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Extending the observational record to provide new insights into invasive alien species in a coastal dune environment of New Zealand

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ABSTRACT

Coastal habitats are regarded to be highly vulnerable to the impacts of invasive alien species. These impacts can be particularly visible in areas of national cultural and heritage significance, raising public awareness of a growing global trend and often requiring urgent changes to management practices. New Zealand has a relatively long history of invasive alien species with the introduction of non-native marram grass (*Ammophila arenaria*) for sand stabilisation and erosion control since the mid-nineteenth century. Of national importance, the sand dunes of the Hokianga Harbour are considered to be the spiritual birthplace of Māori culture in New Zealand and have experienced substantial vegetation change over the last century. Here we report a multi-disciplinary study combining palaeoecology with historic and contemporary observations to better characterise the changing distribution and mechanisms of spread of invasive alien species on the Hokianga headland. Our analysis indicates the vegetation established on the headland is primarily linked to late Pleistocene water-retaining, lignite deposits. We find, however, an abrupt increase in the area colonised by invasive alien species during the late twentieth century, most probably linked to reduced sediment supply in the Hokianga Harbour. Urgent management strategies may be required if the present dune headland is to be conserved, particularly against a backdrop of rising sea level which will most probably limit sediment resupply.

1. Introduction

Habitat and biodiversity fragmentation and losses are of increasing global concern, with greater public awareness of these issues leading to renewed attention on ecological management policies (Early et al., 2016; Haddad et al., 2015; Tucker et al., 2018). Land use changes, climatic changes, anthropogenic activities, and invasive alien species and pathogens are increasing threats to ecosystems (Nentwig, 2007), the impacts of which can be far-reaching and unpredictable, due to highly complex ecosystem and species interactions (Conser & Connor, 2009; Dawson, Jackson, House, Prentice, & Mace, 2011; Thuiller et al., 2008). Invasive alien species are typically recognized as non-native species that once introduced (either accidentally or on purpose), can spread beyond any control efforts (Westbrooks, Manning, & Waugh, 2014). Impacts of invasive alien species are now recognized as a major risk for changes in ecosystem composition and the survival of less competitive (threatened) native species (Liu, Sheppard, Kriticos, & Cook, 2011; Pardini, Vickstrom, & Knight, 2015; Vilà et al., 2011); failure to manage key invasive alien species threats can therefore lead to local/national extinction of native species, and the permanent degradation of native communities (Jay & Morad, 2006). A major challenge for determining the threshold for widespread expansion of invasive species is the limited temporal nature of the observational record (Dakos & Hastings, 2013; Thomas, 2016). Assessing data from different time scales improves understanding of invasive species spread by helping to determine changing baselines of vegetation extent, particularly when the date of initial invasive alien species introduction is unknown. This in turn helps to quantify the resilience of ecological systems.

The combination of increasing human activity in the landscape, exposure to aerial and ocean transportation, climate change and increasing sea level make coastal areas particularly susceptible to the introduction and spread of species (Gregory, 2009; Macdiarmid et al., 2012; Muhlfeld et al., 2014; Stachowicz, Terwin, Whitlatch, & Osman, 2002; Walther et al., 2009). Sand dune communities are particularly vulnerable to invasive species due to the widespread nature of the

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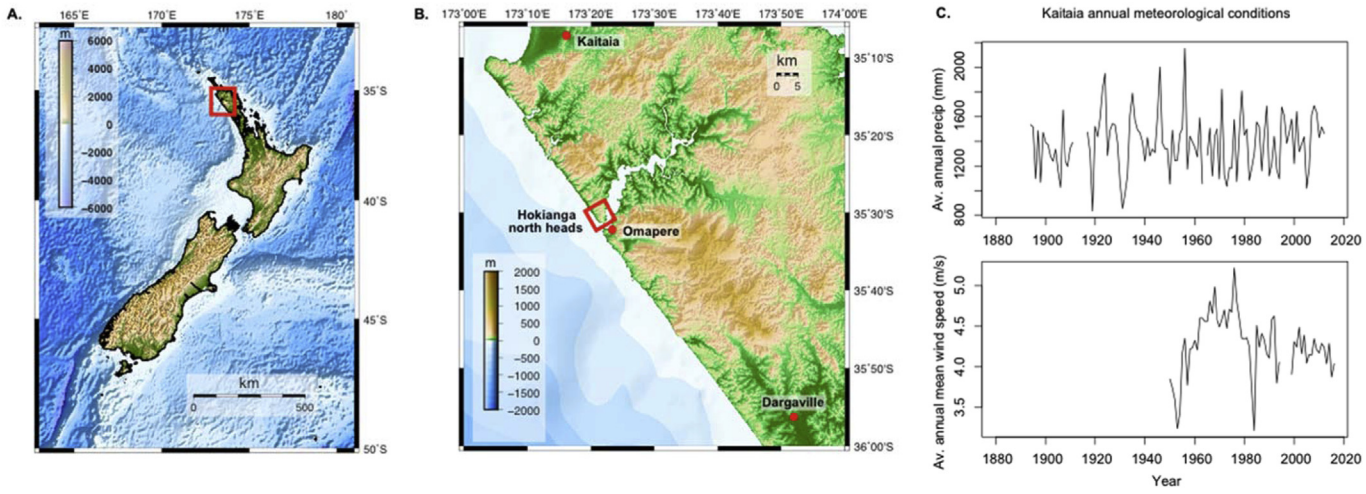

Fig. 1. A. Location of study area within New Zealand (red box); **B.** West Coast of Northland, New Zealand, showing the Hokianga estuary, and the towns of Omapere, Kaitaia and Dargaville (red dots). **C.** Kaitaia average annual rainfall and wind speed (source: New Zealand National Climate Database at http://cliflo.niwa.co.nz/). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

invasive plants and low levels of competition (Baker, 1986; Brown & McLachlan, 2002; Defeo et al., 2009); non-native plants on foredunes, especially invasive grasses, often out-compete indigenous sand binding species and reduce or prevent natural dune form and function. In particular, the expansion of invasive sand-stabilising species is becoming an important ecological problem in coastal dunes in many parts of the world (Barrows, Allen, Brooks, & Allen, 2009; Hilton, 2006; Kutiel, Cohen, Shoshany, & Shub, 2004; Marchante, Kjøller, Struwe, & Freitas, 2008). Dune fixation and stabilisation techniques to convert the land for forestry, farming, and even urban areas have included planting rapid-growth herbaceous and/or woody species; however, over time, these species may exhibit invasive behaviour, causing serious problems for the conservation of the coastal dune ecosystems (French, Mason, & Sullivan, 2011; Seabloom, Ruggiero, Hacker, Mull, & Zarnetske, 2013).

New Zealand is experiencing increasing pressure from invasive alien species, a trend that has been exacerbated since the arrival of Europeans (Goldson et al., 2015; Owens, 2017). The ecology and distribution of many invasive species is relatively unknown with important management implications (Giera & Bell, 2009; Goldson, 2011; Goldson et al., 2015; Peltzer, 2013). An excellent example in this regard is marram grass (*Ammophila arenaria)* which was originally planted throughout New Zealand in the mid 19th century for sand stabilisation purposes and erosion control, primarily to prepare dunes for afforestation with North American conifers, particularly *Pinus radiata* (Hilton, 2006). Several studies from coastal areas of New Zealand have detailed the invasive behaviour of marram grass at the expense of native species such as pingao (*Ficinia spiralis*) and spinifex (*Spinifex hirsutus*) (Dixon, Hilton, & Bannister, 2004; Hilton, 2006; Hilton, Duncan, & Jul, 2005). However, marram grass was not the only non-native plant that was planted on coastal dune areas for back dune stabilisation to support forestry; yellow tree lupin (*Lupinus arboreus*) was also used, in part due to its legume properties of nitrogen fixation (McQueen, 1993). The typical plant community found on coastal dunes of Northland, NZ, include a selection of both native and non-native species. The native species include spinifex, the main dune forming indigenous plant in New Zealand, and pingao, an indigenous sand-binder. In addition to marram grass and lupin, other common invasive alien species in coastal dune communities include pampas grass *(Cortaderia selloana),* and kikuyu (*Pennisetum clandestinum*).

Whilst the distribution of non-native species in New Zealand are relatively well documented (Atkinson & Cameron, 1993; https://www.landcareresearch.co.nz/resources/identification/plants/weeds-key), few long-term (centennial length) records are available, limiting our understanding of the driver(s) of change through the twentieth century. Of particular concern is the time window available to contain the threat of expansion. Once a species has become well established and relatively widespread, eradication or containment is rarely feasible or economic (Westbrooks et al., 2014). Decisions with regards eradication (the permanent removal of all individuals of a species with little or no risk of reinvasion) or containment (ongoing control to prevent spread beyond a defined distribution, including preventing invasion) depends on the timeframes of available action (Simberloff, 2003). Fortunately, for the purposes of monitoring past vegetation changes and impacts, sand dunes provide excellent natural archives on centennial and longer timescales as they are able to preserve macro and microfossils, including tree stumps (Grimm, 2001; Hesse, Telfer, & Farebrother, 2017; Telfer, Thomas, & Breman, 2012).

The Hokianga is located on the west coast of Northland (North Island, New Zealand) and is a coastal area with an extensive dune system on its northern headlands that is also under threat from invasive alien species (Hilton, 2006). The importance of preserving the dunes of the Hokianga Harbour encompasses three main aspects: cultural/historical, tourism/local economy related, and conservation. The Hokianga (full name “Hokianga-nui-o-Kupe”, meaning “the final departing place of Kupe”) is considered to be the spiritual birthplace of Māori culture in New Zealand, and refers to the place where Kupe, the first Māori to discover New Zealand, embarked on his return to Hawaiki after exploring the northern New Zealand coast. The area has particular cultural significance to Māori iwi, with approximately 40 archaeological sites recorded including shell middens, terraces and pits found on the northern headlands, primarily focused around the open and harbour coastlines and related flanks (Northland Regional Landscape Assessment, 2014). As a result, one of the areas local iwi recognise as a priority for preservation is the Kahakaharoa, an area on the northern headlands of the Hokianga Harbour, as the site Kupe's final departure (Fig. 1). In terms of wider local and economic interest, the sand dunes of the Hokianga heads are a central component of the identity of the outer Hokianga and one of the chief scenic attractions of the tourist resorts at Omapere and neighbouring Opononi; with the view from the southern shore of the harbour considered in itself worthy of preservation (Hicks, 1975). As part of a wider ecological area, the sand dunes are noted as a representative site for six ecological units, and location of four species of threatened flora and five species of threatened fauna (Northland Regional Landscape Assessment, 2014). In spite of the significance of the Hokianga, there has been no short- or long-term vegetation-monitoring programme in place. Recent anecdotal evidence