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RESEARCH

Analysis of the population density trend of the finless porpoise based on smart IoT technologies

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Abstract

With the rapid expansion of human activities, natural environmental systems are under severe threat. Yangtze River, the largest river in China, contains abundant biological resources. However, the ecosystem of the Yangtze River has been threatened by the rapid rise of human activities due to economic development in the 1990s. The Yangtze finless porpoise Neophocaena phocaenoides asiaeorientalis is a critically endangered flagship species in the Yangtze River. Although scientists have conducted surveys studying the abundance of Yangtze finless porpoise, the length of the investigation period of these studies was restricted. Here, we reported our meta-analysis results by collecting data on the abundance of the Yangtze finless porpoise population from published papers over 33 years. We found that the pooled effect size using the random effect model across all these studies was – 0.36 (95% confident interval (CI) – 0.48,– 0.24, $P < 0.05$), indicating that the porpoise population has undergone a declining pattern after the year 2003. The operation of the Three Gorges Dam was one important but not the only factor resulting in the decline of the porpoise population. More actions should be taken for porpoise and habitat protection and more studies should be done to assess the impact of dams on the porpoise population in Poyang Lake. Only in this way can marine life be better protected, and the marine environment can better achieve sustainable development.

Keywords Yangtze River · Finless propoise · Population density · Meta-analysis · Ocean species

1 Introduction

With the rapid expansion of human activities, natural environmental systems are under severe threat. The extinction of massive species, which is also known as the sixth major extinction event, was more severe than previous events and triggered entirely by anthropogenic activities (Ceballos et al. 2017; Chapin III et al. 2000). Human activities influence a large variety of environmental factors, including the global nitrogen cycle, urban soil contents, marine ecosystems, and so on (Vitousek et al. 1997; Wei & Yang 2010; Halpern et al. 2008). Like marine, inland aquatic systems including rivers and lakes were also under great threat from human activities (Lewis et al. 2011; Regnier et al. 2013). Overfishing, shipping, releasing of chemicals, and construction of hydraulic engineering cause irreversible negative impacts on urban aquatic resources (Burgess et al. 2013; Gabel et al. 2017; Zhang et al. 2018; Aristi et al. 2014).

Yangtze River is a suitable example to explain how rivers were effaced by anthropogenic activities. Being the largest river in China, the Yangtze River contains abundant biological resources. By having more than 400 fish species, the Yangtze River is the gene pool for fish. Yangtze River also is the representation of the biological diversity of freshwater fishes in China. Containing not only multiple important economic fishes, the Yangtze River also has more than 160 unique species, accounting for over 60% of the total number of unique species in China (Yu 2005). Chinese sturgeons Acipenser sinensis, baiji Lipotes vexillifer, and finless porpoises Neophocaena phocaenoides asiaeorientalis are famous unique species living in the Yangtze River and have significant biological importance (Hung 2017). However, the ecosystem of the Yangtze River has been threatened by the rapid rise of human activities due to economic development in the 1990s. Intemperate overfishing caused a massive reduction in the fish population in the Yangtze River (Chen et al. 2009). The continuous construction of hydraulic engineering, especially the Three Gorges Dam, separated the

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upper and lower regions of the Yangtze River, blocking the path for fish immigration to the ocean (Yang et al. 2006). All these factors threaten the life of the flagship species in the Yangtze River. While Chinese sturgeon has become critically endangered, baiji became functionally extinct in 2007 and it was the first extinct cetacean species entirely caused by human activities (Turvey et al. 2007; Zhang et al. 2020).

The Yangtze finless porpoise is a critically endangered flagship species in the Yangtze River and is the only remaining cetacean species living in the Yangtze aquatic region after the extinction of baiji. The current situation of the Yangtze finless porpoise population cannot be justified in a positive view. The Yangtze finless porpoise population has undergone a continuous decline and the remaining population even started to become fragmented, making the situation even worse (Mei et al. 2014). Moreover, the estimated time of the wild porpoise population to be extinct becomes earlier than the previous estimation (Huang et al. 2017). Fortunately, the Yangtze finless porpoise population has shown the sigh of recovery under the establishment of ex- and insu-protection projects and protective areas by the government and researchers (Wang 2009).

Annual field investigations to examine the population abundance of the Yangtze finless porpoise have been conducted since the year 1984 (Anon, n.d.). Previous studies have covered a wide range of survey locations along the Yangtze River, mainly focusing on the middle and lower sections (Anon, n.d.). Adjacent lakes like Poyang Lake and Dongting Lake are also hot spots for porpoise population analysis, contributing to a broader understanding of the distribution of the finless porpoise population (Dong et al. 2015). Although scientists have conducted surveys studying the population abundance of Yangtze finless porpoise, the length of the investigation period of these studies was restricted. Most studies contained data collected in 2–5 years (Anon, n.d.). Only a few studies showed a large period of up to a decade (Anon, n.d.). Studies also tend to conduct a one-time investigation of the porpoise population along a survey section of the Yangtze River (Zhao et al. 2008). In addition, some papers conducted seasonal surveys in a year to investigate the seasonal changing pattern of the finless porpoise population rather than repeating at the same time intervals annually (Anon, n.d.). These may result in gaps in understanding the pattern of porpoise population change in survey regions over long periods. In the previous studies, different methods of porpoise detection, including eye searching and acoustic surveys, were used in the investigation (Dong et al. 2015; Zhao et al. 2008). The unit used to describe the abundance of the porpoise population also varied among different studies. For example, while some studies directly record the number of porpoises encountered in kilometers, others transformed their raw data into population density or estimated abundance of finless porpoise population (Anon, n.d.). The lack of a uniform unit to describe the results of porpoise population surveys may lead to problems when summarizing and comparing different papers. In conclusion, there is a need to survey the population abundance of Yangtze finless porpoise over a large period at uniform scales to produce a more comprehensive data analysis.

Here, we reported our meta-analysis results by collecting abundance data on the Yangtze finless porpoise population in the median and lower regions of the Yangtze River from published papers over 33 years (from 1984 to 2017). We aimed to investigate the pattern in variation of the finless porpoise population. We also analyzed and compared the abundance data collected before and after 2003, the year of the completion of the construction of the Three Gorges Dam. If the abundance data of the Yangtze finless porpoise collected after 2003 are smaller than that before 2003, we could conclude that there is a decline in population abundance of the finless porpoise population after 2003 and the construction of the Three Gorges Dam may pose an impact on the reduction of porpoise population. Our hypotheses were 1) hydraulic engineering, especially dams, has influenced the porpoise population; 2) the porpoise population shows an overall declining pattern. We then discussed other possible factors that may result in the change of population abundance of the finless porpoise population in the median and lower regions of the Yangtze River. Our results could help to (1) have a better understanding of the change in the population abundance of the finless porpoise population; (2) analyze the impact of anthropogenic activities, especially the construction of dams, on the finless porpoise population; 3) contribute to the conservation of endangered species in the Yangtze River.

2 Methods

2.1 Search and select published studies on the topic

We used electronic databases, including Web of Science, Google Scholar, and China National Knowledge Infrastructure (https://www.cnki.net/) to search for relevant studies investigating the Yangtze finless porpoise population. The search terms we used were Yangtze finless porpoise* AND population* AND distribution. Papers published by recognized experts in the field of porpoise (Ding Wang, Kexiong Wang) were considered as key articles. We also searched relevant secondary articles in the bibliographies of key articles.

2.2 Selection criteria

Among the large number of literature retrieved, we selected those studies in which titles and keywords were associated with the objective of this paper. We then examined the information contained in the abstracts to further narrow down the selection to those studies that met the following criteria:

- Study objects: finless porpoise population in the mainstream of the Yangtze River. The porpoise population in adjacent lakes including Poyang and Dongting lake were ignored.
- Types of method: Boats carried at least two observers traveled along the mainstream of the Yangtze River. The inspectors record the number of sightings of finless porpoises at a fixed interval. The sightings of different sections were collected.
- Types of outcomes: Species abundance (numbers of sightings) at varying distances along the mainstream of the Yangtze River.

2.3 Data extraction

Finally, 13 studies containing survey data of the porpoise population from 1984 to 2017 met the selection criteria for data extraction. In total, 140 datasets and 316 data points were extracted and stored in a single datasheet. The measurements in the datasheet included the survey location, survey time, travel distance, sightings, survey length, and repeated times of survey. In addition, we recorded the calculated variance, and standard deviation or standard error for each study. We used this datasheet to estimate the effect size and variance required for the meta-analysis. We divided 13 studies into 2 subgroups: data collected before the year 2003 and after the year 2003. The year 2003 was selected as a standard as the filling of the reservoir of The Three Gorges Dam was completed in 2003. We assumed that the finless porpoise population was not influenced by The Three Gorges Dam until it was completed in 2003. We also assumed that the finless porpoise population would undergo the continuous impact of The Three Gorges Dam after 2003.

2.4 Effect size calculation: log response ration

For each study, the detection rate of porpoises was calculated as the ratio between the number of sightings and travel distance. We treated the studies investigating the porpoise population after 2003 as the treatment group and studies that before 2003 as the control group. The average detection rate for each study was calculated as the mean value of the detection rates of multiple searches in the same study. We used the natural log response ration for effect size calculation as it is one of the common methods used in meta-analysis. Individual effect sizes were calculated as the natural log ratio between the mean detection rates of studies in the treatment group and the mean detection rate of studies in the control group, for example (1):

$$yi = \text{In}\left(\frac{Yt}{Yc}\right), \tag{1}$$

where yi is the log response ratio; Yt is the mean detection rate of treatment group; Yc is the mean detection rate of the control group. Yc had a constant value in the calculation as the control group was treated as an entirety. The weight for each study was calculated as the multiplicative inverse of the sum of the standard deviation of each study and the square root of τ. The final effective size was calculated by multiplying the effective size with the ratio between individual weight and total weight.

2.5 Variation calculation: log response ration

We also used the natural log response ration for variation calculation to correspond with the method used in effective side calculation. The variance of the log response ratio values for each detection rate and the study was estimated by the following Eq. (2):

$$Vi = \frac{St^2}{\left(Nt \times Yt^2\right)} + \frac{Sc^2}{\left(Nc \times Yc^2\right)}, \tag{2}$$

where St is the standard deviation of the treatment group; Nt is the sample size of the treatment group, which in this case is the average time to conduct one survey; Yt is the mean detection rates of the treatment group; Sc is the standard deviation of the control group; Nc is the sample size of the control group; Yc is the mean detection rate of the control group.

2.6 Data analysis

Meta-analyses were performed using R 4.2.1 software (RStudio Team 2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL). We conducted analysis mainly using the metafor package (Viechtbauer 2010). A Forest plot was produced to assess the heterogeneity of studies. A funnel plot was produced to assess the publication bias.

3 Results

Eight studies accessing the change in the porpoise population were analyzed. The pooled effect size using the random effect model across all these studies was − 0.36 (95% confident interval (CI) − 0.48, − 0.24, $P < 0.05$; Fig. 1), indicating an overall reduction in the porpoise population after the year 2003. Some evidence of heterogeneity was observed in our result ($I^2 = 49.3\%, \tau^2 = 0.01,\ P = 0.05$). No publication

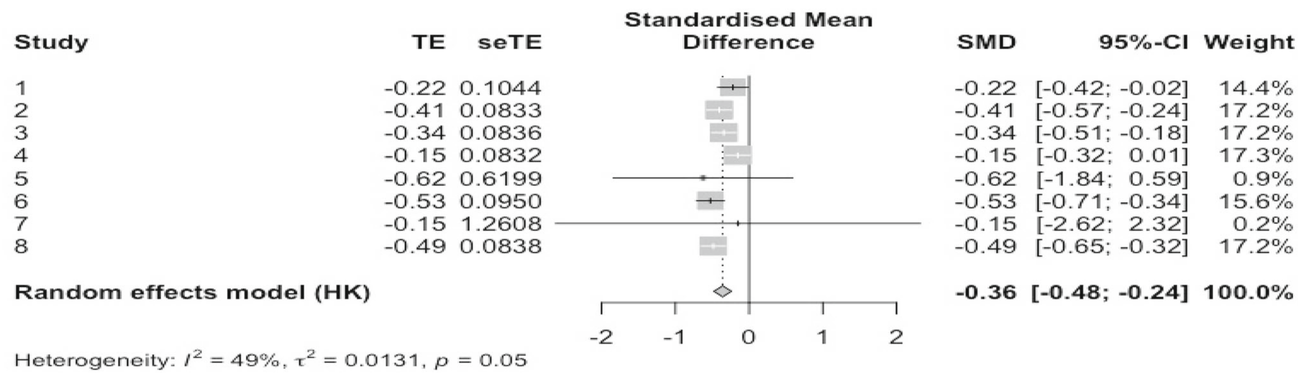

Fig. 1 The forest graph of meta-analysis

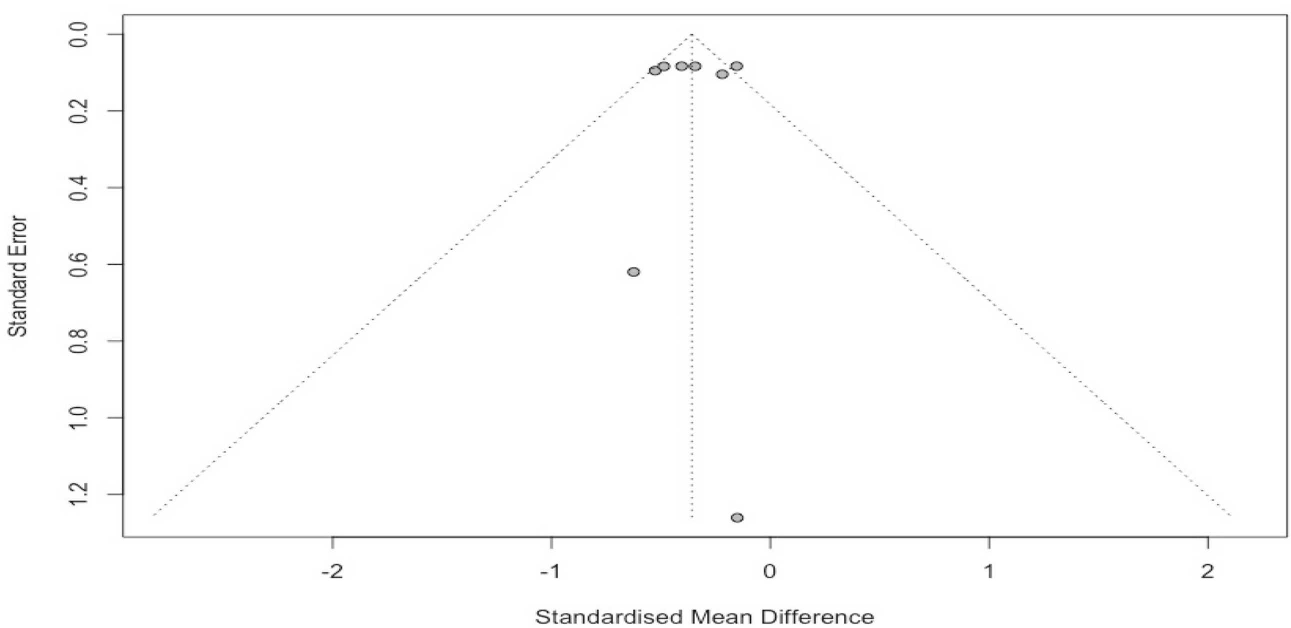

Fig. 2 The funnel graph of meta-analysis

bias ($P = 0.05$; Fig. 2) was observed. Study 5 (standard mean difference(SMD): − 0.62, 95% CI − 1.84, 0.59) and study 7 (SMD: − 0.15, 95% CI − 2.62, 2.32) had small weight compared with other studies. 3 surveys were conducted on 3 adjacent days in study 5. The short length of the survey time would result in the creation of a large bias in the study. In study 7, 6 surveys were continuously conducted from 2014 to 2016. The long-time intervals compared with other studies would create uncertainty in the results. The high uncertainty created by studies 5 and 7 would shift the overall pattern of the results to a declining pattern. After removing studies 5 and 7, the overall pattern still decreased and no large fluctuation was found.

TE represented the value of effect size and seTE showed the value of variance for each study in the treatment group. SMD represented the value of the standardized mean difference and 95% CI showed the value of a 95% confident interval.

The *x*-axis represented the value of the standardized mean difference and the *y*-axis represented the standard error for each study in the treatment group. The points below the area of the dotted line were considered to have no publication bias.

4 Discussion

From our results, the porpoise population has undergone a declining pattern after the year 2003. This finding consisted of the previous prediction of the high probability of extinction (Mei et al. 2012). The Three Gorges Dam was put into use in 2003. The reduction of the porpoise population after

2003 founded in our result may indicate that the reduction of the porpoise population was influenced by the construction of dams. The construction of dams changed the structure of the natural environment. The change in environmental factors like water depth, wetted width, and current velocity had a vital effect on species diversity. A significant decrease in fish abundance and density was observed in many studies (Song and Mo 2021). Dams separated the upstream and downstream of the river. The blocking of paths to travel along the river also blocked migration to the ocean for some fish species. The block of the path between mainstream and tributary was also one severe consequence. The finless porpoise's habitat has been affected by erosion from the downstream side of the dam. With the erosion of the riverbed, the water quantity compromising the porpoise's habitat decreased (Fang et al. 2014). The water levels of adjacent natural lakes also showed decline patterns (Li et al. 2021). Poyang Lake is the largest freshwater lake in China. At the same time, it is one of the traditional habitats of the Yangtze finless porpoise. The seasoning shrinking of Poyang Lake during the dry seasons often forced concentrations of porpoise in narrow channels (Li et al. 2021). The large decrease in water level may result in the blocking of the path to travel between the mainstream and tributary of the Yangtze River, causing the fragmentation of the finless porpoise population. However, the construction of dams was not the only factor threatening the porpoise population. Bycatch of small cetaceans was a significant driver of porpoise population decline and a problem with no simple technical solution (Liu et al. 2017; Brownell Jr et al. 2019). The fish species richness and abundance had significant influences on the occurrence of Yangtze finless porpoise (Zhang et al. 2015). The depletion of fish stocks in the Yangtze River hugely impacted the survival of the porpoise population. Other possible factors including underwater noise or chemical pollution may also influence the health of porpoises, causing the decline of the porpoise population (Wang et al. 2020; Xiong et al. 2019). In conclusion, the construction of dams was one important but not the only factor resulting in the decline of the porpoise population. In addition, the construction of the Three Gorges Dam also brings positive influences. The construction of the Three Gorges Dam has improved the economic development of surrounding cities. The number of tourists visiting those areas has increased since the construction of the Three Gorges Dam. More attention has been paid to the environmental protection of the Yangtze River due to the fame of the Three Gorges Dam. However, it has to be admitted that excessive tourism development could pose a negative effect on the environment. How to balance economic development and environmental protection has always been the focus of our attention. Continuous monitoring of the hydrological environment, rational control of resource development, and promotion of green and environmental-friendly tourism can mitigate the impact of economic development on the environment.

The porpoise population did not show a continuously rapid decreasing pattern, showing the positive effect of conservative and protective projects. Projects including in-situ and ex-situ conservative programmes were applied to porpoise protection in the early 1990s (Wang 2009). Healthy captive-breeding newborns have been produced in these programmes since 2005 (Wang et al. 2005). Protective areas have also been established. Porpoises that were rescued or caught in the Yangtze River have been introduced into these protective areas. Since the successful application of captive breeding techniques to the Yangtze finless porpoise in conservation programmes, the newborn porpoise has annually been reproduced in the protective areas. The little fluctuation was shown in the change in the porpoise population. A positive hypothesis for this is that porpoise has adapted to the current environment. The fish population would gradually be stabilized after the large loss of biomass in the first 5 years of dam construction. (Song and Mo 2021). The stabilization of the porpoise population may bring hope for porpoise conservation. More efforts should be put into conservation projects and more actions should be taken in the protection of natural habitats, especially Poyang Lake. More studies should be conducted to assess the impact of the construction of dams on the porpoise population in Poyang Lake (Han et al. 2020).

There are some limitations of the study. We select the number of sightings of porpoises as an estimation of the porpoise population density. Other values including calibrated porpoise density or encounter rate were also found. However, different calibration methods and units were used in different papers. It was difficult to standardize data with different units. Thirteen papers were selected, and eight papers were finally been used in statistical analysis. The limited number of selected papers may bring bias to the result despite the long-time gap in data collection. Second, we treated the studies before 2003 as a large entity as it was difficult to find consistent data investigating the porpoise population along a fixed section along the Yangtze River. More information could be collected if records of the porpoise population in the same region at different time intervals were found. Finally, some selected studies contained extremely short or long survey lengths, creating bias or uncertainty in the whole data set. It would be better to remove these studies. However, we kept these studies due to the limited number of selected studies.

5 Conclusion and future works

In conclusion, the Yangtze finless porpoise population showed a declining pattern after the operation of the Three Gorges Dam by meta-analysing previous papers investigating the abundance of the finless porpoise population before and after the construction of the Three Gorges Dam. The construction of the Three Gorges Dam could be an influential factor explaining the decrease in the porpoise population. However, the construction of the Three Gorges Dam also brings positive economic influences to the Yangtze River basin. More attention should be paid to investigating how to balance economic development and environmental protection. Rather than the construction of the Three Gorges Dam alone, other factors including overfishing, shipping, and noise pollution also pose significant impacts on the decline pattern of the finless porpoise population. This study highlights the discovery of stabilization of the finless porpoise population. This may imply the effectiveness of the current conservation projects. This could be seen as a sign indicating the possibility for future recovery of the finless porpoise population. This study also analyzed the impact of the construction of the Three Gorges Dam on the mainstream of the Yangtze River. Adjacent lakes including Poyang and Doting Lake are suitable habitats for the porpoise population.

Future studies should be carried out to investigate the impact of other anthropogenic and environmental factors on the abundance of the porpoise population. More actions should be taken on porpoise and habitant conservation to achieve the true recovery of the porpoise population in the future. Future studies investigating the impact of dams and other factors on the porpoise population in other sections of the Yangtze River should be carried out to have a more comprehensive understanding. Based on the findings of this paper, careful consideration should be taken before the construction of other hydraulic engineering on the Yangtze River and adjacent lakes.

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Declarations

Conflict of interest The author(s) declared no potential conflicts of interest with respect to the research, author-ship, and/or publication of this article.

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