



A Retrospective Analysis on the Population Viability of the Yangtze River Dolphin or Baiji (*Lipotes vexillifer*)

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ABSTRACT

Background: *Lipotes vexillifer*, is a functionally extinct species of freshwater dolphin commonly called as Baiji dolphin of Yangtze River, China. The dolphin is thought to be the first one of its kind driven to extinction due to the impact of humans. Yangtze Freshwater Dolphin Expedition carried out in the year 2006 revealed the species as functionally extinct. The present study deals with the population viability analysis of the baiji dolphin using Vortex software and also by consulting historical materials and relevant literature to explore the possible causes of the functional extinction of the baiji in the Yangtze River. The findings are to provide guidance for the effective management of another freshwater mammal, the Yangtze finless porpoise.

Methods: Population viability analysis of the baiji dolphin for various parameters were assessed using Vortex software and other published information and relevant literatures. The analysis were carried out to ascertain the possible causes of the functional extinction of the baiji in the Yangtze River.

Result: Simulation models were employed to identify the reasons for extinction of Yangtze River baiji population by adopting viability retrospective method. The various parameters associated with the population analysis were included to derive logical conclusion. The minimum viable population of the Yangtze River baiji was also identified by adopting various simulation models. The present study is the first attempt to apply the 10,000-time iteration method to the baiji population survivability analysis.

Key words: *Lipotes vexillifer*, PVA, Vortex model, MVP, Habitat.

INTRODUCTION

The baiji or Yangtze River dolphin (*Lipotes vexillifer*, Miller), which inhabits only the middle and lower reaches of the Yangtze River in China, was the world's most endangered cetacean species (Reeves *et al.*, 1994; Reeves *et al.*, 2000; Hu, 2003; Dalton, 2006). A multi-vessel visual and acoustic survey in 2005 of the Yangtze River system did not encounter any baiji, leading the team of international scientists to declare that the baiji was most likely extinct (Turvey *et al.*, 2007). Population models have been successfully applied in species protection (Brook *et al.*, 2000a, 2000b; Lancy, 1993; Chen *et al.*, 1992; Zhang *et al.*, 1994; Zhang *et al.*, 1999) and fish resource assessment (Gayanilo *et al.*, 1996, 2005; Gayanilo *et al.*, 1997; Hacer, 2018; Wu *et al.*, 2018). Research on population dynamics can help people understand the laws of population change and provide decision support and scientific basis for the endangered species protection. Based on this, we analyzed the population viability of the baiji in 1985 using Vortex model 10.3.7.0, to explore the possible causes of the functional extinction of the baiji, to provide guidance for the effective management of another freshwater mammal, the Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*). This suffers from many of the same impacts that affect the baiji and the population of main stream of the Yangtze River have been continuously decreasing in recent years (Zhang *et al.*, 1993; Wang *et al.*, 1996, 1998; Mei *et al.*, 2012; 2014; Huang *et al.*, 2019). The latest research results suggest that the critically endangered Yangtze finless porpoises should be considered a unique incipient species (Zhou *et al.*, 2018).

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MATERIALS AND METHODS

The baiji population was about 300 in the mid-1980s and only about 200 in the early 1990s (Chen *et al.*, 1980; 1989; 1993; Lin *et al.*, 1985; Zhou *et al.*, 1980; 1982; Zhang *et al.*, 2003; Turvey *et al.*, 2007). Because of the small population size of the baiji, opportunities to observe them in the wild were very rare. The baiji's scattered distribution and low density made them difficult to find and count. Population survey results could have large errors. Therefore, using mid-1980s as the starting point for the Yangtze River baiji population viability review, the relative error may be smaller. Lin *et al.*, (1985) found that the baiji was distributed over 17 sections of the Yangtze River, each river segment had 8, 8, 8, 8, 21, 6, 4, 8, 8, 24, 11, 5, 6, 8, 12, 3, 8, respectively.

The total number of baiji was estimated to remain at around 156 individuals. Surveys during 1997-1999 provided a minimum estimate of only 13 animals (Zhang *et al.* 2003). The last authenticated baiji records were of a stranded pregnant female found in 2001 and a live animal photographed in 2002 (Turvey *et al.*, 2007). The MVP concept emerged in 1981 from Shaffer's pioneering paper. Operationally, time horizons of 50-100 years and extinction risk of 5% became the most frequently used criteria (Reed *et al.*, 2003; Lacy *et al.*, 2009; Curtis *et al.*, 2011). The estimation method was: to analyze the population viability of initial population size, Initial population size, N_i in 100 years, when the survival rate of the population reached 95%, N_i was MVP.

The distribution range of the baiji was estimated to extended over 1,559 km (Lin *et al.*, 1985). The baiji was population fragmentation, as the distances between used habitats and groups were increasing (Zhang *et al.*, 2003), suggesting movement between 17 sections of the Yangtze River was now infrequent. So we set up each of the 17 sections diffused 1% to each other, with an equal probability of female and male and a survival rate of 50%. The baiji's mating system was polygyny. Lifespan was about 30 years. The highest reproductive age was 20. The mature age of female was 8 and that of male was 6 (Zhang *et al.*, 1994). The baiji had no record of producing twins in the wild, the proportion of newborn males was set at 0.5, 0.6 and 0.4 respectively, which constituted six simulated scenarios, as shown in Table 1 for details. The population growth of this species should be density-dependent (Zhang *et al.*, 1994). Fowler (1981) considered that the parameter B of the change intensity, taking 2 could better simulate the growth of the density-dependent population and the parameter A of the decrease of the female mating rate also taking 2. For the baiji, if N was close to the environmental capacity K, the proportion of breeding females was 25% and when N was close to 0, the proportion of breeding females was 70% (Zhang *et al.*, 1994). The proportions of old, adult and immature baiji individuals were approximately estimated at 57%, 26% and 17% respectively (Zhang *et al.*, 2003). So the annual reproductive rate of adult female baiji could be about 30% (Zhang *et al.*, 1994).

Zhang *et al.* (1994) the baiji set mortality rate of 30%-60% for 0-1 age group, 10%-20% for 1-2 age group and 5%-10% for the other age groups. An annual rate of population decrease was roughly estimated as 10% (Zhang *et al.*, 2003). Therefore, we set the the baiji 0-1 age group mortality to be 60% for 0-1 age group, 20% for 1-2 age group

and 10% for the other age groups. The baiji was the victim not of active persecution but of incidental mortality resulting from massive-scale human environmental impacts, primarily uncontrolled and unselective fishing (Turvey *et al.*, 2007). So we set up two types of disasters with a frequency of 10% (Zhang *et al.* 1994), simulating the population dynamics at 95% and 95% survival and reproduction rates, respectively.

For the baiji which was distributed over 17 sections of the Yangtze River, we set up two kinds of simulation, one kind was each section had 8, 8, 8, 8, 21, 6, 4, 8, 8, 24, 11, 5, 6, 8, 12, 3, 8 heads of baiji respectively (Lin *et al.*, 1985). The other kind was each section had double heads of baiji mentioned above, as shown in Table 1 for details. In addition to the above 6 simulation scenarios, another 3 simulation scenarios were constructed, for a total of 9 simulation scenarios. Scenario 7 based on scenario 4, with a diffusion survival rate of 100%. In scenario 8 and 9, based on scenario 4, were assumed to have 5% heads diffusion, equal female and male probability and 50% and 100% survival rates, respectively. Brook (2000b) believed that the prediction results of the population viability model were credible when the maximum amount ever distributed in history was taken as the environmental capacity. Zhang *et al.* (1994) set the environmental capacity of the Yangtze River for the baiji at 1,000 heads, taking into account the strong long-distance swimming ability of baiji, in order to conduct more reliable correlation analysis, we set the environmental capacity at 100 for each of the 17 each section. Environmental carrying capacity declined by 5% per year for 15 consecutive years, starting in 1985.

Inbreeding decline was one of the most important factors affecting the long-term survival of small populations. Ralls *et al.* (1988) studied the lethal equivalence coefficient of 40 mammalian populations and concluded that each diploid had 3.14 lethal gene equivalents. So we set 3.14 as the lethality equivalence coefficient of the baiji (Zhang *et al.*, 1994). There was no breakthrough in the artificial breeding of the baiji. Therefore, it was unrealistic to supplement the baiji population in Yangtze river. At the same time, there was no regular fishing of baiji (Zhang *et al.*, 2003). The Chinese government's conservation plan involves capturing baiji in the Yangtze River and subsequently releasing them into a temporary refuge such as Tian-e-zhou semi-natural ex situ reserve (Wei *et al.*, 2002). A female baiji was captured in the main stream of the Yangtze River on 19 December 1995 and was subsequently introduced

Table 1: Different simulation scenarios of the retrospective analysis of the populations viability of the baiji.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Number of simulations	Ten Thousand Times					
Simulated populations	17					
The proportion of newborn males	0.5	0.6	0.4	0.5	0.6	0.4
17 small river segments baiji initial number	8、8、8、 24、11、	8、21、6、 5、6、8、	4、8、8、 12、3、8、	16、16、 16、16、 24、6、16、	16、16、42、 48、22、10、	12、8、 12、16、

into the semi-natural reserve. At the time of capture, she weighed 150 kg and measured 229 cm in body length (Wang *et al.*, 1999), no other fishing reports have been seen since.

RESULTS AND DISCUSSION

The baiji population viability retrospective analysis

It turned out that in six scenarios, the average extinction time of the baiji population was 22.5-28.9 years, between 2007 and 2013. Further simulation analysis revealed that, whether the total number of baiji was 156 or 312, the outcome was similar, the average extinction time of the former was 22.5-24.2 years and the corresponding extinction time of the latter was 26.6-28.9 years, as shown in Table 2 for details.

The average extinction time of the baiji population was between 2007 and 2013, this was more in line with the official announcement (Turvey *et al.*, 2007). It was suggested that the simulation scenario had a better relationship with the historical habitat and the population characteristics of the

baiji. Further simulation analysis revealed that, whether the total number of baiji was 156 or 312, the outcome was similar. Zhang *et al.*, (1994) showed that, under natural conditions, the breeding rate of the adult female baiji was about 30% and the mortality from age 0 to 1 baiji was 30%-60% and from the results of the retrospective analysis, the mortality rate may be closer to 60%, therefore the direct cause of baiji 's functional "extinction" may be "one lower and one higher", that was, the lower rate of the breeding for the adult female baiji and the higher mortality among newborn baiji (Zhang *et al.*, 2003). Habitat destruction and so on, led to the baiji population passive fragmentation distribution, so that the "one low and one high" phenomenon continued to deteriorate (Turvey *et al.*, 2007).

The minimum viable population of the Yangtze River baiji

On the basis of the above, we first adopt a single species model, it was found that, under existing conditions, single change of environmental capacity, initial number, disaster event and sex ratio could affect the population viability of

Table 2: Results of a retrospective population viability analysis of different scenarios of baiji.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
r	-0.0682	-0.0848	-0.0544	-0.0682	-0.0848	-0.0544	-0.0682	-0.0682	-0.0682
λ	0.9341	0.9187	0.9470	0.9341	0.9187	0.9470	0.9341	0.9341	0.9341
Ro	0.4154	0.3323	0.4985	0.4154	0.3323	0.4985	0.4154	0.4154	0.4154
Average generation female	12.89	13.00	12.79	12.89	13.00	12.79	12.89	12.89	12.89
Average generation male	11.52	11.67	11.40	11.52	11.67	11.40	11.52	11.52	11.52
PE	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mean TE	23.7	22.5	24.2	28.1	26.6	28.9	49.1	9.6	49.2

Table 3: MVP simulation results of baiji population under different breeding rate of adult female individuals.

Breeding rate	70%	69%	68%	67%	66%	65%	60%	55%	50%
PE	0.0513	0.0520	0.0524	0.0533	0.0531	0.0489	0.0537	0.0524	0.0544
Mean TE	84.6	85.4	85.8	85.9	85.3	87.4	88.3	89.7	90.6
MVP (heads)	135	145	154	165	175	192	285	450	765

Table 4: MVP simulation results of baiji population under different mortality from age 0 to 1.

Mortality rate	30%	29%	28%	27%	26%	25%	20%
PE	0.0526	0.0470	0.0470	0.0450	0.0475	0.0529	0.0508
Mean TE	90.7	89.9	90.5	90.1	90.4	89.2	87.9
MVP (heads)	800	780	746	690	615	550	420

Table 5: MVP simulation results of baiji population under different environmental capacities.

Environmental capacity (heads)	1000	600	550	500	450	400	350	345	340
PE	0.0500	0.0502	0.0512	0.0496	0.0505	0.0492	0.0512	0.0511	0.0503
Mean TE	76.1	75.8	75.5	77.0	76.5	79.4	78.3	79.6	80.2
MVP (heads)	61	61	63	63	63	63	67	69	71
Environmental capacity (heads)	335	330	325	320	315	310	305	300	291
PE	0.0535	0.0519	0.0516	0.0547	0.0522	0.0507	0.0507	0.0542	0.0535
Mean TE	82.5	81.2	81.8	82.1	82.3	84.3	83.9	84.2	84.5
MVP (heads)	75	76	76	77	78	100	110	125	285

Yangtze River baiji, but could not reach the MVP standard. The MVP with a breeding rate and the mortality from age 0 to 1 was shown Table 3 and 4 for details. Later, we set the breeding rate of the adult female baiji at 50%, the mortality from age 0 to 1 was 30%, MVP of the baiji with different environmental carrying capacity was obtained, as shown Table 5 for details.

In a relatively ideal state, the minimum MVP of the baiji was 61 heads, indicating that the relocation protection was very difficult for the baiji. With the deterioration in the ecological conditions of the Yangtze River because of expanding human activities and the likelihood that this trend may last for many more years, there may be little hope for the long-term survival of baiji in the river (Reeves *et al.*, 2000).

CONCLUSION

This paper analyzed the population viability of the Yangtze River dolphin or baiji (*Lipotes vexillifer*) and 1985 was used as the starting point. It turned out that the average extinction time of the baiji population was 22.5-28.9 years, between 2007 and 2013. It was suggested that when the population was faced with the "Vortex" of extinction, focusing on the protection and restoration of high-quality habitats, especially those related to parents-children, was important for the protection of the endangered species. When the population was at risk of extinction, human-induced migration of the baiji and other species to specific natural habitats and strengthen conservation, may be one of the necessary means.

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