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Human harvest, climate change and their synergistic effects drove the Chinese Crested Tern to the brink of extinction

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ABSTRACT

Synergistic effect refers to simultaneous actions of separate factors which have a greater total effect than the sum of the individual factor effects. However, there has been a limited knowledge on how synergistic effects occur and individual roles of different drivers are not often considered. Therefore, it becomes quite challenging to manage multiple threatening processes simultaneously in order to mitigate biodiversity loss. In this regard, our hypothesis is, if the traits actually play different roles in the synergistic interaction, conservation efforts could be made more effectively. To understand the synergistic effect and test our hypothesis, we examined the processes associated with the endangerment of critically endangered Chinese Crested Tern (*Thalasseus bernsteini*), whose total population number was estimated no more than 50. Through monitoring of breeding colonies and investigations into causative factors, combined with other data on human activities, we found that widespread human harvest of seabird eggs and increasing frequency of typhoons are the major factors that threatened the Chinese Crested Tern. Furthermore, 28 percent of breeding failures were due to the synergistic effects in which egg harvest-induced renestings suffered the higher frequent typhoons. In such combined interactions, the egg harvest has clearly served as a proximal factor for the population decline, and the superimposition of enhanced typhoon activity further accelerated the species toward imminent extinction. Our findings suggest that species endangerment, on one hand, should be treated as a synergistic process, while conservation efforts, on the other hand, should focus principally on combatting the threat that triggers synergistic effects.

1. Introduction

Species go extinct when they are no longer able to survive under changing environmental conditions or against superior competition from other species. So far, research on extinction has focused on why extinct species were prone to extinction (intrinsic biological traits) and what drove them to extinction (extrinsic threats). Intrinsic biological traits might include rarity (Simberloff, 1986; Duncan and Young, 2000; Davies et al., 2000), habitat specialization (Frank and Amarasekare, 1998;

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Owens and Bennett, 2000), trophic level (Holt et al., 1999; Holyoak, 2000), and body size (Burbidge and McKenzie, 1989; Blackburn and Gaston, 1997; Cardillo et al., 2005). Species declines and extinctions have been attributed to a number of extrinsic threats, including habitat destruction and fragmentation (Mace and Balmford, 2000), overexploitation (Price and Gittleman, 2007), local environmental stochasticity (Purvis et al., 2000; Pimm et al., 2006), climate change (Thomas et al., 2004; Sekercioglu et al., 2008), and invasive species (Wilcove et al., 1998; Fritts and Rodda, 1998), but rarely is the cause or causes of extinction clearly understood. Extinction research has been successful in providing some broad generalities that mostly derive from fossil and meta-analytic studies (Diamond, 1989; Raup, 1994; Purvis et al., 2000), but these studies have both limitations and difficulties in discerning exactly what factors were responsible for extinction (Brook et al., 2008). In addition to the "why" and "what" of extinction, it is also important to understand the "how" in conservation biology—how drivers of extinction work. Answering the "how" question is usually dependent on empirical studies, but is crucial for effective conservation and efficient restoration through prioritization of efforts to recover threatened taxa.

Recent researches suggested that different traits usually act jointly to promote extinction risk. For example, deforestation inevitably causes fragmentation, which in turn leads to protracted loss of long-lived taxa, such as tropical trees (Brook et al., 2003); interactions between natural abundance and degree of specialization led to a greater reduction in the growth rates of rare and specialized beetle species in fragments than the sum total of their growth-rate reductions in continuous forests (Davies et al., 2004); an interaction between global warming and disease resulted in the disappearance of 40% of 50 endemic frog and toad species from the highland forests of Costa Rica (Pounds et al., 2006). Overkill, habitat destruction, introduced species and chains of extinction were regarded as the evil-quartet for driving human-caused extinction (Diamond, 1989), and most extinctions might involve an interaction between these factors (Koh et al., 2004; Mora et al., 2007). The role of synergistic effect was suggested for describing simultaneous actions of separate factors (intrinsic biological traits or extrinsic threats) that have a greater total effect on threatened species than the sum of their individual factor effects (Davies et al., 2004; Brook et al., 2008). The implication of synergy model is that by treating extinction as a synergistic process the predictions of risk for most species can approximate reality, and therefore, conservation efforts can be made more effective (Fagan and Holmes, 2006; Malcolm et al., 2006).

However, the synergy model also introduces a big challenge that the policy to mitigate biodiversity loss must accept the need to manage multiple threatening processes simultaneously over longer terms (Brook et al., 2008). This is true if one does not know how the traits interact. We thus hypothesized that, if these traits actually played different roles in the interaction, such as one is active and the other is passive, conservation efforts could focus just on the active process and eliminate the threat of synergistic effect, thereby managing only one threatening factor, instead of multiple ones simultaneously. However, there has been limited understanding so far on how synergistic effects occur and the individual roles of different traits/drivers in the interaction have not been considered. To understand the synergistic effect and test our hypothesis, we examined the 10 year monitoring data of the critically endangered Chinese Crested Tern (*Thalasseus bernsteini*), and combined the data of egg harvest, typhoon and fishing activities, in attempt to detect the factors that led to the endangerment of this species. We also aimed to test whether there is any synergistic effect between the factors or not, and if such effect existed at all, how it happened and the roles of different drivers in the interaction.

2. Methods

2.1. Study species and area

The Chinese Crested Tern has long been a poorly known seabird breeding at remote islands off the southeast coast of China (Collar et al., 2001). The species was considered extinct for 63 years before two small breeding colonies were discovered in the Mazu Archipelago off the Fujian coast and in the Jiushan Archipelago off the Zhejiang coast in 2000 and 2004, respectively (Liang et al., 2000; Chen et al., 2005). The colony in the Jiushan Islands moved to the Wuzhishan Archipelago, about 100 km away, in 2008 (Chen et al., 2005). The total population of Chinese Crested Terns has been estimated at no more than 50 individuals, and the species was and remains categorized as Critically Endangered on the IUCN Red List (Chen et al., 2009; BirdLife International, 2015; IUCN, 2015).

To explore the factors leading to this species' endangerment, we closely monitored the breeding colonies at the Jiushan Archipelago and the Wuzhishan Archipelago in Zhejiang from 2004 to 2013, especially numbers of breeding individuals, breeding success, and the factors limiting colony size and nesting success. In addition, based on the results of previous monitoring, we treated egg harvest and typhoon as two major potential threats, and investigated the status of seabird egg harvest along the coast of Zhejiang Province, and collected data on typhoons impacting the coast of Zhejiang and Fujian Province from 1950 to 2012.

The Zhejiang continental coastline stretches over 2200 km (Fig. 1), from about 27°06′N to 31°11′N, connecting Fujian coast in the south, and facing the East China sea and Taiwan Strait in the east. Of all the islands off the coast of Zhejiang Province, 2886 are uninhabited islands, or 94.3% of the total. Of these, 1383 islands (48%) are situated off the northern coastline of Zhejiang Province, forming the Zhoushan Group. We monitored the breeding colonies of the Chinese Crested Terns in the Jiushan and Wuzhishan archipelago. The Jiushan Archipelago (122°10′E, 29°26′N) is situated 19 km off the coast of Xiangshan County, eastern Zhejiang Province. The Wuzhishan Archipelago (121°50′E, 30°13′N) is located at the mouth of Hangzhou Bay, 7 km offshore of the biggest island of Zhoushan Group.