant population surveys in the elephant camps around Thailand, it was found that the number of captive elephants was fewer than those reported as being owned. This study used the number of captive elephants that were registered. The movement, traveling of captive elephants, the births and deaths that occur over time hinder the registration and tracking of captive Asian elephants. Results of the study showed that the number of adult males aged between $>15-55$ years was 848 elephants, while the number of adult females aged between $>15-55$ was 1,970 elephants. Therefore, the proportion of adult males: females was 1: 2.32. When considering the proportion of the age classes in the population, it was found that calf (age $>0-5$ years) were 257 elephants, juvenile elephants (ages $>5-10$ years) were

789 elephants, adults (ages $>15-55$ years) were 2,818 elephants and senescent elephants (over 55 years old) were 388 elephants, adding to a total of 4,252 elephants, accounting for a structural proportion in the population of 1: 3.07: 10.96: 1.51, respectively, as detailed in Table 2.

Births

From the recorded births of the captive elephant within the 6 years, the number of captive elephants born between 2005-2010 was 376, an average of 62.67 elephants (SE= 4.36) per year. If considering the average number of captive elephants during the same period, the average number of captive elephants in 2005-2010 was 3,807.16 (SE= 227.42) thus, the percentage of birth in the captive elephant population equals 1.70% per year or 1.70 calves per total number of elephants in all age classes of 100 elephants per year.

When considering only the number of adult female elephants in the age range between 15-55 years, which is the period that female elephants are fertile, by using the age structure to calculate the number of fertile female elephants during 2005 to 2010, in which the number of calves was reported and then used to calculate the percentage reproductive rate in the population. It was found that there was a percentage reproductive rate in the population was an average of 2.57%, or 2.57 calves born per 100 adult female elephants per year.

However, when considering the percentage of elephant calves per total number of elephants each year, as shown in Table 2, it was found that the percentage of births in the captive Asian elephant population was declining significantly ($F= 62.85$, $R^2= 0.94$, $P= 0.0014$). As well as, the percentage of calf elephants per 100 female elephants or percentage reproductive rate was found to have decreased steadily. It was found that the reproductive rate also continued to decrease ($F= 61.78$, $R^2= 0.93$, $P= 0.0014$), as detailed in Figure 2 and Table 3.

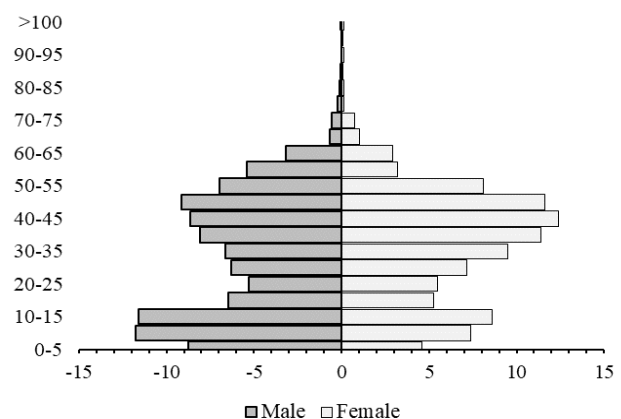


Figure 1. The percentage of Thailand captive Asian elephants in each age class, comparing between male (n= 1,473), female (n= 2,779) and total (n= 4,252) (Sukmasuang et al. 2013)

Table 1. Number of captive Asian elephant separated by sex in each age class (Sukmasuang et al. 2013)

Age class	Male		Female		Total	
	Number	%	Number	%	Number	%
>0-5	129	8.76	128	4.62	257	6.05
>5-10	173	11.75	205	7.38	378	8.90
>10-15	171	11.62	240	8.63	411	9.67
>15-20	95	6.45	147	5.29	242	5.70
>20-25	78	5.29	152	5.47	230	5.42
>25-30	93	6.31	199	7.16	292	6.87
>30-35	98	6.65	264	9.50	362	8.51
>35-40	119	8.08	316	11.37	435	10.23
>40-45	127	8.62	344	12.38	471	11.07
>45-50	135	9.16	323	11.62	458	10.77
>50-55	103	6.99	225	8.09	328	7.71
>55-60	80	5.43	89	3.20	169	3.97
>60-65	47	3.19	81	2.91	128	3.01
>65-70	10	0.68	29	1.04	39	0.92
>70-75	8	0.54	21	0.76	29	0.68
>75-80	3	0.20	4	0.14	7	0.16
>80-85	2	0.14	3	0.11	5	0.12
>85-90	1	0.07	1	0.04	2	0.04
>90-95	0	0.00	3	0.11	3	0.07
>95-100	0	0.00	2	0.07	2	0.04
>100	1	0.07	3	0.11	4	0.09
Summary	1,473	100.00	2,779	100.00	4,252	100.00

Table 2. The number of captive elephants in each age class and the proportion of the age structure in the population (Sukmasuang et al. 2013)

	>0-5 years old	>5-15 years old	>15-55 years old	> 55 years old	Total
Number of elephants	257	789	2,818	388	4,252
Proportion of the population	1	3.07	10.96	1.51	16.54

Mortality

From table 4, it is found that between 2005 and 2010, there were a total of 143 deaths of captive elephants or an average of 23.83 deaths per year ($SE= 3.27$). If considering the average number of captive elephants reported within the same period, according to Table 3, it was found that the average number of captive elephants from 2005 to 2010 was 3,807.16, representing mortality of captive elephants to be 0.64 elephants per 100 captive elephants/year. In all age classes, the mortality trends are decreasing but not significant ($F= 5.68$, $R^2= 0.59$, $P= 0.08$).

Population Viability Analysis (PVA)

Results of assigning the percentage adult female breeding to be 50, 60, 70, 80, 90, and 100% while preserving the mortality of the populations following scenario 1, it was found that the percentage adult female breeding that provided the long-term survival of the

population without extinction, was where percentage adult female breeding equals 80%, which equals to percentage male breeding, following the recommendations by Leimgruber et al. (2008), which is the best situation, so the percentage adult breeding female was set to 80% in every scenario 1-7, meaning the best breeding quality of captive elephants. Furthermore, analysis results show that if the mortality rate is as present and increases to more than 4% from the present rate, there will be no chance of extinction of the captive elephant population. However, if the mortality rate increases to more than 6% of the present value, the increase of the population will start to become negative, having a value of -0.0054, causing the extinction of the captive elephants within 497.0 years and if the mortality rate increases by 8 and 10%, the population increase rate will become -0.0317 and -0.0587 and the extinction will happen in 193.10 and 112.60 years, respectively.

However, if the percentage adult female breeding of the captive elephant population equals to Laos as suggested by Suter et al. (2014), which is 2.3% or the worst situation and the percentage adult male breeding equals 80%, following the suggestion by Leimgruber et al. (2008), it was found that the captive elephants of Thailand will be extinct in every scenario, from 1-7. Furthermore, the population increase rate in every scenario is all negative, having values of -0.0505, -0.0500, -0.0717, -0.0995, -0.1280, -0.1573, -0.1874, and the captive elephant population will be extinct within 176.1, 128.8, 126.7, 93.4, 73.8, 58.3 and 48.1 years from the present, respectively, as detailed in Table 5.

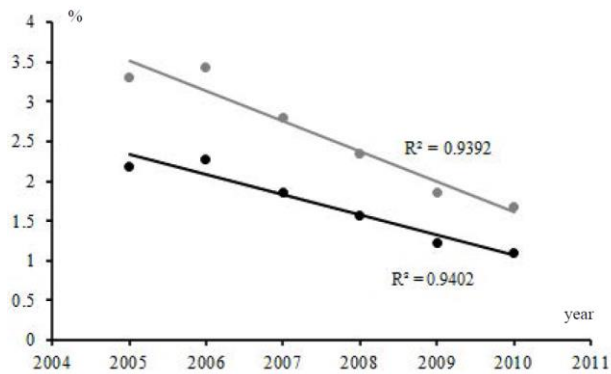


Figure 2. Scatterplot and simple linear regression of percentage of birth rate in the population ($R^2= 0.93$) and percentage reproductive rate ($R^2= 0.94$) of the captive Asian elephant in Thailand cover 6-year period during 2005-2010

Table 4. The number of captive elephants, number of deaths in each year during 2005-2010 and percentage of death in the captive elephant population in Thailand (Sukmasuang et al. 2013)

Year	Number of elephants in every age class	Number of deaths	% of death in population
2005	2,966	22	0.74
2006	3,418	29	0.85
2007	3,676	27	0.73
2008	4,096	35	0.85
2009	4,252	15	0.35
2010	4,435	15	0.33
Average	3,807.16	23.83	0.64
SE	227.42	3.27	0.10

Table 3. The number of captive elephants, number of fertile adult females between 15-55 years old, number of elephant calves born, percentage of births in the population and the reproductive rate of captive elephants in Thailand

Year	Total number of captive elephants in every age class	Number of adult females age between 15-55 years	Number elephant calves born	% of birth in population	% Reproductive rate
2005	2966	1965	65	2.19	3.30
2006	3418	2265	78	2.28	3.44
2007	3676	2436	68	1.85	2.79
2008	4096	2714	64	1.56	2.35
2009	4252	2817	52	1.22	1.85
2010	4435	2939	49	1.10	1.67
Average	3807.17	2522.76	62.67	1.70	2.57
SE	227.42	150.70	4.36	0.20	0.30

Note: Ratio between adult males: adult female, age range between 15-55 years, equal to 1: 2.32

Source: Sukmasuang et al. (2013)

Table 5. Population viable analysis results of captive elephants comparing scenarios with percentage adult female breeding equals 80% as of the percentage adult male breeding and the percentage adult female breeding equals to 2.3%

Scenario	1	2	3	4	5	6	7
When % adult female breeding 80% equals to percentage adult male breeding							
Growth rate	0.0665	0.0674	0.0457	0.0204	-0.0054	-0.0317	-0.0587
SD	0.0169	0.0167	0.0171	0.0172	0.0214	0.0739	0.0833
PE	0.0000	0.0000	0.0000	0.0000	0.0020	1.0000	1.0000
N	2551.44	2551.43	2551.69	2548.37	157.97	0.0000	0.0000
SD	10.79	11.24	10.67	11.78	76.07	0.0000	0.0000
Mean TE	0.0000	0.0000	0.0000	0.0000	497	193.100	112.600
When percentage adult female breeding 2.3% following Suter et al. (2014)							
Growth rate	-0.0500	-0.0500	-0.0717	-0.0995	-0.1280	-0.1573	-0.1874
SD	0.0637	0.0411	0.0620	0.0628	0.0678	0.0724	0.0779
PE	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
N	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mean TE	176.1000	128.8000	126.7000	93.4000	73.8000	58.3000	48.1000

Note: SD: standard deviation, PE: probability of extinction, N: population remained, TE: time of extinction. 1: Scenario 1 Current captive/baseline population 2: Scenario 2 Scenario 1 + 2% lower mortality. 3: Scenario 3 Scenario 1 + 2% higher mortality 4: Scenario 4 Scenario 1 + 4% higher mortality. 5: Scenario 5 Scenario 1 + 6% higher mortality. 6: Scenario 6 Scenario 1 + 8% higher mortality. 7: Scenario 7 Scenario 1 + 10% higher mortality

Discussion

Population characteristics and viability

From the captive elephant data of Thailand, it was found that most of the elephants are owned by private sectors in 153 elephant camps in 51 provinces around Thailand. Most of the captive elephants are in tourist attraction areas. The number of elephant camps with between 1-14 elephants was the highest, with a total of 118 camps. This is followed by 12 camps with 27-40 elephants and 5 camps with 40-53 elephants. The governmental organizations that have elephants in their care include the Thai Elephant Conservation Center, Lampang province (n = 95) and the Elephant Study Center in Surin province (n = 190) under Surin Provincial Administrative Organization. The total number of elephants at the two places equals 285 elephants. The highest number of captive elephants is found in the northeast (n = 1,390), followed by the north (n = 1,278), south (n = 1,060) and central (n = 597) region.

The study results show that the sex ratio of the male: female of the total population is 1:2.07. If considering only the sexually mature male and females between >15-55 years old, the ratio was 1:2.32, which is not much different. This is because most of the captive elephants in Thailand are between >15-55 years old, especially females. The age structure of captive elephants is not evenly distributed between each age class and the age structure of the captive elephants were found to be 1: 3.07: 10.96: 1.51 from the age classes 0-5 years, 5-10 years, 15-55 years and more than 55 years old, respectively. The percentage growth rate in the population is an average of 1.70 elephant calves per 100 elephants in all age classes per year or 0.017 elephant calves/adult female/year. The reproductive population rate is 2.57% elephant calves per 100 adult female elephants per year or 0.0257 elephant calves/adult female/year. The results are similar to Jackson et al. (2019), who found that the fertility rate of captive elephants in Myanmar was 3.1% per year (range = 1.2-5.4%). Jerang et al. (2020) reported that the reproductive rate in the domesticated elephant population in Eastern Arunachal Pradesh, North-eastern India was 0.04 calves/adult female/year, while the mortality rate was 2.2%. Vanitha et al. (2010) reported the reproductive rate of elephants in three management systems of Tamil Nadu, India, in the 10 years during 1996-2005 was 0.065 elephant calves/adult female/year, which is greater than the proportion of birth and reproductive rate of the captive elephant population in Thailand. The reproductive rate in each area varies in terms of environment, maintenance, food, health, breeding opportunities, and population characteristics. Toin et al. (2020) reported the variation of reproductive rate in elephant populations in the 7 elephant camps of Northern Thailand as between 0.03 and 3.55 elephant calves/adult female/year. When considering the trend of births in the total captive population from the aggregate data that can be calculated in Thailand between 2005 and 2010, it was found that the birth trend in the population continuously reduced significantly both in the percentage of elephant calves born in the total captive population and the percentage reproductive rate (see Table 2). This study found that the mortality rate in the captive elephant

population is 0.64 elephants per 100 elephants of every age class per year.

Jackson et al. (2019) reported the mortality rate of captive elephants in Myanmar to be 2.1% per year (range = 0.3-4.2%), 3.28 times more than the rate of Thailand. This shows that the captive elephants in Myanmar cannot survive alone in the long term without capturing approximately 100 wild elephants a year to add to the captive population (Leimgruber et al. 2008; Jackson et al. 2019). Similar to Vanitha et al. (2010), who reported the mortality rate of captive elephants in India per total number of elephants (n = 784) to be 3.95%. The age class of captive elephants with the highest mortality was between 20 and 60 years. It was found that this age class had 430 deaths or 66.22% of the total deaths in all age classes.

Even though the study cannot divide the mortality rate by age classes of the captive elephants because the details were not reported, it is thought that this age class has the highest mortality rate because they are working. However, the death of captive elephants following Mar et al. (2012) was found that, in Myanmar, the mortality rate of young elephants from 0-5 years was 25.6% (n = 975). Between 0-1 years, the elephant calves had the highest mortality of 7.06%. In contrast, the mortality rate of the captive elephants in all age classes in Thailand is 0.64 elephants per 100 elephants of all age classes per year.

The mortality rate of wild elephants reported by Sukumar et al. (1997), that the deaths of elephant calves in the wild to be 19%, which is very high when comparing to the captive elephant population. Analytic results of the lowest population that will be able to maintain for a long time by setting the % adult female breeding and % adult male breeding at 80%, which is the best situation, showed that if the deaths in the population increases by 6% from the present, the captive elephant population will be extinct in 497.0 years and if the % adult female breeding and % adult male breeding is set to 2.3%, the captive elephant population will be extinct in every scenario, even if the mortality rate decreased by 2% from the present.

Management implications

As it is impossible to capture wild elephants to add to the captive elephant in Thailand, there is no exchange population between captive and wild. Therefore, maintaining a long-term captive elephant population on its own is challenging for managing the present captive elephant population, especially increasing the birth rate in the population (Thitaram 2009). Results of this study showed that the population birth rate and reproductive rate in the captive elephant population in Thailand are decreasing significantly. In contrast, the mortality rate has a stable trend. Therefore, the birth rate is the most important condition for maintaining a long-term viable population of captive elephants in Thailand, even though the calculations show that assuming that the mortality rate in captive elephants was 2% lower than the present, the population growth rate will still be negative ($r = -0.05$) and the population will become extinct in 128.80 years (Probability of Extinction: PE = 1.000) in case of percentage female breeding pool was 2.3% as used by Suter et al. (2014).

The main management of the captive Asian elephant population in Thailand was to increase the reproduction percentage of female elephants as much as possible. The ultimate goal is that adult female elephants of the population have a percentage of breeding pool reach 80%. The result was found that although the mortality in the population increased by 4% from the current 0.64 elephants in the 100 elephants, or the mortality increased to 0.67 elephants of the 100 elephants, or approximately 29 elephants/year based on the total captive population of 4,252 elephants. Hayward et al. (2014) reported that the youngest female breeding was 5 years old and the oldest was 53 years old (mean age at first birth: 19.48; median: 19 years) ($n = 416$; born 1941-1990). Therefore, this study considers the age range of female elephants with offspring between 15-55 years. Based on Table 1, there are 1,745 adult female captive elephants in Thailand in such age class out of a total of 4,252 elephants, or 41.04% of the total elephant population. If there is a birth rate per adult female or a percentage reproductive rate of 2.57% elephants per 100 female population/year, there will be about 45 new calf elephants in the Thai captive elephant population per year. Thus, there are about 16 newborns born per year, which is the current state of the elephants that have not resulted in extinction under the assumption that reproductive in the female population or percentage breeding pool is 80%. Thailand's overall extinction threshold is defined as the mortality below 29 elephants per year out of the total population and natality rate of at least 45 elephants per total reproductive female per year. The captive elephant populations of Thailand could increase if these conditions were improved.

In conclusion, important guidelines for managing captive elephants increase the fertility rate and reduce the mortality rate. This is in line with the recommendation of Thitaram (2009). The management of female elephants before, during and after pregnancy is important by enhancing the skills of the staff involved with support from various agencies (Thitaram 2012). An important way to increase the birth rate and reduce the mortality rate of elephant calves is to reduce the work of adult female elephants throughout their lives to increase the chances of reproduction of elephants in elephant camps across the country (Mumby et al. 2013). In addition, the importance of nutritional quality must be emphasized. Food sufficiency in elephant calf, as well as health-related to maternal fertility enhancement, is something that needs to be addressed because it is the leading cause of elephant calf mortality (Mar et al. 2012).

The management of captive Asian elephant populations, although genetic diversity, must be considered. Kriangwanich et al. (2018) reported the genetic diversity of captive Asian elephants in northern Thailand from 97 samples collected in 7 elephant camps. The genetic diversity index was 2.415 ± 0.054 , and the expected heterozygosity was 0.892 ± 0.008 , indicating a good genetic diversity level. The arrangement of inbreeding according to the differences in the genetic cluster in each region should be considered further to reduce the inbreeding risk of captive elephants. The important captive elephant

management strategy is to increase the birth rate, maintain the number of deaths not to increase or reduce the mortality rate, increase the opportunities for the captive elephants to stay together in large areas, as done at the Thai Elephant Conservation Center or the Elephant Study Center, Lampang Province, or the Surin Elephant Study Center, Surin Province, development of artificial insemination (Thongtip et al. 2009), develop captive elephant care and management protocols in elephant camps (Bansiddhi et al. 2018) as well as promoting the well-being of the individual, increase the efficiency of relevant departments, are ways to increase the breeding success of the captive elephants. However, from the way of caring for captive elephants and the importance of the captive elephants to the economy, society of the community and owner (Laohachaiboon 2010), the living conditions of the persons involved must also be developed.

Long-term conservation guidelines for captive elephants and improving the living conditions of the captive Asian elephants to be more suitable, for example, the release of captive Asian elephants back into the wild (Thitaram et al. 2020). In Thailand, operations have continued since 1997 (Elephant Reintroduction Foundation 2022) at Doi Pha Muang Wildlife Sanctuary, Sub Langka Wildlife Sanctuary, Mae Wong Kaeng Krachan National Park and Phu Phan National Park. As a result, sixty-four captive elephants were released into the wild (Angkawanish and Thitaram 2012). This is because captive elephants are able to live well in nature when considering their feeding behaviors, health and calving in the wild. Therefore, it is the hope of conserving the captive Asian elephant population in the future. In addition, the establishment of a specific area for the conservation of wild elephants and the experiment to bring captive Asian elephants to be reared in that area to create a relationship between the captive Asian elephant and wild Asian elephants to occur properly (Rees 2021).

Results of the possibility for the long-term survival of captive Asian elephant population from the information on the age structure, birth rate and mortality rate of the population, as well as other related variables, it was found that from the population of 4,252 captive Asian elephants in Thailand, in the scenario that the reproduction possibility is highest with the percentage adult female breeding of 80% which equals to the value of the males. It was found that if the mortality rate increases by 6% from the present, there is a possibility that the captive Asian elephant population will become extinct within 420.10 years. Even if the mortality rate reduces by 2%, it is still not enough to maintain the captive elephant population. Suppose the mortality rate increases by 2, 4, 6 and 8%, the extinction of the captive Asian elephant population will happen within 204.30, 121.60, 87.90 and 68.00 years, respectively. In the worst possible scenario in which the percentage adult female breeding is 2.3%, as of the situation in Laos (Suter et al. 2014), it was found that the captive elephant population in Thailand will be extinct in all scenarios from 1-7 where the population growth rate will have a negative value in every situation, with values of -0.0505, -0.0500, -0.0717, -0.0995, -0.1280, -0.1573, -0.1874, and the captive

Asian elephant population will become extinct in 176.1, 128.8, 126.7, 93.4, 73.8, 58.3 and 48.1 years. The important management method to maintain the captive Asian elephant population is to increase the birth rate of the elephants, which is found to be decreasing significantly.

ACKNOWLEDGEMENTS

We would like to thank Dr. Patara Chuaplaivech, Director of the National Institute of Elephant Research and Health Service, Department of Livestock Development, for providing information for use in the research project titled the studies of ecology, population, distribution and health to solve elephant problems in Thailand and using to the further research. We also would like to express our recognition to the Unit for Capital Development for Human Resource Development, Capital for Higher Education Development, Research, and Innovation Creation, Office of National Higher Education Science Research and Innovation Policy Council (NXPO) under the research project on the ecology of important wildlife in Khao Yai National Park. In addition, this study was supported by the National Science and Technology Development Agency (NSTDA) under the scholarship contract to support graduate studies from the Thai Institute of Science and Technology Scholarship Program No. SCA-CO-2562-9703-TH.

REFERENCES

- Angkawanish T, Thitaram C. 2012. Behavioral study and monitoring of Asian elephant (*Elephas maximus*) reintroduction under the Queen's initiative. In: Maya Aranovich M, Dufresne O (eds). Elephants: Ecology, Behavior and Conservation. Nova Science Publishers Inc., New York.
- Arivazhagan C, Sukumar R. 2008. Constructing age structures of Asian elephant populations: A comparison of two field methods of age estimation. *Gajah* 29: 11-16.
- Bansiddhi P, Brown JL, Thitaram C. 2020. Welfare assessment and activities of captive elephants in Thailand. *Animals* 10 (919): 1-18. DOI: 10.3390/ani10060919.
- Bansiddhi P, Brown JL, Thitaram C, Punyapornwithaya V, Somgird C, Edwards KL, Nganvongpanit K. 2018. Changing trends in elephant camp management in northern Thailand and implications for welfare. *PeerJ* 6: e5996. DOI: 10.7717/peerj.5996.
- Bansiddhi P, Nganvongpanit K, Brown JL, Punyapornwithaya V, Pongsopawijit P, Thitaram C. 2019. Management factors affecting physical health and welfare of tourist camp elephants in Thailand. *Peer J* 7: e6756. DOI: 10.7717/peerj.6756.
- CITES. 2021. Illegal Trade in Live Asian Elephants: A Review of Current Legislative, Regulatory, Enforcement, and Other Measures Across Range States. www.cites.org/sites/default/files/eng/cop/17/WorkingDocs/E-CoP17-57-01-A5.pdf
- Clutton-Brock J. 2012. *Animals as Domesticates: A World View Through History*. Michigan State University Press, Michigan, USA.
- de Silva S, Leimgruber P. 2019. Demographic tipping points as early indicators of vulnerability for slow-breeding megafaunal populations. *Front Ecol Evol* 7: 1-13. DOI:10.3389/fevo.2019.00171.
- Elephant Reintroduction Foundation. 2022. Elephant Reintroduction Program in Thailand. www.elephantreintroduction.org/eng/menu_en.html
- Hayward AD, Mar KU, Lahdenpera M, Lummaa V. 2014. Early reproductive investment, senescence and lifetime reproductive success in female Asian elephants. *J Evol Biol* 27 (4): 772-783. DOI: 10.1111/jeb.12350.
- He C, Du J, Zhu D, Zhang L. 2020. Population viability analysis of small population: A case study for Asian elephant in China. *Integr Zool* 15 (5): 350-362. DOI: 10.1111/1749-4877.12432.
- IUCN. 2017. International Union for Conservation of Nature (IUCN) Updating 2017 Thailand Mapping of Wild Elephant Presence Sites, Population, and HEC Presence Sites. Bangkok, Thailand.
- IUCN. 2022. The IUCN Red List of Threatened Species. Version 2021-3. <https://www.iucnredlist.org>
- Jackson J, Childs DZ, Mar KU, Htut W, Lummaa V. 2019. Long-term trends in wild-capture and population dynamics point to an uncertain future for captive elephants. *Proc R Soc B* 286: 20182810. DOI: 10.1098/rspb.2018.2810.
- Jerang J, Vanitha V, Baskaran N. 2020. Demography, feeding and keeper status of captive Asian elephants in Eastern Arunachal Pradesh, North-eastern India. *Gajah* 52: 30-38.
- Kriangwanich W, Nganvongpanit K, Buddhachat K, Brown JL, Siengdee P, Chomdej S, Bansiddhi P, Thitaram C. 2018. Genetic diversity and variation in captive Asian elephants (*Elephas maximus*) in Thailand. *Trop Conserv Sci* 11: 1-10. DOI: 10.1177/1940082918816871.
- Lacy RC. 2019 Lessons from 30 years of population viability analysis of wildlife populations. *Zoo Biol* 38 (1): 67-77. DOI:10.1002/zoo.21468.
- Lacy R, Pollak JP. 2021. *Vortex: A Stochastic Simulation of the Extinction Process*. Version 10.5.5. Chicago Zoological Society, Brookfield, Illinois, USA.
- Laohachaiboon S. 2010. Conservation for whom? Elephant conservation and elephant conservationists in Thailand. *Japanese J Southeast Asian Stud* 48 (1): 74-95.
- Leimgruber P, Senior B, Uga, Aung M, Songer MA, Mueller T, Wemmer C, Ballou JD. 2008. Modeling population viability of captive elephants in Myanmar (Burma): Implications for wild populations. *Anim Conserv* 11: 198-205. DOI:10.1111/j.1469-1795.2008.00172.x.
- Lohanan R. 2002. The elephant situation in Thailand and a plea for co-operation. In: Satoo T, Changchui H (eds). *Giants on Our hands; Proceeding of the International Workshop on the Domesticated Asian Elephant*. FAO Regional Office for Asia and the Pacific, Bangkok, 5-10 February 2001. www.coin.fao.org/coin-static/cms/media/9/13171049401100/2002_30_high.pdf#page=45. [Thailand]
- Mar KU. 2013. Birth sex ratio and determinants of fecundity in female timber elephants of Myanmar. *Gajah* 38: 8-18.
- Mar KU, Lahdenpera M, Lummaa V. 2012. Causes and correlates of calf mortality in captive Asian elephants (*Elephas maximus*). *PloS One* 7 (3): e32335. DOI: 10.1371/journal.pone.0032335.
- Menkham K, Sukmasuang R, Pla-ard M, Charaspet K, Panganta T, Trisurat Y, Bhumpakphan N. 2019. Population and habitat use of Asian elephants (*Elephas maximus*) and five ungulate species in Khao Ang Rue Nai Wildlife Sanctuary, Chachoengsao Province, Thailand. *Biodiversitas* 20: 2213-2221. DOI: 10.13057/biodiv/d200815.
- Menon V, Tiwari SKR. 2019. Population status of Asian elephants *Elephas maximus* and key threats. *Intl Zoo Yearb* 53 (1): 17-30. DOI: 10.1111/izy.12247.
- Mossbrucker AM, Imron MA, Pudyatmoko S, Pratje PH. 2016. Modeling the fate of Sumatran elephants in Bukit Tigapuluh Indonesia: Research needs & implications for population management. *J Ilmu Kehutanan* 10 (1): 5-18. DOI: 10.22146/jik.12622
- Mumby HS, Courtiol A, Mar KU, Lummaa V. 2013. Birth seasonality and calf mortality in a large population of Asian elephants. *Ecol Evol* 3 (11): 3794-3803. DOI: 10.1002/ece3.746.
- National Institute of Elephant Research and Health Service. 2013. *Captive Elephant Data*. Department of Livestock Development, Bangkok. [Thailand]
- Pla-ard M, Sukmasuang R, Srinopawan K. 2019. Population characteristics and habitat suitability of Asian elephants (*Elephas maximus* Linnaeus, 1758) in the Khao Yai National Park, Thailand. *Eur J Ecol* 5 (2): 62-71. DOI: 10.2478/eje-2019-0012.
- Pla-ard M, Khioesree N, Sungkalak B, Nathalang A, Thomas W, Uthairatsamee S, Paansri P, Chanachai Y, Sukmasuang R. 2022. Population characteristics and habitat suitability of Khao Yai National Park, Thailand for Asian elephant and five ungulate species. *Biodiversitas* 23: 231-243. DOI: 10.13057/biodiv/d230129.
- Pimmanrojngool V, Wanghongsa S. 2002. A study of street wandering elephants in Bangkok and the socio-economic life of their mahouts. In: Satoo T, Changchui H (eds). *Giants on Our hands; Proceeding of the International Workshop on the Domesticated Asian Elephant*.

- FAO Regional Office for Asia and the Pacific, Bangkok, 5-10 February 2001. www.coin.fao.org/coin-static/cms/media/9/13171049401100/2002_30_high.pdf#page=45. [Thailand]
- Pintavongs W, Chueplaivej P, Boonyasart B, Kidyhoo S, Pravai W, Rattanakunprakarn J, Ounsiri S, Lorsanyaluck B, Sunyathitiseree P, Jittapalpong S, Wajjwalku W, Thongtip N. 2014. Domestic elephant population structure and health status in Thailand. *J Kasetsart Vet* 24 (1): 16-24.
- Prado-Oviedo NA, Bonaparte-Saller MK, Malloy EJ, Meehan CL, Mench JA, Carlstead K. 2016. Evaluation of demographics and social life events of Asian (*Elephas maximus*) and African elephants (*Loxodonta africana*) in North American zoos. *PLoS One* 11 (7): e0154750. DOI: 10.1371/journal.pone.0154750.
- Puyati B, Charoenphan P, Boonyasart B, Kanistanon K, Kampa J. 2015. Detection of elephant endotheliotropic herpesvirus in Asian elephant from organs and trunk swap samples. *Vet Integr Sci* 13 (3): 153-163.
- Radchuk V, Oppel S, Groeneveld J, Grimm V, Schtickzelle N. 2016. Simple or complex: Relative impact of data availability and model purpose on the choice of model types for population viability analyses. *Ecol Model* 323: 87-95. DOI: 10.1016/j.ecolmodel.2015.11.022.
- Rees PA. 2021. Elephants under Human Care: The Behaviour, Ecology, and Welfare of Elephants in Captivity. Academic Press, Elsevier, UK. DOI: 10.1016/B978-0-12-816208-8.00011-7.
- Sakamoto M. 2017. Recent topics on CITES related to Asian elephants in particular. *Gajah* 47: 42-44.
- Schliesinger J. 2015. Elephants in Thailand vol 1: Mahouts and Their Cultures Today. White Lotus Press, Bangkok, Thailand.
- Schmidt-Burbach J, Ronfot D, Srisangiam R. 2015. Asian elephant (*Elephas maximus*), pig-tailed macaque (*Macaca nemestrina*) and tiger (*Panthera tigris*) populations at tourism venues in Thailand and aspects of their welfare. *PLoS One* 10 (9): e0139092. DOI: 10.1371/journal.pone.0139092.
- Schmidt H, Kappelhof J. 2019. Review of the management of the Asian elephant *Elephas maximus* EEP: Current challenges and future solutions. *Intl Zoo Yearb* 53 (1): 31-44. DOI: 10.1111/izy.12233.
- Shaffer LJ, Khadka KK, Hoek JVD, Naithani KJ. 2019. Human-elephant conflict: A review of current management strategies and future directions. *Front Ecol Evol* 6: 235. DOI: 10.3389/fevo.2018.00235.
- Songthammanuphap S, Puthong S, Pongma C, Buakeaw A, Prammananan T, Warit S, Tipkantha W, Kaewkhunjob E, Yindeeyoungyeon W, Palaga T. 2020. Detection of *Mycobacterium tuberculosis* complex infection in Asian elephants (*Elephas maximus*) using an interferon gamma release assay in a captive elephant herd. *Sci Rep* 10 (1): 14551. DOI: 10.1038/s41598-020-71099-3.
- Sukumar R. 1989. The Asian Elephant: Ecology and Management. Cambridge University Press, Cambridge, UK.
- Sukumar R, Krishnamurthy V, Wemmer C, Rodden M. 1997. Demography of captive Asian elephants (*Elephas maximus*) in southern India. *Zoo Biol* 16 (3): 263-272. DOI: 10.1002/(SICI)1098-2361(1997)16:3<263::AID-ZOO6>3.0.CO;2-8.
- Sukmasuang R, Thongtip N, Bhumpakphan N. 2013. The Studies of Ecology, Population, Distribution and Health to Solve Elephant Problems in Thailand. Research and Development Projects to Enhance Integrated Competitiveness Agricultural Research Project, Kasetsart University Research and Development Institute, Bangkok. [Thailand]
- Suter I, Maurer G, Baxter G. 2014. Population viability of captive Asian elephants in the Lao PDR. *Endanger Species Res* 24: 1-7. DOI: 10.3354/esr00578.
- Thitaram C. 2009. Elephant Reproduction: Improvement of Breeding Efficiency and Development of a Breeding Strategy. [Dissertation], Utrecht University, Utrecht. www.dspace.library.uu.nl/handle/1874/36974. [Netherlands]
- Thitaram C. 2012. Breeding management of captive Asian elephant (*Elephas maximus*) in range countries and zoos. *Japanese J Zoo Wildl Med* 17 (3): 91-96. DOI: 10.5686/jjzwm.17.91.
- Thitaram C, de Silva S, Soorae P, Daim S, Pérez ABL. 2020. Guidelines for the rehabilitation of captive elephants as a possible restocking option for wild populations. *Gajah* 52:56-59.
- Thongtip N, Mahasawangkul S, Thitaram C, Pongsopawijit P, Kornkaewrat K, Pinyopummin A, Angkawanish T, Jansittiwate S, Rungsri R, Boonprasert K, Wongkalasin W, Homkong P, Dejchaisri S, Wajjwalku W, Saikhun K. 2009. Successful artificial insemination in the Asian elephant (*Elephas maximus*) using chilled and frozen-thawed semen. *Reprod Biol Endocrinol* 7 (1): 1-8. DOI: 10.1186/1477-7827-7-75.
- Toin P, Brown JL, Punyapornwithaya V, Bansiddhi P, Somgird C, Thitaram C. 2020. Reproductive performance of captive Asian elephants (*Elephas maximus*) in large tourist camps in Thailand. *Anim Reprod Sci* 222: 106606. DOI: 10.1016/j.anireprosci.2020.106606.
- Vanitha V, Thiyagesan K, Baskaran N. 2010. Daily routine of captive Asian elephants (*Elephas maximus*) in three management systems of Tamil Nadu, India and its implications for elephant welfare. *J Sci Trans Environ Technov* 3 (3): 116-122. DOI: 10.20894/stet.116.003.003.002.
- Williams C, Tiwari SK, Goswami VR, de Silva S, Kumar A, Baskaran N, Yoganand K, Menon V. 2020. *Elephas maximus*. The IUCN Red List of Threatened Species 2020: e.T7140A45818198. DOI: 10.2305/IUCN.UK.2020-3.RLTS.T7140A45818198.en.