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Long-term adaptations of a migratory bird (Little Tern *Sternula albifrons*) to quasi-natural flooding disturbance

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ABSTRACT

Population size of migratory birds responds to various types of environmental factors, which affect different stages of bird population. In the current study, we analyzed a long-term avifauna monitoring database to investigate population changes in the migratory bird Little Tern, *Sternula albifrons*, with respect to a quasi-natural disturbance, flooding, induced by a regional characteristic climate pattern, the Korean Monsoon (KM), in the Nakdong River Estuary of South Korea. We scrutinized the time-delayed influence by means of wavelet transformation and year-to-year comparison. Little Tern individuals started to grow in April, and reached its maximum generally in May or June, and an abrupt decrease of individual number was observed after KM occurred. Sequential time-series analysis based on wavelet transformation revealed that the changing pattern of the population size of Little Tern in the estuary was linked to the previous year's flooding (a 9- to 10-month delay), which is regarded as the time difference between Little Tern breeding season and previous KM period. Stronger flooding waters during KM season expelled comparably more individuals of Little Tern from the estuary ($r^2 = 0.595$; $p < 0.05$; $n = 9$), and the more the individuals left, the smaller the bird arrived at the estuary in the next year. Further examination revealed that earlier initiation and longer duration of KM in $year_{t-1}$ negatively affected the newly arriving Little Tern individuals in the current year (i.e., $year_t$; $r^2 = 0.809$ for impact of KM onset, $r^2 = 0.909$ for impact of KM duration; $n = 10$, respectively; $p < 0.005$). The Little Tern population gradually increased when summer flooding was not strong in the previous successive years, from which we concluded that the population of the migratory bird Little Tern tends to adapt to quasi-natural disturbance (flooding) to maintain their population size.

1. Introduction

Population size of migratory birds responds to various types of environmental factors, which affect different stages of bird population. Temperature changes and site quality (including food resources availability) are important in breeding site selection (e.g. Baxter, 1994; Bildstein et al., 1990; Halse and Jaensch, 1989; Maddock and Baxter, 1991; Whitehead and Tschirner, 1990). The population maintenance, partially related to breeding as well, is also affected by foraging and predation (Martin, 1995) and vegetation structure (Deppe and Rotenberry, 2008). In addition, some bird species might consider their prior experiences gained from the area utilized in the previous period (Furness and Monaghan, 1987; Hamer et al., 2001).

Bird populations are believed to adapt to the continuously changing environmental conditions. If the level of changes exceeds the adaptation potential of the population, population of migratory birds may respond negatively to the changes. Some factors such as anthropogenic disturbances often lead to behavioral responses that are detrimental to the species population (Cody, 1985; Martin, 1995; Morse, 1985; Sherry and Holmes, 1985). On the other hand, factors inducing relatively chronic response (compared to 'acute' anthropogenic disturbance) may provide room for adaptation. Climate variation is such an example, which is regarded as quasi-natural environmental change (although human activity is partly involved in the changes). However, despite recent evidence emphasizing potential negative influence of climate on the population dynamics of migratory bird species (see Bairlein and Winkel, 2001; Sillett et al., 2000), little is known about the adaptation

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to climate variation, which are of particular interest in migratory bird population dynamics.

In the eastern Asian region, massive flooding introduced by a typical climate pattern, monsoon, may affect migratory birds (Lee et al., 2010). We assume that the naturally (or quasi-naturally) disturbed habitat due to flooding may still regain bird population annually, unless the area has been almost completely destroyed, because the population has to reproduce. Abandonment of the area would be one choice in completely destroyed conditions; however, it has to be determined whether migratory birds abandon the ancestral habitat due to the natural disturbance. The information will provide an ecological insight into bird adaptation to natural environmental changes compared to their response to anthropogenic disturbances.

Despite the importance of adaptation to natural disturbances (i.e., flooding), unfortunately short-term research data are available on the relationship between flooding and population changes in migratory birds (more or less than 3 years; Burger, 1982; Espie et al., 1998; Shealer et al., 2006). Evidence of population recovery has not been investigated intensively. Some studies have focused on the negative impact of flooding on migratory bird populations, but the pattern of population recovery was not studied over longer periods. In this study, we observed population of Little Tern *Sternula albifrons* for 10 years (Fig. 1) to determine its response to hydrological variations in the Nakdong Estuary, South Korea, which is an important bird habitat in the East Asian–Australasian Flyway (EAAF).

Species selection (i.e., Little Tern as target species) was based not only on the synchronization between hydrological regime and population dynamics, but also on the ecological importance of the species. Little Tern can be found in much of Europe, along the coast and inland parts of Africa, in much of western, central, and the extreme eastern and southern regions of Asia, and in the northern parts of Australasia. Migratory individuals expand their range to include most of the coast of Africa, the Arabian Peninsula, the western coast of India and most of the waters of south-east Asia and Australasia, including New Zealand. One seasonally breeding colony is also present in Hawaii (del Hoyo et al., 1996). National population estimates of the countries in the eastern Asian region are as follows: breeding pairs (BPs) ca. 10,000–100,000 and individuals on migration (IM) ca. 1000–10,000 in China; BP ca. 100–10,000, IM ca. 50–1000, and wintering individuals (WI) ca. 50–1000 in Taiwan; BP ca. 100–10,000 and IM ca. 50–1000 in Korea; and BP 100–10,000 and IM 50–1000 in Japan (Brazil, 2009).

This species is typically found in South Korea from April to August and breeds before concentrated rainfall events (Hong et al., 1998). Although the global Little Tern population is relatively large (ca 190,000–410,000 individuals in the world; BirdLife International, 2013; del Hoyo et al., 1996; Hong et al., 1998), a decline in the population size may occur (IUCN, 2010) due to habitat loss or destruction (e.g. reclamation; Barcena et al., 1984) and human recreational activities (Barcena et al., 1984; del Hoyo et al., 1996). Seasonal hydrologic variability such as artificially induced water-level fluctuations in salt marshes may also threaten their reproductive success (Barcena et al., 1984; Choi et al., 2001; Thyen et al., 2000).

Fig. 1. Little tern *Sternula albifrons* in the Nakdong Estuary (photo taken in May 2007).

To address the effects of flooding on the population dynamics of Little Tern, we proposed three hypotheses: (1) population size of the Little Tern at the study site is affected by the intensity of flooding; (2) flooding has a delayed impact on the species population size dynamics; and (3) the Little Tern population will recover the year following a flooding event. To test the hypotheses, we used 10 years of field observations of Little Tern individuals and river hydrological characteristics (i.e., catchment rainfall and riverine discharge) measured during the same period.

2. Methods

2.1. Study site description

The Nakdong Estuary is located in the southwestern part of Busan Metropolitan City (35°5′N, 128°55′E) in South Korea. This area is the largest breeding habitat and a stopover site (approximately 88.5 km^2 located at the mouth of the Nakdong River; Fig. 2) for migratory birds in South Korea, and lies in the middle of EAAF (Lee, 2007). More than 100 species (ca. 120–200) of migratory birds are observed annually (a total of 150,000–200,000 individuals). They utilize diverse habitats that are formed through the interaction of tides, delta, tidal marshes, and ambient wetlands in the estuarine area. Some internationally endangered species, such as Black-faced Spoonbill *Platalea minor*, Spoon-billed Sandpiper *Eurynorhynchus pygmeus*, and Far Eastern Curlew *Numenius madagascariensis*, have been observed in the Nakdong Estuary, and this area has been recognized as an important habitat for bird species (IUCN, 2010). Furthermore, the Nakdong Estuary is the largest breeding habitat of the Little Tern in South Korea. There is a high diversity in the bird assemblage from November to February. However, due to intense urbanization outside the protected area, migratory bird populations remain at risk.

Because of the importance of the habitat, an ecological modeling approach has been used to discover the pattern of nest site selection in Little Tern (Jeong et al., 2011a), which elucidated the previous site-selection data (Catry et al., 2004; Fasola and Canova, 1992; Goutner, 1990; Snow and Perrins, 1998). Among the various causal factors, dryness of substrate (at a relatively high elevation) is the most important criterion for nest creation (avoiding impact of tidal movement), and flooding inundates the entire nesting habitat with a disastrous effect. Therefore, exploration of the relationship between flooding and the population is important for the preservation of the population of the species.

The Nakdong River, including the main upriver channel of the estuary, extends to ca. 520 km, has a basin area of ca. 23,800 km^2, and is one of the largest river systems in South Korea. The river basin experiences a monsoon climate and summer typhoon events every year (Jeong et al., 2011b), which comprise about 60% of annual mean rainfall (1150 mm; Jeong et al., 2007). During the flooding events, the estuarine area is inundated for 5–10 days, which is a relatively long period for migratory birds to stay in the estuarine area. In an empirical study, Little Tern did not abandon the breeding site and migrate earlier because they have site fidelity and breeding birds attempt to lay eggs and protect offspring even at a high cost for the parents. Excessive reproduction by breeding parents is caused by high mortality and low offspring quality (Romanoff and Romanoff, 1949).

2.2. Data preparation and preliminary investigation

To investigate the Little Tern population, a complete count of individuals was carried out on a monthly basis throughout the entire study period. Bird monitoring was conducted continuously in the