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Incipient Foredunes Developed from Marine-dispersed Rhizome of *Ammophilia arenaria*

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ABSTRACT

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Incipient foredunes may develop by the extension of rhizomes and stolons from established foredunes or the germination of seed from terrestrial or marine provenance (Hesp, 1989). This paper demonstrates that incipient foredunes may also establish from marine-dispersed rhizome of *Ammophila arenaria* (L.) during storm surge conditions.

Two case studies from southern New Zealand are examined. In the Doughboy Bay case rhizome was transported by a combination of fluvial and coastal processes during a storm in the winter of 2007. This rhizome produced a zone of vigorous *A.arenaria* growth, remarkably continuous within the bay, between the toe of the existing foredune and the line of spring high tides. The development of an incipient foredune at Allan's Beach – Hooper's Inlet was monitored following the deposition of large mats of *A. arenaria* rhizome in June 2007. By November 2010 the foredune had attained an elevation of 1.5m and width of 20m. Flowering of *A. arenaria* occurred in February 2010, mostly along the seaward edge of the dune. *A. arenaria* produced horizontal rhizomes during the spring of 2010 and these had colonised a width of the back beach by November 2010.

We propose a that a new type of incipient foredune be added to Hesp's (1989) classification (Type 3) to represent these processes. Accretion is likely to occur more rapidly following rhizome stranding. Unlike seeds, rhizome is capable of producing shoots and initiating dune development in any season. Moreover, pioneer dune plants developed from rhizome probably grow faster and are more robust compared with seeds.

ADDITIONAL INDEX WORDS: *barrier, storm surge, foredune classification*

INTRODUCTION

Incipient foredunes develop as sand is trapped by pioneer plant species between the line of high tide and the established foredune. Hesp (1984, 1989) identifies four modes of incipient dune formation – resulting from sand deposition within and in the lee of discrete plants (1a) and seedlings (1b); and sand deposition within laterally extensive colonies or zones of seedlings (2a) or rhizome-stolon colonisation from the established foredune (2b). These seedlings may develop from marine-dispersed seed or local terrestrial sources.

In this study we demonstrate that incipient foredunes may also form from marine-dispersed rhizome of pioneer plant species, including *Ammophila arenaria* (marram grass) and *Thinopyrum junceiforme* (sea wheat-grass). These species are capable of long-distance marine dispersal and establishment (Konlechner & Hilton, 2009). This process has been recognised by biologists and ecologists (e.g. Wallén, 1980; Karjnyk and Maun, 1980), but has barely been examined from a geomorphic perspective. Heyligers (1985) noted the formation of terraces and ridges from marine-deposited rhizome in southeast Australia. Hilton *et al.* (2006) described the development of an incipient foredune as a result of rapid sea wheat-grass colonisation from rhizome along the Younghusband Peninsula in South Australia.

The current paper is based on observations of incipient foredune development in southern New Zealand, where *A.arenaria* grass has displaced the indigenous pioneer species at many locations or where this process in ongoing. *A.arenaria* has established major foredunes in many embayments, which are commonly scarped in winter during storm events. Such events may disperse large quantities of rhizome, which may be deposited as either individual fragments, or massive tangles of rhizome. Interest in this topic arose from observations of *A.arenaria* plants developed from nodes on stranded rhizome. Invariably this rhizome was located just above the usual reach of spring high tides, sometimes many kilometres from the nearest *A.arenaria* population. Here we document the process of incipient dune formation from stranded rhizome of *A.arenaria*. Secondly, we consider the geomorphic implications of this process in relation to dune morphology and the development of foredunes. We compare the development and morphology of incipient foredunes from stranded rhizome with those described by Hesp (1989).

METHODS AND STUDY SITES

We observed large volumes of the rhizome of *A.arenaria* stranded after significant storms and foredune scarping; at

Hooper's Inlet, adjacent to Alan's Beach in June 2007, and at Doughboy Bay (Stewart Island – Rakiura National Park) in September 2008 (Figure 1). Alan's Beach is located on the Otago Peninsula on the southeast coast of the South Island at S. Lat. 45 degrees. Doughboy Bay is a funnel-shaped, swell-aligned, embayment on the west coast of Stewart Island at S. Lat. 47 degrees. Storm surge in excess of 0.5 and 1.0m occur at Alan's Beach and at Doughboy Bay, respectively, so there is potential for *A.arenaria* rhizome to be deposited well above the level of spring high tides. Tidal range is 1.5 to 2.0m at these sites.

The Doughboy Bay case illustrates the potential for *A.arenaria* to be distributed evenly and widely within an embayment during storm events, and so initiate uniform incipient foredune development. Doughboy contains prograded foredune barriers ('northern' and 'southern') and a third barrier, with transgressive dune forms, the 'central dunes'. Recent progradation of the southern dunes has been attributed to the self-introduction of *A.arenaria* (Hilton, 2009). The Department of Conservation has been engaged in a program of *A.arenaria* eradication at this site since 1999 (Hilton and Konlechner, 2010) and the established foredunes contained no *A.arenaria* when the rhizome was stranded. We are confident that the observed growth arose solely from stranded rhizome. The provenance of the rhizome was almost certainly a patch of *A.arenaria* that lay above an active scarp, close to the mouth of the Doughboy River. During storm events the base of this scarp is vulnerable to wave-cut erosion. We presume a volume of rhizome collapsed into the Doughboy River during the winter months of 2007 – the site is isolated and visits to the site are annual. The rhizome was carried into the bay by the river, to be then washed back onshore by wave action. We observed the stranded rhizome and mapped the growing tillers in October 2008, using GPS. The tillers were subsequently sprayed with herbicide by the Department of Conservation.

The Hooper's Inlet site was more accessible and offered the opportunity of monitoring the development of the incipient foredune from the time of stranding. The site is within an inlet at the rear of a complex barrier. The open coast beach is occasionally scarped during winter storms and quantities of rhizome are deposited on high sections of the beach, at the distal ends of the barrier and at the study site - an embayment within the inlet. This embayment contains a sequence of three foredunes which have formed since the early 1980s. We observed and recorded the development of an incipient foredune within this embayment following rhizome deposition in June 2007. A section of the foredune and stranded rhizome was pegged and surveyed using a total station between 2007 and 2010 (Figure 2). Observations of plant growth were made during surveys, including tiller density, flowering and the development of horizontal rhizome. Individual tillers or clumps of tillers were surveyed in October 2007, four months after the rhizome stranded, and again in February and June 2008. *A. arenaria* was widespread and dense in subsequent surveys, so it was not possible to map individual tillers.

RESULTS

Doughboy Bay – Rhizome Dispersal

The storm (or storms) of the winter of 2007 resulted in rhizome being dispersed and stranded in a semi-continuous line above the usual level of spring high tides around the margins of Doughboy Bay (Figure 3). Rhizome was deposited in a narrow zone, 5-10m wide (Figure 4). In general, all back-beach habitat above the usual reach of spring high tides received rhizome, although not all rhizome produced growth. Rhizome was not deposited (or was subsequently redistributed) across the broad spit of sand between the northern and southern dunes, adjacent to the rhizome source. This surface is swept by waves during storm surge conditions.

Alan's Beach – Incipient Foredune Development

Large quantities of *A. arenaria* rhizome were also deposited at the Alan's Beach site in June 2007. Tangled clumps of rhizome were deposited across the back-beach, between the toe of the established foredune and the usual level of spring high tides, within a zone approximately 20m wide. Shoots emerged from nodes on the rhizome by October 2007, within three months of the stranding event. A broad, convex, dune had developed by November 2008 as the number and density of tillers increased and growing *A. arenaria* started to trap sand. This process continued during 2009 and up to the most recent survey in November 2010.

Development of the incipient foredune is recorded by photographs and as terrain models (Figures 5 and 6). The location

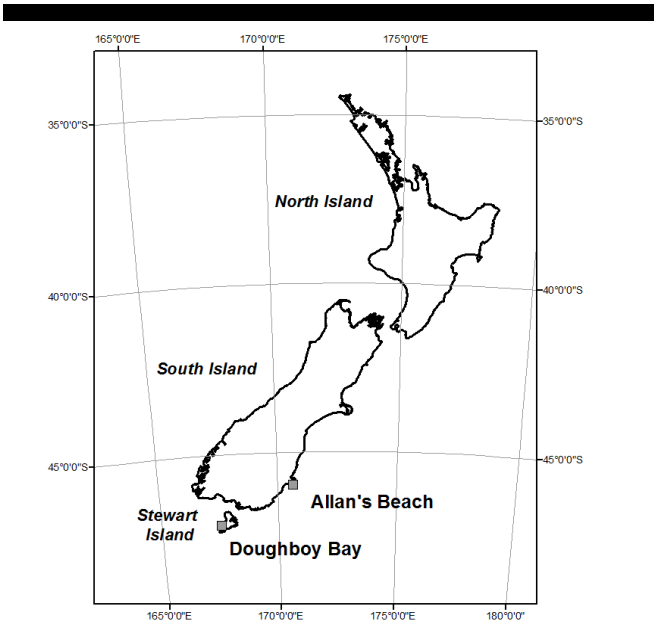

Figure 1. Location of study sites.

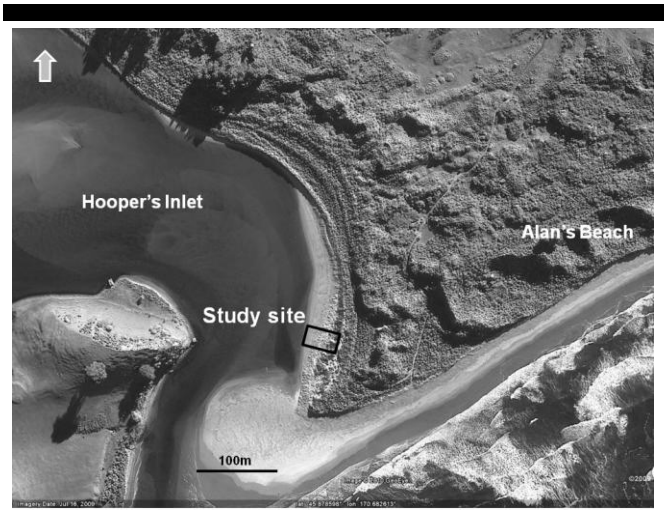

Figure 2. Location of study site; Hooper's Inlet – Alan's Beach, Otago Peninsula.

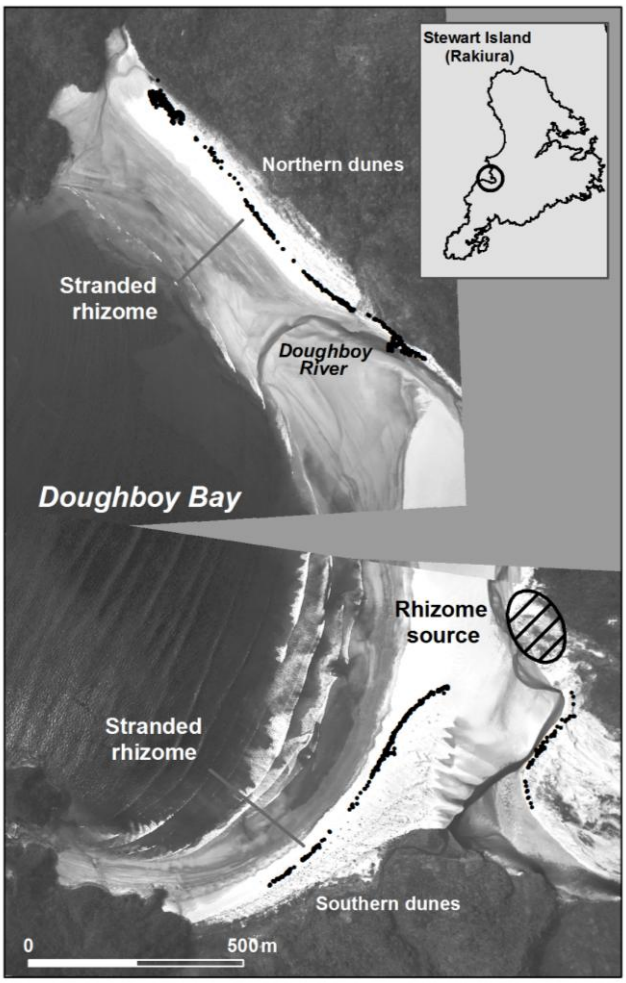

Figure 3. Location of *A.arenaria* developed from stranded rhizome, Doughboy Bay, Stewart Island (September, 2008).

Figure 4. An oblique view of tillers developed from stranded rhizome, northern dunes, Doughboy Bay, approximately 12 months after the stranding event (October 2008).

of the stranded rhizome, as surveyed in October 2007, is indicated in Figure 5a. At this time the back-beach was comprised of semi-buried mats of rhizome and was consequently hummocky. The following surveys, in February and June 2008, showed that the surface of the incipient foredune remained irregular, despite general accretion of 0.4 – 0.5m. The margins of the foredune were eroded prior to June 2008, probably during a spring high tide and minor storm. The foredune was not surveyed during 2009. By 2010 the foredune had accreted substantially, attaining elevations 1.5m above the pre-stranding surface. The foredune is continuous alongshore with a concave stoss face and relatively steep lee slope. A distinct swale has formed between the established foredune and the crest of the incipient foredune.

The rate of accretion was calculated as the change in volume of the incipient foredune between successive surveys. Unfortunately these surveys could not be repeated in 2009, however, some general trends are suggested. The rate of growth of the foredune was initially slow, as *A.arenaria* established tillers from the stranded rhizome, but then accelerated during 2008 and 2009. Rates of accretion slowed during 2010, possibly because of changes in sand supply. The main sand supply is thought to be the spit at the mouth of the inlet. Sedimentation may also have declined because of the increasing tiller density and height and increased slope of the stoss face of the foredune. This foredune is not developing in a high sediment supply environment.

The terrain models indicate the development of the incipient foredune as tiller density increased. The first tillers developed in two zones, at the limit of rhizome deposition (about 12m from datum) and between 20 and 25m from datum. This pattern may be related to environmental conditions, or simply represent the pattern of rhizome deposition. Subsequent surveys, during 2008, show a more even pattern of tillers (Figure 5b-e). The cover of *A. arenaria* during 2009 and 2010 became relatively uniform and only the seaward edge of the tillers was mapped.

The *A.arenaria* flowered for the first time in February 2010. Most inflorescences were located on the seaward edge of the incipient foredune. By November 2010 the *A.arenaria* along the seaward edge had also extended horizontal rhizomes, approximately 1-2m from the original population (Figure 5e). *A. arenaria* grass is now attempting to colonise the narrow back-beach environment between the developing incipient foredune and the line of spring high tides, which now is only a few metres wide.

DISCUSSION

The Development of Prograded Foredune Barriers

Incipient foredunes can form rapidly as a result of marine-dispersed stranded *A.arenaria* rhizome. The northern and southern barriers in Doughboy Bay comprise a sequence of three to four ridges which have formed since the early 1950s and the arrival of *A.arenaria*. The incipient foredune at the Alan's Beach site is the most recent in a series of four ridges. The incipient foredune described is one of sequence of four, which appear to have formed over a 40 year period. The first foredune ridge is present in a 1982 aerial photograph. Continued progradation of the barrier into Hooper's Inlet will probably be constrained by the proximity of the main tidal channel.

The erosion, dispersal and stranding of *A.arenaria* rhizome may be the primary mechanism of incipient foredune development in both the cases examined. The antecedent

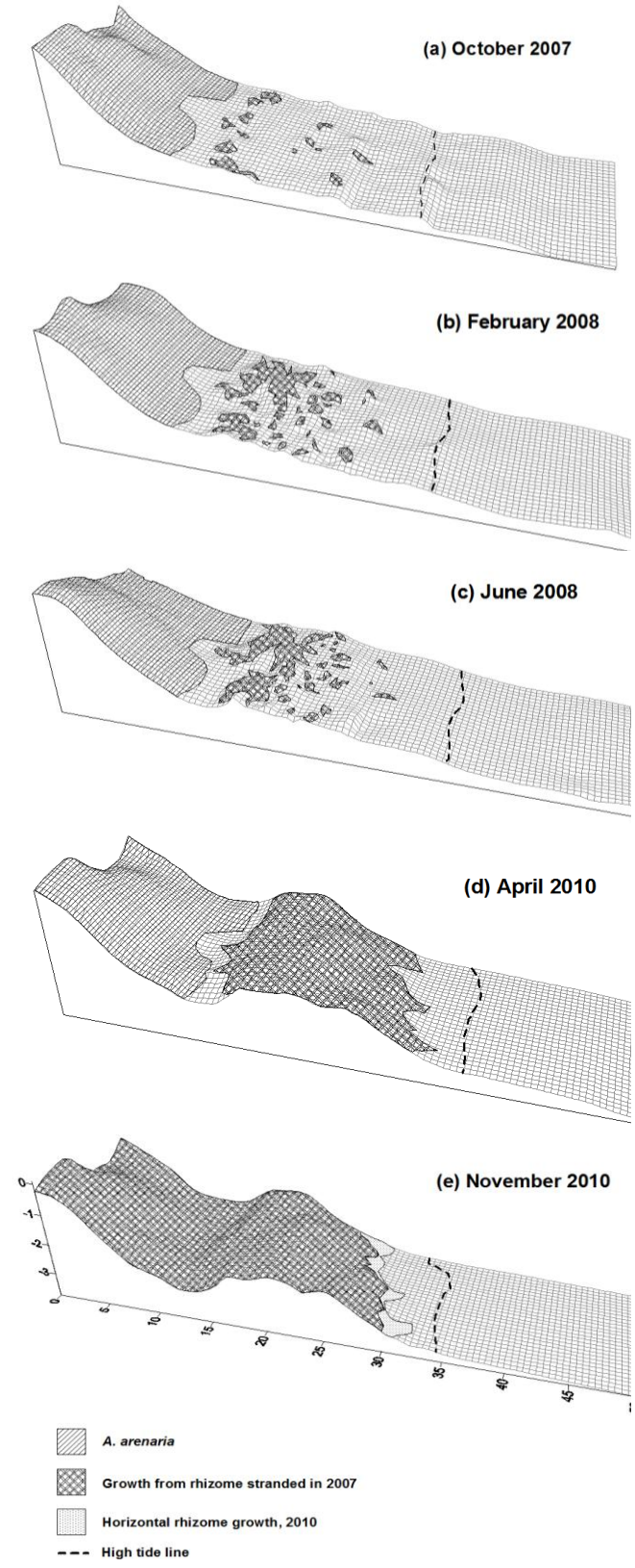

Figure 5. Terrain models of a section of the developing incipient foredune, October 2007 to November 2010.

Figure 6. Development of the Alan's Beach incipient foredune: (a) June 2007 – *A.arenaria* rhizome stranding; (b) November 2008 - development of a low incipient foredune; and (c) November 2010 – the current foredune.

conditions include a width of back-beach above the usual reach of spring high tides and typical storm surge; a source of *A. arenaria* rhizome; and the conditions that are likely to occur during a severe storm event, including an energetic nearshore circulation and high storm surge. In the Doughboy case the near-uniform deposition of rhizome around bay may have been helped by the transport of the rhizome into the bay by the Doughboy River. The accretion and survival of any incipient foredune will depend on the continued availability of sand during a period of reduced or nil storm surge/wave activity. We observed the establishment and erosion of

incipient foredunes formed in association with stranded rhizome along the open coast of Alan's Beach.

Comparison with incipient foredunes associated with plants derived from terrestrial or marine-deposited seed

We propose that a new type of incipient foredune be added to Hesp's (1989) classification – Type 3. The origin of this form is different to the other types but, more importantly, accretion is likely to occur more rapidly and at any time of the year. Unlike seeds, rhizome is capable of producing shoots and initiating dune development in any season. Moreover, pioneer dune plants developed from rhizome tend to grow faster and be more robust compared with seeds (Maun, 2009).

The process of incipient foredune formation is probably accelerated when large mats of rhizome strand, although short lengths of rhizome, containing just one or two nodes, may produce shoots if they nodes receive some sand cover. Large mats of rhizome are likely to establish shadow dunes and encourage sand deposition, as well as providing a suitable microclimate for shoot formation.

CONCLUSIONS

Incipient foredunes develop from the rhizome of pioneer dune species dispersed and deposited by marine processes. To date this process has received relatively little attention from geomorphologists, however, the case studies illustrate this process has the potential to form uniform Type 1 (Hesp, 2002) foredunes over relatively short periods. On prograding coasts dominated by *A.arenaria* in southern New Zealand this process may account for the recent formation of prograded foredune barriers.

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