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Coastal dune activity and foredune formation on Moreton Island, Australia, 1944–2015

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ABSTRACT

The stabilization process of coastal dunes is complex, involving feedback mechanisms and lag times between changes in climatic conditions, vegetation establishment and dune movement. In this study our aim was to examine changes in dune activity and in the establishment of foredunes on Moreton Island, Australia. We used historical aerial photos, satellite images and Lidar data to quantify changes in bare sand areas, dune movement rates, foredune development and coastline changes between 1944 and 2015. We used wind data (1957–2016), to quantify changes in sand drift potential (DP) and in wind directionality, and wave data (1977–2016) to examine changes in wave height and wave direction. We found that transgressive dunes on Moreton Island have started stabilizing in the early 1970s, after a series of continuous foredunes developed on the eastern coast of Moreton Island, in spite of the increase in DP values. Foredunes have started establishing in the 1960s and 1970s during a period of lower wave height and decreased wind directionality. Once established, these foredunes have diminished sand supply to the transgressive dunes, causing a phase shift in the state of dune activity on the island. Coastal dune activity should therefore be examined over time scales of several decades at least, in order to quantify trends and to understand the underlying and causes to observed processes. Understanding the factors responsible for foredune formation is important for explaining dune stabilization on Moreton Island.

1. Introduction

The beach-dune system represents a highly dynamic biogeomorphic ecosystem where shifts between active and stable states can take place over several years (Hugenholtz and Wolfe, 2005), and where both active and stable dunes can co-exist under the same climatic conditions (Tsoar, 2005). Within this ecosystem, three separate areas may be distinguished on land: (1) the sandy beach which is shaped by the waves, the sediments they deposit and erode, and the wind which can entrain sand grains (Bauer et al., 2009; Defeo et al., 2009); (2) the foredunes, which are formed behind the beach, if the conditions for vegetation growth and trapping of sand by vegetation are met (Hesp, 2002; Dillenburg et al., 2016); (3) the back dunes, which may be composed of a variety of aeolian features, including blowouts, relict foredune plains, beach ridge plains, parabolic dune fields, as well as transgressive dune fields (where active sand dunes migrate inland, burying vegetation on their way; Hesp and Thom, 1990; Hesp, 2013).

Research on dune activity has developed climatic indices (mostly based on rainfall, evaporation and wind regime) to explain the shifts between active and stable states of sand dunes (Fryberger and Dean, 1979; Lancaster, 1988; Tsoar, 2005). Later models and indices recognized the biogeomorphic and hysteretic nature of this ecosystem, and that there are lag times representing the time it takes for the dunes to respond and recover from disturbances to dune vegetation (Hugenholtz and Wolfe, 2005; Thomas et al., 2005; Yizhaq et al., 2007; Hesse et al., 2017). In addition to climatic variability, human activity can also be driving shifts in the state of activity of coastal dunes, with certain human activities favouring dune stabilization (e.g., intentional dune fixation; Avis, 1989; Hilton, 2006), and others leading to dune reactivation (e.g., over grazing; Levin and Ben-Dor, 2004). While the central role of foredunes within the ecosystem of coastal dunes has been noted (Short and Hesp, 1982; Short, 1988; Hesp, 2002), relatively few studies have aimed to quantify recent changes in foredunes' size, the factors driving those changes, and the consequences of changes in the foredunes on the transgressive dunes behind the foredunes (see Curr et al., 2000; Seeliger et al., 2000; Claudino-Sales et al., 2008; Miot da Silva and Hesp, 2010; Keijsers et al., 2015).

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The coastal dunes in south east Queensland represent one of the world's oldest, largest and continuous systems of coastal dunes (Miot da Silva and Shulmeister, 2016). This coastal dune system stretches from the Gold Coast to Fraser Island (over 400 km), has started forming about 750,000 years ago (Tejan-Kella et al., 1990; Lees, 2006; Ward, 2006; Queensland Parks and Wildlife Service, 2007), and is comprised of several major complexes: South and North Stradbroke Islands, Moreton Island, Bribie Island, Cooloola and Fraser Island (Fig. 1). The undisturbed and isolated nature of Moreton Island affords scientific opportunities to study the island's flora, fauna, and natural ecosystems, especially the geomorphological mechanisms involved in dune processes and coastal environs (Queensland Parks and Wildlife Service, 2007). Understanding the significance of these mechanisms may provide important information for the management of coastal zones under future climate variabilities. Understanding coastal dynamics is also pertinent for managing human settlements, and this is particularly true for south east Queensland where Moreton Island is situated. Population growth and coastal urban centers make this region one of Australia's most vulnerable to climate risk. Accordingly the region and has been a focus for climate adaptation research (McAllister et al., 2014) and our study contributes to an integrative understanding of coastal dynamics and potential future scenarios for coastal settlements (e.g., Stewart et al., 2014; Fletcher et al., 2016; Traill et al., 2011).

Most research on the geomorphology of the coastal dunes of south east Queensland was focused on their geology and paleoclimate (e.g., Thompson, 1992; Longmore, 1997; McGowan et al., 2008; Moss et al., 2013; Petherick et al., 2017). The few studies devoted to the recent geomorphology of these dunes, have quantified some of the dynamics of these dunes (Stock, 1990), have modelled the dynamics of these dunes (Yizhaq et al., 2013), explained differing morphologies of the transgressive dunes as a function of spatial variability in wind regime (Levin et al., 2014), attributed changes in dune activity to changes in tropical cyclones (Levin, 2011) and noted the effects of grazing by macropods (Ramsey and Wilson, 1997) and disturbance by human activity to foredunes (Thompson and Schlacher, 2008).

The goal of this paper was therefore to examine dune activity and dune formation on Moreton Island since the 1940s, and to understand the factors driving these processes.

More specifically, we aimed to address the following questions:

1. What were the dynamics of dune activity and foredune formation on Moreton Island?
2. What were the relationships between foredunes and transgressive dunes' activity on Moreton Island?
3. Can the observed changes in dune activity and foredune formation on Moreton Island be explained by climatic factors?

2. Methods

2.1. Study area

Moreton Island is a wedge-shaped sand island located about 40 km east of Brisbane (Queensland, Australia). It forms the eastern part of Moreton bay on the south east coast of Queensland, Aus-

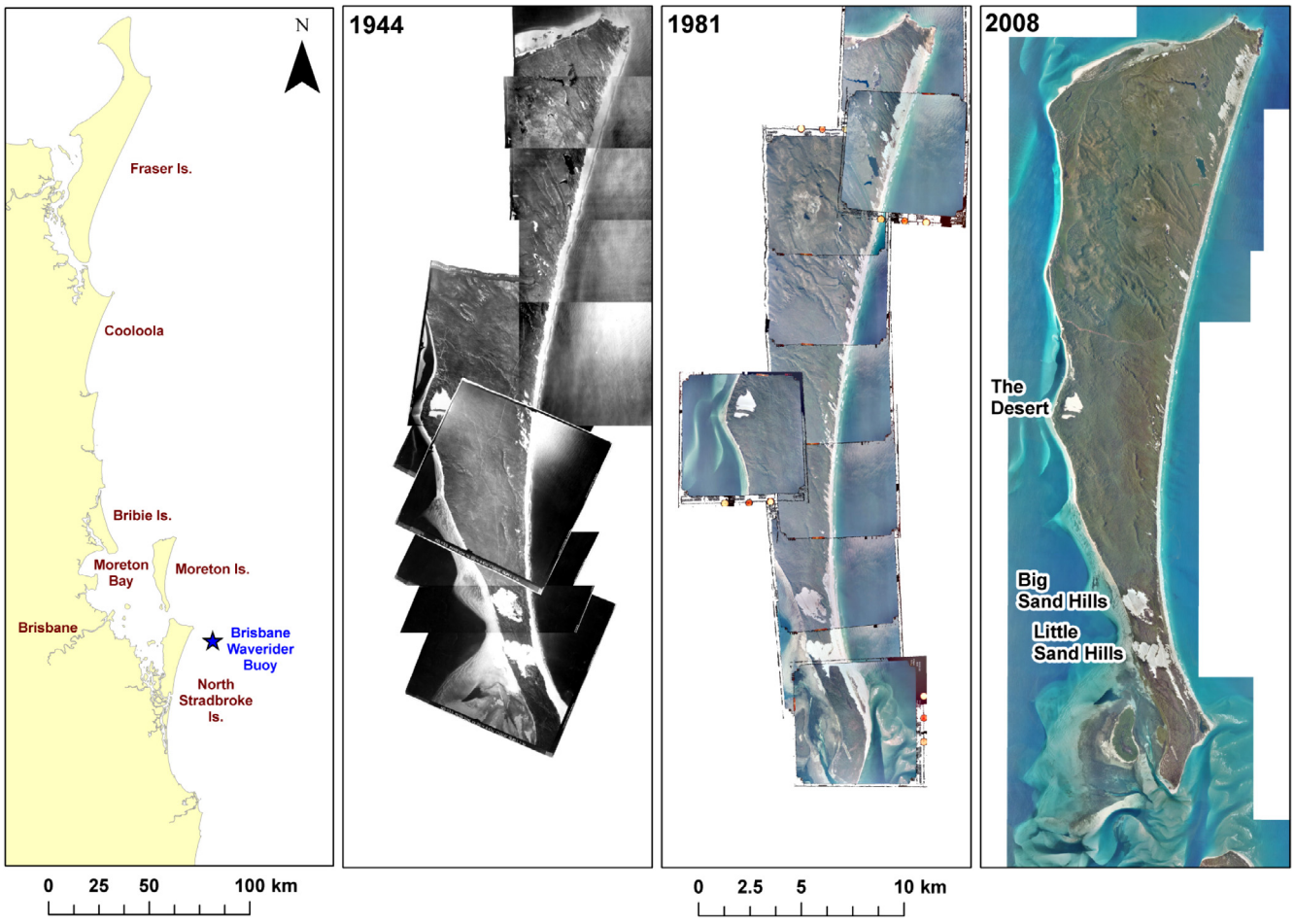

Fig. 1. Location map of Moreton Island (southeast Queensland, Australia), and mosaics showing the active dune areas in 1944, 1981 and 2008.