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Morphological response of coastal dunes to a group of three typhoons on Pingtan Island, China

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ABSTRACT

Pingtan Island (Fujian, China) was severely impacted by a group of three typhoons in a sequence of Nepartak, Meranti, and Megi during the summer of 2016. Field investigations were conducted on the island before and after the typhoons using high-precision RTK GPS technology and surveying methods, and we analyzed the morphological responses of three types of coastal dunes (coastal foredunes, climbing dunes, and coastal sand sheets) to the typhoon group. The maximum height decrease among coastal foredunes was 2.89 m after the typhoon group landed; dune volume increased by 0.9%, and the windward side showed a slight height increase, whereas that of the slope crest and leeward slope were slightly lower than the values before the typhoon group landed. The maximum height decrease among climbing dunes was 1.43 m, and dune volume decreased slightly by 0.1%; the height change among climbing dunes differed in magnitude between sites. Among coastal sand sheets, the maximum height increase was 0.75 m, and dune volume increased by 1.5%; the height of frontal coastal sand sheets increased markedly as result of storm surge washover deposits, whereas the heights barely changed at the middle and trailing edges. The above results suggest that the typhoon group imposed significant morphological changes on coastal dunes. However, the features of morphological responses differed between the three types of coastal dunes studied, and also among dunes of the same type based on local characteristics. Furthermore, coastal dunes showed no cumulative effects in their responses to the typhoon group, despite the individual typhoon impacts on coastal dune morphology.

1. Introduction

Coastal storms (typhoons and hurricanes) are widely recognized as the most important drivers of morphological changes observed in beach-dune systems (Tătui et al., 2014). Dune systems not only protect coastal communities from flooding, but also host both environmentally and economically important areas (Hanley et al., 2014). Consequently, analyzing storm effects on coastal dunes is of great relevance for obtaining a comprehensive understanding of the morphological evolution of coastal dunes, which is fundamental to effective coastal planning and management.

Storm impacts on coastal dunes have received widespread attention, especially along with the application of new technologies such as real-time kinematic (RTK) GPS, light detection and ranging (LiDAR) and terrestrial laser scanning (TLS) methods(Łabuz, 2016). Many studies have analyzed hurricane impacts on North American coastal dunes (Wang et al., 2006; Wang and Horwitz, 2007; Houser et al., 2008; Houser and Hamilton, 2009; Priestas and Fagherazzi, 2010; Houser et al., 2015) and the response of European Atlantic coastal dunes to storms (Pye and Blott, 2008; Esteves et al., 2012; Furmańczyk et al., 2012; Gervais et al., 2012; Suanez et al., 2012; Anthony, 2013). Those studies mainly focused on the responses of coastal dunes to a single storm event. A single storm can cause rapid morphological changes on coastal dunes, but, generally, dunes recover slowly following a storm (Wang et al., 2006). The time required for a coastal dune to recover to its pre-storm state is termed as the “recovery period” (Dissanayake et al., 2015a). If a second storm even event undergoes within the recovery period of a previous event (Dissanayake et al., 2015a), coastal dunes can show more significant morphological changes. By definition, due to their cumulative effects, storm groups (successive storm events) should result in more pronounced morphological changes on coastal dunes compared with a single storm (Ferreira, 2005; Vousdoukas et al., 2012). However, the cumulative effect of storms depends on the local geometry of beach-dune systems (Dissanayake et al., 2015a). In fact, the effects of storm groups (successive storm events) should be considered because a storm season often consists of a number of storm events.

The winter of 2013/2014 in northwestern Europe was characterized

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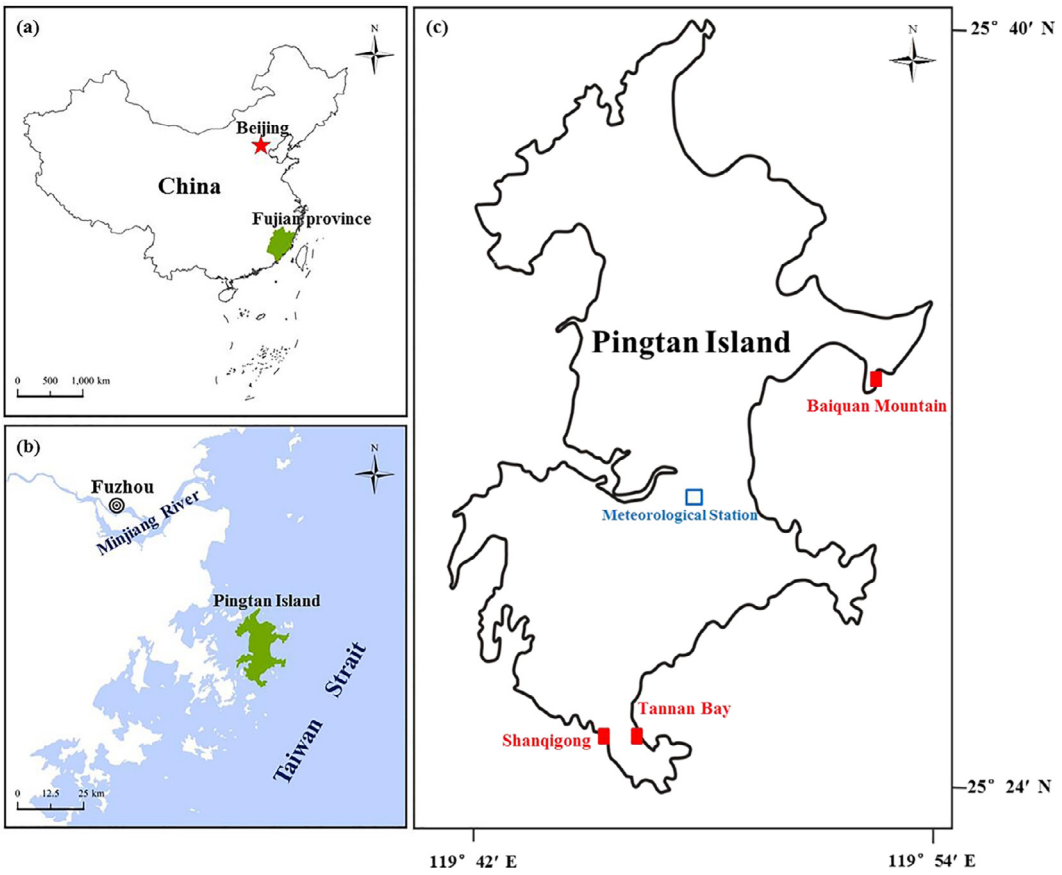

Fig. 1. Location of the three study sites on Pingtan Island, Fujian Province.

by extreme storm clusters that impacted many dune systems. The responses of these systems to those events have been documented in France, Ireland, and the UK (Castelle et al., 2015; Dissanayake et al., 2015a,b,c; Kandrot et al., 2016; Pye and Blott, 2016). Castelle et al. (2015) found that the storms during winter 2013/2014 caused as much as 30 m of dune retreat along the Gironde coasts in southwest France. Similarly, Kandrot et al. (2016) found that they caused major (> 50 m) dune recession on the southwest coast of Ireland. Dissanayake et al. (2015a,b,c) applied the XBeach numerical model to investigate the impacts on beach-dune evolution on the Sefton coast, UK. They concluded that morphological change occurred during each storm in the cluster, and that the initial storm impact can act to enhance or reduce the system resilience to subsequent impacts; however, overall, the cumulative impact is controlled by the magnitude and number of storms. While current studies of the impact of storm group on the morphological features of coastal dunes have made some progress, knowledge of the impact of storm group on different types of coastal dunes is scarce, in particular, there is lack of field observation data.

China's coastal areas are frequently hit by typhoons. According to the China Meteorological Administration (CMA)'s tropical cyclone (TC) database, from 1949 to 2015, 260 typhoons made landfall in China (an average of 3.9 per year), of which 230 (89.0%) occurred on the southeast coast (Yang et al., 2017a). The coastal dune region in southeastern China accounts for more than 70.0% of the total dune area in China (Yang et al., 2017a), and typhoons play a major role in the formation and evolution of coastal dunes in this region. However, to date, there has been limited research on the impacts of typhoons on coastal dunes in China (Dong et al., 2016a,b; Zhang et al., 2016; Yang et al., 2017b), especially with regard to the impacts of typhoon groups on coastal dune morphology.

The present study examines the following topics: (1) morphological changes of different types of coastal dunes in response to typhoon groups; (2) whether dunes show cumulative morphological changes in response to typhoon groups. These findings will be useful for obtaining a comprehensive understand of the morphological evolution of coastal dunes and will also provide a useful reference for sustainable coastal management.

2. Material and methods

2.1. Study area

Pingtan Island is the fifth largest island in China, and it is located off the eastern coast of Fujian Province (25°15′–25°45′ N, 119°32′–120°10′ E) facing the Taiwan Strait (Fig. 1). Coastal dunes on Pingtan Island cover an area of 86.6 km^2. Morphologically, the main types of coastal dunes include embryo dunes, coastal foredunes, transverse dunes, climbing dunes, and coastal sand sheets. The Minjiang River mouth is the main sediment source for the coastal dunes; the dune surfaces consist of medium and fine sands, and *Spinifex littoreus (Burm. f.)* is the dominant plant species. The trailing edge of the dunes contains planted *Casuarina equisetifolia*, which form a protective forest. Pingtan Island has a south subtropical oceanic monsoon climate with an annual mean temperature of 19 °C, precipitation amounting to 1100 mm, and a mean annual wind speed of 4.8 $m{\cdot}s^{-1}$ (prevailing NNE). The island has a semi-diurnal tide with a mean tidal range of approximately 4.0 m and spring tidal range of 6.0–7.0 m.

Data show that Pingtan Island was hit by two to five typhoon groups during 2006–2015 (106 typhoon events in total), and these typhoons mostly occurred in July and September. Typhoon events were often accompanied by wind speeds of up to 17.2 $m{\cdot}s^{-1}$, which likely had an important influence on the evolution of the coastal dunes. Meanwhile, typhoon events also produce heavy precipitation in amounts of at least 10–30 mm and up to more than 100 mm; this will retard sand transport.