

***Ammophila arenaria* (marram grass) persistence through seedling recruitment**

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Summary This paper considers the potential for an invasive dune plant, marram grass (*Ammophila arenaria* (L.) Link), to form a seed bank. Understanding the seed bank of an invasive plant is critical when attempting eradication. Removal of the current population can be achieved relatively easily. Subsequent control of regeneration from the seed bank, however, requires a sustained commitment of time and resources. The persistence of the seed bank, in particular, determines the duration of the control operation. The seed bank of marram grass was evaluated at Doughboy Bay, Stewart Island, in southern New Zealand. Marram grass seeds can persist for at least 9 years. Activation of the seed bank is related to the morphodynamics of the system; erosion exposes seed that can then germinate. Any agency attempting to control marram grass must commit to at least a decade of control to ensure success.

Keywords Seed bank, weed eradication, marram grass.

INTRODUCTION

Dune systems are one of New Zealand's most threatened ecosystems. Since the early 1990s the area of active dune systems in New Zealand has declined by about 70% (Hilton 2006). The loss of New Zealand's dune systems is primarily due to the deliberate introduction and subsequent dispersal of marram grass. Invasion by marram grass results in a rapid conversion of the geomorphology and ecology of the system – marram grass stabilises active dunes, accelerates vegetation succession and displaces indigenous dune flora and fauna (Cooper 1958, Buell *et al.* 1995, Hertling and Lubke 1999, Hilton *et al.* 2005). The impact of marram grass on the New Zealand coast is such that currently only 60 dune systems retain high natural values. The remainder are dominated by marram grass.

Control of marram grass has now commenced in some dune systems. The Department of Conservation (DoC) has been systematically spraying marram grass in Stewart Island and Fiordland since 1999. Marram grass has been difficult to eradicate. Regeneration from rhizome is common following spray application. Annual application of herbicide for at least 5 years is

required to ensure mortality of deeply rooted fore-dune plants. Backdune marram may succumb more rapidly. Furthermore, reinvasion by marine dispersal of rhizome fragments can occur over long distances (Konlechner and Hilton 2009). To date, there has been no consideration of the potential for marram grass to form a persistent seed bank in relation to control operations. Current literature indicates that marram grass does not form a persistent seed bank. Seeds are reported to last less than 1 year in the soil (Knevel 2001). Furthermore, seedling mortality is high and establishment from seed is thought to occur only infrequently (Huiskes 1979). These conclusions are not consistent with observations of marram regeneration in southern New Zealand – further consideration of the persistence of seed is warranted.

MATERIALS AND METHODS

Study site The seed bank of marram grass was examined at Doughboy Bay, Stewart Island (Figure 1). Until recently the study site consisted of a sequence of foredunes formed in association with marram grass invasion since the early 1950s (Hilton *et al.* 2005). Eradication of marram grass commenced in February 1999 with the aerial application of a systemic, grass-selective herbicide (Gallant-NF™, active ingredient haloxyfop-R methyl ester). This herbicide has been applied annually since 1999, using a range of methods. The density of marram grass has declined from approximately 70% to almost 0%. For further details of the eradication program and associated geomorphic impacts see Hilton *et al.* (2005) and Hilton *et al.* (2009).

This site provides a unique opportunity to examine the seed bank of marram grass. Flowering ceased within the study site following the first application of herbicide. Small pockets of marram grass continued to flower 300 m from the study site, but the related seed is unlikely to have dispersed as far as the study site. Flowering has occurred downwind of the study site and across the Doughboy River, a permanent water course. Regeneration from seed in the study area must be from seeds produced in the last flowering event (spring/summer 1998–1999) or from earlier events.

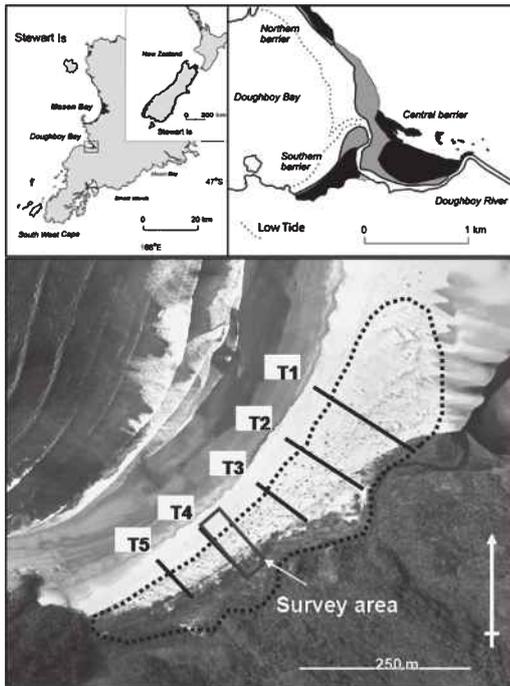


Figure 1. Location of the survey area and shore-normal total station transects on the southern barrier, Doughboy Bay, Stewart Island. The extent of the supra-tidal dune system in February 1999 is indicated (dotted line).

Method The seed bank was examined by recording and mapping seedling emergence in a 0.21 ha area over the period 2005 to the present.

All seedlings were counted and mapped annually using a Leica total station. The Leica allowed the location of seedlings to be mapped to within 1 cm accuracy. The timing of mapping varied from year to year but always occurred in winter after the likely germination period. The surveys were conducted every 13 months on average. Some seedling mortality between germination and survey should be anticipated, hence we cannot report the absolute number of seedlings that emerged each year. All seedlings were sprayed by the Department of Conservation during the summer months and/ or physically removed by the authors.

We anticipated that removal of the marram grass canopy would result in increased shear stress and sedimentation (sand erosion, transportation and deposition) across the barrier. The prevailing winds are onshore westerlies, so we anticipated sedimentation would occur more or less normal to the barrier, which has a northeast-southwest orientation. A series of shore-normal transects was, therefore, established

and surveyed annually using the total station. Morphological change is represented as profiles along these transects.

RESULTS

Marram grass seed continued to germinate in the study site 9 years after the last flowering event. No seedlings were observed between 1999 and 2005, 5 years after eradication commenced. Seedlings have been recorded each year subsequently. Seedling density in the survey site has not been high, ranging from a maximum of 0.12 to a minimum of 0.02 seedlings m^{-2} in 2006 over the area occupied by mature marram grass at the commencement of eradication (Figure 2).

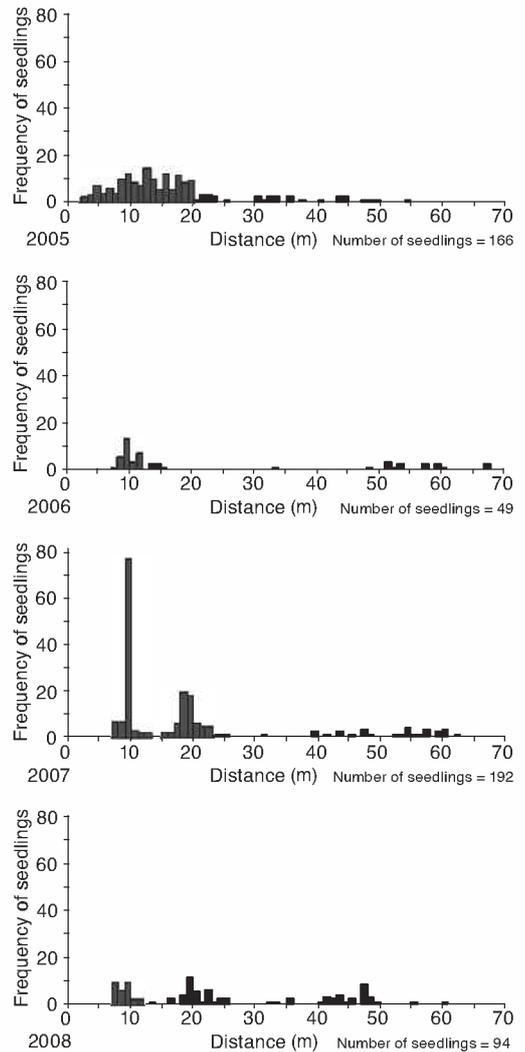


Figure 2. Annual distribution of seedlings with distance from mean high water (0 = mean high water).

Seedling counts do not capture any mortality between germination and mapping. Nonetheless seed recruitment appears to follow a biennial cycle with a flush of seedlings produced every second year. Seedling numbers reduced by 30–50% in the following years.

Seedling regeneration from the seed bank is related to the patterns of erosion and accretion in the study site. Over the duration of the study the barrier has retreated landward by approximately 10 m (Figure 3). Two zones are recognised. Seaward of 25 m, as measured from the mean high tide line, the barrier has lowered. Landwards of 25 m, the barrier has accreted. This pattern has been consistent from year to year. This pattern was, in general, uniform alongshore. The majority of seedlings were recorded within the erosion zone between 3–25 m from the mean high tide (Figure 2). There was a scatter of seedlings across the remainder of the barrier. In general, most seedlings were located across the upper stoss face of the foredune, just below the crest (Figure 4).

DISCUSSION

Marram grass seeds are able to persist for much longer in the soil than previously suggested by Knevel (2001). Seedlings are still establishing in the study area, 9 years after the removal of the flowering population, with no apparent decline in seedling numbers. Over the entire study site seedling density was not high, but even the survival of a few marram grass seedlings to maturity requires expensive and ongoing treatment. Once established, marram grass can spread through the rapid production of horizontal rhizomes (Huiskes

1979). This vegetative reproduction allows marram grass to rapidly colonise new habitats. Marram grass at Mason Bay, 15 km north of the study site, invaded 16.5 ha within 20 years of its initial introduction to the dune system (Hilton *et al.* 2005). The rate of spread is exponential. Marram grass can produce seed after 2 years (Huiskes 1979). Any seed production would add to the seed bank increasing the time to eradicate marram grass from a dune system by at least a decade. Control agencies must be prepared to commit to control for at least a decade to ensure eradication, possibly longer. This will involve at least biennial visits to the site to ensure plants are sprayed before they flower.



Figure 4. The stoss face of the foredune after marram eradication. The arrow indicates where most seedlings have been observed. The shadow dunes have formed under planted *Desmoschoenus spiralis* (pikao).

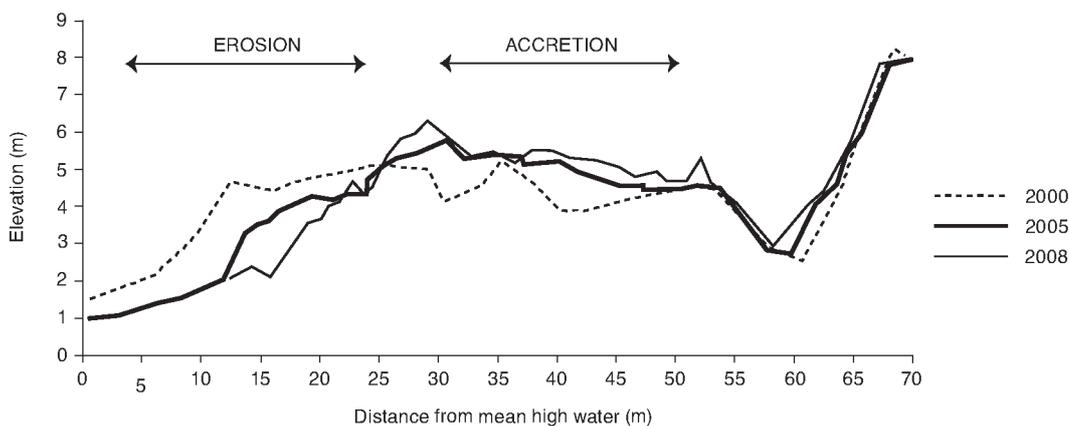


Figure 3. A comparison of the first (2000), 2005 and most recent (2008) profiles surveyed across T4. Erosion is occurring seawards of 25 m. Landwards of 25 m the barrier is accreting.

Activation of the seed bank is related to the morphodynamics of the dune system. For the most, seedlings only established where the trend was erosional. Where sand was accumulating the seed bank is not disturbed. Erosion, however, removes sand, concentrates the seed and exposes seed to fluctuating light and temperature, which triggers germination. The formation of the seed bank may itself be related to the morphodynamics of the dune system, as each foredune formed. Marram grass traps sand, resulting in vertical accretion of the foredune. This process facilitates rapid burial of the seed and development of a seed bank. Without burial germination would be high and little seed would enter the seed bank.

Maintaining substrate stability would prevent regeneration from the seed bank. This would be inappropriate, however, when attempting to restore dune systems on exposed coasts in New Zealand. Substrate instability is a quintessential quality of the ecology of southern New Zealand dune systems. Southern dune systems exhibit a high level of dynamism, a sparse vegetation cover and high levels of habitat heterogeneity. The purpose of marram grass regeneration is to provide for the restoration of these qualities. The only way to manage marram grass regeneration from seed bank is commitment to a long term control strategy and systematic eradication of seedlings as they emerge.

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