Gaining New Ground: *Thinopyrum junceiforme*, A Model of Success Along the South Eastern Australian Coastline.

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Abstract

Thinopyrum junceiforme or Sea wheat-grass is a rhizomatous perennial grass native to Europe. In Australia, this invasive alien plant has colonised the coast in three south eastern states: Tasmania, Victoria, and South Australia. The very first specimen of *T. junceiforme* was collected from Victoria nearly 90 years ago, and was probably initially accidentally introduced via ballast. Sand stabilisation trials may have assisted in the spread of the plant locally, however, drift card and bottle studies indicate a number of potential pathways for the dispersal of the plant between the south eastern Australian states. *T. junceiforme* does not have the status of some introduced plants such as Marram grass, however, current awareness of the plant is greater than originally thought and it is predominantly perceived in a negative light due to its potential impacts on shorebirds, native vegetation and coastal geomorphology and beach-dune processes.

Thinopyrum junceiforme demonstrates the ability to disperse both by seed and by rhizome fragments. Its ability to delay germination while floating and the capacity of seeds to germinate well subsequent to prolonged immersion is interpreted as a significant advantage to *T. junceiforme's* survival and spread. The presence of multi-noded rhizome fragments and seasonal conditions may influence the regenerative capacity of rhizomes, but ultimately catastrophic erosional events may affect its ability to establish on some parts of the coast. Beach replenishment activities have replicated the fragmentation process that facilitates dispersal and overcomes bud dormancy under natural conditions.

Thinopyrum junceiforme has become established along much of the length of the Younghusband Peninsula. The rapidity of its colonisation at approximately 18.571 ha/yr far exceeds the rate of Marram grass colonisation (1.875 ha/yr) on Stewart Island, New Zealand. By virtue of its presence this alien coastal grass has altered the vegetation composition of the peninsula, and the native grass *Spinifex sericeus* is no longer the primary coloniser along this part of the coast. *T. junceiforme* has also modified the dune environment by colonising pre-existing dunes as well as forming new dunes seaward of the established foredunes on the barrier. Consequently, *T. junceiforme* has impacted on the ecology and the geomorphology of the Younghusband Peninsula and may be classed as one of only a small group of invasive species designated as 'transformer' species.

Declaration

I, Kristine Faye James, certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide.

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Dedicated to Charlie.


CHAPTER 1. INTRODUCTION

> '*…the new-comers, finding a suitable soil and climate, spread with an alarming rapidity, and becoming possessors of the ground, ejecting the indigenous herbaceous plants, and taking their places'* (Schomburgk 1879)

This thesis presents a model of invasion of the alien coastal plant *Thinopyrum junceiforme* along the south eastern Australian coastline. This first chapter provides the context to the research, identifies gaps in the research literature on *T. junceiforme* and outlines the aims, objectives and layout of the thesis.

1.1 BACKGROUND

The ability of some alien plants to modify the ecology and/or geomorphology of coastal ecosystems outside of their native environment is not a new concept. In 1958 Elton produced what is widely now considered to be a seminal work on invasion ecology describing the ecological 'explosions' that may result from the introduction of insects, birds and other animals and plants to new areas around the world. Elton (1958 p. 26) commented, for example, on a 'plant that has changed part of our landscape', *Spartina townsendii*. *S. townsendii* is, Elton noted a 'useful plant, because it stabilizes previously bare and mobile mud between tide-marks, on which often no other vascular plant could grow, helps to form new land and often in the first instance provides salt-marsh grazing. Its effects upon the coastal pattern are, however, not yet fully understood… ' (p. 26).

Wells et al. (1986 p. 24, 25) called plants that may change the landscape, or more precisely '…the character, condition, form or nature of natural ecosystems over a substantial area', 'transformer species'. Transformers comprise only a small group (10%) of invasive species (Richardson et al. 2000 p. 93). So what then defines an invasive species? As noted by Richardson et al. (2000 p. 93) 'Much confusion exists in the English language literature on plant invasions concerning the terms 'naturalized' and 'invasive' and their associated concepts' and so before proceeding any further it seems pertinent to clarify these terms. Firstly, alien species are those that have been introduced deliberately or accidentally by humans (p. 98) over 'a major geographical barrier' (Richardson et al. 2000 p. 93). Naturalisation of alien species occurs when reproduction is consistent and plants are able to '…sustain populations over many life cycles without direct intervention by humans (or in spite of human intervention); they often recruit offspring freely, usually close to adult plants, and do not necessarily invade natural, seminatural or human made ecosystems' (p. 98). In turn, invasive species are naturalised species '…that produce reproductive offspring, often in very large numbers, at considerable distance from parent plants…' (p. 98) or '…sites of introduction' (p. 93) and consequently '…have the potential to spread over a considerable area' (p. 98). The scales of invasion, which vary according to the mechanism of spread are approximately greater than 100 m in less than 50 years for species 'spreading by seeds and other propagules' and for species spreading vegetatively, more than 6 m in 3 years (Richardson et al. 2000 p. 93, 98).

Often forming monocultures and dominating ecosystems (Sheppard et al. 2010), transformer species may be divided into eight categories according to their impacts: i. 'excessive users of resources', ii. 'donors of limiting resources', iii. 'fire promoters/suppressors', iv. 'sand stabilizers', v. 'erosion promoters', vi. 'colonizers of intertidal mudflats/sediment stabilizers', vii. 'litter accumulators' and viii. 'salt accumulators/redistributors' (Richardson et al. 2000 p. 98). Elton's *Spartina townsendii* would fall into category 6, 'colonizers of intertidal mudflats/sediment stabilizers'. In this research the 'sand stabilizer' category of transformer species is of most interest. A well known example of a sand stabiliser transformer species is *Ammophila arenaria* (Marram grass) (Richardson et al. 2000 p. 98), a plant that has been utilised for dune stabilisation in Australia and around the world (Bird 1984). It is contended in this thesis that the comparatively less well known alien grass *Thinopyrum junceiforme* also falls into this category of transformer species in south eastern Australia.

1.2 *THINOPYRUM JUNCEIFORME* IN AUSTRALIA

Thinopyrum junceiforme (formerly known by a number of synonyms including *Elymus farctus*) is a rhizomatous perennial grass native to Europe. It was probably initially accidentally introduced to Australia via ballast (Heyligers 1985). Heyligers (1985) was one of the first people to draw attention to *T. junceiforme* or Sea wheat-grass in the mid 1980s in his observations on the impact of introduced species on coastal dune environments in south eastern Australia. Heyligers (1985) compared alien species such as *T. junceiforme* along with *Cakile maritima* subsp. *maritima*, *Euphorbia paralias* and *Ammophila arenaria* with their native 'counterparts', in terms of their roles in dune formation, sand trapping capacity and response to sand accumulation. Heyligers (1985 p. 37) observed that alien '... grasses and herbs are more efficient than native species at colonizing the backshore and trapping sand. Due to their presence, therefore, either dunes are formed where none would have come into existence otherwise, or the formation of foredune terraces and ridges is enhanced and larger dunes are built up…'.

A year after Heyligers' paper was published, a 'baseline study' of *Thinopyrum junceiforme* in South Australia was undertaken by Mavrinac (1986). In surveys on the Fleurieu Peninsula and on the South East coast of South Australia, Mavrinac found *T. junceiforme* dominated the most sea-ward parts of the coast, backed by the native *Spinifex sericeus* (p. 58). Noting Heyligers' (1985) observations of the dune building ability of *T. junceiforme*, Mavrinac (1986) suggested the plant had potential for use as a sand stabiliser (p. 64), which would 'not conflict with the native species (*S. sericeus*), because of the fairly distinct location of growth on dune systems' (p. 63). Mavrinac (1986 p. 65) concluded in his report that there was '..a lack of information about Elymus growing in South Australia' and that 'more research has to be carried out on the grass'.

More recently, Hilton and Harvey (2002) investigated the invasion of alien dune grasses including *Thinopyrum junceiforme* on Sir Richard Peninsula, a Holocene coastal barrier forming the western boundary of the mouth of the River Murray in South Australia. According to Hilton and Harvey (2002 p. 188) these grasses '..pose a significant threat to the natural character of the Sir Richard Peninsula and adjacent' areas. Hilton and Harvey (2002) proposed that it was probably during the early to mid 1980s when *T. junceiforme* established on Sir Richard Peninsula, where its spread has been described as 'dramatic'. They suggested that native foredune species may be displaced by *T. junceiforme*, which had colonised the seaward slope of the pre-existing foredune as well as forming a new foredune up to 10 m wide on much of the peninsula (Hilton & Harvey 2002). Implications of the new, rapidly built *T. junceiforme* foredune included the potential to restrict blowout development and sand movement between the beach and dune ecosystems (Hilton & Harvey 2002 p. 188).

Shortly after the paper by Hilton and Harvey (2002), research was undertaken on the southern part of the flanking spit of Younghusband Peninsula by Harvey et al. (2003). Surveys by Harvey et al. (2003 p. 34) found that *Thinopyrum junceiforme* colonised areas between erosional foredune knobs as well as forming laterally extensive continuous foredunes with a distinct monoculture especially along the stoss slope. Like Mavrinac (1986) they also found that the most seaward parts of the coast were dominated by *T. junceiforme*. The results of terrain and species analysis led them to suggest that *T.*

junceiforme had '...the potential to alter the ecology and geomorphology of the Coorong foredune' (Harvey et al. 2003 p. 34).

The pioneering work of Heyligers (1985), as well as the work of Mavrinac (1986), Hilton and Harvey (2002), Harvey et al. (2003) and others (Hilton et al. 2006, Hilton et al. 2007), have provided the overall impetus for this research project on *Thinopyrum junceiforme.* Initially, the entire project was to focus on the potential impacts, and thus the transformer status, of *T. junceiforme* on the Younghusband Peninsula in the nationally and internationally significant Coorong National Park in South Australia. However, a review of the literature revealed that aside from the aforementioned papers that focussed predominantly on the plant's impacts, there was little other information available on *T. junceiforme* in an Australian context. Consequently, the research project was modified to incorporate a number of gaps identified in the research. The research gaps identified and resulting research questions are discussed in the following section.

1.3 RESEARCH GAPS AND QUESTIONS

According to Hilton et al. (2007 p. 227), while alien species such as Pyp grass and Sea wheat-grass 'pose a major threat' to coastal ecosystems in South Australia, 'they have attracted relatively little attention and there is a lack of awareness of these species in terms of their exact location; the direction, rate and mechanisms of spread…'. Similarly, Hilton et al. (2006) commented that 'There has been no work, to date, on processes of *Thinopyrum* dispersal'. Heyligers (1985 p. 41) also suggested that 'no data appear to be available…..on the floating capability of 'fruits''. Consequently, there is a considerable gap in our knowledge of *Thinopyrum junceiforme* in Australia.

In contrast, at the international level much research has been undertaken on the ecology/ecological tolerances of *Thinopyrum junceiforme* including major theses by Nicholson (1952) and Harris (1982) and related papers by Harris and Davy (1986a, 1986b, 1987, 1988). Quantitative comparative data has also been provided by Benecke (1930), Rozema et al. (1983), Woodell (1985), and Sykes and Wilson (1988, 1989, 1990a, 1990b) (see Chapter Two for an overview) and there is little reason to repeat experiments for which there are conclusive results. However, the opportunity exists to contribute new knowledge to the understanding of *T. junceiforme*, both in an Australian and international context. Consequently, a number of questions are posed in this research, which are grouped under the following headings: the Spatial and Temporal dimensions of invasion; Awareness of the plant; Dispersal; and Impact.

- **Spatial** and **Temporal** dimensions of invasion

What are the spatial and temporal dimensions of the invasion of *Thinopyrum junceiforme* in Australia? What is its scale of spread? Can *T. junceiforme* be classed as an 'invasive' species according to the scales set out in the literature? What mechanisms have assisted its introduction to Australia and its subsequent spread? What pathways exist for its dispersal?

- **Awareness**

What is the awareness of *Thinopyrum junceiforme* in Australia? What are people's perceptions of the plant? What experiences have people had with the plant?

- **Dispersal**

Can *Thinopyrum junceiforme* seed float on seawater? How do seeds react to disturbance? What is the viability of seed that sink in the ocean? Have anthropogenic (sand replenishment) activities assisted in the spread of *T. junceiforme* by rhizome fragments?

- **Impact**

Has *Thinopyrum junceiforme* had a demonstrable effect on the ecology and dunes on the Younghusband Peninsula? Can the plant be classed as a transformer species as set out in the literature? What is the rate of spread along the Younghusband Peninsula and how does this compare to other alien species like Marram grass?

These research questions are reflected in the research objectives described below.

1.4 RESEARCH AIM

In essence, the aim of this research is to present a model of *Thinopyrum junceiforme* invasion along the Australian coast, based on the questions and objectives posed in this thesis.

1.5 RESEARCH APPROACH AND OBJECTIVES

This research employed a bio-geomorphic approach using a combination of field work, greenhouse experiments and desktop research to achieve the research objectives. There are five main objectives in this research. The first two objectives aim to ascertain the spatial and temporal dimensions of invasion and current awareness of *Thinopyrum junceiforme* in Australia. The following two objectives focus on the dispersal of the plant by seed and by rhizomes, and the final objective focuses on ascertaining the potential impact of *T. junceiforme* on the Younghusband Peninsula in the Coorong National Park.

1. To establish the spatial and temporal dimensions of invasion of *Thinopyrum junceiforme* in Australia.

Using Australian herbarium collections this objective seeks to establish not only the distribution of *Thinopyrum junceiforme* in Australia, but also its spread over time. This spatio-temporal analysis aims to shed light on the potential means of introduction and patterns of spread along the Australian coastline.

2. To gauge people's knowledge, experience and opinions of *Thinopyrum junceiforme*.

Unlike the well known Marram grass, it was thought that *Thinopyrum junceiforme* largely 'flies below the radar' in Australia. That is, it was thought to have a very low profile and has spread largely unnoticed along the coastline. Consequently, an online questionnaire was devised and disseminated with the aim that it would assist in determining the perceived status of this alien plant in Australia.

3. To establish *Thinopyrum junceiforme*'s potential for spread by seed using oceanic transport as a vector for dispersal.

This objective aims to investigate *Thinopyrum junceiforme's* potential for spread by seed in relation to factors important in oceanic hydrochory: the ability to float, the ability to delay germination while floating and a tolerance to salinity, in a series of greenhouse experiments.

4. To document the regenerative ability of *Thinopyrum junceiforme* by rhizomes in transported sand on the Adelaide Metropolitan Coast

This objective aimed to observe the regenerative ability of *Thinopyrum junceiforme* rhizome fragments contained in sand that was placed on a beach on the Adelaide metropolitan coast for coastal management purposes, and to determine whether such activities have been assisting in the spread of the plant along this coast.

5. To document the potential impact of *Thinopyrum junceiforme* on the vegetation and dune environment of the Younghusband Peninsula.

Objective five aimed to determine whether *Thinopyrum junceiforme* has altered the ecology and geomorphology of the Younghusband Peninsula. To gauge this potential impact, and to determine whether the plant may be classed as a transformer species, field work was undertaken along the Younghusband Peninsula to document the distribution, rate of spread, and dune forms initiated by *T. junceiforme* on the barrier.

1.6 Organisation of the Thesis

This research is organised as follows: Chapters One and Two comprise the Introduction and an Overview of *Thinopyrum junceiforme*, respectively. Chapters Three, Four, Five, Six and Seven address the objectives described above, and Chapter Eight presents the conclusions of the research. The main thesis chapters addressing the objectives (3,4,5,6 and 7) are described below.

Chapter Three analyses the distribution and spread of *Thinopyrum junceiforme* in Australia, as interpreted through the collation and analysis of Australian herbarium collections accessible on-line via Australia's Virtual herbarium (AVH).

Chapter Four presents the results from the Sea wheat-grass questionnaire that aimed to collect information on respondents' knowledge, experience and opinions of *Thinopyrum junceiforme.* Results from a broad range of respondents including all levels of government, industry, community, conservation or environmental groups, students, and other interested individuals are analysed and discussed.

Chapter Five examines the colonisation potential of *Thinopyrum junceiforme* by seed under oceanic conditions. Greenhouse experiments are conducted to explore three main aspects: i. *T. junceiforme's* buoyancy or floating capacity; ii. *T. junceiforme's* germination response to variable periods of floating on seawater, and iii. *T. junceiforme's* germination response following complete submersion in seawater.

Chapter Six documents the regenerative ability of *Thinopyrum junceiforme* rhizomes in an area under going sand replenishment on the Adelaide metropolitan coast. This chapter presents the results of 7 months of monitoring the regenerative behaviour of transported rhizomes.

Chapter Seven discusses the results of vegetation surveying and observations on dune forms initiated/colonised by *Thinopyrum junceiforme* along the length of the peninsula. Data was analysed with a view to determining a rate of spread and the impacts of *T. junceiforme* on the ecology and geomorphology of the Younghusband Peninsula.

CHAPTER 2. *THINOPYRUM JUNCEIFORME* – AN OVERVIEW

> *Thinopyrum junceiforme 'unites in itself the necessary resistance to salt, wind and sand which fits it for the position of pioneer upon sand flats'* (Benecke 1930).

This chapter provides an overview of *Thinopyrum junceiforme* in regard to its taxonomy and nomenclature, its ability to tolerate stresses associated with coastal environments, its method of spread and dune formation and its seasonal ecology in a South Australian context.

2.1 *THINOPYRUM JUNCEIFORME* – TAXONOMY AND NOMENCLATURE

> 'Thinopyrum' – a Greek derivation of '*thino*-, a combining form of *this*, a shore weed, and *pyros*, wheat' (Löve 1984 p. 475).

The genus *Thinopyrum* was described by Löve (1984 p. 475) as comprising rhizomatous grasses 'growing on sandy shores'. Native to Eurasia, the genus comprises 'up to 15 species' 'but the number recognised depends on generic concepts', as discussed below (Jessop et al. 2006 p. 275). *Thinopyrum* occurs in the (grass) family Poacaeae (formerly Gramineae) in the tribe Triticeae.

Endemic 'to much of Europe' (Jessop et al. 2006 p. 279) *T. junceiforme* is a coastal coloniser found in the strandline as well as on foredunes (Harris & Davy 1986a). In Britain, it is regarded as '..one of the primary colonizers in any dune succession originating in the strandline' but 'is perhaps even more characteristic of the next phase of succession, as it develops dense swards on the persistent, established foredunes….' (Harris & Davy 1986a p. 1046).

The following taxonomical description of *Thinopyrum junceiforme*, shown in Figure 2.1, is taken from Jessop et al. (2006) from the Grasses of South Australia, p. 278-279.

Thinopyrum junceiforme (Á.Löve & D.Löve) Á.Löve, *Taxon* 29: 351 (1980)

> Perennial with tufts arising from extensive rhizomes. **Culms** 0.25-0.8 m high, only branched towards the base, glabrous. **Leaf blades** glabrous below finely hairy above; sheaths glabrous; ligule irregularly toothed, minutely ciliate, 0.3-1 mm long, glabrous.

Inflorescence 5-26 cm long, 1-2 cm broad, very readily disarticulating. **Spikelets** not disarticulating. **Glumes** subequal or the upper longer, veins conspicuous, awnless, glabrous (densely pubescent inside), 7-11 veined, 10-17 mm long. **Lemmas** glabrous or scabrid on the midrib, awnless or with a minute point, 10-17 mm long. **Palea** ciliate.

Figure 2.1. *Thinopyrum junceiforme* on the Younghusband Peninsula. Source: Photograph by the author.

Synonyms (Jessop et al. 2006)

- *Elytrigia junceiformis* Á.Löve & D.Löve, *Rep.Univ.Inst.Appl.Sci.Reykjavik, Dept.Ag.Bull.* ser. B, 3:106 (1948).

- *Agropyron junceiforme* (Á.Löve & D.Löve) Á.Löve & D.Löve, *Rep.Univ.Inst.Appl.Sci. Reykjavik, Dept.Ag.Bull.* ser. B, 3:106 (1948).

- *Agropyron junceum* (L.) P.Beauv. subsp. *boreali-alanticum* Simonet & Guinochet, *Bull.Soc.Bot.Fr.* 85: 176 (1938).

- *Elymus farctus* (Viv.) Runemark ex A.Melderis subsp. *boreali-alanticus* (Simonet & Guinochet) A.Melderis, *Bot.J.Linn.Soc.* 76: 383 (1978).

- *Elymus farctus* sensu Jessop, Fl.S.Aust. 4:1882 (1986), non (Viv.) Runemark ex A.Melderis.

Thinopyrum junceiforme or Sea wheat-grass has a number of synonyms reflecting differing generic approaches or treatments of Triticeae. According to Barkworth (2000 p. 110) ‘Taxonomists, both past and present, differ considerably in their generic treatment of the Triticeae’ (see Barkworth 1992, 2000 for an overview). Löve, for example, took a genomic approach, although as noted by Barkworth (2000 p. 114), in the absence of data for ‘several of the taxa’, the ‘classical morphological-geographical concept’ was applied (Löve 1984 p. 426). Melderis used a self-described combination of ‘cytogenetical evidence’ and ‘morphological characters’ in his classification published in *Flora Europaea* (see Melderis & McClintock 1983 p. 391). Crawley (1982 p. 69), in reviewing the third edition of the ‘Excursion Flora of the British Isles’ comments: ‘The greatest difference between the second and third editions is in nomenclature. Traditionalists will be appalled at the number of name changes that conforming with the Flora Europaea has required; gone are whole genera such as *Agropyron*, *Helictotrichon* and *Catapodium* (replaced by *Elymus*, *Avenula* and *Desmazeria)*. Generations of field course students raised on *Agropyron junceiforme* have now to switch to the almost unbelievably discordant *Elymus farctus’.*

In the literature and other sources of information, inconsistencies exist regarding the nomenclature of *T. junceiforme*. While the number of synonyms may contribute to this, the main issue relates to the nomenclature of two Thinopyrum species: Löve’s *T. junceiforme* and *T. junceum* (or the *Elymus farctus* subsp. *boreali-atlanticus* and *E. farctus* subsp. *farctus* of Melderis). Most commonly, as confirmed by the Australian Plant Name Index (APNI) (APNI 2012), the synonym *Agropyron junceum* (i.e. *T. junceum*) has been misapplied to *T. junceiforme*, the application of *Elymus farctus*, (without identifying subspecies) is also common. Consequently, in some cases it is difficult to determine the identity of *T. junceiforme* and *T. junceum* in the literature. The major work of Nicholson (1952), for example, is based on an ecological study of *Agropyron junceum*, yet Gimingham (1964 p. 93) refers to Nicholson’s ‘detailed investigation of the autecology of *Agropyron junceiforme’*. Similarly, Harris and Davy (1986b p. 1057) who carried out work on *Elymus farctus* subsp. *borealiatlanticus* or *Agropyron junceiforme* (and hence, *T. junceiforme*), comment that ‘specific data concerning the germination requirements of *E. farctus* is sparse apart from the data of Nicholson (1952)’. Heyligers (1985) too also refers to Nicholson’s work in a discussion on the germination of *Elymus farctus*.

In Australia the introduction of both *Thinopyrum junceiforme* and *T. junceum* have been ‘widely recorded’, but of the specimens examined thus far, only the latter is held in

Australian Herbaria according to Simon and Alfonso (2011). These two 'morphologically variable' species can only be 'unequivocally' distinguished by chromosome number and anther length (Simon & Alfonso 2011): *E. farctus* subsp. *boreali-atlanticus* - anthers 6-8mm, 2*n*=28 (Löve's *T. junceiforme)* and *E. farctus* subsp. *farctus* - anthers 10-12 mm, 2*n*=42, 56 (Löve's *T. junceum),* according to the descriptions of Melderis (1980 p. 198).

Other species of the genera *Thinopyrum* recorded in Australia are *T. distichum*, *T. pycnanthum, T. elongatum* and *T. ponticum* (Atlas of Living Australia 2012a). There appears to be some confusion regarding the latter two species (*T. elongatum* and *T. ponticum).* They may sometimes be regarded as the same plant with the former listed as a synonym of the latter (see, for example, The Royal Botanic Gardens and Domain Trust 2012) or *T. ponticum* may be considered a subspecies of *T. elongatum* (Jessop et al. 2006).

Note that in this chapter alternative names for *Thinopyrum junceiforme* used by authors will be presented for the first time in square brackets, for the rest of the thesis *Thinopyrum* or *T. junceiforme* is used.

2.2 *THINOPYRUM JUNCEIFORME* AS A SUCCESSFUL COASTAL COLONISER

Plants growing in coastal dune environments, particularly the beach-dune environment, encounter a range of stresses including salt spray, soil (or root) salinity, inundation, and burial (Hesp 1991). As indicated in the introduction (Chapter One), considerable international research has been undertaken on *Thinopyrum junceiforme* including the major theses of Nicholson (1952) [*Agropyron junceum*] and Harris (1982) [*Elymus farctus*], the related work of Harris and Davy (1986a, 1986b, 1987, 1988) [*Elymus farctus* subsp. *borealiatlanticus*] and studies by authors including Benecke (1930) [*Agriopyrum junceum*], Meijering (1964) [*Agropyron junceum boreoatlanticum*], Rozema et al. (1983) [*Elytrigia junceiformis*], Sykes and Wilson (1988, 1989, 1990a, 1990b) [*Elymus farctus*], and Woodell (1985) [*Elymus farctus*]. These works provide insights into the ecology and ecological tolerances of *T. junceiforme*, at various stages of its growth, which enable it to be a successful coloniser of coastal environments.

2.2.1 Soil salinity, salt spray and tidal inundation

2.2.1.1 Soil salinity

Early experiments were undertaken by Benecke (1930) on the salt tolerance of the coastal grasses *Ammophila arenaria, Elymus arenarius* and *Thinopyrum junceiforme.* Despite an issue relating to the 'over-estimation' of salt tolerance of these species, Rozema et al. (1985) commented that Benecke provided '…the first convincing experimental demonstration of *Elytrigia junceiformis* of the foredunes to be less salt sensitive than *Ammophila arenaria* growing on higher levels of the primary dune ridge' (p. 516-517). These results are confirmed by the comparative experiments of Sykes and Wilson (1989 p. 177) which indicated that *A. arenaria* 'showed somewhat less tolerance to salt' than *T. junceiforme.*

According to Heyligers (1985) adult plants of *Thinopyrum junceiforme [Elymus farctus]* are able to withstand a wide range of soil salinity. Meijering (1964) suggested that it is the development of an extensive root system that enables *T. junceiforme* to cope with both the high salinities associated with inundation during storms, as well as the low salinities associated with the diluting affect of rainfall.

It is interesting to note that while the results of Sykes and Wilson (1989 p. 176, 177) found that *T. junceiforme* was very tolerant of (root) salinity, experiments indicated that the relative growth rate (RGR) of *T. junceiforme* was greatest at 0.75% salt concentration (in comparison to both lower and higher concentrations of salt) (see Table 2.1). Consequently, Sykes and Wilson (1989 p. 176) proposed [after Barbour (1970)] that *T. junceiforme* may be a 'facultive halophyte'; that is, plants demonstrating 'optimal growth at moderate salinity'. Similarly, Heyligers (1985 p. 31, 41) suggested that *T. junceiforme* plants 'perform best when soil water is brackish', between 1.6-2.4% as reported by Werner (1960) and Steude (1961) in Meijering (1964).

Table 2.1. RGR of *Thinopyrum junceiforme* under different salt concentration treatments (Sykes & Wilson 1989).

	Salt %					
	0.0	0.25	0.50	0.75	1.00	2.0
RGR	0.177	0.203	0.224	0.282	0.106	0.068

2.2.1.2 Salt spray

In their experiments to determine the tolerance of 29 plant species to salt spray, Sykes and Wilson (1988) used a 3.5% solution of sea salt, which was applied to the plant via overhead spraying. Sykes and Wilson (1988) used the indices of live leaf area and relative growth rate (RGR) to measure tolerance to salt spray and concluded that *Thinopyrum* *junceiforme* was 'little affected by salt spray'. It is interesting to note that Sykes and Wilson (1988 p. 159) also pointed out that their results found '..little correlation between tolerance to salt spray and tolerance to root salinity'. While *T. junceiforme* was tolerant to both, some species were tolerant to one or the other (e.g. *Austrofestuca littoralis* could tolerate 'medium' soil salinity but was unable to tolerate salt spray), or neither (Sykes & Wilson 1988 p. 159).

According to the comparative study of Rozema et al. (1983) the relative tolerances to salt spray and soil salinity helped explain the habitat preferences of *Thinopyrum junceiforme* and the related saltmarsh plant *Elytrigia pungens* and *E. repens,* an inland species. Comparisons between the species indicated that *T. junceiforme* was the most tolerant of salt spray, while *E. pungens* was the most tolerant to soil salinity: hence their positions on the dunes, and in the saltmarsh, respectively. Both factors 'contribute to the exclusion of the sensitive *E. repens* from coastal sites' (Rozema et al. 1983 p. 455).

2.2.1.3 Tidal inundation

Another important aspect of *Thinopyrum junceiforme's* tolerance to salinity is its ability to tolerate salt water inundation or 'periodic submergence' (Nicholson 1952 p. 162). According to Sykes and Wilson (1989 p. 177), it is probably the duration of inundation that is the 'key to its survival in high salt concentrations'. 'Short periods' of inundation may be tolerated, as they noted in the literature (eg. Tansley 1939, Gimingham 1964, Chapman 1976). As mentioned above, Meijering (1964) also suggested that it is the development of an extensive root system that enables *T. junceiforme* to cope with the high salinities associated with inundation during storms.

2.2.1.4 Seed germination and salinity

In terms of the effect of salinity on seed germination, the results of Nicholson (1952) and Woodell (1985) showed that there was little or no germination of *Thinopyrum junceiforme* in full strength seawater. Nicholson (1952 p. 74) consequently concluded that *T. junceiforme's* '...tolerance range of germination to salt concentration is not great'. However, an alternative interpretation of these results is presented in Chapter Five.

2.2.2 Burial

The response to burial by *Thinopyrum junceiforme* has been discussed by a number of authors including Harris (1982), Harris and Davy (1986b, 1987), Nicholson (1952) and

Sykes and Wilson (1990a, 1990b). Responses have been recorded for both mature plants and seedlings, and seed and rhizome fragments.

2.2.2.1 Mature plants

Experiments by Sykes and Wilson (1990a) demonstrated that *Thinopyrum junceiforme* did not tolerate full burial but was tolerant of partial burial (two-thirds of plant height). It demonstrated better tolerance to this than *Ammophila arenaria*, indicated according to Sykes and Wilson (1990a) by the minimal variation in total dried weight of *T. junceiforme* between unburied and (partially) buried plants, which was 29.80 grams and 27.72 grams, respectively. In contrast, the total dried weight for *A. arenaria* decreased dramatically: from 8.65 grams to 1.15 grams for unburied and buried plants, respectively (Sykes & Wilson 1990a). Similar responses to burial by the two grasses were found in terms of 'internode elongation, tiller production and adventitious rooting just below the sand surface' (Sykes & Wilson 1990a p. 176). According to Nicholson (1952 p. 132), in the field the process of complete burial results in shoot death, bud activation and the production of vertical rhizomes, which upon reaching the sand surface produce new shoots, and tillers, and is a process that is constantly repeated (p. 132-133).

2.2.2.2 Seedlings

Harris and Davy (1987) examined the response of *Thinopyrum junceiforme* seedlings to burial. They found *T. junceiforme* could tolerate full burial for 7 days (but died after 14 days) (Harris & Davy 1987). Harris and Davy (1987 p. 591) noted reductions in total dry mass comprising predominantly stem and root material and suggested that during burial *T. junceiforme* sacrificed these parts to sustain photosynthetic material, a survival strategy facilitating the best prospect for growth upon re-emergence following brief periods of burial. Certainly, following 7 days of burial, it was found that plant growth swiftly recommenced (Harris & Davy 1987). According to Harris (1982 p. 141) the most important factors in *T. junceiforme* seedling survival of burial include the age and size of the plant and the extent of burial. There appears to be a high tolerance to full burial in seedlings that have just emerged, this tolerance then decreases, but rises again when the plant has grown and has developed reserves and the ability to 'respond actively' to burial (Harris 1982 p. 141).

2.2.2.3 Darkness

According to Harris and Davy (1987), the effects of burial might include physical damage, constraints on gaseous exchanges and effects related to darkness. Sykes and Wilson (1990b p. 799) conducted experiments to gauge the tolerance of plants to darkness in a lightproof box, in an attempt to 'separate the dark survival component from the growth response one' during burial. *Thinopyrum junceiforme* demonstrated the ability to survive in darkness for 64 days, exceeding the tolerances of most other species tested. Only 4 other species survived for a longer time, including mature *Ammophila arenaria* plants whose survival time was almost double that of *T. junceiforme.* Sykes and Wilson (1990b) suggested that this is a realistic response as *T. junceiforme* inhabits more unstable locations where burial is usually short-term.

2.2.2.4 Seeds

In terms of seed germination and burial, in a comparative study Harris (1982) found that *Thinopyrum junceiforme* could emerge from depths of 3.8 cm, 7.6 cm and 12.7 cm but not 17.8 cm (p. 60). Comparatively, the coastal grass *Leymus arenarius* arose from similar depths but at a slower rate (p. 60). The maximum depth from which *Ammophila arenaria* could arise was 7.6cm (p. 60). According to Harris (1982), the large size of the seeds of *T. junceiforme* and *L. arenarius* compared to *A. arenaria* may be a determining factor in their ability to emerge from a greater depth (p. 59). Extrapolating his results from two seed germination experiments, Harris (1982 p. 71) determined that burial of seeds at depths greater than around 14 cm would inhibit emergence. In terms of the darkness aspect of burial, Nicholson (1952) found very little difference between seed germination rates in light or darkness and concluded that 'light is not essential for germination' (p. 65).

2.2.2.5 Rhizomes

In an experiment similar to the one undertaken on seed burial, *Thinopyrum junceiforme* rhizome fragments, bearing one to three nodes were buried at depths of 3.8 cm, 7.6 cm, 12.7 cm and 17.8 cm (Harris & Davy 1986b). Results indicated that rhizome fragments with only one node, like the seeds, emerged from all depths except 17.8 cm (Harris & Davy 1986b) but no depth was limiting to the two and three noded fragments. It was found that 'overall, at any given depth, fragments with more nodes produced more emergent shoots and produced them more quickly' (Harris & Davy 1986b p. 1059). A peak in the 'regenerative ability' of the rhizomes, defined as the 'production of roots and shoots at the same node' was identified 'in later winter-early spring' after which there was 'a sharp decline in late-spring-early summer' (Harris & Davy 1986b p. 1060).

2.3 *THINOPYRUM JUNCEIFORME* DUNE FORMATION AND METHOD OF SPREAD

The most comprehensive ecological studies of *Thinopyrum junceiforme* have been the MSc thesis of Nicholson (1952) and the PhD of Harris (1982). Nicholson (1952) used a combination of fieldwork at St. Cyrus in the United Kingdom, and laboratory experiments, to gain baseline ecological data on *T. junceiforme* particularly in relation to the reproduction of the plant by seed and rhizomes. Nicholson (1952) found that *T. junceiforme* could spread by both seed and rhizomes. However, he suggested that the plant is '...not a prolific seeder and many spikelets do not produce mature seed' (p. 57). Moreover, '.. seed production may be erratic with marked variation from year to year....' (Nicholson 1952 p. 57). Consequently, the main method of spread for *T. junceiforme* is via asexual methods: 'the plant is well adapted for propagation by vegetative means and this appears to be the principal method of spread and multiplication' (Nicholson 1952 p. 51).

The sea has an important role in the dispersal of *T. junceiforme.* Seed or fruit, are shed in spikelets and are predominantly found in close proximity to the parent plant (Nicholson 1952 p. 55). They are entrained and transported by the sea to new areas 'unimpaired' in a process considered by Nicholson (1952 p. 55) to be '..the principal means of seed dispersal'. In terms of vegetative dispersal, rhizomes are severed from the parent plant during periods of erosion and the fragments may be transported by the sea (or wind) a '..considerable distance'; once 'deposited in a suitable environment, adventitious roots arise from the nodes and shoots are developed from the axillary buds' (Nicholson 1952 p. 83).

Nicholson investigated in detail *Thinopyrum junceiforme*'s spread by 'vegetative means', its role in the formation of 'embryo' dunes (also known as incipient dunes – for an explanation of these dunes see Hesp 1984, 1989, and Chapter 7), and its response to burial, as indicated above. Figure 2.2, from Nicholson's thesis, provides an overview of *T. junceiforme*'s vegetative spread and role in 'embryo' dune formation. Typically, young plants on the foreshore, that have arisen from seed or rhizome fragments, provide a sufficient degree of wind resistance to encourage sand deposition/accumulation around the shoots, forming a distinctly shaped mound (Figure 2.2a,b) (Nicholson 1952 p. 138). Prostrate shoots help to bind the sand and with tiller production adventitious roots spread throughout the mound (Figure 2.2b) (Nicholson 1952 p. 140). With continuing sand deposition, which may all but cover the existing shoots, rhizomes of 'limited growth' form and new shoots are produced at the sand surface (Figure 2.2c) (Nicholson 1952 p. 140). When completely buried, the process described earlier (in section 2.2.2.1) commences: i.e. the production of vertical rhizomes, which in turn produce new shoots at the sand surface (Figure 2.2d) (Nicholson 1952 p. 140). As shown in Figure 2.2e, horizontal rhizomes producing shoots 'some distance away' from the main complex may result in the formation of a new embryo dune (Nicholson 1952 p. 140). According to Nicholson (1952 p.140, 141), 'this process may be repeated by horizontal rhizomes in other directions', eventually resulting in 'a whole series' of embryo dunes which may coalesce.

Initially, the embryo dunes are seaward of the low (*Thinopyrum junceiforme*) foredune and are 'quite distinct from it' but eventually they may become incorporated into the foredune by rhizome spread (Nicholson 1952 p. 141).

Figure 2.2. *Thinopyrum junceiforme*'s vegetative spread and role in 'embryo' dune formation. Source: Nicholson (1952). Note: 'E' has been added to the original diagram.

The sequence of events as described by Nicholson (1952) may at times be disrupted by the dynamism that may characterise the coastal environment. In December 1977, for example, Harris (1982) found that in the Holkham National Nature Reserve at Norfolk in the United Kingdom (UK), *Thinopyrum junceiforme* 'was prominent in the strandline in the form of scattered, isolated clumps of tillers associated with low, flat embryo dunes' (p. 10).

However, in January 1978 this coast had undergone severe erosion and ‘the strandline, embryo dunes and developing foredunes’ were removed ‘leaving the near vertical face of the outer main ridge fronted only by bare sand to seaward’ (p. 12). Of the vegetated foredunes only a ‘sparse ‘stubble’ of torn, upright rhizomes’ remained (Harris 1982 p. 12). It was this scenario that 30 years after Nicholson’s (1952) thesis appeared, influenced Harris (1982) to investigate ‘the nature of some of the adaptations’ of *T. junceiforme* facilitating its success in surviving the stresses of burial and erosion on the north Norfolk coast in the UK.

In the first instance, Harris (1982) sought to determine the mode of strandline re-colonisation following the severe erosion described above. According to Harris (1982) ‘newly-established tillers in the strandline may be derived from seeds, or buds carried on rhizome fragments, or they may be linked by rhizomes to established ‘parent’ tillers’ (p. 16). The former two are ‘parentally independent and offer the possibility of dispersal over long distances, while intact rhizomes are parentally dependent for their initial establishment and are restricted to distances governed by the limits of supportive rhizome growth’ (p. 16). When Harris (1982) excavated tillers to determine whether they were derived from seed or from rhizome fragments he found that the number of seeds and rhizome fragments producing tillers was similar (p. 18) and that the mean number of tillers per seed and per rhizome fragment were not significantly different (p. 17).

Further investigations by Harris (1982) highlighted the precarious situation of *Thinopyrum junceiforme* in the strandline, where flowering and tiller density were much lower compared to the foredune. In fact, ‘..no tillers in any of the strandline quadrats survived the winter of 1979, or the period of accretion during the spring of 1980’ (Harris 1982 p. 54). Thus, during his study of the Norfolk coast Harris (1982) found that the sequence of events leading to the formation and coalescence of embryo dunes described by Nicholson (1952) above did not occur, reflecting the fact that ‘appropriate conditions allowing the dune-building sequence to begin do not occur every season…’ (p. 54).

2.4 SEASONAL ECOLOGY OF *THINOPYRUM JUNCEIFORME* ON THE YOUNGHUSBAND PENINSULA

2.4.1 Background

A study was undertaken on the seasonal ecology of *Thinopyrum junceiforme* on the southern Younghusband Peninsula to obtain baseline data on the plant under (South) Australian conditions as most existing studies have been undertaken in the northern hemisphere. This fieldwork was essentially a background study to assist in familiarisation with the plant and also with the Younghusband Peninsula in preparation for the investigations focussing on the potential impact of *T. junceiforme* on the coastal dunes and vegetation of the barrier (Chapter Seven).

2.4.2 Methods

2.4.2.1 Site selection and location

The Younghusband Peninsula, a Holocene coastal barrier in the Coorong National Park, was selected for seasonal monitoring (Figure 2.3) of *T. junceiforme* for the aforementioned reasons. A full description of the geomorphology, climate, tides, morphodynamics and vegetation of the peninsula is provided in Chapter Seven.

Site selection along the Younghusband Peninsula was influenced by two main considerations. Firstly, site access was an important consideration; travelling along the Younghusband Peninsula ocean beach can be difficult at certain times of the year, particularly winter. A decision was thus made to ensure that sites selected were within walking distance (eg. 1 km) from an ‘all seasons’ beach access track in case of inclement weather. The closure of the beach north of Tea Tree Crossing between 24 October – 24 December each year to protect the Hooded Plover excluded sites in the northern part of the peninsula. This limited site selection to that part of the peninsula approximately 1 km north of 42 Mile Crossing to the southern park boundary, excluding the area in the vicinity of the seasonal Wreck Crossing.

The second factor influencing site selection related to Aboriginal heritage factors. The Department of Aboriginal Affairs and Reconciliation and the National Parks & Wildlife Service Coorong National Park Cultural Ranger were consulted regarding sites for monitoring and some sites were excluded due to Aboriginal heritage significance.

Once the site selection criteria had been met, two monitoring sites, at 1 km and 500 m north of 28 Mile Crossing, in the Coorong National Park, were finally selected. Research by Harvey et al. (2003) near the vicinity of 28 mile Crossing (150 m and 2000 m south of the beach access) indicated that dune form in this area ranged from gently sloping, continuous dunes, to erosional and discontinuous dunes, backed by extensive deflation zones. Sea-wheat grass was present on the foredune crest, and stoss and lee slopes in these areas (Harvey et al. 2003).

Figure 2.3. Location of the study area. Source: Adapted from Paton (2010).

2.4.2.2 Surveying and Monitoring

The belt transect method (Kent & Coker 1992) was used to record vegetation data at the two sites north of 28 Mile Crossing. It involved the use of a transect line along which quadrats were contiguously placed (Kent & Coker 1992). The 'traditional' square shaped quadrat (Kent & Coker 1992), running sequentially along the length of the (belt) transects was used to measure the desired vegetative parameters, using a collapsible plastic square with extendable legs. A similar method was used previously by James (2004) to record coastal dune vegetation on a former flood tide delta in the River Murray mouth estuary of South Australia.

At each site two plastic posts, 80 cm high and spray painted one end, were inserted into the dune crest, and a GPS reading taken, to permanently mark the beginning of each transect. Permanent posts could not be placed in the dune base or beach due to the potential hazard they created for beach users (P. Hollow, District Ranger, NPWSA Coorong and Lakes District, Pers. Comm., 2/1/2007). Instead, using the two crest posts, a temporary base post could be accurately positioned using triangulation to enable the accurate repositioning of the transect line on each occasion monitoring took place. It should be noted that the final position of the base post varied depending on vegetation presence. That is, while the start of the transect was fixed at the dune crest, the final length was determined by changing population parameters, due for example, to erosional events.

2.4.2.3 Data collection

Vegetation data were collected each season, at three monthly intervals in autumn (March) 2007, winter (July) 2007, spring (October) 2007 and summer (January) 2008. At each site, a tape measure (transect) was laid out between the dune crest and dune base, perpendicular to the coast. Starting at the dune crest and working down the dune stoss slope, species composition was recorded per 1 m square quadrat. The 1 m square frame was subdivided into 100 subdivisions (10 x 10 cm) and shoot frequency was also estimated. Through visual estimation a cover score was also given to *Thinopyrum junceiforme* per quadrat. Scores used to make estimates (Table 2.2) were similar to those used by James (2004) and were based on a modified Braun-Blanquet scale.

Table 2.2. Cover scores based on a modified Braun-Blanquet (1965) scale modified by Heard and Channon (1997) and James (2004).

Score	**Definition**
1	Less than 5%
2	5-25%
3	25-50%
4	50-75%
5	greater than 75%

2.5 RESULTS

2.5.1 Autumn 2007

2.5.1.1 Transect 1 (1 km north 28 Mile Crossing)

In autumn Transect 1 comprised nine 1 m square quadrats (Figure 2.4). Vegetation composition comprised *Thinopyrum junceiforme, Spinifex sericeus, Euphorbia paralias* and *Leucophyta brownii* (Figure 2.4). *T. junceiforme* occurred in all quadrats. The native coastal grass *S. sericeus* was present in seven of nine quadrats, while the introduced *E. paralias* occurred in five of the nine quadrats. *L. brownii* was recorded in only one quadrat near the dune crest and this was the first and last time this plant was recorded.

Cover of *Thinopyrum junceiforme* was 25-50% in the first three most landward quadrats, then decreased to 5-25% in quadrats four to eight, and to less than 5% in the most seaward quadrat (Figure 2.4). *T. junceiforme* frequencies ranged from between 5 and 78% across Transect 1, while *Spinifex sericeus* frequencies ranged between 2 and 42%. *Euphorbia paralias* and *Leucophyta brownii* recorded maximum frequencies of 4% (Figure 2.4).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Species	**Cover***	3	3	3	2	2	2	2	2	1
TJ	**Frequency**	62%	76%	78%	60%	67%	71%	72%	49%	5%
SS	**Frequency**	11%	-	6%	42%	37%	3%	18%	2%	-
EP	**Frequency**	-	-	3%	2%	1%	3%	4%	-	-
LB	**Frequency**	-	4%	-	-	-	-	-	-	-
		Dune crest to sea →								

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme*, SS - *Spinifex sericeus*, EP - *Euphorbia paralias*, LB - *Leucophyta brownii*

Figure 2.4. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 1 autumn (March) 2007.

2.5.1.2 Transect 2 (500 m north 28 Mile Crossing)

Transect 2 comprised eight 1 m square quadrats (Figure 2.5). Species composition comprised *Thinopyrum junceiforme* and *Euphorbia paralias*. *T. junceiforme* occurred in all eight quadrats while *E. paralias* occurred in quadrats one to five (Figure 2.5). Cover of *T. junceiforme* was 25-50% in quadrats one to four. Cover reduced to 5-25% in quadrats five and six and to less than 5% in the most seaward quadrats of seven and eight (Figure 2.5). Frequencies for *T. junceiforme* ranged between 4 and 69 % over the transect and for *E. paralias*, between 1-7% (Figure 2.5).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Species	**Cover***	3	3	3	3	2	2	1	1
TJ	**Frequency**	64%	61%	67%	67%	69%	65%	4%	4%
EP	**Frequency**	1%	1%	5%	7%	3%	-	-	-
		Dune crest to sea →							

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme,* EP - *Euphorbia paralias*

Figure 2.5. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 2 autumn (March) 2007.

2.5.2 Winter 2007

2.5.2.1 Transect 1 (1 km north 28 Mile Crossing)

In winter Transect 1 comprised nine quadrats from crest to base (Figure 2.6). Composition of Transect 1 during winter comprised *Thinopyrum junceiforme*, *Spinifex sericeus* and *Euphorbia paralias* (Figure 2.6). *T. junceiforme* occurred in all quadrats. The native coastal grass *S. sericeus* was present in three quadrats: one, eight and nine. *E. paralias* also occurred in three quadrats – three, five and six (Figure 2.6).

Cover of *Thinopyrum junceiforme* was 5-25% in quadrat one (dune crest) then increased to 25-50% in quadrats two to seven. Cover then decreased to 5-25% in quadrat eight and to less than 5% in the most seaward quadrat (Figure 2.6). Frequency of *T. junceiforme* ranged between 2 and 84% across Transect 1. For *Spinifex sericeus* frequency ranged from 5-11% and for *Euphorbia paralias*, between 1-6% (Figure 2.6).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	1	2	3	4	5	6	7	8	9
Species	Cover*	2	3	3	3	3	3	3	2	1
TJ	Frequency	67%	75%	75%	73%	82%	84%	81%	57%	2%
SS	Frequency	9%	-	-	-	-	-	-	11%	5%
EP	Frequency	-	-	6%	-	4%	1%	-	-	-
		Dune crest to sea ⟶								

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme*, SS - *Spinifex sericeus*, EP - *Euphorbia paralias*

Figure 2.6. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 1 winter (July) 2007.

2.5.2.2 Transect 2 (500 m north 28 Mile Crossing)

Transect 2 comprised eight quadrats. Species present were *Thinopyrum junceiforme* and *Euphorbia paralias*. *T. junceiforme* occurred in all quadrats while *E. paralias* occurred in quadrats one to five (Figure 2.7). Cover of *T. junceiforme* was 25-50% in quadrats one to four. Cover decreased to 5-25% in quadrats five and six, and to less than 5% in the most seaward quadrats of seven and eight (Figure 2.7). Frequency ranged from 6-83% for *T. junceiforme* and 6-48% for *E. paralias* (Figure 2.7).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	1	2	3	4	5	6	7	8
Species	Cover*	3	3	3	3	2	2	1	1
TJ	Frequency	82%	77%	83%	70%	62%	75%	7%	6%
EP	Frequency	48%	25%	36%	9%	6%	-	-	-
		Dune crest to sea ⟶							

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme*, EP - *Euphorbia paralias*

Figure 2.7. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 2 winter (July) 2007.

2.5.3 Spring 2007

2.5.3.1 Transect 1 (1 km north 28 Mile Crossing)

In spring, the number of quadrats had decreased to eight in Transect 1. Species composition comprised *Thinopyrum junceiforme* and *Euphorbia paralias. T. junceiforme* occurred in all quadrats. *E. paralias* occurred in quadrats one to six (Figure 2.8). Cover of *T. junceiforme* was 25-50% in quadrats one, three and six, and 5-25% in the remaining quadrats of two, four, five, seven and eight (Figure 2.8). Frequency of *T. junceiforme* ranged between 48-98% and for *E. paralias* between 1-9% (Figure 2.8).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Species	**Cover***	3	2	3	2	2	3	2	2
TJ	**Frequency**	96%	85%	97%	97%	92%	98%	83%	48%
EP	**Frequency**	2%	8%	3%	9%	7%	1%	-	-
		Dune crest to sea →							

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme*, EP - *Euphorbia paralias*

Figure 2.8. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 1 spring (October) 2007.

2.5.3.2 Transect 2 (500 m north 28 Mile Crossing)

Transect 2 comprised eight quadrats from crest to base. Composition comprised three plants: *Thinopyrum junceiforme*, *Euphorbia paralias* and *Cakile maritima* subsp. *maritima*. *T. junceiforme* occurred in all quadrats. *E. paralias* occurred in all quadrats except six and eight, and *C. maritima* subsp. *maritima* occurred only in the most seaward quadrat (eight) (Figure 2.9). Cover of *T. junceiforme* was 25-50% in quadrats one, two and four and 5-25% in quadrats three, five, six and seven. It decreased to less than 5% in quadrat eight (Figure 2.9). Frequency for *T. junceiforme* ranged between 19-99%, for *E. paralias* between 1-11%, and for *C. maritima* subsp. *maritima* was 1% (Figure 2.9).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	1	2	3	4	5	6	7	8
Species	**Cover***	3	3	2	3	2	2	2	1
TJ	**Frequency**	99%	95%	94%	93%	96%	91%	67%	19%
EP	**Frequency**	5%	3%	7%	11%	4%	-	1%	-
CMM	**Frequency**	-	-	-	-	-	-	-	1%
		Dune crest to sea ⟶							

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme,* EP - *Euphorbia paralias,* CMM – *Cakile maritima* subsp. *maritima*

Figure 2.9. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 2 spring (October) 2007.

2.5.4 Summer 2008

2.5.4.1 Transect 1 (1 km north 28 Mile Crossing)

Transect 1 comprised eight quadrats from crest to base. Three species were recorded in summer in Transect 1: *Thinopyrum junceiforme, Spinifex sericeus* and *Euphorbia paralias*. *T. junceiforme* occurred in all quadrats, while *S. sericeus* occurred in quadrats two and three, and *E. paralias* in quadrats five and six (Figure 2.10). Cover of *T. junceiforme* was 25-50% in quadrats one and six and 5-25% in the remaining quadrats (Figure 2.10). Frequency for *T. junceiforme* ranged between 49-92%, between 6-26% for *S. sericeus,* and for *E. paralias* between 3-31% (Figure 2.10).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	1	2	3	4	5	6	7	8
Species	**Cover***	3	2	2	2	2	3	2	2
TJ	**Frequency**	92%	59%	78%	67%	64%	85%	73%	49%
SS	**Frequency**	-	26%	6%	-	-	-	-	-
EP	**Frequency**	-	-	-	-	31%	3%	-	-
		Dune crest to sea ⟶							

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme,* SS - *Spinifex sericeus,* EP - *Euphorbia paralias*

Figure 2.10. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 1 summer (January) 2008.

2.5.4.2 Transect 2 (500 m north 28 Mile Crossing)

In summer Transect 2 comprised eight quadrats from crest to base. *Thinopyrum junceiforme* and *Euphorbia paralias* were the only species present. Once again, *T. junceiforme* was present in all quadrats. *E. paralias* occurred in quadrats one to five (Figure 2.11). Cover of *T. junceiforme* was 25-50% in quadrats one to five and seven, and decreased to 5-25% in the remaining quadrats of six and eight (Figure 2.11). Frequency for *T. junceiforme* ranged between 48-86% and for *E. paralias,* between 3-22% (Figure 2.11).

Flowering of *Thinopyrum junceiforme* was not observed during this season.

	Quadrat #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Species	**Cover***	3	3	3	3	3	2	3	2
TJ	**Frequency**	80%	72%	84%	80%	86%	80%	74%	48%
EP	**Frequency**	22%	4%	3%	22%	4%	-	-	-
		Dune crest to sea →							

Cover * - Cover scores for *Thinopyrum junceiforme* (TJ) only.
Species: TJ - *Thinopyrum junceiforme*, EP - *Euphorbia paralias*

Figure 2.11. Vegetation composition, frequency and cover (*Thinopyrum junceiforme* only) of Transect 2 summer (January) 2008.

2.5.5 Summary of transect data

2.5.5.1 Transect 1

In the first two monitoring periods of autumn and winter *Thinopyrum junceiforme* was recorded in nine quadrats in Transect 1. In spring, the number of quadrats had decreased to eight. The reduction in number of quadrats was probably the result of an erosional event in October removing *T. junceiforme* in the most seaward quadrat.

In addition to *Thinopyrum junceiforme,* three other species were recorded in Transect 1 over the monitoring period. They were the native coastal grass *Spinifex sericeus*, the introduced *Euphorbia paralias* and the native coastal shrub *Leucophyta brownii*. Both *T. junceiforme* and *E. paralias* were present in Transect 1 across all monitoring seasons. *S. sericeus* occurred in all seasons except spring and *L. brownii* was present only in the first monitoring season in autumn.

Cover of *Thinopyrum junceiforme* in Transect 1 quadrats ranged over the cover classes 25-50%, 5-25% and >5% (Table 2.3). In autumn, the season in which monitoring commenced, a cover of 25-50% occurred over the first three quadrats, followed by a lower cover of 5-25% over the subsequent five quadrats, with >5% cover in the final quadrat. In winter, the cover of *T. junceiforme* in the first quadrat was 5-25%, while the following six quadrats recorded a higher cover of 25-50% representing a two fold increase in the occurrence of this cover class from the previous season. Again, cover in the final quadrat was >5%. With the disappearance of quadrat nine, the cover class >5% was not recorded again. In spring, cover of *T. junceiforme* was 25-50% in only three quadrats: one, three and six, while in the remaining five quadrats a cover of 5-25% was recorded. In the final season of monitoring in summer, *T. junceiforme* was found to have a cover of 25-50% in only two quadrats, one and six, while its cover in the 5-25% cover class increased to six quadrats (Table 2.3).

Table 2.3. Cover of *Thinopyrum junceiforme* in Transect 1. Cover classes = 25-50% (3), 5-25% (2) and >5% (1).

Quadrat #	autumn	winter	spring	summer
Q1	3	2	3	3
Q2	3	3	2	2
Q3	3	3	3	2
Q4	2	3	2	2
Q5	2	3	2	2
Q6	2	3	3	3
Q7	2	3	2	2
Q8	2	2	2	2
Q9	1	1		

Seasonal frequencies of *Thinopyrum junceiforme* in Transect 1 are summarised in Table 2.4. Results show that frequencies in autumn averaged 60%. In winter, average frequencies increased slightly to 66.22%, with increases of *T. junceiforme* in six of nine quadrats (Table 2.4). By spring, the number of quadrats decreased from nine to eight, and all quadrats except quadrat eight recorded an increase in *T. junceiforme* frequencies. In spring, average frequencies recorded for Transect 1 quadrats was 87%, and represented the highest averages recorded over the monitoring period. In the final monitoring period of summer, six of eight quadrats recorded a reduction in average frequencies, with that season recording an average of 70.875% (Table 2.4).

Table 2.4. Summary of frequencies of *Thinopyrum junceiforme* in Transect 1 and percent change between seasons.

Quadrat #	autumn	winter	% change	spring	% change	summer	% change
Q1	62	67	5	96	29	92	-4
Q2	76	75	-1	85	10	59	-26
Q3	78	75	-3	97	22	78	-19
Q4	60	73	13	97	24	67	-30
Q5	67	82	5	92	10	64	-28
Q6	71	84	13	98	14	85	13
Q7	72	81	9	83	2	73	-10
Q8	49	57	8	48	- 9	49	1
Q9	5	2	-3				
ave	60	66.22		87		70.875	

Flowering of *Thinopyrum junceiforme* was not recorded during any season.

2.5.5.2 Transect 2

In all monitoring periods Transect 2 comprised eight quadrats.

In addition to *Thinopyrum junceiforme,* two other species, both introduced, were recorded in Transect 2. These were *Euphorbia paralias*, present also in Transect 1, and the Sea-Rocket *Cakile maritime* subsp. *maritima*. While *E. paralias* was present in all monitoring seasons, *C. maritima* subsp. *maritima* was recorded in only one quadrat, and in only one season: spring.

Cover of *Thinopyrum junceiforme* in Transect 2 ranged over cover classes 25-50%, 5-25% and >5%. Similar cover values for *T. junceiforme* were recorded for the seasonal monitoring periods of autumn and winter, with 25-50 % cover recorded in the first four quadrats, followed by 5-25% cover in quadrats five and six, and > 5% in the remaining two quadrats (Table 2.5). In spring, cover of *T. junceiforme* at the 25-50% level decreased to three quadrats (one, two and four), four quadrats recorded 5-25% cover, and the final quadrat again recorded > 5% cover. In summer, *T. junceiforme* recorded an increase in the cover class 25-50%, which was recorded in six of eight quadrats, with the remaining two quadrats comprising 5-25% cover (Table 2.5).

Table 2.5. Cover of *Thinopyrum junceiforme* in Transect 2. Cover classes = 25-50% (3), 5-25% (2) and >5% (1).

Quadrat #	autumn	Winter	Spring	summer
Q1	3	3	3	3
Q2	3	3	3	3
Q3	3	3	2	3
Q4	3	3	3	3
Q5	2	2	2	3
Q6	2	2	2	2
Q7	1	1	2	3
Q8	1	1	1	2

Seasonal frequencies of *Thinopyrum junceiforme* in Transect 2 are summarised in Table 2.6. Results show that frequencies in autumn averaged 50.125%. In winter, frequencies increased to an average of 57.75%, with increases of *T. junceiforme* in nearly all quadrats (Table 2.6). In spring all quadrats had recorded an increase in frequencies with an average frequency of 81.75% recorded - an increase of 24% from winter. In summer, six of eight quadrats recorded a reduction in average frequencies, with the final monitoring season recording an average frequency of 75.5%.

Table 2.6. Summary of frequencies of *Thinopyrum junceiforme* in Transect 2 and percent change between seasons.

Quadrat #	autumn	Winter	% change	Spring	% change	summer	% change
Q1	64	82	18	99	17	80	-19
Q2	61	77	16	95	18	72	-23
Q3	67	83	16	94	11	84	-10
Q4	67	70	3	93	23	80	-13
Q5	69	62	-7	96	34	86	-10
Q6	65	75	10	91	16	80	-11
Q7	4	7	3	67	60	74	7
Q8	4	6	2	19	13	48	29
ave	50.125	57.75		81.75		75.5	

Flowering of *Thinopyrum junceiforme* was not recorded during any season.

2.6 DISCUSSION

The seasonal ecology of *Thinopyrum junceiforme* is discussed in relation to composition, frequency, cover and incidence of flowering.

2.6.1 Composition

In addition to *Thinopyrum junceiforme*, common to both monitoring sites, over all seasons, was the presence of *Euphorbia paralias*, an introduced perennial herb spreading by seed (Heyligers 1985). While its frequencies were low compared with those of *T. junceiforme*, a notable increase in its frequency (in Transect 2) was observed in winter. Although its frequencies never approached that of *T. junceiforme*, this plant, which may produce over 20 000 seeds per plant annually (Heyligers 2002), was a constant presence in both monitoring sites.

In contrast, *Leucophyta brownii* and *Cakile maritima* subsp. *maritima* were recorded only once during the monitoring period, in low frequencies (4 % and 1% for *L. brownii* and *C. maritima* subsp. *maritima*, respectively) and each only in one quadrat (in Transect 1 for *L. brownii* and in Transect 2 for *C. maritima* subsp. *maritima*). The loss of *C. maritima* subsp. *maritima*, a drift line pioneer tolerating environmental stresses such as salt spray and (partial) sand burial (Heyligers 1985 p. 29), from the most seaward quadrat may have been due to tidal activity/erosion and/or vehicular disturbance. In contrast, the loss of *L. brownii* near the crest of the dune may have related to other forms of disturbance such as pedestrian activity (two sets of school holidays occurred between the two monitoring periods), or to other conditions unfavourable to seedling survival.

The native *Spinifex sericeus,* a stoloniferous perennial coastal grass, occurred in three of the four monitoring periods but was present only in Transect 1. It may (or may not be) coincidental that it was absent only in spring, the month that frequencies of *Thinopyrum junceiforme* were at their highest point, even though maximum growth rates of *S. sericeus* are (also) in spring and summer (Bergin 1999 p. 4). In this research, maximum frequencies for the native grass were recorded in autumn.

2.6.2 Frequency of *Thinopyrum junceiforme*

Results indicated that seasonal trends in *Thinopyrum junceiforme* frequency could be discerned. Results show that the highest average frequencies for monitoring sites were recorded in spring. Total frequencies across all quadrats for both transects for *T.*

junceiforme confirm that highest frequencies occurred in spring (Table 2.7 below). Total frequencies across all quadrats for both Transects 1 and 2 for *T. junceiforme* were lowest in autumn and this is supported by the average frequencies shown in the results.

Average frequencies show a seasonal trend of changing frequencies with highest averages in spring, decreasing through summer to a low in autumn, and then increasing again in winter. Total frequencies (Table 2.7) supported this trend in Transect 2 but in Transect 1 there was a slight anomaly where total winter frequencies exceeded summer frequencies.

In its native environment the growing season for *Thinopyrum junceiforme* is predominantly spring/summer (Nicholson 1952 p. 47), and for the most part the results here reflect this ie. the peak in spring. The winter frequencies, particularly in Transect 1, were not expected. One explanation may be that the winters here are less severe than in the plants native environment and hence some growth may produced. The native *Spinifex sericeus,* for example, experiences peak growth in spring/summer as noted above but according to Hesp (1984) ‘rhizome growth may take place throughout the year’ (p. 80).

Table 2.7. Total frequencies (%) per season for *Thinopyrum junceiforme* for Transects 1 and 2.

Season	Transect 1	Transect 2
autumn	540	401
winter	596	462
spring	696	654
summer	567	604

2.6.3 Cover of *Thinopyrum junceiforme*

Despite being only 500 m apart, cover values obtained for *T. junceiforme* varied between monitoring sites and few comparative similarities could be drawn. After careful consideration of the data obtained analysis indicated that while cover values for *T. junceiforme* provided no clear seasonal trends for Transect 1, the results from Transect 2 were more amenable to a seasonal interpretation. It could be expected, for example, that summer cover values in both transects would be higher after the spring flush of plant growth. In both transects in spring the 25-50% cover class occurred in 37.5 % of quadrats. In Transect 2, cover values in the 25-50% class did increase during summer, occurring in 75% of quadrats. In contrast, in Transect 1 the 25-50% class decreased, occurring in only

25% of quadrats. The winter cover values, like frequency above, provide another example of the disparity between the two monitoring sites. In Transect 1, six of nine quadrats recorded cover values of 25-50% in winter, while Transect 2 recorded cover values of 25-50% in four of eight quadrats in winter. Given the observations made about the growing season of *T. junceiforme,* it would be expected that little change would have been observed in cover values between autumn and winter. For Transect 2 this was true and that transect in fact recorded no change in any cover class. In contrast, Transect 1 actually recorded an increase in winter with the 25-50% cover class increasing from occurrences of 33.33% of quadrats in autumn to 66.66% in winter. Again climatic differences between Australia and Europe may provide an explanation, although, the observation that the regenerative ability of rhizomes is greatest in late winter-early spring (Harris & Davy 1986b p. 1060) may suggest that the area has been subject to erosion, resulting in rhizome fragmentation and subsequent regeneration.

2.6.4 Flowering of *Thinopyrum junceiforme*

Flowering of *Thinopyrum junceiforme* was not observed at any time over the entire monitoring period in Transects 1 or 2. The plant, in its home range, apparently requires vernalisation and flowers in summer (Nicholson 1952 p. 55). Consequently, there was an expectation for flowering in the warmer seasons following winter in the study area. The possibility of it flowering at other times was not excluded as Jessop et al. (2006 p. 279) indicated it flowers 'throughout the year but especially Dec.-July'.

Flowering of *Thinopyrum junceiforme* can be influenced by several factors, and plant 'source' may be an important factor. According to Nicholson (1952 p. 51) plants derived from rhizomes may flower in their first season whereas plants derived from seeds do not flower 'until the second or third seasons..'. Location is another factor. In his study Harris (1982) recorded flowering (albeit at low levels) in all foredune quadrats, but observed that flowering in strandline quadrats was 'rare' (Harris 1982 p. 50 & 52). He suggested low flowering in foredune areas may relate to grazing, although 'reserve depletion of tillers' could neither be confirmed or ruled out (Harris 1982 p. 53).

It is difficult to determine why flowering was not recorded in either monitoring site during the study period while (viable) seeds from flowering plants were obtained just south of the study area in January 2007, and thus explanations relating to vernalisation could be excluded. One explanation may be that plants in the areas studied were derived from seed and were only in their first or second season of growth. Another explanation may be that both areas were recovering from a previous catastrophic event, and that resources were too low for flowering. Certainly Short and Hesp (1980) indicated that along this stretch of coast foredunes are highly erosional and major foredune erosion occurs around every 3-5 years (p. 173). It may also support Nicholson's (1952 p. 57) assertions regarding the erratic and variable seed production of the plant.

2.7 SUMMARY

In its native environment the main growing season for *Thinopyrum junceiforme* is in spring/summer. Cover values and frequencies obtained for *Thinopyrum junceiforme* on the southern Younghusband Peninsula tend to support this, with average and total frequencies peaking in spring and with increases in summer cover values following the spring flush of growth, followed by a decrease in autumn, with little change between autumn and winter seasons (Transect 2). However, there were some anomalies, particularly in Transect 1. Higher than expected winter values may reflect climatic differences between the plant's native environment and conditions in Australia. Alternatively, it may reflect rhizome fragmentation and subsequent regeneration due to a previous period of erosion.

Flowering was absent over the entire monitoring period in both transects, despite viable seed being collected from inflorescences near by in the same year monitoring commenced. The fact that no transect recorded cover values exceeding 25-50% may support an explanation relating to recent establishment or re-establishment following a catastrophic event, or may reflect the assertion of Nicholson (1952) that flowering is characteristically erratic and variable.

CHAPTER 3. *THINOPYRUM JUNCEIFORME* IN AUSTRALIA: A SPATIO-TEMPORAL ANALYSIS USING HERBARIUM RECORDS

"Herbaria are treasure chests of information" (Heyligers 1998 p. 662)
"A well-annotated herbarium specimen is a priceless record that appreciates in value as time goes by!" (Heyligers 1998 p. 662)

This chapter provides an overview of the spatial and temporal distribution of *Thinopyrum junceiforme* in Australia, as interpreted through the collation and analysis of Australian Herbarium records. It also aims to shed light on the potential means of introduction and patterns, pathways and scale of spread along the Australian coastline.

3.1 BACKGROUND

3.1.1 Previous uses of herbarium records

According to Crawford and Hoagland (2009 p. 652), 'Herbaria are underutilized institutions that contain a large repository of historical and geographical information'. Nonetheless, herbarium records have been used in a variety of studies with a range of applications. They have been used in phenological studies to examine changes in the flowering period of plants in response to changes in climate in the United States (Primack et al. 2004), in the southern hemisphere along the Victorian coastline of Australia (Rumpff et al. 2010) and the sub-alpine and alpine regions of mainland Australia (Gallagher et al. 2009). Herbarium records have also been used in entomological studies such as investigating the history of leafminer insects on *Eucalypts* in southwest Western Australia (Abbott et al. 1999) and in a variety of agricultural studies including the measurement of changes in the size of American ginseng plants, to assist in assessing possible impacts of harvest (McGraw 2001) and in establishing the distribution of Tamarind trees (Bowe & Haq 2010).

Many investigations (eg. Stadler et al. 1998, Salo 2005, Barney 2006, Miller et al. 2009) have utilised herbarium records to study the invasion history of introduced species, including the study by Rodman (1986) of Sea-Rockets in Australia and the investigation of Rozefelds et al. (1999) on weed invasion in Tasmania since the 1970s. Aikio et al. (2010a p. 370) utilised herbarium records to examine 'lag-phases', which could be described as the period of '…little or no increase in species occurrence followed by an increase–phase in which species occurrence rises rapidly' of introduced species in New Zealand, which they found was on average 20-30 years.

3.1.2 Criticism of the use of herbarium records

Despite their widespread use and applications, some criticism has been levelled at herbarium records. According to Delisle et al. (2003 p. 1040) 'Numerous biases complicate the use of herbarium specimens for the historical reconstruction of biological invasions'. Rozefelds et al. (1999), for example, suggested that post 1970 collections in Tasmania are dominated by specimens from more populated urbanised areas. They suggest the high numbers of records from the east coast of Tasmania reflects the inclusion of Hobart in the east coast region and believe that this has resulted in 'a southern Tasmanian bias in collections…' (p. 27). Similarly, according to Aikio et al. (2010b p. 1746), in New Zealand, specimens are not '…systematically distributed; rather, they tend to cluster around urban areas. For this reason, conurbations are often perceived as hotspots for the spread of invasive species'. Likewise, Crawford and Hoagland (2009 p. 659) suggest that collections may reflect '…opportunistic and non-systematic plant collecting…' and that in Oklahoma, the focus of their study, specimen distribution '…follows a pattern correlated with population centres and botanically 'interesting' areas'.

On a different level, Rich and Woodruff (1992), suggested factors such as plant visibility and abundance may introduce bias into plant records, as may seasonality (Rich & Woodruff 1992 p. 86, Delisle et al. 2003 p. 1034). Similarly, Stadler et al. (1998), who used herbarium records to investigate the weed invasion processes in East Africa, suggested that biased records may result from collectors who focus on the more 'rare and more spectacular plant species' in contrast to introduced species (p. 20). A collector's 'taxonomic awareness' (Rich & Woodruff 1992 p. 76) and field identification (Delisle et al. 2003 p. 1034) ability may also affect records. Rich and Woodruff (1992 p. 76) also noted that 'it has also become more acceptable to record all introductions as they have become more widespread....' which has resulted in '...exaggerated rates of increase'.

Rich and Woodruff (1992 p. 76) also commented that 'It is often said that the distribution of plants reflects the distribution of botanists.....'. Similarly, Rozefelds et al. (1999 p. 27), in their study of Tasmanian weed flora noted that some taxa (eg. Cyperaceae) seemed to be 'over represented', which they thought may relate partly 'to having a specialist ….. with an interest in monocots employed ...'. The authors suggested it might also relate to the preparation of The Student's Flora of Tasmania Part 4b, which 'saw collectors and field staff focusing on the monocots...' (Rozefelds et al. 1999 p. 27). According to Crawford and Hoagland (2009 p. 658) historical occurrences such as the establishment of Oklahoma's universities '…influenced the temporal plant collecting pattern…'.

In contrast, the absence of certain taxa from collections may reflect one of two possibilities: that the plant was absent or that it has been under collected. Heyligers (1998) undertook a study to address this very problem. He compared herbarium records with coastal field survey data from NSW to help determine whether 'gaps' in the herbarium data related to the 'under collection' of data or because the coastal plants being investigated were actually absent. This is a valid point and one emphasised by others such as Holland (1975 p. 477) who warned that 'the nonavailability of a collection record is not evidence for the plant's absence'. While Heyligers' (1998 p. 645 & 650) study found that the herbarium records were chiefly 'representative of the overall distribution patterns' that less intensive collection methods in some areas had resulted in 'gaps in the herbarium records which, more often than not, ('*especially in the case of the more common species'*) were not reflecting the true situation in the field'. He continued: 'Contrary to what one would like to assume, even for widespread and common species (like *Spinifex sericeus*) the herbarium records may give incomplete coverage in the field' and consequently, 'there is no escape from actual checking in the field' (Heyligers 1998 p. 662). Similarly, Rodman (1986 p. 161) suggested that herbarium records, while valuable 'can provide only an imperfect guide ....and ideally should be supplemented with first-hand observations'.

Additional factors such as the accessibility of the sampling area may also affect plant records (Rich & Woodruff 1992 p. 84, Delisle et al. 2003 p. 1034). Not only may accessibility restrict sampling in a certain area, it may affect the spread of weeds into the area. Rozefelds et al. (1999 p. 27), for example, noted that in some areas of Tasmania, such as Mt. Wellington, there was a lack of post 1970s records, which they suggested was 'probably due to the geographical barriers that topography, altitude and climate pose to introductions of new weeds in these regions…'. On the other hand, geographic features such as '… canyons, mountains, unique rock outcrops and other topographically outstanding elements have lured botanists to collect many specimens to document their distinctive flora' (Crawford & Hoagland 2009 p. 659).

Aside from bias in herbarium collections for the reasons just described, collections may contain errors. According to MacGillivray et al. (2010 p. 431) collections may be '…prone to error, especially in relation to spatial positioning and scientific naming'. Miller et al. (2007 p. 414), for example, investigating the geographical range of *Banksia hookeriana*, found herbarium records errors included 'false identification', 'confusion of place names', and 'inappropriate interpretation of imprecise locations'. It is interesting to note that while Miller et al. (2007 p. 414) also referred to errors relating to 'false transcription of records to a digital database', MacGillivray et al. (2010 p. 431) believed that the procedure of transferring data from herbarium specimens to an online database, such as with Australia's Virtual Herbarium, '…has incorporated careful revision'.

Despite the criticisms listed in this section, herbaria are used for a wide variety of studies as they comprise an invaluable repository of information. They are particularly useful for documenting invasion histories and provide 'a record of the timing of new weed introductions, information on weed distributions and a means of following weed spread.' (Rozefelds et al. 1999 pp. 30-31). While bias may exist in the herbarium records, 'it does not invalidate the records, but requires that care is taken with interpretation' (Rich & Woodruff 1992 p. 73).

3.2 Methods

3.2.1 Australia's Virtual Herbarium (AVH)

Herbarium records were the principal data used to ascertain the distribution of *Thinopyrum junceiforme* in Australia. To ascertain the Australian distribution of *T. junceiforme* and identify Australian herbaria in which records of *T. junceiforme* were held, Australia's Virtual Herbarium (AVH) (http://chah.gov.au/avh/) was consulted. The AVH is an online or internet based database containing plant specimen data from Australian herbaria. At present, more than 80% of the 6 million Australian herbarium specimens have been incorporated into the AVH (Council of Heads of Australasian Herbaria Inc, [CHAH] 2010). It should be noted that the AVH comprise data from the larger Australian state/territory herbaria, but does not include data from university herbaria (Brendan Lepschi, Curator, CANB, Pers. Comm., 2006), which generally hold smaller collections established primarily as teaching resources (Cowley & West 1999). The incorporation of data from university herbaria is part of 'plans for future development' (CHAH 2010).

Data in the AVH can be accessed online via the 'query AVH' page (http://chah.gov.au/avh/public_query.jsp). On this page the user enters the 'taxon name' and may choose to include 'uncertain identifications'. The 'output format' options are i. map, ii. HTML table (to view in browser) or iii. CSV (Comma Separated Values) file. If the 'Map' option is selected, the user is able to choose whether geographical and environmental map layers are required[1]. Options for displaying the data are also given where results can be provided, for example, 'by herbaria,' or 'by species' (where a search of multiple species is undertaken). In response to a taxon query, the AVH returns a 'dot' map showing locations of the plant queried; it also indicates total number of records mapped, and number of records per State/Territory herbaria. Data points may be queried and layer options changed, once the map is produced. Options for map download in a number of formats such as JPEG and PDF are provided. If the HTML table (to view in browser) option is selected, a table is provided with records of the taxon queried. Table fields include: Source institute, Accession number, Scientific name, Family, Genus, Species epithet, Collector, Collecting number, Collecting date, State, Near named place, Latitude, Longitude, Geocode source and precision and Record update date. The CSV file contains the same data which is downloaded to the user's computer via a zip file. Instructions for use of the AVH can be found on the AVH website, (see http://chah.gov.au/avh/public_query_help.jsp).

The individual herbaria identified by AVH as holding collections of *Thinopyrum junceiforme* were determined after performing an AVH search, and were subsequently contacted to obtain their records of *T. junceiforme* to supplement and cross reference with the AVH records to check for any inconsistencies.

The AVH was consulted twice during the research to gauge the number of records of *Thinopyrum junceiforme* held by Australian herbaria. A preliminary search was conducted in 2005 to gain an overview of the plant's distribution according to herbarium data. A later search was conducted in 2010 upon which the current results (below) are predominantly based. Once compiled, herbarium records were sorted and analysed. Incomplete records were excluded from analysis (unclear or missing date or location). Specimens known to be cultivated were also excluded (Crawford & Hoagland 2009).

[1] Terrain, temperature, rainfall and so forth

3.3 RESULTS

3.3.1 Herbarium records of *Thinopyrum junceiforme* in Australia

In 2005 the AVH returned sixty six (66) records for *T. junceiforme* held in Australian herbaria, as summarised in Appendix 1. Records were returned from five Australian state/territory herbariums - the Tasmanian Herbarium (HO), the Australian National Herbarium (CANB/CBG), the National Herbarium of Victoria (MEL), the Queensland Herbarium (BRI) and the State Herbarium of South Australia (AD) – abbreviations refer to herbarium codes and are from Cowley and West (1999).

Five years later in 2010 the AVH returned one hundred and thirty four (134) records for *T. junceiforme* from Australian herbaria, just over double the number of records found in 2005 (Appendix 2). Records were returned from the Tasmanian Herbarium (HO), the Australian National Herbarium (CANB/CBG), the National Herbarium of Victoria (MEL), the Queensland Herbarium (BRI), the State Herbarium of South Australia (AD) and also the National Herbarium of New South Wales (NSW).

Comparison of data from 2005 and 2010 (Table 3.1) show an increase in herbarium records of *Thinopyrum junceiforme* for all herbaria except the Queensland Herbarium (BRI), as well as the addition of another herbarium holding *T. junceiforme* records: The National Herbarium of New South Wales (NSW).

Table 3.1. Comparison of number of herbarium records for *Thinopyrum junceiforme* in 2005 and 2010.

State/territory	**Herbarium**	**No. of records 2005**	**No. of records 2010**
Tasmania	Tasmanian Herbarium (HO)	9	18
Canberra	Australian National Herbarium (CANB/CBG)	13	17
Victoria	National Herbarium of Victoria (MEL)	23	32
Queensland	Queensland Herbarium (BRI)	5	5
South Australia	State Herbarium of South Australia (AD)	16	61
New South Wales	The National Herbarium of New South Wales (NSW)	-	1
	Total:	**66**	**134**

Reasons for the increase in numbers of records (68 records) between 2005 and 2010 may be due to a number of factors such as the collection of new specimens; new acquisitions from other herbariums; and/or the continuing digitisation of existing records via the AVH project. While acquisition numbers between herbariums may differ, data such as specimen collection date and record update date, which were provided with the original AVH data table but not shown here due to space constraints, may assist in identifying the source(s) of the increase in *Thinopyrum junceiforme* records held in Australian herbaria between 2005 and 2010. Data from each herbarium were examined in turn to determine the source of increase in records.

Tasmanian Herbarium (HO)

Records for HO doubled between 2005 (9) and 2010 (18). The AVH data table (not shown) indicated all records for HO were updated in May 2007. Examination of the collection date indicates that none of the additional 9 records for HO were newly collected specimens as all had a collection date prior to October 2005. Consequently, the source for the 9 new records must be new acquisitions from other herbariums (duplicates) and/or continuing digitisation of existing records via the AVH project.

Australian National Herbarium (CANB/CBG)

In 2005 the AVH returned 13 records and in 2010 it returned 17 records suggesting 4 new records during that time. However, analysis indicates that records for the Australian National Herbarium increased by 6 between 2005 and 2010 as two records present in 2005 were not present in 2010 (hence 6 and not 4 new records). The AVH data table indicates only one record was updated between 2005 and 2010, but not all records have a record update date. Examination of the collection date indicates that none of the additional 6 records for the Australian Herbarium were newly collected specimens as all had a collection date prior to October 2005. Consequently, the source for the new records must be new acquisitions from other herbariums (duplicates) and/or continuing digitisation of existing records via the AVH project

National Herbarium of Victoria (MEL)

Records for MEL increased by 9 between 2005 and 2010. The AVH data table indicates that between October 2005 (23 records) and November 2010 (32 records) various records had been updated in November 2005, early 2006 and late 2007. Examination of the collection date indicates that none of the additional 9 MEL records were newly collected specimens as all had a collection date prior to October 2005. While 2 (additional) records had no date listed in the AVH (Accession #'s 626891A and 626849A), additional enquiries

(Catherine Gallagher, National Herbarium of Victoria, Pers. Comm, 2005) indicated collections were from 1933. Consequently, the source for the new records must be new acquisitions from other herbariums (duplicates) and/or continuing digitisation of existing records via the AVH project.

Queensland Herbarium (BRI)

Records for BRI remained the same between 2005 and 2010 (5 records).

State Herbarium of South Australia (AD)

Records for the State Herbarium of South Australia increased by 45 between 2005 and 2010. The AVH data table indicates that between October 2005 (16 records) and November 2010 (61 records) various records had been updated in December 2005, and May, July and December 2009, and January 2010. Examination of the collection date indicates that most (43) of the 45 additional records for AD were newly collected specimens all having a collection date of 2009, with the remaining 2 records probably duplicates (acquisitions from other herbariums).

The National Herbarium of New South Wales (NSW)

The National Herbarium of New South Wales (NSW) did not hold any records for *Thinopyrum junceiforme* in 2005. However, by 2010 the AVH indicated NSW held one record for *T. junceiforme*. The record was added in January 2008. Examination of the collection data indicates that this was not a newly collected specimen as it had a collection date prior to October 2005. Consequently, the source for the new record must be a new acquisition from another herbarium, that is, a duplicate.

The preceding analysis indicates that according to the AVH the final number of herbarium records for *Thinopyrum junceiforme* in Australia in 2010 was 134, and that there were 43 new records (43 newly collected specimens) for *T. junceiforme* which came from AD (The South Australian State Herbarium). The remaining 25 records appearing between 2005 and 2010 probably reflect the acquisition of existing records between herbariums (duplicates) and/or the continuing digitisation of existing hard copy records via the AVH project.

It should be noted that not all herbarium specimens appear on the AVH for various reasons. The Australian National Herbarium Specimen Information Register (ANHSIR)

(URL: http://www.cpbr.gov.au/cgi-bin/anhsir), for example, lists a number of herbarium records of *Thinopyrum junceiforme* lodged at CANB that are not listed by the AVH. They include several specimens collected from Spain, Sweden, The Netherlands and the United Kingdom, and it is their overseas origin that likely precludes their inclusion in the Australian database. There are also four specimens held in CANB which were cultivated from seed imported from overseas, and these specimens are probably not on the AVH because they were deliberately cultivated in a controlled setting.

Also absent from the AVH is a herbarium specimen that is probably the 'oldest Australian specimen', which is lodged at the University of Melbourne herbarium (In correspondence between P. Heyligers and H. Lee, Latrobe University, 1988, as provided by P. Heyligers, formerly of the CSIRO, September 2005). Certainly, upon inquiry N. Middleton, of the University of Melbourne Herbarium (MELU), confirmed the existence of a MELU herbarium record collected by A.C. Gates at Geelong in 1923. In addition, MELU held herbarium specimens for the plant collected from Queenscliff, Victoria in 1959 and from Wilsons Promontory National Park, Victoria in 1964. As already mentioned, University herbarium data is not yet incorporated into the AVH. According to the MELU website currently '..only approximately 4% of the MELU collection is databased. Once substantially complete the MELU database will be linked to the Australian Virtual Herbarium' (MELU Herbarium Database, Modified 09 March 2011, URL: http://www.botany.unimelb.edu.au/ herbarium/database.html). These specimens have been incorporated into the final examination of the data (Appendix 3) as have 2 additional, new records from Tasmania. One record from AD has been removed due to insufficient information (collector id. and collection date). Hence, 138 records are shown in Appendix 3.

It is important to note some issues with the data. As mentioned above, the data contains duplicate entries where specimen data from one herbarium is acquisitioned by other herbariums and may be indicated by records having identical information (date, collection name, etc), except for the acquisition number. Duplicates are not indicated on the AVH. Another factor to consider are 'multisheets'. Multisheets are where there are several records sharing the same date, locality and collector 'probably because there was too much material to fit on one sheet' (C. Gallagher, Pers. Comm. 2005). According to Gallagher these 'should be treated as separate collections'.

3.3.2 The spatial and temporal distribution of *Thinopyrum junceiforme* from herbarium records

To gain an overview of the spatial and temporal distribution of *Thinopyrum junceiforme* it was necessary to sort the herbarium data according to date collected and the geographic location in which the plant was found. Appendix 3 and Figure 3.1 provide an overview of the spatial and temporal distribution of *Thinopyrum junceiforme* in Australia which appear to be limited to the south eastern states of Victoria, Tasmania and South Australia.

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Figure 3.1. The spatial and temporal distribution of *Thinopyrum junceiforme* from herbarium records. Source: Australia's Virtual Herbarium.

The following section reviews the spatial and temporal distribution of *T. junceiforme* in each state beginning in Victoria from where the first specimen was collected (see Appendix 3).

3.3.2.1 Victorian collections

As shown in Appendix 3 the earliest herbarium record for *Thinopyrum junceiforme* in Victoria, in fact Australia, was collected in 1923 at Geelong, Port Phillip Bay. 10 years later in 1933, more samples were collected from Port Phillip Bay, at Ricketts Point by E.J. Sonnenberg and nearby Mentone by R.A. Black. Samples from the 1940s and 1950s were also collected from various locations around Port Phillip Bay such as Altona and Swan Island by J.H Willis, author of 'Handbook to Plants in Victoria', West Port Melbourne by R.V. Smith, and Queenscliff by E.J. Sonnenberg, and further east in the vicinity of Western Port by T.B. Muir. Three samples were collected in the 1960s, at Portsea and the Mornington Peninsula again in Port Phillip Bay and one further east at Wilsons Promontory. In the late 1970s, a sample was collected west of Port Phillip Bay, near Anglesea. A number of samples were collected in the 1980s, extending from Port Phillip Bay in the Mordialloc (A.J. Brown) and the St. Leonards/Pt. Arlington (J.Z. Yugovic) areas, to localities further east at Phillip Island by P. Heyligers (Woolamai Beach), Waratah Bay (Shallow inlet) by P. Heyligers and A.C. Beauglehole, and again, Wilsons Promontory (A.C. Beauglehole). Some distance from the coast, a sample was also collected at Bells Swamp in Central Victoria, nearly 160 km away from Port Phillip Bay (Great Circle Distance, Geoscience Australia [http://www.ga.gov.au]) by A.C. Beauglehole during this period. The 1990s also saw a number of specimens collected, again at localities associated with Port Phillip Bay (Queenscliff – C. Le Breton; Mc Crae-Walsh, N.G.); as well as localities further to the east (Western Port - I.C. Clarke, Sandy point – A. Payget), again extending to Shallow Inlet near Wilsons Promontory (P.C. Heyligers). The remaining specimens were collected in 2004 from Black rock in Port Phillip Bay (V. Stajsic), and further east at Somers (J.R. Hoskings and V. Stajsic) and Waratah Bay (I.C. Clarke).

3.3.2.2 Discussion of Victorian collections

With the exception of specimens from the coastal town of Anglesea and inland at Bells Swamp, collections of *Thinopyrum junceiforme* appear to be associated with three main areas along the Victorian coast: Port Phillip Bay, Western Port Bay and the Wilsons Promontory/ Waratah Bay area (Figure 3.1). According to Heyligers (1985, 1986) *T. junceiforme* was probably accidentally introduced into Port Phillip Bay, where the earliest specimens were collected during the 1920s, 1930s and 1940s, through ballast water. It is also possible that a similar method of introduction occurred for Western Port, which recorded its first specimen in 1957 at San Remo. Both areas incorporate commercial ports with a long colonial history. Port Phillip Bay hosts the Port of Melbourne and the Port of Geelong. The former has the most ship visits per annum[2], but receives only 'relatively small' amounts of ballast [3]because most ships at that port 'both load and unload cargo' (EPA 1996 p. 117, 121). The Port of Geelong, has the second highest number of ship visits per year [4], but the least amount of ballast is discharged there[5] as most ships are 'fully laden with cargo' and therefore are not carrying substantial ballast (EPA 1996 p. 117, 121). It is Western Port, the second area of concentrated collections as described above, that is the recipient of 'the most ballast water of all the ports'[6], while having the 'second smallest number of ship visits per year' [7] because most ships come there to load cargo, and thus enter with much ballast (EPA 1996 p. 117, 121).

According to the National Research Council (U.S.) Committee on Ships' Ballast Operations (1996 p. 25) 'The major purposes of ballasting a vessel for a voyage are to increase its manageability (and safety), particularly under heavy weather conditions; control its draft and trim for maximum efficiency; and control its stability to ensure safe passage'. Prior to the use of water as ballast from the 1880s, solid ballast such as sand, rocks and other heavy items were used (National Research Council (U.S.) Committee on Ships' Ballast Operations 1996 p. 22). Ballast water and sediment discharged and taken on board during shipping operations '..frequently contain abundant living organisms reflecting in large part whatever is in the water around and under the ship at the time of ballasting.' (National Research Council (U.S.) Committee on Ships' Ballast Operations 1996 p. 11). According to the World Wildlife Fund's (WWF) (2009 p. 1) 'Silent Invasion' report :*'Every day, every hour, an estimated 7,000 marine and coastal species travel unnoticed across the world's oceans, silently stowed away in ships' ballast water tanks. When released in a new environment, these unwanted travellers can become invasive, outcompeting and changing native flora and fauna and resulting in irreversible ecological change and economic loss.'*

Thinopyrum junceiforme probably made its way to Australia in ballast water from Europe via either the Suez Canal, which opened in 1869 (Fitchett 1980), or via the Cape of the Good Hope which is the older route also known as the 'clipper way' (Chichester 1966).

[2] 2651 visits Aug 1994-July 1995 (EPA 1996)
[3] 1,419,600 tonnes estimated (EPA 1996)
[4] 342 visits Aug 1994-July 1995 (EPA 1996)
[5] 1,080, 200 tonnes estimated (EPA 1996)
[6] 2,262, 100 tonnes estimated (EPA 1996)
[7] 258 visits Aug 1994-July 1995 (EPA 1996)

Both were well-established routes between England and Australia, although later the Panama Canal offered an alternative route (Fitchett 1980). As a point of reference, in 1914 there were six passenger liner companies regularly using these routes: two, P&O and the Orient line, which also had mail contracts, used the Suez, while the remaining four travelled via the Cape of Good Hope (Fitchett 1980). The distance and time taken for the journey between Europe and Australia was influenced by factors such as the 'home' port (Fitchett 1980), the conditions experienced on the route taken: along the clipper way, for example, delays caused by the Doldrums or dangers encountered in the 'iceberg zone' of the Roaring Forties (Chichester 1966), and also whether travel was under sail or steam: while steam ships spelt the demise of the sailing ship, the latter were still in use in the late 1800's (Fitchett 1980). The route also influenced the distance of the journey with the route to Australia via the Suez being shorter than the clipper way (Fitchett 1980 p. 9).

While not directly comparable due to different home ports and subsequent ports of call, using the distances given in The Times Shipping Number 1912 (The Times 1913) and Hardy (1941), the Suez route from the UK (London) to Australia, stopping at Fremantle, Adelaide and Melbourne was 11,525 nautical miles and the clipper route from the UK (Southampton) to Australia direct from Cape Town to Melbourne was 11,814 nautical miles. According to Museum Victoria (nd) by the 1900s, steam ship transport and the Suez route meant the journey to Australia was reduced to '35 or 40 days'.

While ballast contamination may have been the initial mode of introduction of Sea wheat-grass in Port Phillip Bay, its spread may have been assisted by deliberate plantings. The Victorian Soil Conservation Authority (SCA) report of 1963 referred to trials for sand stabilisation which were undertaken at Queenscliff in 1962 and it was determined that '...the most successful primary stabilizers were marram grass (*Ammophila arenaria*) and sea wheat (*Agropyron junceiforme*)' (SCA 1963 p. 33). Other SCA reports (1964 p. 34, 1965 p. 29) have referred to the planting of '*Agropyrum junceum* (ex Israel)' in the area.

In the Wilsons Promontory area trials were also undertaken. Heyligers (2006) noted that Sea wheat-grass, along with Marram grass and some native species were used in sand stabilisation trials by the Soil Conservation Authority (SCA) in the 1950s in the area. According to an SCA report of 1959, the National Parks Authority requested assistance from the Soil Conservation Authority regarding erosion/sand stabilisation problems in some of its parks including Wilsons Promontory (SCA 1959-60 p. 14). A later SCA report indicated that the request for assistance was taken up: 'The experimental plot at Wilsons Promontory has given useful information about species for control of foreshore sand drift. Marram Grass (*Ammophila arenaria*) and *Agropyrum junceiforme*, one of the sea-wheat grasses, have made rapid and effective growth' (SCA 1960-61 p. 25). The SCA reports of 1961 and 1962 referred to the continuing trials at Picnic Point, which occurs just south of Tongue Point on the west side of Wilsons Promontory (SCA 1961-62 p. 32, SCA 1962 p. 25).

The SCA report of 1964 (SCA 1964 p. 34) referred to the use of plants for sand stabilisation that had been brought into the country by the CSIRO. Australia has had a long history of plant importations. Primarily this has occurred for economic purposes, to increase pastoral productivity (Cook & Dias 2006). According to Cook and Dias (2006) the number of plants introduced by the CSIRO's Plant Introduction Service from 1924 to 2000 was nearly 8300 species, with 2250 species being grasses (Cook & Dias 2006). Records indicate that *Thinopyrum junceiforme* was imported into Australia (as *Agropyron junceum* and *Agropyron junceum* spp.) by the Plant Introduction Section of the CSIR and CSIRO in the late 1940s, and early 1950s and 1960s (CSIR 1947, CSIRO 1952, CSIRO 1960a,b; ANHSIR 2011) from locations such as Bulgaria, Israel, Rumania and Portugal. It was also imported later in the 1980s, and specimens have been grown in pots from seed collected in The Netherlands and Greece in 1985 (ANHSIR 2011).

In addition to the three main areas identified above (Port Phillip Bay, Western Port and the Wilsons Promontory/Waratah Bay area) in the late 1970s, two additional samples were collected in Victoria as indicated earlier. One sample was collected west of Port Phillip Bay near Anglesea, a coastal town approximately 35 km from Geelong. It was collected from the mouth of the Angelsea River, but it is unclear whether it was an isolated plant or part of a larger population on this coast. Possibly, seed or rhizome fragments were washed ashore here from larger populations further east during storms. The SCA report of 1963 referred to the planting of Marram grass in this area to combat erosion but no mention is made of *Thinopyrum junceiforme* (or its synonyms) (SCA 1963 p. 24).

Occurring in non-coastal surrounds is the specimen collected at Bells Swamp, a 14 hectare wetland reserve in central Victoria. Investigations reveal a plant list for Bells Swamp compiled by the Castlemaine Field Naturalists Club in 2009 and reproduced in Kelsall et al. (2010). According to the Field Naturalists Club list, two 'wheat' grass plants occur in the reserve: *Elymus scaber var scaber* (Common wheat-grass) and *Lophopyrum ponticum* (Tall wheat grass) (synonym [and henceforth] *Thinopyrum ponticum*), *Thinopyrum junceiforme* does not appear on the list. It seems likely that *T. ponticum* was mistakenly identified as *T. junceiforme*: *T. junceiforme* appears to colonise coastal areas (Chapter Two) whereas *T. ponticum* apparently has '… extraordinary ecological amplitude, invading saltmarsh, wetlands, grasslands, estuaries, coastal cliffs, waterways, roadsides and some woodlands and tolerating drought, frost, salinity, alkalinity and waterlogging' (Booth et al. 2009 p. 4).

Thinopyrum ponticum is an invasive species, but with a twist, it has been cultivated and promoted for saline soils: 'Victorian farmers have been encouraged and subsidised to plant Tall Wheat Grass (*Lophopyrum ponticum*) as a salt-tolerant pasture. It has already escaped cultivation at hundreds of sites, and according to a Victorian Government assessment, it could invade more than 10 million hectares of Victoria' (Booth et al. 2009 p. 4). Consequently, it seems more likely that the record for Bells Swamp was a case of mistaken identity. Vegetation surveys in the area once the swamp has drained may verify this.

3.3.2.3 Tasmanian collections

The earliest record for *Thinopyrum junceiforme* for Tasmania is from Rocky Cape Black River road in 1948 by W.M. Curtis (Appendix 3). No further specimens were lodged for that state for almost another 3 decades, when in 1975 specimens were collected from Flinders Island by D.I. Morris and J.S. Whinray, a year later in 1976 by M. Allan and again in 1982 by D.I. Morris. In 1986 a specimen was collected from Circular Head, north west of Rocky Cape by A.M. Buchanan. In the 1990s specimens were collected from Cape Portland on the north eastern tip of Tasmania (D.F. Steane), Three Mile Sand (north west coast) and Bridport (north east coast) by P. Heyligers, and Sisters Beach on the north west coast of the state (G.N. Batianoff) and again from Flinders Island (Pats River – T. Rudman). In the 2000s, specimens were collected from near Arthur River (north west Tasmania) (R.B. Schahinger), from Somerset Beach on the north west coast (A.M. Buchanan), and the Georgetown and Beechford coastal Reserves by M.L. Baker in 2005 on the north east coast. The most recent specimens were collected by P.A. Tyson in 2008 from West Cove Erith Island in Bass Strait and by A. Povey in 2010 at Ulverstone East (west bank of Buttons Creek) on the northern coast of the state.

3.3.2.4 Discussion of Tasmanian collections

Herbarium specimen collections from Tasmania (Figure 3.1) indicate that *Thinopyrum junceiforme* is widespread but confined to the north of the state, including off-shore Flinders Island. It differs from other important coastal weeds of the State such as Marram grass which '...is widespread in all bioregions with the exception of the west and southwest bioregions where it is localised' (Rudman 2003 p. 3). However, unlike *T. junceiforme* Marram grass was introduced into Tasmania in the 1800s and used extensively for dune stabilisation and pastoral purposes (Pemberton & Cullen 2004). That being said, there is apparently some suggestion that unauthorised planting of Sea wheat-grass has occurred on the north west coast of the state (T. Rudman, Pers. Comm. 2005).

Probably, Sea wheat-grass found its way to Tasmania via Bass Strait, brought over by currents from Victoria. Certainly, Rudman (2003 p. 2) suggested this mode of dispersal is likely for Sea-wheat grass and other invasive species found on the Tasmanian coast: '*ocean currents carry new beach weed invaders south from the mainland and rapidly across the north and down the western coastline of Tasmania. The east and southern coastlines are less rapidly invaded due to the influence of southerly currents for some of the year on those coasts. Sea spurge, sea wheat grass and beach daisy all follow this pattern of establishment'.*

According to Heyligers (2007 p. 167), drift card and bottle studies are 'relevant to the dispersal of buoyant plant propagules'. Previous studies using these methods confirm the potential of ocean currents to aid in the dispersal of weeds to Tasmania. According to Hilton et al. (2004) such flotation devices, '...released between Kangaroo Island (SA) and 90-Mile Beach (NSW), a distance of 1200 km, have been recovered on Tasmanian beaches. ….. Those released north of Tasmania, in the vicinity of 90-Mile Beach, Victoria, have been recovered from the north coast, Flinders Island and the east coast of Tasmania...' (Hilton et al. 2004 n.p.). According to these authors such studies '…demonstrate the high exposure of the north and northwest' (Hilton et al. 2004 n.p.), and clearly the distribution of *Thinopyrum junceiforme* in Tasmania (Figure 3.1) reflects these observations.

It is possible that *Thinopyrum junceiforme* made its way over to Flinders Island and mainland Tasmania from plantings on Wilson Promontory, as most specimens found there post-date plantings there by the SCA, although, this may merely reflect an artefact of the collection regime for the plant in Tasmania. Certainly, the first specimen collected in Tasmania (Rocky Cape) was in 1948 (thus, pre-dating the SCA plantings). This specimen was collected by the Tasmanian botanist, Dr Winifred Curtis, who wrote 'The Student's Flora of Tasmania', part 1 of which was published in 1956 (Curtis 1956). Apparently, for the purpose of the Flora's production 'With few exceptions, descriptions were written from fresh material collected during vacations by Winifred....' (Kantvilas 1991 p. 3). Consequently, the production of the State's Flora no doubt influenced the collection of *T. junceiforme* at this time and was responsible for it being recorded for the first time in Tasmania, even though it did not appear in the initial volumes which covered Gymnosperms and Dicotyledons (later versions - Parts 4A and 4B - covered Monocots [Duretto 2009]). One of the very next samples collected (in 1975 from Flinders Island) was by Curtis's co-author of subsequent Tasmanian Floras, D.I. Morris, who was a weed officer for the Department of Agriculture and an honorary member of the Tasmanian Herbarium; he was also involved in the production of publications on Tasmanian weeds (Department of Primary Industries, Parks, Water and Environment 2010).

The 1948 specimen collected by Curtis may have either found its way over from another mainland source, for example, Port Phillip Bay, although it may be entirely possible it arrived in ballast from ships docking at the nearby port of Stanley to the west or Burnie to the east, both towns established by the Van Diemans company in the 1820s (Pink 2005a, b).

3.3.2.5 South Australian collections

The first herbarium record for *Thinopyrum junceiforme* in South Australia comes from Long Beach in the south east of the state collected by P.C. Heyligers in 1983 (Appendix 3). In 1984 D.J.E. Whibley collected a specimen from metropolitan Henley Beach. Two years later in 1986 samples were collected from the south east of the state from Butcher Gap Conservation Park (P. Gibbons) and Younghusband Peninsula (P.C. Heyligers), as well as metropolitan Semaphore (P.C. Heyligers). In 1989 specimens were collected from the metropolitan beaches of West Beach (A.G. Spooner) and again Semaphore (R. Bates), as well as Canunda National Park (P. Heyligers) in the south east. In the 1990s specimens were collected from Hindmarsh Island (D. Owen) and 'Surfers' (west of Goolwa) (R. Taylor) on the Fleurieu Peninsula. In the 2000s samples were collected from metropolitan Henley Beach (D.J.E. Whibley) in 2002 and from Parsons Beach on the Fleurieu Peninsula in 2009 by R. Taylor. The remaining 41 specimens were collected by C.J. Brodie in 2009 with locations ranging from North Haven (at the northern limits of the Adelaide metropolitan coast) to Normanville on the Fleurieu Peninsula, to Piccaninnie Ponds in south east South Australia near the South Australian – Victorian Border. Aside from the North Haven and Normanville specimens, the localities of specimens are restricted to the south east and include Barker Knoll, Beachport, Bernouilli Conservation Park, Bucks Bay, Cadara Swamp, Canunda National Park, Carpenter Rocks, Coorong National Park, Cape Douglas, Fox Beach, The Granites, Cape Jaffa, Kingston S.E., Little Dip Conservation Park, Long Beach, Nene Valley, Nora Creina Bay, Oil Rig Square, Post Office Rock, Rivoli Bay, Robe and Cape Thomas.

3.3.2.6 Discussion of South Australian collections

Thinopyrum junceiforme was first collected in South Australia by Petrus Heyligers who has kept records of observations of the presence/absence of this plant in South Australia between Port Adelaide and the Victorian border since 1978. This first specimen of *T. junceiforme,* collected in the south east of South Australia, occurred much later than compared with the other states: about 60 years after the first specimen was collected in Victoria and nearly 40 years after it was first collected in Tasmania. Following the collection of this first specimen, a number of other specimens were collected, predominantly from the 1980s, from two widely separated geographical areas; from the south east of the state and from many kilometres away, along a number of the metropolitan Adelaide beaches (Figure 3.1). While a few more specimens were collected in the intervening time, it was in 2009 that a significant influx of herbarium specimens of *T. junceiforme* in South Australia occurred. The collector of these specimens was C.J. Brodie who undertook '… a targeted weed survey for *The Limestone Coast and Coorong Coastal Action Plan*' (C. Brodie, Pers. Comm., 2011). The plan is described as 'a coastal conservation assessment and coastal action plan for the South East coast between the Murray River Mouth and the South Australia – Victoria border' (Caton et al. 2011). When undertaking the plan it was found that there was a dearth of data for environmental weeds for the area and so consequently, a weed survey was undertaken '...to supplement what little information there was in the databases' via a collaboration between the South Australian State Herbarium and DENR Coastal Management (Caton et al. 2011 p. 151). Results of the weed surveying led Brodie to conclude that *T. junceiforme* was under represented in the herbarium records in the south east of the State (Brodie 2010).

While it appears to have been under-represented in the herbarium records (Brodie 2010), it is still likely that the plant was not present in the study area much earlier than its collection by Heyligers. This is because while it is an isolated coast which may not lend itself to frequent specimen collection, Hilton and Harvey (2002) noted that in a comprehensive study along the Coorong foredune undertaken predominantly in 1979, Short and Hesp (1980) did not refer to the presence of *T. junceiforme*. Similarly, in a vegetation survey of the Younghusband Peninsula in 1981, Douglas et al. (1982) also made no reference to this plant.

3.4 Discussion

3.4.1 Potential pathways of dispersal between the Australian states

For *Thinopyrum junceiforme* the ocean has not been a barrier, but a vector for its dispersal. From its source area in Victoria *T. junceiforme* probably found its way to Tasmania via Bass Strait, a likely scenario based on previous studies using drift cards and bottles. In fact, the movement of the plant between all three south eastern states may result from water movements in the area. Tasmania may, for example, provide a source of plant material for dispersal to South Australia and Victoria as drift card studies from the CSIRO indicate releases from the north west coast of Tasmania made their way to the mainland including to Angelsea, Victoria (the outlier identified in herbarium records for that state) and Meningie, South Australia (Anon 1985). Drift bottle studies also demonstrated that releases from Cape Northumberland in South Australia found their way to south west Victoria, and releases from Cape Otway, Victoria, found their way to the south east of South Australia and Kangaroo Island (Olsen & Shepherd 2006 p. 116).

Analysis of early CSIRO drift bottle programs undertaken by Olsen and Shepherd (2006) to examine lobster larval dispersal indicated that while there is some variability in the '…seasonally reversing surface water masses', surface water tends to flow along the South Australian coast to the east through Bass Strait and to the south east past the west coast of Tasmania in winter, and in summer reverses to flow west – north west and north east - north west (Olsen & Shepherd 2006 p. 115, Vaux & Olsen nd). The surface water movements appear to be important in the dispersal of lobster larvae which predominantly rely on such passive means of transport (Olsen & Shepherd 2006 p. 119) and similarly provides *T. junceiforme* with a mode of transport and an ongoing opportunity for spread between the south eastern states.

3.4.2 Introduction and scale of invasion

As indicated in Chapter 1, according to Richardson et al. (2000) an alien species usually overcomes a major geographical barrier assisted either accidentally or deliberately by humans. *Thinopyrum junceiforme,* as mentioned above, probably initially arrived in Australia from Europe accidentally via ballast (a distance of over 11,500 nautical miles via either route) hence meeting the first criteria of Richardson et al. (2000). If the alien species successfully becomes naturalised it may subsequently be considered invasive if it is able to give rise to self sustaining populations at locations further than 100 m in less than 50 years (via seeds 'and other propagules') and for plants spreading vegetatively, over 6 m in around 3 years (Richardson et al. 2000 p. 93). *T. junceiforme* exceeds this scale spectacularly if applied to the distance between the first location it was found in each State and the time it took to arrive (or be recorded) in each respective location. It was, for example, first recorded in Victoria in Geelong in 1923, then in Tasmania at Rocky Cape in 1948, and subsequently in South Australia at Long Beach in 1983. Hence, it took 25 years to spread from Victoria to Tasmania, over a distance of 319 km[8] and 35 years to spread from Tasmania to South Australia over a distance of 672 km[9] or 60 years to spread from Victoria to South Australia over a distance of 430 km[10]. Hence, *T. junceiforme* may be considered an invasive species in Australia.

3.4.3 Other species of the Genus Thinopyrum in herbarium records

As indicated in Chapter Two, *T. distichum*, *T. pycnanthum* and *T. elongatum/ T. ponticum* and have also been recorded in Australia (Atlas of Living Australia 2012b), with some confusion existing regarding the status of *T. elongatum* and *T. ponticum*. Herbarium records from the AVH show that *T. elongatum* has been recorded in South Australia, Victoria, Tasmania and New South Wales with a total of 55 records (see AVH *http://www.chah.gov.au/avh/avhServlet*) with *T. ponticum* being recorded in Victoria and Tasmania with a total of 11 records (see AVH *http://www.chah.gov.au/avh/avhServlet*). *T. pycnanthum,* also referred to as *Elytrigia pungens, Triticum pungens, Elymus pungens* and *Agropyron pycnanthum,* has been recorded in Victoria and the ACT. The Canberra record, from 1962, refers to cultivated plants with seeds from France (Atlas of Living Australia 2012c).[11]

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[8] Calculated using 'As the Cocky flies', Geoscience Australia: http://www.ga.gov.au/cocky/distance.jsp
[9] As above
[10] As above
[11] Not listed on AVH

Unlike the other species that tend to be distributed in the south eastern States, *T. distichum* is the only species that has herbarium records for Western Australia, the state to which it is entirely restricted. According to herbarium records, of which there are 16 (see AVH *http://www.chah.gov.au/avh/avhServlet*), the South African plant was first collected in 1957 from Geraldton, a 'port city' nearly 425 km north of Perth, and the coastal suburb of Mahomet Flats. Given the areas maritime history it is likely it arrived in ballast. The plant was next recorded in the 1970s at Lancelin, 127 km north of Perth. Research by Petrus Heyligers suggests that the plant was imported from South Africa by the Department of Agriculture for 'dune reclamation work in the Lancelin area…' (Heyligers 1987).

It is interesting to note that most species of the genus *Thinopyrum* just described appear to be confined to the south eastern Australian states. They form part of an 'invasion hotspot' which are 'areas of potentially suitable climate for multiple non-native plant species' (O'Donnell et al. 2012 p. 1). Aside from having a favorable climate, these areas are seemingly related to regions of 'high population density' and are characterised by factors such as the deliberate, 'frequent and widespread' introduction of exotic species and the presence of many 'introduction pathways' (O'Donnell et al. 2012 p. 8). Another invasion hotspot occurs in the south west corner of Western Australia, but it is the former region that has the higher invasion potential and 'reflects the historical pattern of plant introductions in Australia' (O'Donnell et al. 2012 p. 8).

3.4.4 Influences on herbarium collections

Collections of *Thinopyrum junceiforme* in Australia have not been a purely random exercise: collector's interests, their jobs, and associated projects have had some influence on the existence of herbarium records of the plant. In Tasmania, for example, the production of the floras may have influenced collection of the plant firstly by W. Curtis and later, by D.I. Morris. In South Australia, the production of *The Limestone Coast and Coorong Coastal Action Plan* has also influenced the substantial increase in herbarium specimens for *T. junceiforme* in the area. Collections in all states (where it is known to occur) have been enhanced also by the work of Petrus Heyligers, formerly of the CSIRO, whose research into coastal weeds is reflected in his numerous related publications.

3.5 SUMMARY

Herbarium records indicate *Thinopyrum junceiforme* has been collected from the wild from three south-eastern Australian states: Tasmania, Victoria, and South Australia which form part of a ‘zone of high invasion potential’ (O’Donnell et al. 2012). The first specimen of *T. junceiforme* was collected from Victoria in the 1920s. Probably, the plant was initially accidentally introduced via ballast from Europe. Sand stabilisation trials by the Soil Conservation Authority may have assisted in the spread of the plant in this State. Collections are restricted to Port Phillip Bay, Westernport and the Waratah Bay/Wilsons Promontory area. Specimens of *T. junceiforme* were collected in Tasmania from the late 1940s. This and subsequent specimens are all restricted to northern Tasmania and it is likely that colonisation has resulted from dispersal of plant material across Bass Strait. In South Australia, specimens of *T. junceiforme* were not collected until the 1980s. Restricted to the Adelaide metropolitan coast and the south east of the State, evidence suggests it is under-represented in the herbarium records. The spatio-temporal scale of spread of *T. junceiforme* in Australia qualifies it as an invasive species according to the scale of Richardson et al. (2000).

CHAPTER 4. ANALYSING THE AWARENESS AND PERCEPTIONS OF *THINOPYRUM JUNCEIFORME* USING AN ONLINE SURVEY

This chapter focuses on results from a Sea wheat-grass questionnaire, an electronic survey that aimed to collect information on a targeted sample's knowledge, experience and opinions of the alien grass. It was hypothesised that the plant largely 'flies below the radar' and that the questionnaire would assist in confirming this opinion, or otherwise.

4.1 BACKGROUND

4.1.1 The pros and cons of electronic questionnaires

Analysis of survey literature indicates that there are both advantages and disadvantages to using electronic surveys. The main points relevant to this research are summarised below, although the results should be interpreted with some degree of caution due the varying methodologies (eg. number of contacts, mixed mode) and circumstances (eg. population surveyed, topic of survey) of the studies from which the results are derived. Indeed, according to Cole (2005 p. 424) 'A review of literature suggests that mixed findings on electronic modes of data collection, to a large extent, are due to the mixed methods that have been employed in Web-based surveys'.

4.1.2 Benefits of electronic surveys

One of the positive benefits of email in survey work often cited in the literature, and referred to as '…a key benefit to email surveys' (Sheehan & McMillan 1999 p. 48), is the quicker speed of survey return compared to mail surveys (eg. see Sheehan & McMillan 1999, Sheehan & Hoy 1999). A distinction should probably be noted between email surveys which 'Up until a few years ago' were 'the predominate means of Internet surveying' (Solomon 2001 p. 2) and surveys using email and a web link (web surveys), which are often grouped under the generic 'electronic survey' (Shih & Fan 2008).

In their study, Smee and Brennan (2000) noted the speed of response return to their surveys was from fastest to slowest: email, web and finally postal surveys, although they found the difference between the two electronic formats was only 'slight' (p. 1203). The results of other studies seem to confirm that the early assertions made about email and traditional mail can be translated to web surveys, with for example, responses of 5.97 days (Cobanoglu et al. 2001 p. 3) and 9.22 days (Truell et al. 2002 p. 47) for web surveys and 16.46 days (Cobanoglu et al. 2001 p. 3) and 16.43 days (Truell et al. 2002 p. 47), for mail.

These results are comparable to that of Schaeffer and Dillman (1998 p. 389), who found response rates for a mail survey and a survey which was contained in the body of an email, averaged 9.16 days for email and 14.39 days for mail. Moreover, they cite that 17.6% of email survey responses were received on the day they had been emailed, with over 50% returned prior to the return of the first postal survey. Alternatively, it should be noted that some studies have found the difference between response speeds of mail and email to be not significant (see Tse et al. 1995).

Another benefit of email in survey work often cited in the literature is the lower costs involved, compared to mail surveys (Sheehan 2001, Sheehan & Hoy 1999). Cobanoglu et al. (2001 p. 2) found that web surveys were the most 'cost efficient' compared to fax and mail surveys, the latter of which involved 'considerable labour and financial resources'. According to Cole (2005 p. 423), who undertook a literature review on electronic surveys 'there seems to be a consensus that electronic surveys in general are less expensive than the traditional mail surveys because they do not involve printing, folding, envelope stuffing, and mailing costs'. Although, Umbach (2004 p. 24) suggested that 'The costs of building the Web form, managing email addresses, sending invitation and reminder emails, and maintaining computer networks cannot be overlooked'.

Other potential advantages of electronic surveys may include longer responses/comments to open ended questions (Seguin et al. 2004 p. 417, Schaefer & Dillman 1998 p. 389), and responses that may be more '..clarifying and illuminating' and 'insightful' (Mehta & Sivadas 1995 p. 10). Other authors found electronic surveys had a higher rate of completion (fewer items left uncompleted) (Schaefer & Dillman 1998 p. 388, 389, Truell et al. 2002 p. 48), although, Truell et al. (2002 p. 48) found this to be 'inconsistent' with previous studies that indicated 'similar' levels of completeness. On the other hand, Cole (2005 p. 428) found that his mail survey had fewer missing items than his web survey, contrary to previous studies such as that by Schaefer and Dillman (1998), which he attributed to formatting differences.

4.1.2.1 Specific benefits of the online component

The online (Web link) component gives added benefit to surveys than if email alone had been used. One benefit of the email-online combination is that respondents don't have to deal with an email attachment (if the survey was sent as an attachment), which may include saving the attachment to their computer and re-attaching the completed survey to a reply. According to Seguin et al. (2004) this may be difficult with some email programs and may require a higher level of computer skill to perform. Alternatively, and particularly in ‘the early years of email use’ (Truell 2003 p. 31), surveys have been presented in the email body (eg. see Schaefer & Dillman 1998, Seguin et al. 2004, Truell 2003). Although, using this option the survey may suffer from poor formatting options and the possibility of being accidentally modified. Some technical difficulties may also be experienced by respondents using this method (see Sheehan & McMillan 1999 p. 51). Alternatively, clicking on a survey link in the body of the email transports the respondent directly to the survey online, which has all the benefits of formatting and functionality, and consequently overcomes ‘the limitations of the e-mail format’ (Smee & Brennan 2000 p. 1201). However, on the negative side Schaeffer and Dillman (1998) suggested that some emails may not support hyperlinks, and that subsequently, the link may have to be pasted into the respondents’ internet program, an added step which could lead to reduced response rates, although, according to Solomon (2001 p. 2) ‘Modern email packages automatically convert universal resource locators (URLs) or web-addresses in the text of an email into a hyperlinks’.

4.1.3 Problems with electronic surveys

4.1.3.1 Concerns with unsolicited email questionnaires

Some authors have considered that email based surveys may have cause for ‘ethical concern’ in that ‘unsolicited email invades a person’s private space’ (Yun & Trumbo 2000). In their study, Mehta and Sivadas (1995 p. 10) received so many complaints from respondents about an unsolicited email survey the authors sent to them, that they abandoned the survey ‘half way’, concluding that it was obvious unsolicited emails were not acceptable. Sheehan and Hoy (1999) in their study also received complaints: ‘Several individuals receiving the solicitation email censured the researchers for sending out unsolicited emails, and accused the researchers of ‘spamming’’ (p. 12). According to these authors the definition of spamming varies. Their internet service provider regarded spamming ‘as unsolicited email that was of a commercial nature, or of a political nature, or that in some way caused distress to the receiver’ (p. 12). According to the Australian Government’s Australian Communications and Media Authority (ACMA) ‘In Australia, spam is defined as 'unsolicited commercial electronic messages'’ (ACMA nd).

In their study, Sheehan and Hoy (1999 p. 8) sent potential respondents a ‘solicitation’ to participate in their survey a week before the survey was sent, and suggested that ‘The solicitation e-mail provided potential respondents with the chance to opt out...’.

4.1.3.2 Confidentiality and anonymity of email surveys

Email is not an anonymous technology (Schaefer & Dillman 1998). While sending individual personalised emails to individual survey respondents would be ideal (see Schaefer & Dillman 1998), it is not a realistic option in most circumstances when compared to the convenience of sending one email to a list of recipients. When sending an email to a number of addresses, the names or organisations in the multiple recipient list can be suppressed using the BCC or blind carbon copy feature resulting in the words ‘undisclosed recipient’ in the ‘To’ line, although this is considered ‘inappropriate’ by some (Schaefer & Dillman 1998). Another concern with email is that whether the BCC method is used, or if personalised emails are sent (see Schaefer & Dillman 1998), the respondent’s identity may be revealed in the ‘from’ line when replying (Sheehan & Hoy 1999).

In their study Schaefer and Dillman (1998 p. 382) suggested that their topic was not related to ‘a particularly sensitive issue’ and concluded that ‘assurances of confidentially should be more than adequate’. According to Sheehan and Hoy (1999 p. 4, 5) ‘..confidentiality can be guaranteed through confidentiality assurances. …. Assuring that responses will be confidential throughout the data collection process should help to build respondent trust and enhance response rates’.

4.1.3.3 Technical issues

Technical issues that may affect survey responses may relate to the respondents’ Internet connection and computer/software issues (Solomon 2001 p. 3); mention has also already been made of URLs failing to connect to the survey page via a hyperlink (Schaeffer & Dillman 1998 p. 392). Again as mentioned above, modern technology should mean that some issues become less of a reality (see Solomon 2001).

Undeliverable or invalid email addresses may also be a problem (Seguin et al. 2004 p. 418), and prevent potential respondents from participating (Truell et al. 2002 p. 48). Although, an advantage of invalid email addresses is that the numbers of emails that can not be delivered can be determined (Sheehan 2001 p. 2).

The most obvious technical issue is that potential respondents need to have access to the technology (email, internet) (Truell et al. 2002 p. 48), a lack of which may restrict the sampling frame (Mehta & Sivadas 1995 p. 2), and cause ‘coverage bias’ (Solomon 2001 p. 3) and is why a ‘mixed mode’ approach is recommended by some (Cobanoglu et al. 2001). Again, it is thought that this will become less of an issue over time (Solomon 2001 p. 4).

4.1.3.4 Response rate

One of the mostly commonly cited problems with electronic surveys is varying/low response rates. According to Sheehan and McMillian (1999 p. 46) ‘Response rates to e-mail surveys…..do not consistently show benefits over postal mail and, in some cases, fall below what may be seen as acceptable levels of response’. Schaefer and Dillman (1998 p. 379) also suggested that ‘electronic mail has generally failed to meet the standard set by comparable mail techniques’. Studies in the literature reflect these mixed results, for example, the study by Seguin et al. (2004 p. 418) found email response rates were lower than postal, whereas Cobanoglu et al. (2001 p. 4) found web results were better than mail surveys, while Truell et al. (2002 p. 47) found no significant or practical difference between mail and internet surveys. Most recently, Shih and Fan’s (2008) analysis of 39 comparative studies of web and mail surveys found that mail surveys had an approximately 10% higher response rate than web surveys. The main issue with lower response rates appears to be the potential for bias in survey results (Shih & Fan 2008 p. 16).

4.1.3.5 Conclusions

Electronic surveys have both advantages and disadvantages in comparison to mail surveys. Advantages such as cost and time efficiency are the main positives influencing the use of electronic surveys in this study, as well as the suggestion by Mehta and Sivadas (1995 p. 10) that more ‘insightful’ responses may be gained.

4.2 METHODS

4.2.1 Questionnaire medium

In this research an electronic medium, comprising an email and online (Web) combination was chosen. Using this approach, the email contained a ‘covering letter’ explaining the research and inviting potential participants to participate in the survey. If the recipients of the email were willing to participate in the survey they could choose to do so by clicking a link (the survey’s URL) placed in the email body. The link also allowed the respondent to ‘opt out’ if desired.

In addition to the email-online approach, a link to the survey was also placed on the Marine and Coastal Community Network (MCCN) website.

4.2.2 Structure of the survey

The questionnaire used in this study was a self-administered survey comprising a series of 19 questions divided into three thematic sections (See Appendix 4). The first section focused on participant details such as organisational affiliation and state, and served to provide information on the types of respondents participating in the survey. The second section, forming the main body of the survey, focused on the participant's knowledge, opinion and experience of Sea wheat-grass and comprised those questions seen as most critical to meeting the aims of the survey. The third and final section of the survey sought to ascertain the respondent's perceptions on coastal and coastal weed management to provide additional background and perspective on the respondent's views and opinions.

The survey comprised a combination of open-ended questions and closed-ended multiple choice questions where one or more answers may be selected depending on the nature of the question (See Appendix 4). No question had a 'required answer'. An effort was made to present a short and concise survey, which was quick and easy to undertake, so attempts were made to keep open-ended questions to a minimum. However, their use was seen as particularly necessary for those questions where the respondent's personal views and opinions, in their own words, were required.

4.2.3 Survey guidelines

The questionnaire was prepared following Taylor (2007) *Studying People. Guidelines on the ethical conduct of research in the Humanities and Social Sciences* and the *National Statement on Ethical Conduct in Human Research* (2007), which is both a legal and University regulation (Taylor 2007 p. 2-3).

4.2.3.1 Participant Information Sheet

A Participant Information Sheet is usually provided to all potential survey respondents to provide information about the project, upon which an informed decision to participate in the research can be made (Taylor 2007). The Participant Information Sheet for this research occurred in the form of a 'welcome' page on the survey website. Personal information such as the researcher's name and organisational affiliation were provided first, and then the research topic was introduced. The purpose and rationale of the questionnaire were then explained, followed by a statement claiming that participation in the study was voluntary and strictly confidential. A contact email address for further information was also provided. Much of this information was also provided in the initial introductory letter emailed to potential participants.

4.2.3.2 Consent to participate in the research

Usually respondents are provided with a consent form, which they sign, to agree to participate in the research, and which contains a number of conditions and options designed to protect their interests (Taylor 2007). In the case of questionnaire responses that are anonymous consent forms do not need to be provided to participants (Taylor 2007). As this study will not be identifying individuals in the results, a consent form was not provided to respondents.

4.2.4 Confidentiality and anonymity

Emails were sent using the BCC method so that recipients were unable to see the email addresses of other recipients receiving the same email. Given that the introduction letter (in the email) stated that other councils or weed societies from other states were also being approached for participation in the survey, and given that these email address were obtained from the public domain, this precaution was more of a courtesy then a necessity. In regard to the anonymity, the respondent's identity was protected when undertaking this survey in several ways. For example, the respondents had no need to reply to the email sent as they are directed toward the online survey via a link. In addition, when submitting the survey the respondent's IP address (perhaps the computer equivalent to a name being displayed in the 'from' line when replying to an email) was not saved in the results.

Overall, whether respondents participated in the survey via the link in the email, or via the link on the MCCN website, the study is confidential and anonymous to the extent that individuals were not linked to the responses given, when presented in the thesis. Respondents were not asked to provide personal information such as their name in the survey and while organisational affiliation was requested voluntarily for analytical purposes, an individual's response was not tied to their organisational affiliation, if provided. Assurances of confidentiality were also given on the 'welcome' page of the survey.

4.2.5 Intended participants of the questionnaire

A broad range of respondents was encouraged to participate in the questionnaire, whether they be associated with government organisations, industry, community, conservation or environmental groups, landholders, students, educators, researchers or other individuals interested in or working in areas with coastal and/or weed management. To cover this broad range of participants, questionnaires were directed towards coastal Councils (LGAS/MAVS) and weed societies in Victoria, Tasmania and South Australia, the Victorian Coastal Council (VCC) and the Marine and Coastal Community Network (MCCN).

4.2.6 Survey design

4.2.6.1 SurveyMonkey tool

The Sea wheat-grass questionnaire was designed using the 'online survey tool' SurveyMonkey (http://www.surveymonkey.com/Default.aspx). This survey tool guides the user through all steps required in the creation of a survey from survey design to dissemination. In Australia, it has been recommended for design of online surveys by the technical and internet staff of the Faculty of Education at Monash University (http://insite.education.monash.edu.au/techservices/web/0nline-surveys.html). It is also supported, with licensing available, by the University of Western Sydney (http://www.uws.edu.au/about/adminorg/academic/itd/surveysupport). The Survey Monkey program has been used by various Australian organisations to host surveys, including for example, the Knowledge for Regional NRM Programme team (see http://www.rkrk.net.au/index.php/how_to_conduct_an_online_survey), the Local Government Association of South Australia (see http://www.lga.sa.gov.au/site/page.cfm?c=14916) and Public Libraries Australia (see http://www.pla.org.au/documents/newsletter/PLANews_Sept_07.pdf).

4.2.6.2 Design using SurveyMonkey

The SurveyMonkey program was employed in this research following an initial preparatory stage during which survey questions were devised and refined to best meet the aims of the survey. Within the SurveyMonkey program the first step was in the 'design' section of the software where the options of selecting a survey template (eg. Academic, marketing) or designing the survey from 'scratch' were provided. In the following 'edit' screen the look and style of the survey was determined by selecting a colour scheme from of a variety of templates. Questions were then added from the list prepared earlier. When adding a question to the survey a choice of type of question formats (eg. Multiple choice, Matrix of choices, rating scale etc.) as well as a series of respondent choice formats (eg. drop down menus, horizontal buttons or columns of buttons) was provided. Other options in this section, some of which depended on question type, included whether an answer to a question was required or whether space for additional comments was required. After spell-checking and saving a question, it was displayed on the main edit screen. To insert the next question, the process was repeated using the 'add question' option. During this design stage questions could be edited, moved or deleted, and options including adding a progress bar or displaying page numbers, were available. After all questions were entered into the survey, a welcome page introducing the survey and its aims, and instructions for participating in the survey, including the ability to exit the survey at any time, was added to the beginning of the survey.

4.2.7 Questionnaire dissemination

4.2.7.1 Priming the collection process

Once the survey design process was complete, the 'collect responses' section of the SurveyMonkey program was entered, to generate a link to the survey to be included in an email message (or inserted into a web page). A number of collectors was generated, each with its own individual link, to differentiate between different groups of respondents. This allowed the number of responses per group, and time of last response, to be monitored on the collectors page on the SurveyMonkey website, where all responses were held. A number of setting and restrictions were available so that each collector could be tailored to the specific needs of the survey. Under settings, for example, choices related to allowing multiple responses from the same computer, and allowing respondents to edit their responses, and whether or not to save the respondent's IP address in the results was provided. The last option was declined to preserve respondent's anonymity. Restrictions included setting a cut-off time/date after which responses would not be accepted, and setting a maximum response rate.

A 'test' collector was first set up and the questionnaire sent out to a number of known respondents as a pilot survey to check for any problems with survey content or any issues with the online approach.

4.2.7.2 Contacting potential respondents

To avoid sending unsolicited emails to coastal Councils in each State, the Australian Local Government Association (ALGA) and the local government Natural Resources Management (NRM) facilitators from Victoria, Tasmania and South Australia were contacted for assistance in administering the survey. It was also thought Councils may be more willing to participate in the survey if approached by someone, such as an NRM representative, with whom they were already familiar; and in effect was seen as a form of survey 'pre-notification'. Unfortunately, this approach was not successful. The Victorian NRM representative did not respond to the request for assistance. The South Australian representative while initially responding favourably was unable to assist thereafter. The Tasmanian NRM representative responded and while not able to help with contacting the relevant Tasmanian councils, did advertise the questionnaire in an electronic newsletter. ALGA was then contacted for assistance in contacting the relevant councils. While initial correspondence was promising, ALGA was delayed in offering assistance due to work schedules so an alternative approach was taken.

Alternatively, the internet was consulted for maps of councils in Victoria, Tasmania and South Australia. From the maps the coastal councils in each state were identified and the internet again consulted to obtain contact email addresses. Using these email addresses, an unsolicited, non-personalised email letter introducing the study and inviting interested staff to participate in the survey, for which a link was included, was sent to each council. This method did not seem entirely inappropriate given the circumstances, and followed guidelines which stated that approaching potential respondents in an unsolicited manner is (only) '.. appropriate if the individual's name and contact details have been obtained from a publicly accessible source' (Taylor 2007 p. 9).

A follow-up / reminder email, which included the text of the original email and the link, was sent to Councils approximately 6 weeks later in an attempt to boost the response rate (Schaefer & Dillman 1998).

In addition to the coastal councils, similar requests for participation in the survey were sent to the Weed Management Society of SA Inc (WMSSA), the Weed Society of Victoria, the Tasmanian Weed Society Inc., and the VCC. The MCCN was also asked to assist with the survey, as many organisations, groups and individuals ranging across government, industry and the community utilise the MCCN (MCCN 2008) and it was thought to be a potentially useful forum from which information on Sea wheat-grass could be distilled from a broad range of participants. The MCCN obliged by advertising the questionnaire, along with an introduction to the research (and link to the survey) on their website in the 'New Marine and Coastal Research Section' and in their E-News. A number of 'interested' persons (3), who became aware of the survey, also requested to participate in the research and are listed under 'miscellaneous' participants.

4.2.8 Analysis

For each closed questions the overall response rate (%) was calculated, as well as the rate (%) per individual response. For open-ended questions the overall response rate (%) was also calculated and examples of the responses provided. Sometimes these were categorised to identify themes in the responses. However, attempts were made to resist categorising the responses too vigorously (a method used with open-ended questions, usually for coding for use in a statistical package) as a statistical package was not used for analysis, and to maintain the unique views and opinions of each respondent.

The process of analysis was aided by the SurveyMonkey tool, which calculates and displays summary response data in the 'analyze' section of the program.

4.3 RESULTS

The results of the survey are presented in three parts: Part A. Participant Profile; Part B. Participants' knowledge, opinion and experience of Sea wheat-grass; and Part C. Participants' perceptions on coastal weeds and coastal weed management. Firstly, an overview of the response rate is given.

4.3.1 Overview of response rate

A total of 46 people responded to the Sea wheat-grass survey (Table 4.1). Nearly 40% of responses were from coastal councils. Table 4.2 shows the response rate for the coastal councils in relation to the number of invitations sent out.

Email replies denoting 'failed delivery' and 'over-quota mailbox' reduced the response rate for this survey.

Table 4.1. Overview of response rates.

Respondents	# of responses
Coastal Councils	18
Weed Societies	10
Other participants	18
Total	**46**

Table 4.2. Coastal council's survey response rate.

Coastal Council	# of invitations	# of responses
SA	34	8
Vic	24	3
Tas	24	7
Total	**82**	**18**

Responses from the other survey participants – the MCCN, weed societies and so forth, are shown in Table 4.3. Most responses (14) came through the MCCN, followed by the Weed Management Society of SA, the Weed Society of Victoria and miscellaneous participants, and the Tasmanian Weed Society and Victorian Coastal Council (Table 4.3).

Table 4.3. Survey response rate – MCCN, weed societies and miscellaneous.

Name	# of invitations	# of responses
MCCN	-	14
Tasmanian Weed Society	-	1
Weed Society of Victoria	-	3
Weed Management Society of SA	-	6
Victorian Coastal Council	-	1
Misc	-	3
	Total	**28**

4.3.2 Part A. Participant Profile

Q1. *To which type of organisation do you belong?*

Question One sought to determine the respondent's organisational affiliation(s). All 46 respondents answered this question. Most respondents (39.1%) were affiliated with Local Government; 28.3% were associated with community/conservation/environmental organisations, and 17.4% with State government. The remaining approximately 15% of respondents were from the Commonwealth government, Industry/private sector, and the education, student and individual categories (Figure 4.1).

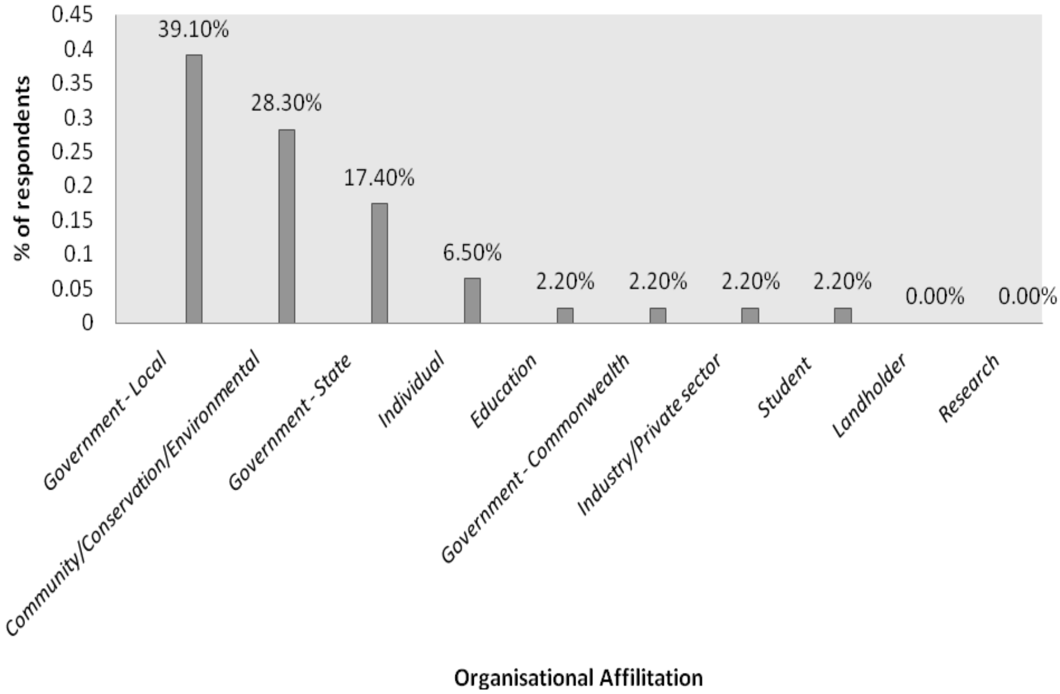

Figure 4.1. Organisational affiliation of survey respondents.

Q2. *Which categories best describe your organisation's work (or your own research/work)?*

Question Two sought to ascertain a description of the respondent's place of work. Most respondents (45) answered this question. Exactly 60% of respondents indicated they were associated with natural resources management, 55.6% with weed management, and 51.1% with coastal conservation/rehabilitation/biodiversity. Nearly forty nine percent were associated with coastal management/protection, 44.4% with coastal maintenance /on ground works and 33.3% with policy/planning. The remaining categories of tourism/recreation, cultural heritage, research and 'other' received between 17.8 – 13.30% of responses (Figure 4.2).

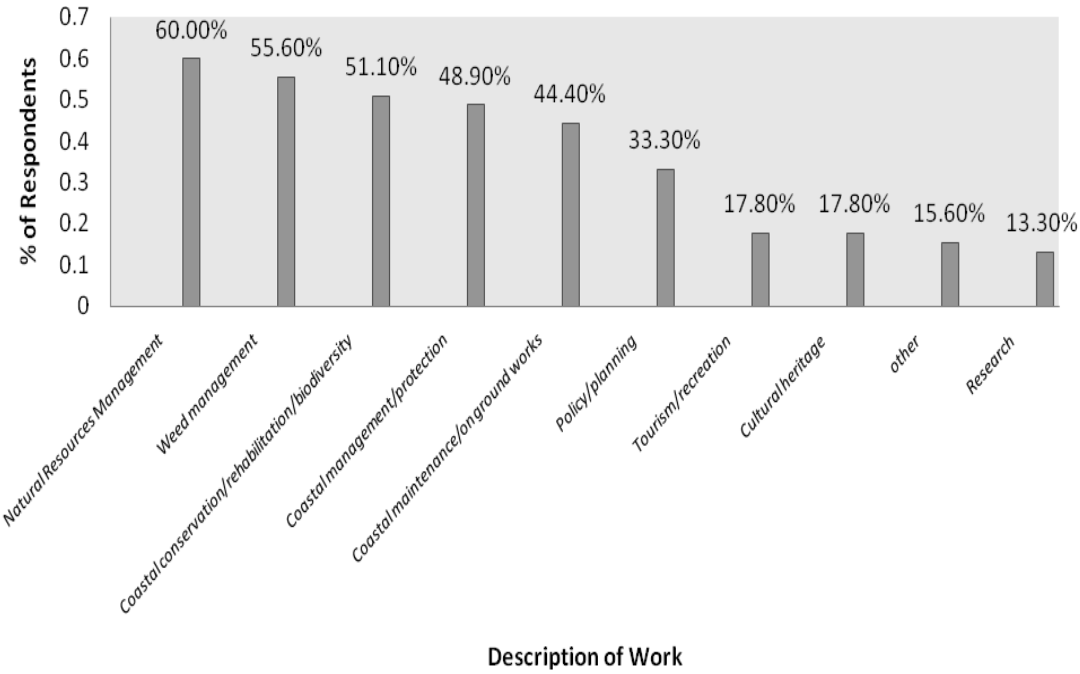

Figure 4.2. Description of survey respondents' work.

Q3. *If you are comfortable to do so, please provide the name of your organisation.*

Respondents were then asked to name their organisation if they felt comfortable in doing so. Over 80% or 37 respondents chose to name their organisation, but to preserve the respondent's anonymity they will not be revealed here. However, results of Question 1 (above) provide a clear indication of the affiliation of the respondents participating in the survey (eg. local, state and commonwealth government, community/ conservation/ environmental organisations, industry/private sector, and educators, students and individuals).

Q4. *Which state do you live in?*

Respondents were then asked to nominate the State in which they lived. Most respondents (45) answered this question. Results indicated most respondents were from South Australia (33.3%), with Tasmania and Victoria equal second (24.4%). New South Wales and Western Australia had 8.9% and 4.4% respondents respectively, and Queensland and the Australian Capital Territory each had 2.2% respondents. There were no responses from the Northern Territory (Figure 4.3).

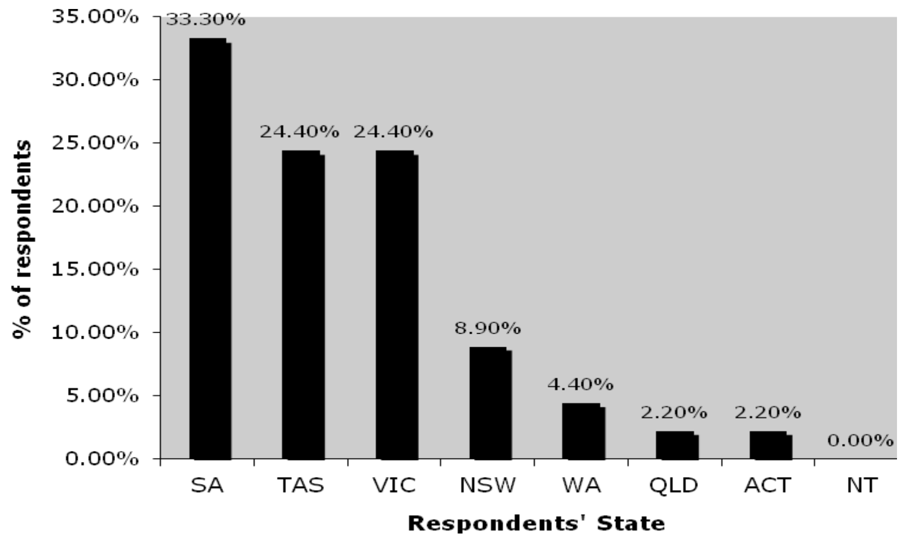

Figure 4.3. Respondents' State of residence.

4.3.3 Part B. Participants' knowledge, opinion and experience of Sea wheat-grass

Q5. *Do you know of Sea wheat-grass or have you had direct experience with Sea wheat-grass?*

Question Five sought to establish the respondent's familiarity with Sea wheat-grass. A total of 44 respondents answered this question. While 31.8 % (or 14) respondents answered that they did know of Sea wheat-grass, the same number indicated they have had direct experience with Sea wheat-grass, thus a total of 63.6% of respondents knew of or had direct experience with the plant. The remaining 36.4% of respondents indicated that they did not know of or have experience with Sea wheat-grass. Those who did not know of Sea wheat-grass were asked to skip to Question 16 of the survey.

Q6. *Does your knowledge /experience of Sea wheat-grass come from the plant growing in your state or region in which you work?*

Those participants that knew of or had direct experience with Sea wheat-grass were then queried whether their knowledge/experience came from the plant growing in the state or region in which they worked. A total of 29 respondents answered this question. Nearly 76% (or 22 people) responded affirmatively that their knowledge/experience of Sea wheat-grass came from the plant growing in the state or region in which they worked. Most respondents were from South Australia (8), closely followed by Tasmania and Victoria (6 each) and 1 each from New South Wales and Western Australia[1].

Q7. *If you answered 'yes' to the previous question, approximately how long has Sea wheat-grass been present in this area?*

An open ended question in which respondents who answered yes to the previous question, were asked to estimate how long had Sea wheat-grass been present in their area. Respondents could leave a blank space or enter 'don't know' if they were unsure. A total of 20 responses were given. Nearly half (8) answered 'don't know'. Of the remaining twelve respondents, one respondent estimated 'over 30' years and another, 'many years'. Three respondents referred to the earliest herbarium record for their state (1986) which in 2008 would have been 22 years. One respondent indicated 15 years but suggested it was 'probably much longer'. Three respondents indicated that Sea wheat-grass had been present for approximately a decade viz the responses 'at least 10 years', '10 years at least' and '10 +' years. The remaining respondents indicated that Sea wheat-grass had been in their area(s) from around '7 years' to 'less than 5 years', with one respondent indicating that they '..have known about it for 5 years'.

Q8. *How common would you estimate Sea wheat-grass is in this area?*

Respondents were then asked to estimate how common Sea wheat-grass was in their area by selecting the 'common/widespread', 'limited in distribution' or 'unsure' option. A total of 21 respondents answered this question. Of the three possible options provided almost half or 47.6% of respondents indicated that it was 'common/widespread' and 42.9% of respondents indicated it was 'limited in distribution'. The remaining respondents were 'unsure' (Figure 4.4).

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[1] The result from Western Australia may be a case of mistaken identity as *Thinopyrum distichum* tends to grow there, not *T. junceiforme*, according to Herbarium records.

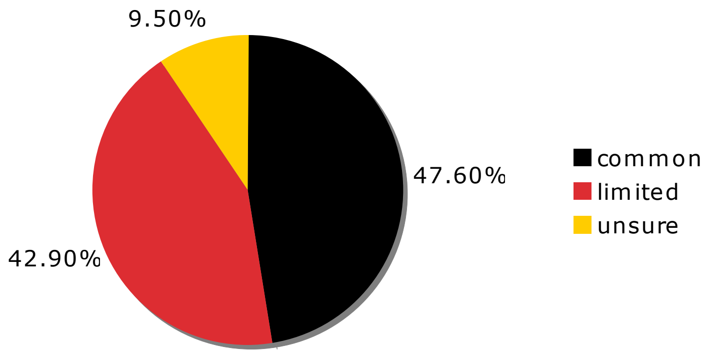


Figure 4.4. Distribution of Sea wheat-grass according to survey respondents.

Q9. *If Sea wheat-grass is not present in your area, please briefly explain how you have become aware of the plant.*

An open ended question for those respondents whose knowledge /experience of Sea wheat-grass did not come from the plant growing in the state or region in which they worked (see question 6). While the seven respondents answering 'no' to Question Six were directed to this question, nine respondents actually answered it. Of those nine, four respondents had not known of the plant prior to undertaking the Sea wheat-grass survey/or contact with me. The remaining respondents had become aware of Sea wheat-grass in a variety of ways such as:

- ✍ '*By State survey.....*';
- ✍ '*via a field trip on the North coast and knowledge of some beach weed issues…*';
- ✍ '*media, friends and study*';
- ✍ *'Publication "Are You Growing Invaders? Coastal Weeds of Tasmania"',* and
- ✍ *'Through the Coastcare network and the Tasmanian Beach Weed Strategy'.*

Q10. *In your opinion is Sea wheat-grass…… a beneficial plant along the coast [or] a problem plant along the coast…?*

Respondents were then asked their opinion of Sea wheat-grass in terms of whether they felt it was a beneficial or a problem plant along the coast. The options of 'neither of the above' and 'don't know' were also given. A total of 27 respondents answered this question.

Only 1 responded it was 'A beneficial plant along the coast'. Most, or 77.8% of respondents, answered that it was 'A problem plant along the coast' (Figure 4.5). To the options of 'neither of the above' and 'don't know', 11.10% and 7.40% of respondents answered, respectively (Figure 4.5).

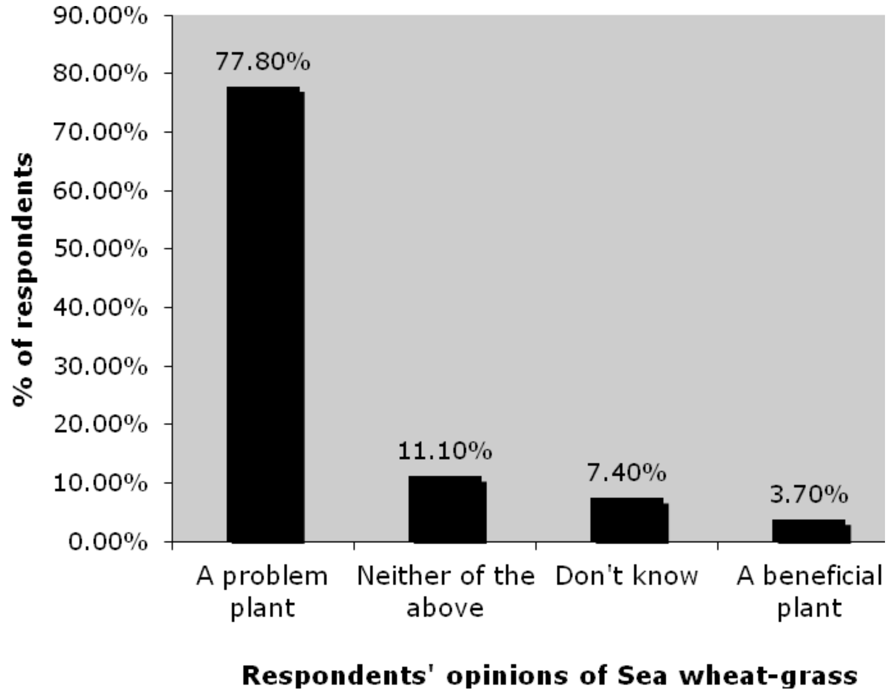


Figure 4.5. Respondents' opinions of Sea wheat-grass.

Q11. *If you view Sea wheat-grass as a beneficial plant, please provide a brief statement as to why.*

An open ended question enabling respondents regarding Sea wheat-grass as a beneficial plant (see Question Ten), to provide a brief statement as to why. Two people responded to this question (even though only one respondent stated it was beneficial in the previous question). Reasons given for it being beneficial were:

✍ '*It may be considered to have some beneficial stabilisation properties under certain circumstances, particularly where other natural conservation values are not present. However this does not neccessarilly (sic)follow that it is the ideal stabilising plant to have under those circumstances!*'

✍ *'It is quick to bind dunes and hold sand'*

Q12. *If you view Sea wheat-grass as a problem plant, please provide a brief statement as to why.*

Another open ended question enabling those respondents viewing Sea wheat-grass as a problem plant to provide an explanation for this point of view. A total of 20 respondents answered this question. Respondents listed one to multiple reasons why they viewed Sea wheat-grass as a problem plant. To aid interpretation, the potential impacts were categorised under three main headings: 'impacts on shorebirds', 'impacts on native vegetation', and 'impacts on coastal geomorphology and beach dune processes'. They are indicated under these categories below:

✍ impacts on shorebirds (7 respondents):

'impact on nesting birds in dune systems', 'potentially affecting beach nesting birds', 'detrimental to …bird feeding habits', 'potentially displaces shore nesting birds', 'potential impacts for shorebirds', 'potential to change…..habitat for beach nesting shorebirds', 'restricting juvenile beach inhabiting birds such as Hooded plovers, red capped plovers, oystercatchers, from escaping waves'.

✍ impacts on native vegetation (11 respondents):

'competes with the indigenous plants', 'replaces native vegetation', 'replaces local species and impacts on biodiversity', 'outcompetes for nutrients and space with desirable plants', 'potentially effecting…strandline plant species', 'crowds out Spinifex and other native plants', 'outcompetes indigenous plants', 'strongly competes with Spinifex', 'dislocate native species', 'potential impacts for……coastal vegetation', 'outcompeting the native vegetation'.

✍ impacts on coastal geomorphology and beach dune processes (14 respondents):

'impact on dune formation', 'shapes dunes in a different way to natives due to different habits', 'prevents the movement of sand on beaches', 'affecting geomorphic processes and values (including unvegetated and unstable sand)', 'over-stabilises primary dunes, preventing natural mobility, and causing erosion during high tides. It consequently alters wave patterns near shore…', 'Builds steep incipient dunes or platforms which do not normally exist on the beach in front of normal dunes causing high tide waves to lose energy quickly and create washing machine like action which takes sand from the shortened beach areas causing short steep beaches. Ties up sand in normally mobile areas not allowing the normal steady sand exchanges between coast and sea', 'prevents the normal constructive and erosive processes of beach building occurring', 'It does bind sand to form dunes, but they are lower in profile to dunes formed by Spinifex, therefore the resulting swale formed behind does not protect native swale species as much.', 'changes to

geomorphology', 'alters the geomorphology of the dunes', 'Traps sand and alters the sand flows and beach landcsapes' (sic), *'Locks up sand and deprives the beach of sand further down the coast; Causes the high water line to move further seaward', 'Potential to change beach processes', 'Creates a cliff edge on the beach at high water mark'.*

Q13. *Are you aware if measures have been used to control Sea wheat-grass in your state or another area?*

Respondents were then asked whether they were aware of control measures being used on Sea wheat-grass. A total of 27 respondents answered this question. While 33.3% (or 9 respondents) answered 'yes', double this number (18) answered 'no'.

Q14. *If you answered yes to the previous question, could you briefly provide details?* An open-ended question enabling respondents to expand their response to the previous question regarding Sea wheat-grass control. A total of 9 respondents provided answers, some comprising multiple parts as paraphrased here:

✍ *'.... herbide (sic) management and time consuming hand weeding ....';*

✍ *'Very limited control has been undertaken, some glyphosate and hand pulling. A strategic plan for management of sea wheatgrass has been developed.....';*

✍ *'We have tried unsuccessfully to outcompete it with Spinifex runners.';*

✍ *' I think they do community weeding ...';*

✍ *'... eradication zones established ...';*

✍ *'Unsure of what techiniques(sic) but was under impression that some work had been done….';*

✍ *'... funding currently being sought. Some control measures have been done in Coorong National Park, S.A.';*

✍ *'hand weeding';*

✍ *'herbicide control using both Glyphosate and grass-selective herbicides'.*

Q15. *Do you believe Sea wheat-grass should undergo weed control in your state or another area?*

Continuing on the topic of control, respondents were asked whether they believed Sea wheat-grass should undergo weed control in their state or another area. A total of 27 respondents answered the question. Most, or 66.7% of respondents answered 'yes', 11.1 % answered 'no', and 22.2% of respondents answered 'don't know' (Figure 4.6).

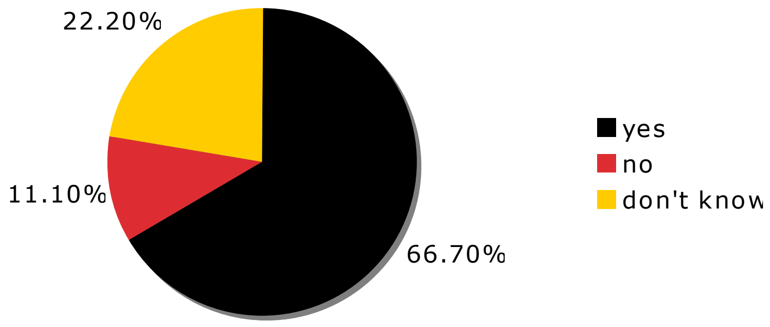


Figure 4.6. Should Sea wheat-grass undergo control?

4.3.4 Part C. Participants' perceptions on coastal weeds and coastal weed management

Q16. *In your opinion, what are the worst coastal weeds in your state or region in which you work?*

Respondents were then asked to list the worst coastal weeds in the state or region in which they worked, to assist in further divining current perceptions of Sea wheat-grass. A total of 35 respondents answered the question.

Respondents had the option of listing up to 4 weeds. All (100%) listed at least 1 weed, and 71.4%, at first glance, listed 4 weeds. However, on closer inspection it appeared that two respondents incorporated 5 (not 4) plants into their answer, and another respondent provided a comment and not a weed as part of their answer. Overall, 46 different weeds were listed[2]. Table 4.4 shows 14 of the weed species listed by respondents and they represent those species that were listed by at least 3 respondents. The most commonly

[2] It should be noted that in some responses, sometimes the scientific name of the weed was given and/or sometimes just a common name (with various spellings), and so in some cases some interpretation and presumption was involved in identifying weeds. For example, two respondents listed *Acacia cyclops* and three respondents listed Coastal Wattle as important weeds in their area. In the Flora of SA (Jessop & Toelken 1986) the common name for *Acacia cyclops* is Western Coastal Wattle, and Coastal Wattle is listed as the common name for *Acacia longifolia* var *sophorae* (Jessop & Toelken 1986). However, in other sources, such as the Western Australian Florabase, *Acacia cyclops* was found to be listed as Coastal Wattle (see http://florabase.dec.wa.gov.au/browse/profile/3282, accessed 3/4/09). The names given in Jessop and Toelken (1986) were used for the purposes of this research.

referred to weeds were Boneseed/Bitou bush, listed by 37.1% of respondents (Table 4.4). The remaining 32 species (not shown) were referred to by 5.71% or less of respondents, i.e. they were listed by only 1 (23 species) or 2 respondents (9 species).

Table 4.4. Worst coastal weeds listed in rank order.

Coastal weed	% of respondents
Boneseed / Bitou bush (*Chrysanthemoides monilifera* subsp. *monilifera* / *Chrysanthemoides monilifera* subsp. *rotundifolia*) [3]	37.1
African Boxthorn (*Lycium ferrocissimum*)	31.4
Bridal Creeper (*Asparagus asparagoides*)	28.6
Marram grass (*Ammophila arenaria*)	25.7
Sea Spurge (*Euphorbia paralias*)	25.7
Myrtle leaf Milkwort (*Polygala myrtifolia*)	17.1
Gazania (*Gazenia rigens*)	11.4
Mirror Bush (*Coprosma repens*)	11.4
Sea wheat-grass (*Thinopyrum junceiforme)*	11.4
Coastal wattle (*Acacia longifolia* var *sophorae*)	8.6
Coastal tea tree (*Leptospermum laevigatum*)	8.6
Pyp Grass (*Ehrharta villosa ([*var *maxima*??])	8.6
Italian Buckthorn (*Rhamnus alaternus*)	8.6
African or Dune onion weed (*Trachyandra divaricarta*)	8.6

Q 17. '*Today coastal areas may face a range of management issues, including for example, protection works, amenity and infrastructure maintenance, tourism and weed management. In your opinion, what are the most significant issues currently facing coastal areas?'*

An open-ended question in which respondents were asked to list the most significant issues currently facing coastal areas with a view to gauging the comparative importance of weed management. Respondents were able to list up to 4 issues. A total of 36 survey participants responded to this question. All (100.00%) provided at least one response, and 24 provided four responses. Given the nature of open questions, sometimes more issues were provided (than requested). Issues/concerns were extensive and were sorted into groups of similar issues to aid interpretation. The top 10 issues/concerns (those referred to by 3 or more

[3] These species are treated together following the WoNs listing where the 'two taxa together are treated as one of the twenty WONS' (Thorp & Wilson 2009).

respondents) are shown in Table 4.5. Other issues (not shown) included concerns related to stormwater, population, protection works, sand management, poor or lack of management, education and public awareness.

Table 4.5. Top ten issues/concerns faced in coastal areas.

Issues/concerns	% of respondents
Public access /recreational activities and impacts [4]	72.2
Weed management	63.9
Development/urban encroachment	61.1
Coastal erosion	33.3
Global change/climate change/sea level rise/change	25
Pest animals	16.7
Litter/pollution	13.9
Loss, removal or degradation of coastal vegetation	11.1
Biodiversity	8.3
Infrastructure maintenance	8.3

Q18. *'In your opinion, what are the key policies, plans or guidelines influencing coastal weed management in your state or region in which you work'*

To understand the factors guiding weed management, respondents were asked to list the key guiding coastal weed management in their area. A total of 31 respondents answered this question. All (100%) provided 1 response, and 41.9% of respondents provided 4 responses. Some respondents provided more than 4 responses due to the nature of the open question. Responses were grouped into eight categories (Table 4.6):

Table 4.6. Key policies, plans or guidelines influencing coastal weed management.

Key policies, plans and guidelines	% of respondents
Council/LGA strategies/plans or policies	64.5
Regional strategies/plans or policies	64.5
Other/undetermined (not specific enough)	64.5
State strategies/plans or policies	45.2
Acts of Legislation	19.4
Park/Reserve Plans	12.9
Community	12.9
National strategies/plans or policies	6.5

[4] A large over-arching category. Just over 42% of responses in this category specifically related to vehicular access and impacts (eg. 4 wheel drives and motor bikes) in coastal areas

Q19. *'Any other comments you wish to make?'*

At the conclusion of the survey, respondents were given the opportunity to make a comment. A total of 15 respondents commented, the contents of which varied widely, as paraphrased below:

✍ *"There aren't always enough resources to put coastal weed management policies into practice by local governments or community groups."*

✍ *"Marram grass has 'stabilised' local dune system so that locals would not see its removal as beneficial. Too much infrastructure would be at risk if it was removed."*

✍ *".... Much money is spent on workshops, reports etc and yet policies are implemented without sufficient back-up for on-the-ground work."*

✍ *"We deal with many weed species. On recieving (sic) this survey I Googled Sea wheat-grass and could find only one image of limited quality. ..."*

✍ *"Before this survey I had no knowledge of this weed. I have since researched it (and not found that much information) and talked to others about it…"*

✍ *"...protection of beach nesting shorebirds and aboriginal heritage on weed affected beaches and dune systems needs carefull (sic) integration in control programs"*

✍ *"....we should begin to consider where infrastructure protection on the coast ceases and where biodiversity and geomorphological process protection begins."*

✍ *"There is a serious lack of state-wide committment to control of coastal weeds. Control is done on an ad hoc basis - depending on the motivation of individual agency staff or coastal volunteers"*

✍ *"Any information that you have gleaned from your PHd studies or elsewhere that you can share for better management would be much appreciated."*

✍ *"Implementation lags way behind Strategy requirements"*

✍ *"…lack of funding….. hence management of many coastal areas does not occur (including weed managment)".*

✍ *"There is often a conflict between management of the coastal strip and adjacent land"*

and

✍ *"Weeds are not my responsibility…";*

✍ *"New to Coastcare so my knowledge at present is limited but growing!";*

✍ *"i hope this helps…"*

4.4 Discussion

This section discusses the results from the 2008 Sea wheat-grass questionnaire. Discussion starts with a profile of the survey respondents, followed by a discussion of the knowledge/experience of Sea wheat-grass held by these respondents. Next an overview of the temporal and spatial distribution of Sea wheat-grass according to the survey respondent's observations/recollections is provided. Respondents' perceptions of Sea wheat-grass are then discussed, followed by discussion of the potential bio-geomorphological impacts perceived by survey respondents, and, the importance of Sea wheat-grass in comparison to other weeds. Discussion then focuses on the management and control of Sea wheat-grass, concluding with some general comments from respondents. Firstly, a few comments on the response rate are made.

4.4.1 Response rate

The Sea wheat-grass questionnaire received 46 responses, but clearly had the potential to achieve more. One reason contributing to the response rate may have been a lack of introduction to coastal councils (see methods) according to the initial plan. In an attempt to boost the response rate (Schaefer & Dillman 1998), a follow-up / reminder email was sent to Councils approximately 6 weeks after the first invitation. Nearly 45% of the responses from coastal councils were received after the reminder and consequently supports the use and importance of survey follow-ups.

How significant is the response rate to this research? The Sea wheat-grass survey was a targeted survey – it aimed to gain information from people working/studying /interested in coastal areas – it was not a general (public) survey, and responses were never going to be extrapolated to the general public. Predominantly, the survey sought to gain insight into the knowledge and experience coastal workers had with Sea wheat-grass. Whether the response rate had been higher or lower than that received, the outcome would still be relevant and significant to the research. It is thought that unfamiliarity with the plant may have discouraged some participation, even though the survey actually encouraged those unfamiliar with the plant to participate.

4.4.2 Profile of survey respondents

Most respondents of the Sea wheat-grass survey were from Local Government, followed by the community/conservation/environmental sector, and then State Government. Areas of employment/research which included Natural Resources Management, followed by weed management and then coastal conservation/rehabilitation/biodiversity. Most respondents were from South Australia, followed equally by Tasmania and Victoria. As discussed below (*Friend or foe - perceptions of Sea wheat-grass)* one might expect responses from this target audience to be different from other sectors of the community such as the general public (not surveyed).

4.4.3 Knowledge/experience of Sea wheat-grass in Australia

Information about *Thinopyrum junceiforme* can be found in scientific articles (eg. Heyligers 1985, 2006; Hilton & Harvey 2002); State Floras (eg. Jessop & Toelken 1986) and Guides (eg. Jessop et al. 2006); weed strategies (eg. Rudman 2003); vegetation management plans (eg. Petherick 2005), coastal action plans (Caton et al. 2009a,b) and other sources. Despite the information sources, my initial impression was that Sea wheat-grass predominantly 'flew beneath the radar' and did not appear to have the profile of some other introduced coastal colonisers such as Marram grass. Certainly, while a plethora of research exists for Marram grass, comparatively little exists for *T. junceiforme.* A search of the Web of Knowledge/Web of Science database (Thomson Reuters 2012), for example, found 76 articles with *'Ammophila arenaria'* in the title, compared with 8 for *'Thinopyrum junceiforme'*. Although, articles were also found for its synonyms *Elymus farctus (5), Agropyron junceum (9)* and *Elytrigia junceformis (1).*

However, results of the Sea wheat-grass survey indicated over half of all respondents either knew of or had direct experience of Sea wheat-grass. Hence, knowledge of the plant was not as limited as initially presumed, although, a few respondents did indicate that their awareness of the plant actually came from undertaking the Sea wheat-grass survey. Other ways respondents had become aware of the plant included surveys/field trips, through coastal care organisations, weed publications, weed strategies and 'media, friends and study'. For other (most) respondents, their knowledge /experience of Sea wheat-grass came from the plant growing in the state or region in which they worked.

4.4.4 Temporal and spatial distribution of Sea wheat-grass

As mentioned above, many respondents indicated that they knew of Sea wheat-grass as it grew in the state or region in which they worked. Analysis revealed most respondents, were from South Australia, closely followed by Tasmania and Victoria. Responses were also recorded for NSW and Western Australia, even though surveys were not targeted at these states, their participation was encouraged via the MCCN collector. It should be noted that the result from Western Australia is almost certainly a case of mistaken identity as *Thinopyrum distichum* tends to grow in that State, not *T. junceiforme*, according to herbarium records (see Chapter Three).

For those indicating that their knowledge/experience of Sea wheat-grass came from the plant growing in their area, almost half indicated that Sea wheat-grass was ‘common/widespread’ while almost the same number indicated it was ‘limited in distribution’. Responses may reflect in part the availability of suitable habitats for growth/invasion, and also perhaps the differing perceptions of respondents in regard to the interpretation of ‘common/widespread’ and ‘limited in distribution’.

In addition to the distribution and prevalence of Sea wheat-grass, respondents were asked to comment on how long Sea wheat-grass had been present in their respective areas. This question was asked keeping in mind that various factors may influence responses, such as, how long the respondent had worked/lived in the area, and when they had become aware of the plant’s presence. While a number of respondents were ‘unsure’ how long Sea wheat-grass had been present in their area, estimates ranging from ‘over 30’ years to ‘less than 5 years’ were provided by other respondents. The latter may represent more recent invasions, or perhaps reflect an increased awareness of the existence or identity of the plant.

4.4.5 Friend or foe - perceptions of Sea wheat-grass

The Sea wheat-grass survey, as discussed elsewhere, was aimed toward people working in /interested in coastal areas, and one might expect responses from this target audience to be different from other sectors of the community such as the general public. Hertling and Lubke (1999) undertook a survey on public perceptions of Marram Grass in South Africa. They found interesting results when people were shown three pictures of coastal scenery, and were asked to select what they thought was ‘typical’ of South Africa. More people selected the pictures that contained the introduced Marram grass or species not occurring naturally on that part of the coast, than the picture showing native vegetation colonisation. Moreover, most (94%) people did not realise that Marram grass was introduced in South Africa (Hertling & Lubke 1999). For members of the public that use the coast for leisure, and have no professional (work) or general interest in its geomorphology/ecology, this result does not seem surprising. It may have provided an interesting facet to the current study if members of the public, in addition to the target audience, were surveyed in regard to their perceptions of Sea wheat-grass.

When respondents were asked about their perceptions of Sea wheat-grass, survey results showed both negative and positive perceptions of Sea wheat-grass were held, although the former were far more frequent than the latter. Few people responded that Sea wheat-grass was beneficial along the coast. The benefits given for Sea wheat-grass related to its sand binding/stabilisation ability, and as indicated by one respondent it may have benefits *".. under certain circumstances, particularly where other natural conservation values are not present".* However, the respondent cautioned that it *".. does not neccessarilly (sic) follow that it is the ideal stabilising plant to have under those circumstances!"*

That one or two respondents viewed Sea wheat-grass as a potentially beneficial plant is not surprising as introduced plants have long been used for their sand binding ability and Marram Grass (*Ammophila arenaria)* is a case in point. Once considered the '...most widely planted dune stabiliser in southern Australia' (Cullen & Bird 1980 p. 43) and 'used extensively in stabilisation programs in Victoria, Tasmania, NSW and South Australia' (Bergin et al. 1997 p. 431) the use of Marram Grass for sand stabilisation purposes is becoming increasingly questioned with concerns relating to its impact on the geomorphology and ecology of coastal areas (eg. Hilton & Duncan 2001). For similar reasons many respondents of the survey viewed Sea wheat-grass as problematic along the coast.

4.4.6 Perceived impacts of Sea wheat-grass along the coast

Three clear themes emerged from the responses of respondents viewing Sea wheat-grass as problematic along the coast. These potential bio-geomorphological impacts could be summarised as:

i. impacts on shorebirds;

ii. impacts on native vegetation; and

iii. impacts on coastal geomorphology and beach-dune processes.

Issues relating to impacts of Sea wheat-grass on shorebirds identified by respondents included potential habitat change and shorebird displacement. These concerns are supported in the literature. In Tasmania, for example, Rudman (2003) has identified six birds that may be potentially affected by Sea wheat-grass colonisation including the

Hooded and Red capped plovers (*Thinornis rubricollis* and *Charadrius ruficapillus*, respectively), as well as species listed as rare (Fairy Tern, *Sterna nereis nereis*) and endangered (Little Tern, *Sterna albifrons sinensis*) under the Threatened Species Protection Act 1995. Impacts on shorebirds are intimately related to the impacts of Sea wheat-grass upon coastal geomorphology and native vegetation. One respondent, for example, expressed concerns regarding the ability of juvenile shorebirds from 'escaping waves', which would clearly be related to a reduction in beach width. Hilton and Harvey (2002 p. 188) have also commented on the potential impact of *Thinopyrum junceiforme* on shorebird habitat by reducing beach width. An added complication of reduced beach width is the potential increase of shorebird nest destruction on beaches permitting vehicular access, such as in the Coorong National Park. Although, the beach in the Park north of Tea Tree Crossing is closed (to vehicles) between 24 October – 24 December each year to protect the Hooded Plover.

In relation to impacts on native vegetation, issues strongly identified in the survey included competition and displacement of native plants by Sea wheat-grass. Once again the concerns of respondents are supported in the literature. According to Hilton and Harvey (2002 p. 188), for example, on Sir Richard Peninsula in South Australia Sea wheat-grass 'largely displaces' native frontal dune species such as *Spinifex sericeus*. That being said, competition and displacement of native plants are impacts commonly ascribed to weeds in general and are not the exclusive monopoly of Sea wheat-grass as indicated in the introductory quote in Chapter One of this thesis by Schomburgk (1879). Alternatively, it is interesting to note the observations of Heyligers (2006 p. 593) who found the modification of the coastal geomorphology on the sand spit of Shallow Inlet at Wilsons Promontory, in the form the development of ridges and dune fields by Sea wheat-grass (and Marram Grass), has provided '..opportunities for *Spinifex sericeus* and *Austrofestuca littoralis* to establish as well…'.

The remaining concerns of respondents in the trilogy of potential impacts of *Thinopyrum junceiforme* were impacts on coastal geomorphology and beach dune processes. Most commonly, this included the ability of the introduced grass to trap sand and inhibit sand mobility. Certainly, according to Rudman (2003 p. 7), in Tasmania, Sea wheat-grass 'traps and stabilises sand where native vegetation does not generally occur, thereby altering the natural landforms and preventing the movement of sand'. Essentially, the plant stabilises sections of the coast and may prevent 'foredune disturbance' such as the development of blowouts (Hilton & Harvey 2002).

Sea wheat-grass may also initiate new dunes seaward of existing dunes, according to survey respondents. As indicated earlier in Chapter One, Heyligers (1985 p. 37) suggests that greater efficiency of some exotic species at '...colonizing the backshore and trapping sand' has resulted in the development of dunes '…where none would have come into existence otherwise…'. Dune morphology may also be influenced by Sea wheat-grass according to respondents, which may in turn be influenced by a number of factors such as wind, forming low, wide foredunes where wind conditions are moderate, and a hummocky morphology under increased wind conditions (Heyligers 1985).

Consequently, results of survey respondents indicate that Sea wheat-grass effectively alters the pre-existing coastal landscape, with accompanying geomorphological and ecological implications.

4.4.7 The importance of Sea wheat-grass in comparison to other weeds

Sea wheat-grass survey results indicated that Sea wheat-grass was reasonably well known by coastal workers, with over half of all respondents indicating they knowledge of or direct experience with the plant. This being said, how did Sea wheat-grass compare in status to other coastal weeds and how is this reflected in the literature?

There are various sources that enable insight into which plants are considered to be coastal weeds. In Victoria, the Department of Sustainability and Environment (DSE) provides a map which divides the coast into seven 'coast action zones' and for each zone lists the 10 most serious coastal weeds (DSE 2007). Overall there are 33 coastal weeds listed across the coast ranging from the Far Southwest Region to the East Gippsland Region. In South Australia the Coastcare Community Handbook (Brooke et al. 2001) provides descriptions of some coastal weeds. While 18 weeds are described it is stated in the text that '...over 500 introduced species have been recorded...' along the coast in this state (p. 111). Coastal weeds are also listed in the SA Coast Protection Board's 2003 'Garden Plants that are Known to Become Serious Coastal Weeds'. In Tasmania, coastal weeds can be found listed in the guide to Coastal and Environmental Weeds of Tasmania (Connolly 2003) and sources such as the Tasmanian Beach Weed Strategy (Rudman 2003). A consolidated list from these sources is shown in Table 4.7.

Table 4.7. Examples of coastal weeds from South Australia, Tasmania and Victoria. * indicates coastal weeds common to all three states.+ indicates most commonly listed weeds by respondents in the Sea wheat-grass survey (Source: Compiled from Connolly 2003, DSE 2007, Brooke et al. 2001, SA Coast Protection Board 2003, Rudman 2003). NOTE: This is not an exhaustive listing of coastal weeds.

	Coastal Weeds	*SA*	*Vic*	*Tas*
	Agapanthus praecox ssp. Orientalis		*X*	*X*
	Agave americana	*X*		
	Allium triquetrum		*X*	
+	*Ammophila arenaria*	*X*		*X*
	Anagallis arvensis	*X*		
	Arctotheca calendula			*X*
	Arctotheca populifolia	*X*		*X*
	Arctotis stoechadifolia	*X*		
	Argyranthemum frutescens	*X*		
*+	*Asparagus asparagoides*	*X*	*X*	*X*
	Asparagus scandens			*X*
	Cactaceae		*X*	
	Cakile maritima ssp maritime	*X*		
	Carpobrotus edulis	*X*		
	Centranthus ruber			*X*
	Chamaecytisus palmensis			*X*
*+	*Chrysanthemoides monilifera [spp. Monilifera]*	*X*	*X*	*X*
*+	*Coprosma repens*	*X*	*X*	*X*
	Cortaderia species			*X*
	Cotoneaster species			*X*
	Crataegus monogyna			*X*
	Crocosmia x crocosmiiflora			*X*
	Cynodon dactylon		*X*	
	Cytisus scoparius			*X*
	Delairea odorata		*X*	*X*
	Dipogon lignosus	*X*	*X*	
	Echium plantagineum		*X*	
	Ehrharta erecta		*X*	
	Ehrharta villosa var maxima	*X*		*X*
	Erica lusitanica		*X*	*X*
*+	*Euphorbia paralias*	*X*	*X*	*X*
	Euphorbia terracina	*X*		
	Foeniculum vulgare			*X*
	Fuschia magellanica			*X*
+	*Gazania rigens/sp.*	*X*		*X*
	Genista monspessulana			*X*
	Hakea suaveolens		*X*	
	Hedera helix		*X*	*X*
	Homeria Spp.		*X*	
	Ilex aquifolium			*X*
	Ipomoea indica		*X*	
	Leptospermum laevigatum	*X*	*X*	
	Leucanthemum vulgare			*X*
	Leycesteria formosa			*X*
	Lonicera japonica		*X*	*X*
	Lupinus arboreus			*X*
*+	*Lycium ferocissimum*	*X*	*X*	*X*
	Nassella trichotoma			*X*
	Oxalis pes-caprae		*X*	

	Paraserianthes lophantha		X	X
	Passiflora mollissima			X
	Pennisetum clandestinum		X	
	Pennisetum setaceum	X		
	Phormium tenax			X
	Pinus radiate			X
	Pittosporum undulatum		X	X
*+	*Polygala myrtifolia*	X	X	X
	Psoralea pinnata			X
	Rhamnus alaternus	X	X	
	Rosa rubiginosa			X
	Rubus fruticosus		X	
	Salix species			X
	Secale cereal	X		
	Senecio angulatus			X
	Senecio elegans			X
	Senecio jacobaea		X	X
	Solanum linnaeanum		X	
	Sollya heterophylla			X
*	*Spartina x townsendii / anglica*	X	X	X
+	*Thinopyrum junceiforme*	X		X
	Trachyandra divaricata	X		
	Tradescantia albiflora		X	
	Tradescantia fluminensis			X
	Typha latifolia			X
	Ulex europaeus			X
	Vinca major		X	X
	Watsonia meriana		X	X
	Zantedeschia aethiopica			X

Table 4.7 indicates coastal weeds common to each of the south eastern states of South Australia, Tasmania and Victoria are: *Asparagus asparagoides* (Bridal creeper), *Chrysanthemoides monilifera [ssp. Monilifera]* (Bone seed), *Coprosma repens* (Mirror bush), *Euphorbia paralias* (Sea spurge), *Lycium ferocissimum* (African boxthorn), *Polygala myrtifolia* (Myrtle-leaved milkwort) and *Spartina anglica* (Common cord grass). Of these seven weeds, six were most commonly listed by survey respondents of the Sea wheat-grass survey. While South Australia and Tasmania listed *Thinopyrum junceiforme,* it is interesting to note it was not considered a serious enough weed to be included in any zone across the Victorian coast according to the DSE (2007) state map. Although, it is important to note that the resources used to compile the data (Table 4.7) comprised only a selection of the existing resources. Certainly, various other documents exist that contain weed lists in the form of management plans, bioregion descriptions, and so forth.

As indicated in the results section, Sea wheat-grass was listed in the top 14 worst coastal weeds (out of the 46 different species) by respondents to the Sea wheat-grass survey. Consequently, it seems that the plant certainly does not have the status of some other coastal weeds such as those listed, but it appears that its profile is not as low as originally thought.

4.4.8 Management and control of Sea wheat-grass

When respondents were asked to list the most significant issues currently facing coastal areas, many issues were identified but there were three main themes that dominated: public access to and impact on coastal areas, weeds/weed management, and coastal development/urban encroachment. Respondents were then asked to list the key policies, plans or guidelines influencing weed management in their area. A plethora of legislative acts, policies, strategies, programs and initiatives guide weed management in Australia, at the national, state, regional and local level, was reflected by the responses of the respondents in the survey.

Primarily, weed management legislation and policy is the responsibility of each state/territory government, although the Commonwealth 'provides national policy leadership and direction ….' and '…..administers legislation, policies, programs and associated activities to manage weeds at a national level' (Thorp & Wilson 2008).

4.4.8.1 National initiatives

Two national initiatives reported by survey respondents to influence weed management were the Australian Weeds Strategy and the Weeds of National Significance (or WONS). According to the Natural Resource Management Ministerial Council (NRMMC), the Australian Weeds Strategy '…provides a framework to establish consistent guidance for all parties, and identifies priorities for weed management across the nation…' (NRMMC 2007 p. 2). This national weed initiative does not relate specifically to coastal areas, but recognises that weeds '…have major economic, environmental and social impacts in Australia, causing damage to natural landscapes, agricultural lands, waterways and coastal areas' (NRMMC 2007 p. 5).

The WONS is a group of twenty[5] (out of a potential 71) plants nominated from around the country. The plants on this list are considered to be so significant that they require '…coordination among all levels of government, organisations and individuals with weed management responsibilities' (Thorp & Wilson 2009). Each plant on the WONS list '..has

[5] Bitou Bush and Boneseed are dealt with as one on the WONS list (Thorp & Wilson 2009).

a strategic plan…'; 'a Management Coordinator and a National Management Group/Steering Committee' (Thorp & Wilson 2009). While the WONS does not relate specifically to coastal weeds, it includes weeds that occur in coastal areas. Two weeds mentioned by respondents in the Sea wheat-grass survey are included on the WONS list, boneseed/bitou bush and Bridal creeper, and a further three were nominated to be included on the list.

4.4.8.2 State initiatives

A number of survey respondents indicated that acts of legislation influenced weed management in their state/region. As already indicated weed management legislation is primarily the responsibility of each state/territory government. As a result there are different acts of legislation that deal with weeds across the nation, a fact not escaping the Australian Weeds Strategy which suggested the establishment of a '...nationally consistent legislation to address weed problems' (Strategic action 3.3.3) (NRMMC 2007 p. 17).

State weed management acts referred to by respondents included Victoria's *Catchment and Land Protection Act 1994*; South Australia's *Natural Resources Management Act 2004* and the New South Wales (NSW) *Noxious Weeds Act 1993*.

States/territories may have more than one act that deal with weeds; for example, NSW also has the *Threatened Species Conservation Act 1995*. The invasion of *Chrysanthemoides monilifera* into native plant communities, for example, has been classified as a 'key threatening process' under the Act consequently requiring the development of a Threat Abatement Plan (TAP)[6] for that plant (NSW Government 2009). Certainly, one respondent of the survey referred to the Bitou Bush TAP as an influence on weed management. Similarly, in Victoria, 'Environmental weeds are listed under the *Flora and Fauna Guarantee Act 1988* as a threatening process for native vegetation' (DSE 2011).

Respondents indicated that proclaimed noxious weeds were another influence on weed management. State/territory weed legislation provide for the proclamation of declared/noxious weeds. As set out in the respective legislation, each state/territory has its own system with specific weed categories or classes which may relate to the plants' status

[6] Nationally, under the EPBC Act 1999 weeds may also be addressed via the preparation of TAPS for threatening processes (see DEWHA 2009a).

and control requirements, as well as providing specific prohibitions such as those relating to sale, import or transport of the plant. According to the Department of the Environment, Water, Heritage and the Arts (DWLBC), in South Australia approximately 110 plants have been declared under the NRM Act (DWLBC 2009a), including several plants mentioned by survey respondents including African Boxthorn, Boneseed and Bridal Creeper (DWLBC 2009b).

Other weed management initiatives, policies and strategies, and the authorities responsible for these, vary between the Australian states and territories. Moreover, while some strategies or policies directly focus on weed management issues, for example, State weed strategies, others may *include* weed management as just one of several issues to be addressed. Weed strategies referred to by survey respondents included the South Australian Weed strategy (Weed Strategy Committee 1998) and WeedPlan - Tasmania's Weed Management Strategy (Tasmanian Weed Management Committee 2005).

Strategies or policies including but not focussing on weed management include state coastal policies and biodiversity strategies. In terms of the former, some respondents looked to the Victorian Coastal Council’s (VCC) Victorian Coastal Strategy (eg. VCC 2002, 2008) for guidance in weed management. Biodiversity strategies referred to included the South Australian ‘*No Species Loss’* Biodiversity Strategy (DEH 2006) and the NSW biodiversity strategy.

Another (state) strategy referred to by survey respondents specifically deals with *coastal* weeds: Rudman’s (2003) ‘Tasmanian Beach Weed Strategy’, which deals with five coastal weeds: Sea Spurge and Beach daisy, and the grasses Marram Grass, Sea wheat-grass and Pyp grass. According to Rudman (2003 p. 2) the beach weeds strategy may be a more efficient means of beach weed management compared to being declared under the 1999 Weed Management Act ‘*as natural processes are the major cause of weed spread*’. Rudman most likely is referring to the fact that in part, being declared under the 1999 Act means that a person is prohibited from importing, buying, selling or propagating a declared plant (section 56) and is suggesting that for the most part these beach weeds are not spreading via these means, but by the tides and other natural coastal processes. Although, it is important to note that some plants such as Marram grass have in the past been planted in coastal areas to arrest sand drift, from where they have spread, so consequently may be better suited to declaration under the act.

4.4.8.3 Regional strategies and plans

Survey respondents referred to a number of regional strategies/plans influencing weed management in their areas, with reference frequently made to Natural Resource Management (NRM) strategies and plans. There are 56 NRM regions, 'based on catchments or bioregions' in Australia (Commonwealth of Australia 2010). In South Australia survey respondents referred to NRM plans from 2 regions (out of the States' 8 NRM regions), the Adelaide and Mt Lofty Ranges (AMLR) and Eyre Peninsula (EP) NRM regions, as well as referring to advice and directives from NRM officers, with regard to weed management.

In Tasmania there are three NRM Regions; the north west, the north and the south NRM regions. Survey respondents referred to the Tasmanian Coastal Weed Strategy for the Cradle Coast NRM Region (Cradle Coast Natural Resource Management Committee (Tasmania) 2008a), the Weed Hygiene Action Plan (Cradle Coast Natural Resource Management Committee (Tasmania) 2008b), and the King Island weed management strategy (North 2003), all from the north west or Cradle Coast NRM Region; and the Southern Tasmanian Weed Strategy (Schrammeyer 2005) produced by the southern NRM region.

In Victoria reference was made to the Port Phillip and Western Port NRM region, *viz* the Port Phillip and Western Port Regional Catchment Strategy 2004-2009 (Port Phillip and Western Port Catchment Authority [PPWCMA] 2004). In the same State, respondents referred to Coastal Action Plans (CAPS) (including estuary plans), which along with Coastal Management Plans (and the Coastal Strategy) form part of strategic coastal planning in Victoria. According to the guidelines for the preparation of the CAPS, the CAPS have a 'regional, strategic approach' and so 'differ significantly from management plans' (VCC 2005). Thus, the management plans tend to be more local in nature, and so consequently there is a plethora of them (see Coastal Planning, http://www.coastlinks.vic.gov.au/coastal plans.htm).

Also referred to in the survey was South East Queensland's Regional Coastal Management Plan (EPA 2006) and the North Coast Weed Advisory Committee's NSW Northern Rivers Invasive Plants Action Strategy (Oakwood 2009). The overarching aim of the invasive plants strategy '..is to provide a regional framework to guide and enhance weed management across the entire region....', being a region of 50, 000 square km, with 18 local government areas (LGAs) and three existing weed advisory committees (Oakwood 2009).

4.4.8.4 Local strategies and plans

Many references were made to council/local government area (LGA) strategies, plans and policies by survey respondents. In many cases fairly generic references were made by respondents such as ‘local area management/weed management plans’ and ‘weed lists’, council or LGA ‘policies’, ‘policy document’, ‘environment policy’. Also listed were local ‘coastal action plans’ (CAPS), ‘coastal management’, ‘coastal development policies/control’, ‘beach cleaning’ and ‘roadside vegetation’ procedures. No specific mention was made of local pest management plans or invasive species strategies. In a survey of coastal councils undertaken by the Australian LGA (ALGA), Shepherd (2005 p. 15) found that almost half of the 82 councils participating ‘*..reported having and implementing an invasive species strategy. The rates differed greatly around the states, however this may be influenced by state government requirements. For instance, 83 per cent of Queensland councils have a strategy. Councils in Queensland are now required by the state government to have regional pest management plans, a process that can assist councils to develop their own local invasive species strategy. Only 15 per cent of South Australian councils reported having such a strategy’*.

Alternatively, survey respondents did refer to Council Biodiversity Strategies, Planning Schemes, and Bushland Management Plans. A specific plan referred to by respondents was the 2006 Environment and Land Management Plan for the Great Ocean Road by the Great Ocean Road Coast Committee (GORCC). According to the plan, ‘invasive weeds’ are seen ‘…as the greatest threat to our coast’s natural values with urgent and effective management action needed to ensure is biodiversity values are not lost over the next decade or so’ (GORCC 2010). The plan could be seen as both regional and local, involving several reserves and communities within the region.

Respondents also referred to management plans for parks, and for other designated areas such as local reserves, and ‘site specific vegetation management plans’. The need for individual maintenance plans was also referred to.

Community involvement was also referred to by respondents, in relation to community 'management and knowledge', the work of coast care groups, and coast care community manuals.

There was a number of other quite varied responses from survey respondents in relation to factors influencing weed management, from 'maintaining indigenous landscape', 'native plant preservation', and 'plant provenance' to factors hindering weed management such as 'insufficient funding', 'insufficient staff', and 'inexperienced staff'.

4.4.8.5 Should Sea wheat-grass be controlled?

Many respondents thought Sea wheat-grass should undergo weed control in their state or another area; only very few thought otherwise. There was no provision in the survey for respondents to discuss their responses, although an earlier question on whether respondents viewed Sea wheat-grass as a beneficial or problematic plant, would probably explain most of the responses.

Many respondents were not aware whether measures had been undertaken to control Sea wheat-grass in their state or another area. However, some *were* aware that measures had been undertaken to control Sea wheat-grass, and were able to provide details on the types of control measures used.

Control measures discussed by respondents included 'on the ground' measures such as hand weeding, herbicide control, and a combination of both of these methods. Rudman (2003 p. 8) recommended rhizome removal (for small areas) and advised on the availability of 'aquatic registered herbicides' for control. Areas that have undergone treatment should be monitored for the appearance of new plants (Rudman 2003). Attempts have also been made 'to outcompete it with Spinifex runners' (unsuccessfully). Other responses may relate to Rudman's (2003) beach weed strategy (see above) viz the development of a 'strategic plan for management' and the 'Establishment of eradication zones' for Sea wheat-grass.

4.4.9 Final comments

At the conclusion of the survey, respondents were given the opportunity to make comments. Contents of comments received varied widely. Some comments from survey respondents related to issues around weed management. Mentioned specifically were the lack of resources, funding, and 'on ground' support for weed management/policy implementation. On the same topic, there was the perception that there are significant delays in the implementation of strategies, and that weed control is '*ad hoc'* and lacks a 'state wide commitment'.

An interesting angle raised by some respondents was that some introduced weeds (eg. Marram) may be perceived as beneficial for stabilisation and that removal may be seen as detrimental in relation to infrastructure protection; moreover there was the suggestion that the costs of control may be seen to exceed the benefits of control.

Another comment related to the way in which this research (*viz* the survey) has raised awareness of *Thinopyrum junceiforme*. Thus while knowledge of the plant was not as limited as initially presumed, its profile is not as well known as that of other coastal weeds such as Marram Grass. One issue compounding this may be that suggested by one respondent, which was the limited amount of images of the plant on the internet which could be compared with the plethora of information available for Marram grass. There was also a suggestion that the results of this research be shared for management purposes.

4.5 SUMMARY

Over half of all respondents undertaking the Sea wheat-grass survey indicated they either knew of or had direct experience of Sea wheat-grass, predominantly in South Australia, Tasmania and Victoria, where it was observed as being common or widespread as well as limited in distribution, and had been present from over 30 years to less than 5 years.

Very few people thought Sea wheat-grass was beneficial in relation to its sand binding/stabilisation ability, while most people viewed it as a problem along the coast in relation to impacts on shorebirds, native vegetation, and on coastal geomorphology and beach-dune processes. Many people thought Sea wheat-grass should undergo some form of weed control, and some respondents were aware that measures had already been undertaken to control the coastal grass.

Sea wheat-grass was seen as one of the worst coastal weeds in the state or region in which respondents worked and clearly it appears that its profile is not as low as originally thought.

CHAPTER 5. COLONISATION POTENTIAL OF *THINOPYRUM JUNCEIFORME* BY SEED: THE ROLE OF OCEANIC HYDROCHORY

> *'...non-buoyancy in the great majority of plants has had a far reaching influence not only on plant distribution, but on plant development. The plant world would be transformed if all seeds and fruits floated in sea-water'* (Guppy 1906 p. 98)

In Chapter Three a number of potential pathways for dispersal between the three south eastern Australian states was established. This chapter seeks to establish *Thinopyrum junceiforme's* potential for spread by seed using such pathways, that is, using the ocean as a vector for dispersal.

5.1 BACKGROUND

5.1.1 Oceanic hydrochory

There are many modes by which seeds may disperse, and hydrochory relates to dispersal by water, which may include watercourses and sea currents. According to Guja et al. (2010 p. 1182) 'Oceanic hydrochory is a less recognised yet potentially important method for dispersal'. Certainly, according to Ridley (1930 p. 244) 'In the case of newly-formed islands, or islands in which the vegetation has been destroyed, sea-dispersed plants form the most important part of the first vegetation to cover the ground'.

In terms of distance of dispersal, it is thought that '...the distances seeds can travel by the sea unharmed and in a fit stage for germination are the longest of any method of transport, certainly over 1,000 miles' (Ridley 1930 p. 242). However, transport by ocean currents disperses (comparatively) fewer species than other methods according to Ridley (1930 p. 243). Species utilising oceanic hydrochory for dispersal are 'limited' because as Ridley (1930) notes:

- 'the seeds or fruit must be able to float for a long period of time without absorbing water (and so becoming waterlogged or commencing to germinate too soon)' and
- 'They must be able to establish themselves when landed….' 'That is to say they must resist the action of salt of all stages of their growth' (p. 242).

5.1.2 Studies on seed dispersal and buoyancy

Recent studies investigating the dispersal of alien species using methods such as testing seed buoyancy and viability, and analysis of current regimes, have been undertaken by Heyligers (eg. Heyligers 2007). Historically, seed dispersal, buoyancy and plant distribution have also long been a source of interest to investigators including Charles Darwin (1809 – 1882) and Henry Brougham Guppy (1854-1926). Charles Darwin was interested in the viability of seeds following immersion in salt water in relation to plant distribution. In his own words: '....it occurred to me that it would be worth while, in relation to the distribution of plants, to test how long seeds could endure immersion in sea-water, and yet retain their vitality' (Darwin 1857 p. 130). Darwin also believed that ocean currents would assist in dispersing seeds: '...I assumed that plants, with ripe seeds, washed into the sea by rivers, landslips, &c., might be drifted by sea-currents during a period of some weeks' (Darwin 1857 p. 134, 135). After a number of seed experiments which he reported jointly with the results of Rev. M.J. Berkeley (who in combination had tested the viability of 17 grass species), Darwin appeared to be somewhat disappointed with the results. Despite finding that 64 out of 87 different kinds of seeds survived 28 days immersion (Darwin 1857 p. 133), he wrote: '...I soon became aware that most seeds .... sink in water; at least I have found this to be the case, after a few days, ... so that such seeds could not possibly be transported by sea-currents beyond a very short distance.....' (Darwin 1857 p. 135).

Following additional experiments Darwin (1859) concluded '*...that the seeds of 14/100 plants of any country might be floated by sea-currents during 28 days, and would retain their power of germination. In Johnston's physical Atlas, the average rate of the several Atlantic currents is 33 miles per ...; on this average, the seeds of 14/100 plants belonging to one country might be floated across 924 miles of sea to another country; and when stranded, if blown to a favourable spot by an inland gale, they would germinate'* (Darwin 1859 p. 360). Darwin later revised this down to 10/100 plants and 900 miles of sea when he considered that seed buoyancy would probably be reduced in the open ocean due to its 'violent movement' (p. 359, 360).

Two years after Darwin's death in 1882, H.B. Guppy's (1906) '...interest in plant dispersal..' developed while a surgeon on the H.M.S. *Lark*: '...in the Solomon Islands, I made some observations on the stocking of a coral island with its plants...'. A few years later in 1888 he undertook similar research on Keeling Atoll and West Java (p. vii) and between 1890-1896 he investigated the British Flora ‘...mainly from the standpoint of dispersal by water...’ (p. viii).

Guppy (1906) presented buoyancy data on the ‘….seeds or seed-vessels’ of over ‘300 British flowering plants’ (p. 535); noting that Gramineae, ‘...which possess as a rule but little buoyancy, except through air-bubbles...’, was under-represented in the experiments (p. 24). Results for two hundred and sixty plants were Guppy’s own results with the remainder from the observations of others like Darwin (p. 24), of whom he says ‘long ago established the capacity of seeds to germinate after prolonged immersion in seawater’ (p. 539, 544). In his experiments Guppy found that in 75% of cases ‘... sinking took place at once or within a week; whilst 80, or 25 per cent, floated for a longer period, usually a month or more, and about 60, or 20 per cent, floated for several months’ (p. 24). Guppy defined non-buoyant seeds as ‘...those that sink at once or within a week...’ and suggested that ‘...the proportion of plants with non buoyant seeds or seed vessels for the whole British flora....’ is about 90% (p. 25).

As for the mechanisms of buoyancy, Guppy adopted and modified the buoyancy classification scheme of the botanist A.F.W. Schimper (1856-1901) (See Guppy 1906 p. 104). More recently, Gunn and Dennis (1999 p. 4), in their ‘*World guide to tropical drift seeds and fruit’*, adopted and modified the previous classifications of Guppy (1906), Schimper (1891) and the naturalist John Muir [Muir (1937)], as paraphrased here:
Group one: ‘Buoyancy due to cavity in disseminule’ (may be in seed or fruit)*
Group two: ‘Buoyancy due to light weight cotyledonary tissue’;
Group three: ‘Buoyancy due to a fibrous or corky coat, or a combination of both’;
Group four: ‘Buoyancy due to thinness of disseminule’;
Group five: ‘Buoyancy due to a combination of above factors’.

*in grasses ‘ aerenchymatous tissues’ or tissue with air filled cavities ‘...in inflorescence parts’ (Cheplick 1998 p. 86).

5.1.3 *Thinopyrum junceiforme* seeds as dispersal units

5.1.3.1 The relative importance of seeds and rhizomes in the dispersal of *Thinopyrum junceiforme*

Thinopyrum junceiforme can spread by seed or by rhizomes, as indicated in Chapter Two. While Nicholson (1952 p. 51) suggested that the main method of spread for *T. junceiforme* is via asexual methods (Chapter Two), Harris (1982) and Harris and Davy (1986a) found comparable results between seed and rhizome fragments producing tillers (p. 18). Harris and Davy (1986a) suggested they were 'of very similar importance in founding new clumps' (p. 1045), calculating that the average probability of tillers (clone) arising from seed and from a rhizome fragment was .51 and .49, respectively (p. 1048). They also 'contributed similarly to tiller densities…' (p. 1045).

5.1.3.2 Floating capacity of *Thinopyrum junceiforme* seeds

The ocean has an important role in the dispersal of *Thinopyrum junceiforme* seed. After flowering, the axis or rachis of the *T. junceiforme* inflorescence (Figure 5.1) eventually becomes 'rigid and brittle' and breaks up (Nicholson 1952 p. 55). As indicated in Chapter Two, seed or fruit, are shed in spikelets which are entrained and transported by the sea to new areas 'unimpaired', a process considered by Nicholson (1952 p. 55) to be '..the principal means of seed dispersal'. This is an important observation, as indicated by Ridley (1930 p. 333) who suggested that 'It is quite possible that the grains of some of the sea-sand grasses ...have been sea-drifted, but it is doubtful whether they would stand sea action'. Nicholson's account suggests that *T. junceiforme* seeds or more precisely spikelets are to some extent buoyant. As indicated in Chapter One, Heyligers (1985 p. 41) observes that there is no information in the literature on the buoyancy of *T. junceiforme*, although, he suggests that it can float for up to 2 weeks. This author has undertaken experiments on the buoyancy and viability of many seeds/fruits of coastal plants some of which has been published as indicated above (P. Heyligers, Pers. Comm., 2007). The source of this estimate of 2 weeks is likely from unpublished experimental data which indicate that spikelets 'floated at best for 3 weeks'.

Figure 5.1. *Thinopyrum junceiforme* inflorescence (a), spikelet (b). Source: Photograph by the author.

5.1.3.3 The tolerance of *Thinopyrum junceiforme* seeds to salinity

As indicated in Chapter Two, a number of previous studies have shown that *Thinopyrum junceiforme* has a considerable tolerance of salinity, both in terms of salt spray and soil or root salinity. However, while some mature coastal plants may have a tolerance to salinity or grow in saline habitats, germination of its seeds may display a sensitivity to salt (Guja et al. 2010). In seed germination trials Nicholson (1952 p. 70) found that *T. Junceiforme* germination was 'completely inhibited' by seawater, 22.5% germination was found in diluted seawater and 39.2% in distilled water. In similar experiments using distilled water and Sodium Chloride solutions, Nicholson (1952 p. 73, 74) found 47.5% germination for the distilled water and the 0.5% NaCL solution, 37.5% germination for the 1.0% NaCL solution and 5.0% germination in the 2.0 % NaCL solution. There was no germination in the 3.0 % and 3.5% solutions.

In Woodell's (1985) experiments *T. Junceiforme* germinated in fresh water (53%), half strength seawater (18%), and full strength seawater (5%) but did not germinate in one and a half strength seawater. When seeds were transferred from seawater to distilled water treatments the germination response increased: distilled water (76%), half strength seawater (53%), full strength seawater (47%), and one and a half strength seawater (28%). It is interesting to note that once transferred out of the seawater solution, the germination response for half strength seawater was equivalent to the initial germination response in distilled water. It is possible this reflects a natural response: Woodell (1985 p. 228) suggests that under natural conditions rainfall following immersion may stimulate germination. This, and the fact that *T. Junceiforme* germinated in half strength seawater may also lend weight to the suggestion the plant is a facultive halophyte (see Chapter Two).

The results of Woodell and Nicholson indicate that there is low or no germination of *Thinopyrum junceiforme* in full strength seawater. According to Nicholson (1952 p. 74) results of his experiments suggest that *T. Junceiforme's* '...tolerance range of germination to salt concentration is not great'. However, an alternative interpretation may be more appropriate: as noted above by Ridley, it is important that while floating in seawater seeds do not commence germinating 'too soon'. Some researchers consider this a survival mechanism whereby the seed will wait to germinate in 'suitable habitats' (Guja et al. 2010). Moreover, the results of Woodell tend to suggest seeds *are* tolerant to salinity in regard to the germination viability recorded following transfer to distilled water treatments. Thus, they have resisted 'the action of salt', as suggested by Ridley (1930 p. 242), in the 'immersion' part of the experiment.

5.2 METHODS

The factors important in oceanic hydrochory, as pointed out by Ridley (1930) are the ability to float 'without absorbing water'; (Darwin also suggests disturbance is important); the ability to delay germination while floating, and a tolerance to salinity reflected by the ability to establish subsequent to exposure. Hence experiments were carried to out to determine:

i. The floating capacity of T. junceiforme, with and without disturbance, and noting any germination;

ii. The germination response of T. junceiforme to variable periods of floating on seawater, and

iii. The germination response of T. junceiforme following complete submersion in seawater

5.2.1 Dispersal units used in experiments

While *Thinopyrum junceiforme* seed or fruit (known as a caryopsis), are shed in spikelets (Figure 5.1), florets (fruit and the enclosing bracts, lemma and palea) were used in the buoyancy experiments in this research. The floret is a common dispersal unit for grasses; it is 'rarely a seed' (Clayton 1990 p. 43). The floret was used instead of a spikelet as it was the most efficient way to determine whether a seed was present, given Nicholson's (1952 p. 57) observations that *T. junceiforme* is '...not a prolific seeder and many spikelets do not produce mature seed' (Chapter Two). The outer layers or bracts of each spikelet were removed and if a seed was felt within the remaining bracts (lemma and palea) it was put aside for use in the experiments.

5.2.2 Seed source

Thinopyrum junceiforme seeds were sourced from inflorescences on plants growing along the Younghusband Peninsula foredune in the Coorong National Park. Many inflorescences were collected given Nicholson's (1952) observations on *T. junceiforme's* seed production.

5.2.3 Description of experiments

5.2.3.1 Experiment 1a. The buoyancy or floating capacity of *Thinopyrum junceiforme* seeds (without disturbance)

This experiment involved floating *Thinopyrum junceiforme* seeds on seawater in a closed container and monitoring the buoyancy (and germination) of seeds over time. Three time periods or treatments were devised:

Treatment 1 – 7 days

Treatment 3 – 14 days

Treatment 3 – 21 days

Procedure

Seeds were placed in sealed containers containing seawater collected from the Southern Ocean near Goolwa, South Australia. 'Natural' seawater from the Southern Ocean (35-36 ppt, Gorman et al. 2010) was used in this study because while artificial /synthetic sea salts such as Instant Ocean ® (Aquarium Systems), have been used to formulate salt solutions in a variety of studies (for example, Erickson & Young 1995 and Griffiths & Orians 2003), there has been much debate regarding the ingredients, manufacturers claims and consistency of such products (see review by Borneman 2006).

Twenty five seeds were used per container with 3 replicates (75 seeds) per treatment. Each container was treated with 500 ml of seawater and sealed to reduce evaporation (Okusanya 1979). Each treatment also included a container with distilled water and 25 seeds, as a control (Okusanya 1979).

Containers were randomly assigned a treatment (7, 14 or 21 days x 3) and then arranged in a randomised complete block design whereby each container/treatment was randomly assigned a block (one treatment per block x three blocks), and each block was arranged randomly on the bench. This design was used to help account for any variation in environmental influences having the potential to affect experiment results (eg. light gradient).

Lines were marked on containers at the level of saltwater and topped up as required (Okusanya 1979). The buoyancy of seeds was monitored daily, with the number of seeds sinking (or germinating) each day recorded.

5.2.3.2 Experiment 1b. The buoyancy or floating capacity of *Thinopyrum junceiforme* seeds with disturbance

This experiment involved floating *Thinopyrum junceiforme* seeds on seawater in a closed container and monitoring the buoyancy of seeds over time. A regular disturbance regime was implemented to mimic conditions in the open ocean. Periods of disturbance were imposed over 2 days at intervals of every 3 days, for as long as seeds remained afloat. Disturbance involved using a Southern Pride food grade wooden stirrer to vigorously swirl around the container for up to 10 seconds, once a day.

As per experiment 1a, seeds were placed in sealed containers containing 500 ml seawater collected from the Southern Ocean near Goolwa. 25 seeds were used per container with 3 replicates (75 seeds). Each treatment included a control (distilled water). Containers were arranged on benches in a randomised complete block design. Lines were marked on containers at the level of saltwater and topped up as required. The buoyancy of seeds was monitored daily, with the number of seeds sinking (or germinating) each day recorded.

5.2.3.3 Experiment 2. The germination response of *Thinopyrum junceiforme* to variable periods of floating on seawater

In this experiment, the viability of seeds after floating on seawater for 7, 14 and 21 days was tested. At the end of each time period or treatment in experiment 1a (above) seeds were removed from the treatment containers and rinsed with distilled water. They were then placed in a petri dish lined with filter paper and watered with Rowater High Grade Distilled Water. Germination was monitored for 6 weeks.

5.2.3.4 Experiment 3. The germination response of *Thinopyrum junceiforme* following complete submersion in seawater

In this experiment, the viability of seeds after complete submersion in seawater was tested using seeds that had sunk in Experiment 1b (above). Seeds were submerged for a minimum period of 19 days following day 16 of experiment 1b. The length of submersion exceeding 19 days was variable depending on when seeds had sunk in the earlier experiment (see results).

The viability of the submerged seeds was determined by removing seeds from the treatment containers and rinsing them with distilled water. They were then placed in a petri dish lined with filter paper and watered with Rowater High Grade Distilled Water. Germination was monitored for 6 weeks.

In the experiments described above no environmental controls (temperature, light, humidity) were applied. Long term climate statistics (BOM 2012) indicate that for the period of experimentation maximum daily temperatures average 22.1^{o}degrees (October), 25.4^{o}degrees (November) and 27.9^{o}degrees (December) and daily minimum temperatures average 9.1^{o}degrees (October), 11.5^{o}degrees (November) and 13.6^{o}degrees (December). Daily sunshine hours average 7.8 hrs (October), 9.4 hrs (November) and 10.00 hrs (December) (BOM 2012). Relative humidity at 9 am averages 60% (October), 52% (November) and 49% (December) and at 3 pm: 48% (October), 40% (November) and 38% (December) (BOM 2012).

5.2.4 Analysis

Analysis of variance (Anova) was used to determine whether there was a significant difference in seed buoyancy between the 21 day, 14 day and 7 day experiments, and whether there was a significant difference between the commencement of germination and also the germination rate between the 21, 14 and 7 day experiments.

5.3 RESULTS

5.3.1 The buoyancy or floating capacity of *Thinopyrum junceiforme*

5.3.1.1 Buoyancy- no disturbance

The buoyancy (and germination) of *Thinopyrum junceiforme* seeds was monitored over 7, 14 and 21 day periods. 98 % of *Thinopyrum junceiforme* seeds remained floating over both the 7 day and 14 day experiments (Table 5.1). In the 21 day experiment seed buoyancy was 84 %, and this was predominantly due to the loss of 12 seeds to germination in the control.

Anova was used to see whether there was a significant difference in seed buoyancy between the 21 day, 14 day and 7 day experiments. Results indicated there was no statistically significant difference [$F(2,9) = 1.597826$, $p = 0.254782$] in the seed buoyancy between the different treatments.

Table 5.1. Buoyancy- no disturbance– seeds remaining afloat over the designated periods of 7,14 or 21 days.

Period	Rep 1	Rep 2	Rep 3	Control	%
21 days	24	22	25	13**	84
14 days	24	25	25	24	98
7 days	25	24	25	24	98

**12 seeds germinated and were discarded leaving only 13 seeds in control.

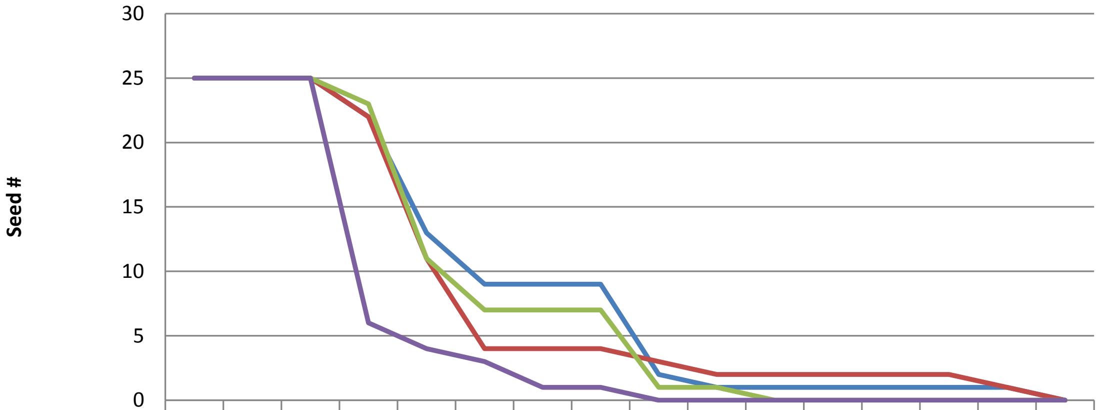
5.3.1.2 Buoyancy - with disturbance

This experiment focussed on *Thinopyrum junceiforme's* buoyancy or floating capacity incorporating regular disturbance to attempt to mimic conditions in the open ocean. Periods of disturbance occurred over 2 days at intervals of every 3 days, thus disturbance was on 4d and 5d, 9d and 10d, and 16d (see Table 5.2).

No seeds sank in the first few days of the experiment during which time there was no disturbance. Seeds began to sink on the day disturbance commenced (4d). Buoyant seed numbers remained stable on days 6, 7 and 8 in the seawater treatments when disturbance did not occur (see Table 5.2). Seeds began sinking again when disturbance recommenced on days 9 and 10, followed by another stable period. All seeds had sunk within 16 days of the experiment commencing (Table 5.2).

The control (distilled water) experienced a significant loss in numbers on day 4 when disturbance commenced (Table 5.2), and prior to the subsequent disturbance session on day 9 all seeds had sunk.

Table 5.2. Buoyancy of *Thinopyrum junceiforme* seeds with disturbance.



	1 d	2 d	3 d	4 d	5 d	6 d	7 d	8 d	9 d	10 d	11 d	12 d	13 d	14 d	15 d	16 d
Rep 1	25	25	25	22	13	9	9	9	2	1	1	1	1	1	1	0
Rep 2	25	25	25	22	11	4	4	4	3	2	2	2	2	2	1	0
Rep 3	25	25	25	23	11	7	7	7	1	1	0	0	0	0	0	0
Control	25	25	25	6	4	3	1	1	0	0	0	0	0	0	0	0

5.3.2 The germination response of *Thinopyrum junceiforme* to variable periods of floating on seawater

This experiment monitored the viability of *Thinopyrum junceiforme* in terms of its ability to germinate *after* floating on seawater for periods of 7, 14 and 21 days (without disturbance). After each 7, 14 or 21 day period had passed, seeds were removed from sea water, placed in a new petri dish and watered with distilled water. Germination (rate and timing) was monitored for 3 weeks.

5.3.2.1 Commencement of Germination

Seed germination commenced from 7 days (Control, 14 days) to a maximum of 22 days (Replicate 3, 21 days) (Table 5.3). The average was 13 days for germination to commence. No matter the time periods (i.e. following the 7, 14 and 21 day periods), germination always commenced first in the Control (Table 5.3).

Analysis of variance (Anova) was used to see whether there was a significant difference between commencement of germination between the 21 day, 14 day and 7 day experiments. Results indicated there was no statistically significant difference [$F(2,9) = 0.156$, $p = 0.857824$] in germination time between the different treatments.

Table 5.3. Commencement of germination (days).

Period	Rep 1	Rep 2	Rep 3	Control
Following 21 days	16	12	18	10
Following 14 days	11	9	22	7
Following 7 days	15	13	13	10

5.3.2.2 Germination rate

A total of 139 seeds from 280 seeds germinated; thus an overall germination rate of 49.64 % was achieved for the seed germination trial. More precisely, there was 52.04% germination following 7 days floating (including all replicates and control), 43.87% germination following 14 days floating (including all replicates and control), and 53.57 % germination following 21 days floating (including all replicates and control) (Table 5.4). Closer examination of individual replicates shows a greater variation, ranging from a germination rate of only 24% (Replicate 3, 14 days) to 81.81% (Replicate 2, 21 days) (Table 5.4).

Anova was used to determine whether there was a significant difference in the germination rate between the 21 day, 14 day and 7 day experiments. Results indicated there was no statistically significant difference [$F(2,9) = 0.1571$, $p = 0.856912$] in the germination rate between the different treatments.

Table 5.4. Germination rate.

Period	Rep 1	%	Rep 2	%	Rep 3	%	Control	%	Total %
21 days	14	**58.33**	18	**81.81**	9	**36**	4**	**30.76**	53.57
14 days	15	**62.5**	8	**32**	6	**24**	14	**58.33**	43.87
7 days	12	**48**	15	**62.5**	18	**72**	6	**25**	52.04

** Note 12 seeds previously germinated in flotation trial only 4 seeds germinated in the second part of the trial.

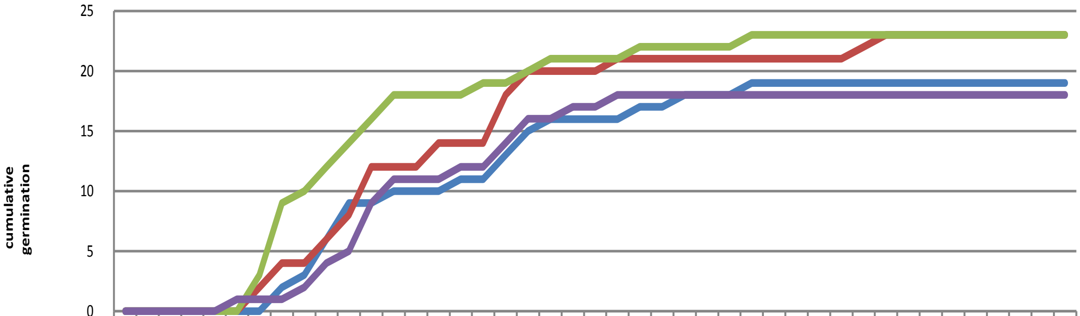
5.3.3 The germination response of *Thinopyrum junceiforme* following complete submersion in seawater

This experiment monitored *T. junceiforme's* germination response following complete submersion in seawater using seeds that had sunk in the experiment involving disturbance. Seeds were submerged for 19 days following day 16 of the experiment. However, as seeds began sinking on day 4 of the previous experiment some seeds may have been submerged for up to 32 days. The viability of the submerged seeds was tested by removing them from the seawater and placing them in a new petri dish moistened with distilled water. They were monitored over the following 6 weeks.

5.3.3.1 Germination of sunken seeds

Germination commenced from day 6 in the Control. Germination of seeds that had been submerged in seawater commenced on day 7 (Reps 2 and 3) and day 8 (Rep 1). Cumulative germination of *Thinopyrum junceiforme* seeds is shown in Table 5.5. There was no germination over the last 8 days of the six week monitoring period. The germination rate was 92% for replicates 2 and 3, 76% for replicate 1 and 72% for the control (note: 2 seeds germinated in the control (distilled water) during the 19 day submersion period and were removed). An overall germination rate of 85% was achieved (including 2 seeds germinating in the control), or 83% excluding the seeds germinating in the control.

Table 5.5. Cumulative germination of *Thinopyrum junceiforme* seeds following (a minimum of) 19 days submersion in seawater. Note: 2 seeds germinated in the Control during the 19 day submersion period and were removed.



	1 d	2 d	3 d	4 d	5 d	6 d	7 d	8 d	9 d	10 d	11 d	12 d	13 d	14 d	15 d	16 d	17 d	18 d	19 d	20 d	21 d	22 d
Rep 1	0	0	0	0	0	0	0	2	3	6	9	9	10	10	10	11	11	13	15	16	16	16
Rep 2	0	0	0	0	0	0	2	4	4	6	8	12	12	12	14	14	14	18	20	20	20	20
Rep 3	0	0	0	0	0	0	3	9	10	12	14	16	18	18	18	18	19	19	20	21	21	21
Control	0	0	0	0	0	1	1	1	2	4	5	9	11	11	11	12	12	14	16	16	17	17

	23 d	24 d	25 d	26 d	27 d	28 d	29 d	30 d	31 d	32 d	33 d	34 d	35 d	36 d	37 d	38 d	39 d	40 d	41 d	42 d	43 d
Rep 1	16	17	17	18	18	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Rep 2	21	21	21	21	21	21	21	21	21	21	21	22	23	23	23	23	23	23	23	23	23
Rep 3	21	22	22	22	22	22	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
Control	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

5.4 DISCUSSION

Like Ridley (1930), Lesko and Walker (1969) suggested that oceanic transport requires:

i. 'seeds/fruit to be able to float on sea water',

ii. 'that germination is inhibited by seawater', and

iii. 'seeds/fruit to be able to maintain germination viability' p. 733.

Thinopyrum junceiforme appears to meet these criteria as indicated by the results of the experiments conducted in this research, as discussed below.

5.4.1 The buoyancy of *Thinopyrum junceiforme* seed

Results indicated that almost all (98%) *Thinopyrum junceiforme* seeds remained floating over the one and two week periods, and nearly 85% over the three week period. Overall, 280 *T. junceiforme* seeds remained floating at the end of the experiment, thus exceeding Heyligers' (1985) suggestion that it can float for up to 2 weeks. Experiments were conducted in a protected environment and results suggest calm conditions would be conducive to *T. junceiforme's* transport by currents under such conditions. While the mechanism of buoyancy was not determined during this research, the tissue with air filled cavities in the inflorescences (see above) seems most likely (Cheplick 1998 p. 86) given the way in which seeds are dispersed naturally in spikelets.

The buoyancy or floating capacity of *Thinopyrum junceiforme* was further tested by incorporating regular disturbance to attempt to mimic conditions in the open ocean. Such disturbance was employed because Darwin suggested buoyancy would probably be reduced in the open ocean: *'...plants exposed to the waves would float for a less time than those protected from violent movement as in our experiments'* (p. 360). Ridley (1930 p. 333) also suggested that it would be doubtful as to whether the seeds of coastal grasses '.. would stand sea action'. Again, as *T. junceiforme's* seed is shed in spikelets this may afford the seed some protection against 'sea action'. Certainly, Nicholson (1952 p. 55) suggests that 'many seeds are washed away by the sea and re-deposited in other areas are unimpaired....'.

Experimental data showed that seeds commenced to sink on the day disturbance commenced. A clear pattern emerged whereby stable periods in which no seeds were lost alternated with periods in which *Thinopyrum junceiforme* seeds would sink, which in turn was associated with the disturbance regime. The experiment was terminated because all seeds had sunk within 16 days of commencement. The association between seeds sinking with disturbance appears to confirm Guppy's and Ridley's concerns about the effect of conditions in the open ocean upon seeds. Consequently, it is possible that florets became waterlogged with disturbance and sank with each disturbance event.

It is interesting to note that the control (distilled water) experienced a significant loss in numbers (19 seeds) on day 4 when disturbance commenced, and prior to the subsequent disturbance session on day 9 all seeds had sunk. In a buoyancy experiment also incorporating disturbance, Okusanya (1979 p. 300) commented that five of the seven species in their trial '...sank with the first few shakings, *especially in distilled water'*. (my emphasis) Consequently, the density of salt water may also contribute to (seed) buoyancy as per the Archimedes' principle. However, Guppy (1906) would vehemently disagree: 'the buoyancy of seed and fruits has no direct relation to the density of sea-water, and even if the ocean was deprived of all its dissolved salts, the agency of the dispersal of plants by currents would not be materially affected' (p. 98).

5.4.2 The germination of *Thinopyrum junceiforme* seed during and after floating on seawater

An overall germination rate of around 50% was achieved by *Thinopyrum junceiforme* seed that had been floating on seawater for between one to three weeks. There was no significant difference in the germination rate, nor the commencement of germination, with regard to the floating period (7, 14 or 21 days). During these trials no *Thinopyrum junceiforme* seed germinated in seawater (premature germination only occurred in distilled water (the control)), thus increasing the plant's potential for establishment and survival. According to Guja et al. (2010 p. 1185) '..while most of our study species survived in sea water and did not germinate whilst floating, there is the potential for oceanic dispersal and germination once lower salt concentrations are encountered when washed ashore'.

After being submerged for a minimum of 19 days, an overall germination rate of 85% was achieved with the sunken seeds after being transferred to fresh water. Moreover, the viability of seeds submerged in seawater was greater (85%) than seeds that were floating undisturbed on seawater (50%). While the experiments indicated that disturbance undoubtedly eventually caused all seeds to sink, the ability to germinate well following prolonged immersion suggests a significant survival advantage. While prolonged immersion in this study referred to a minimum of 19 days, unpublished research by Heyligers suggests that viability may be maintained under much longer periods of immersion (P. Heyligers, Pers. Comm., 2007). These experimental data suggest that *Thinopyrum junceiforme* has the potential to germinate and establish following immersion in the ocean and re-deposition on-shore where fresher water (for example, in the form of rainfall) may be available (Guja et al. 2010, Woodell 1985).

Darwin commented that sunken seeds '...could not possibly be transported by sea-currents beyond a very short distance' (Darwin 1857 p. 135). However, Ridley (1930 p. 251) suggested that sunken seeds may spread in a 'leap frog' manner along the coast: '...if my suggestion that sunken seeds may be washed up in shallow seas with sand in storms is correct', [it] 'may account for the travelling of plants from bay to bay, or mud-bank to mud-bank, although the seeds or fruit do not float. The distance that such plants could travel, although not to be compared with those of floating seeds, is of some importance as allowing the plants to make their way along the coasts of a mainland'.

5.5 Summary

Experiments indicate that the buoyancy or floating capacity of *Thinopyrum junceiforme* under calm conditions was very good with 280 of 300 seeds remaining floating in the seawater and control (distilled water) treatments. No seeds germinated while floating on seawater, which may be interpreted as a survival mechanism. The effect of disturbance was to cause all seeds to sink. However, the high germination rate of *T. junceiforme* seeds following disturbance and sinking, which are conditions that may be found in the open ocean, as well as the ability to withhold germination while floating, appear to be significant mechanisms for the plants survival and spread.

CHAPTER 6. THE REGENERATIVE POTENTIAL OF *THINOPYRUM JUNCEIFORME* RHIZOMES IN TRANSPORTED SAND ON THE ADELAIDE METROPOLITAN COAST

This chapter focuses on the survival and establishment of *Thinopyrum junceiforme* rhizomes, fragmented and transported by machinery to a new location on the metropolitan Adelaide coastline in the City of Charles Sturt (Figure 6.1) in sand used for beach replenishment purposes. This investigation was carried out to assess the possible role of human activities in the spread of *T. junceiforme*, and to assess the regenerative ability of rhizomes.

6.1 BACKGROUND

6.1.1 *Thinopyrum junceiforme* on the Adelaide metropolitan coast

Most of the native vegetation along the highly urbanised Adelaide metropolitan coast has been cleared (PPK Environment and Infrastructure 2001 p. 4). Prior to settlement the pre-European vegetation of the coast comprised an *Olearia axillaris/Acacia longifolia* subsp *sophorae* open heath (Kraehenbuehl 1996). However, during settlement it was the coastal dunes that '..were among the first areas to feel the brunt of the colonists'', which were 'levelled for construction', as well as being subjected to 'overgrazing' and the 'introduction of competitive alien plants' (Kraehenbuehl 1996 p. 6).

Thinopyrum junceiforme was not noted on the metropolitan coast until 1984 at Henley Beach according to herbarium records (Chapter Three). Certainly, it was not noted by Cleland (1935) who surveyed the area from Outer Harbour to Sellicks Hill, nor in the Culver Report (The University of Adelaide Civil Engineering Department 1970), although a number of other alien plants were noted by these authors.

In addition to Henley Beach (1984, 2002), herbarium records indicate *Thinopyrum junceiforme* was also recorded on the metropolitan coast at Semaphore (1986, 1989), West Beach (1989), and at North Haven in 2009. However, the records do not appear to reflect the true situation along the metropolitan coast as determined by analysis of the information in the 'Metropolitan Adelaide and Northern Coastal Action Plan' (Caton et al. 2009a & b).

In their Coastal Action Plan (CAP) Caton et al. (2009a) divided the coast into 24 cells or 'small sub regional landform units' (p. 3) ranging from Sellicks Beach to the northern boundary of the Mallala Council, a total of 273 km (p. 31). Sellicks Beach is designated cell MA1 and ‘the mangrove/saltmarsh coast from Port Adelaide to the northern boundary of the region’ comprised cells MA15-24 (p. 32).

Analysis of the cell descriptions in Caton et al. (2009b) indicated that *Thinopyrum junceiforme* occurred in 13 of the 24 cells covered by the CAP, namely: Sellicks Beach (MA1), Silver Sands (MA2), Snapper Point (MA3), Port Willunga (MA4), Maslin Beach (MA5), Moana (MA6), Seaford (MA7), Port Noarlunga (MA8), Christies Beach (MA9), Port Stanvac (MA10), Holdfast Bay (MA12), Patawalonga to Point Malcolm (MA13) and Le Fevre Peninsula (MA14).

Figure 6.1 a,b. Location of the study area on the metropolitan Adelaide coast. Source: LGA SA, ‘Council Maps’, http://www.lga.sa.gov.au/sitepage.cfm?u=209, June 2012.

Thinopyrum junceiforme did not occur in Hallett Cove (MA11), most of which comprises 'low undulating coastal plateau, with cliffs and shore platforms…..' (Caton et al. 2009b p. 163), nor was the plant present in cells MA15-24, from Port Adelaide (MA15) to the northern boundary of the region, that is, the 'mangrove/saltmarsh coast'.

The occurrence of *Thinopyrum junceiforme* on the metropolitan coast identified by herbarium records represented only two cells (MA13 and MA14), compared to the 13 cells it actually is known to occur in, according to the CAP (Caton et al. 2009b). Moreover, the 'terrestrial habitat descriptions' provided for each cell in Caton et al. (2009b) provide a valuable insight into the nature and extent of *T. junceiforme* invasion in some areas. In the two cells for which there are herbarium records, for example, Caton et al. (2009b) commented that between the Patawalonga and Point Malcolm (MA13), 'Much of the coastline is artificially replenished and any dune building is largely a grassland of **Thinopyrum junceiforme*' (p. 206). At Le Fevre Peninsula (MA14) the coast is described as 'largely a **Thinopyrum junceiforme* grassland with emergent *Nitraria billardierei* in the foredune' (p. 224).

It is possible that coastal management, in the form of sand replenishment, has assisted in the spread of *T. junceiforme* along the Adelaide metropolitan coast.

6.1.2 Sand replenishment along the Adelaide metropolitan coast

There is a number of issues that have influenced the management of the Adelaide coastline including the absence of a (natural) continuing supply of sand to the coastal system; development on coastal dunes depriving the coastal system of that sand, and a northward littoral drift of sand that has resulted in erosion in some areas of the metropolitan coast and sand accumulation in others (The Coastal Management Branch 1984).

Sand replenishment has long been part of the beach management along the Adelaide coast, with early recommendations for this form of coastal management made by the so-called 'Culver Report' of 1970 (The University of Adelaide Civil Engineering Department, 1970). Reviews of the Adelaide coastline (1984, 1992, 1997) viewed sand replenishment '...as the most cost-effective way of maintaining sandy beaches and protecting property on the foreshore' (DEH 2005 p. 1). The most recent review *viz Adelaide's Living Beaches: A Strategy for 2005–2025* recommends the continuation of sand replenishment involving the emplacement of '160,000 cubic metres of sand each year at strategic locations on southern and central beaches to maintain the sandy foreshore, build up dune buffers, and protect coastal infrastructure' (DEH 2005 p. 3).

Sources of sand for replenishment include 'the northern beaches and ….accumulations at Glenelg and at the Torrens outlet...' (The Coastal Management Branch 1984 p. 2) and from offshore sources obtained via dredging (DEH 2005 p. 1). In addition, coarse sand from Mt Compass, located in investigations undertaken to locate new sources of sand, will also be used in sand replenishment (DEH 2005 p. 2, 3).

The management of Adelaide's metropolitan beaches via sand replenishment has been described as 'demonstrably successful' with 'protective sand dunes that have now built up at Brighton, Henley South and Grange......' (DEH 2005 p. 1). Coastal councils have assisted with coastal management by installing drift fencing, constructing walkways and by employing planting programs (DEH 2005 p. 1). In the study area, the City of Charles Sturt has been responsible for the production of a series of vegetation management plans for their 11.3 km long coastline (available from the Council's website http://www.charlessturt.sa.gov.au/site/page.cfm?u=176) and have erected drift fencing in areas along the beach to encourage artificial dune formation and infrastructure protection (Cordingley & Petherick 2005 p. 13). Revegetation and other works have also been undertaken by groups such as the Henley and Grange Dunecare Group (Cordingley & Petherick 2005 p. 17).

6.1.3 The potential mode of spread of *Thinopyrum junceiforme* along the Adelaide metropolitan coast

The preceding section has shown that *Thinopyrum junceiforme* occurs along much of the Adelaide metropolitan coastline. This chapter explores the possibility that its spread may have been assisted by transport of rhizomes in sand used in sand replenishment. In the dispersal of *T. junceiforme* by rhizome fragments the following factors are important: buoyancy, the process of fragmentation, rhizome fragment length and number of nodes, and the timing of fragmentation.

6.1.3.1 Buoyancy

One of the factors associated with oceanic hydrochory is buoyancy or the ability to float (Chapter Five). Recent research by Konlechner and Hilton (2009) found that rhizomes of *Ammophila arenaria* (Marram grass) retained buoyancy in seawater for 161 days while remaining viable for 70 days. The presence of hollow internodes may assist in rhizome buoyancy (Knevel 2001 p. 179), and certainly Konlechner and Hilton (2009) found the presence of more than one node appeared to be 'the most significant factor influencing rhizome buoyancy' (p. 435) as the 'sealed internodes allows rhizomes to float for long periods' (p. 436). In this chapter buoyancy was not of primary importance as rhizome fragments were largely transported to new locations on the metropolitan coast by machinery for sand replenishment purposes.

6.1.3.2 Fragmentation

Under natural conditions, rhizomes are usually broken during periods of erosion, and then transported, sometimes for 'considerable distances', to new sites by the sea (or wind) (Nicholson 1952 p. 83). According to Harris (1982 p. 72) disturbance has a two-fold effect on *Thinopyrum junceiforme*: via fragmentation and 'physical displacement' it enables the plant's dispersal 'away from the parent plant' and the fragmentation process facilitates the breaking of dormancy of axillary buds. As noted in earlier research by Nicholson (1952 p. 82) fragmentation from the parent plant enables it to overcome the 'inhibitory effect' of the apical bud. Exposure to light, through erosion/disturbance, may also have the same response (Nicholson 1952 p. 83, see also Harris 1982).

A number of studies have been undertaken on the factors involved in overcoming bud dormancy. Cordazzo and Davy (1999), for example, found that fragmented *Panicum racemosum* rhizomes showed a 'significantly higher' rate of sprouting compared to 'intact fragments' probably due to the removal of apical dominance due to fragmentation (or exposure to light) (p. 523). Overcoming dormancy '…in *Panicum racemosum* by fragmentation during storms waves ensures a continuation of the regenerative ability of rhizome fragments similar' to species such as *Thinopyrum junceiforme* (Cordazzo & Davy 1999 p. 523). Prior to their transport, rhizomes in this study were separated from parent plants or fragmented by artificial mechanical means, hence assisting in the breaking of bud dormancy.

6.1.3.3 Fragment length and number of nodes

The length and number of nodes of the rhizome fragments were important because as previous research shows not all nodes on fragmented *Thinopyrum junceiforme* rhizomes produce both roots and shoots, with some only producing either one (Nicholson 1952 p. 83, 84). This is significant because while rhizome fragments can propagate 'with at least one node' (Nicholson 1952 p. 83), its survival may be tenuous, particularly in low moisture areas, and if only shoots are produced (Nicholson 1952 p. 84, 86). Consequently, multi-noded rhizomes have the best chance of survival, as suggested by Harris and Davy (1986b), who found in burial trials (see Chapter Two) that 'At any given depth fragments with more nodes produced more emergent shoots and produced them more quickly' (p. 1059).

6.1.3.4 Timing of rhizome fragmentation

The timing of rhizome fragmentation is another important aspect of rhizome regeneration, regardless of whether it has occurred artificially or under natural conditions. Harris and Davy (1986b p. 1060) found that the greatest regenerative ability of *Thinopyrum junceiforme* is 'in late winter-early spring followed by a sharp decline in late spring-early summer'. During these seasons regenerative potential may be affected by the redistribution of nutrients from rhizomes to 'new growing points of roots and shoots' (Harris 1982 p. 178).

6.2 METHODS

6.2.1 Site selection

Site selection involved locating an area along the Adelaide metropolitan coast that had recently undergone sand replenishment. An ideal study area was located in the sub-regional landform unit MA13 (Patawalonga to Point Malcolm) at Henley Beach South, a coastal residential suburb in the City of Charles Sturt on the Adelaide metropolitan coastline approximately 10 km west from the Adelaide CBD. In March 2006 this area had undergone beach replenishment using 25 000 m^3 of sand (P. Johnson, Pers. Comm., 2008). The sand, containing *Thinopyrum junceiforme* rhizome fragments, was sourced from south of the River Torrens (Figures 6.2, 6.3), an artificial outlet constructed in the late 1930s to alleviate flooding when the river used to debauch into an area behind the frontal dunes called the Reedbeds.

6.2.2 Site description

The study area was located within the Henley South and West Beach Coastal Reserve (Figure 6.1). The reserve is described as a 'flat sandy beach', comprised predominantly of siliceous Holocene sands, and 'backed by vegetated low to medium sized dunes that range from approximately 10 to 125 m in width' (Cordingley & Petherick 2005 p. 15). 'Little remnant vegetation and no distinct vegetation communities exist. This can be attributed to the dunes' relatively recent formation and a history of poor management' (Cordingley & Petherick 2005 p. 16). A total of 96 plants has been recorded in the Reserve, 70 of which are introduced species (Cordingley & Petherick 2005 p. 17). *Thinopyrum junceiforme* has been identified as the 'dominant weed' in the *Spinifex sericeus/Atriplex cinerea/Ficinia nodosa* Tussock Grassland formations[1] occurring in the most exposed, dynamic and unstable sections of coast in the reserve (Cordingley & Petherick 2005 p. 39, 41).

Within the Reserve, the study site comprised a replenished section of beach, approximately 400 m long, which was backed by one low dune vegetated by native and exotic plants including *Ammophila arenaria, Spinifex sericeus, Cakile maritima* subsp. *maritima, Gazania* species, *Carpobrotus rossii, Pennisetum clandestinum, Ficinia nodosa, Euphorbia paralias* and *Thinopyrum junceiforme*. This area was backed by a road (the Esplanade) and residential housing. Seaward of the low dune was an old partially buried drift fence, a strip of sand (just over 6 metres wide) and a drift fence made of shadecloth and permapine posts. The drift fencing, erected along the beach between South and Lexington Streets, was put in place by the City of Charles Sturt Council to encourage artificial dune formation for the protection of residential housing (Cordingley & Petherick 2005 p. 10).

Figure 6.2. Sand sourced from south of the River Torrens outlet. Source: Photograph by the author.

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[1] The reserve has been divided into vegetation communities to 'act as a guide for future rehabilitation works' (Cordingley & Petherick 2005 p. 16)

Figure 6.3. *Thinopyrum junceiforme* fragments in transported sand from south of the River Torrens Outlet. Source: Photograph by the author

6.2.3 Study site units

The study site was divided into three sections by access walkways that enabled pedestrian access to the beach (Figure 6.1). Section Three was the longest section at 176 m (across the beach). It was bounded by walkways 63 and 64 and had an average beach width of 14.33 – 15.51 m. Section Two, bounded by walkways 64 and 65, was 127.5 m long (across the beach) and had an average beach width of 14 – 15.51 m. The shortest section was Section One at 115 m long (across the beach). It was bounded to the north by walkway 65 and had an average beach width of 17.74 – 19.52 m. While pedestrian walkways determined the length of each section along the beach, the varying width of each section depended on the artificial boundaries resulting from the placement of the 25 000 m^3 of sand (Figures 6.4 a,b).

6.2.4 Vegetation monitoring

Monthly monitoring took place over a 7 month period between July 2006 and January 2007. It involved monitoring the net changes in *Thinopyrum junceiforme* plant numbers over time in each section using a grid system. Each section was transformed into a grid by laying out measuring tapes across its length along the beach, and at right angles to the coast, between the fixed point of the backing drift fence and the variable seaward edge of the transported sand. Systematic observations of *T. junceiforme* were made in each 1 m square grid cell defined by the tape measures. The scale of presence/absence per square metre was fine enough to provide an adequate representation of plant increase and loss over the area monitored. It should be noted that while repeated monitoring took place, there may be inherent inaccuracies as the study area lack fixed dimensions that could be 100% replicated. That is, while the backing drift fence was permanent, no fixed points defined its dynamic seaward edge as a point of reference as given the nature of this busy metropolitan beach no permanent fixtures could be installed on the beach

Figure 6.4a. Sand deposited at the study site, view seaward. Source: Photograph by the author.

Figure 6.4b. Sand deposited at the study site, view landward. Source: Photograph by the author.

6.2.5 Monitoring erosion of emplaced sand in the study area

In addition to monitoring *T. junceiforme* colonisation, the sand that had been placed on the beach was monitored in relation to erosion of its most seaward edge. Erosion of the emplaced sand was monitored to determine the consequences on colonising plants. The width of the beach in each section was recorded by measuring the distance between the most seaward edge of the transported sand, and the drift fencing, which was a static permanent point, at regular intervals along the length of the beach each month.

Prior to undertaking fieldwork a work permit was obtained from the City of Charles Sturt council. The study was terminated in January 2007 because of beach erosion and the construction of a new fence seaward of the existing drift fence (Figure 6.5).

Figure 6.5. New fence being constructed seaward of existing drift fence used in this study. Photograph taken in February 2007. Source: Photograph by the author.

6.3 RESULTS

6.3.1 Section One

6.3.1.1 Beach width

Beach width for Section One for the period July 2006 – January 2007 is shown in Figure 6.6. Figure 6.6 shows that maximum beach width for Section One occurs in the first three months of monitoring (July, August and September), with slightly higher averages being recorded for July. Average beach widths of between 16.95-16.17 m were recorded between July and September 2006. A period of erosion was experienced subsequent to the first three months of monitoring, resulting in a reduction of average beach width of just over

5 m between September and October 2006. The months of October, November and December remained relatively constant with new average widths of between 11.13 – 11.65 m (Figure 6.6). Once again, a period of erosion was recorded in January 2007, with average beach width dropping to 5.03 m after the loss of over around 6.5 m of sand between the final two months of monitoring in Section One (Figure 6.6).

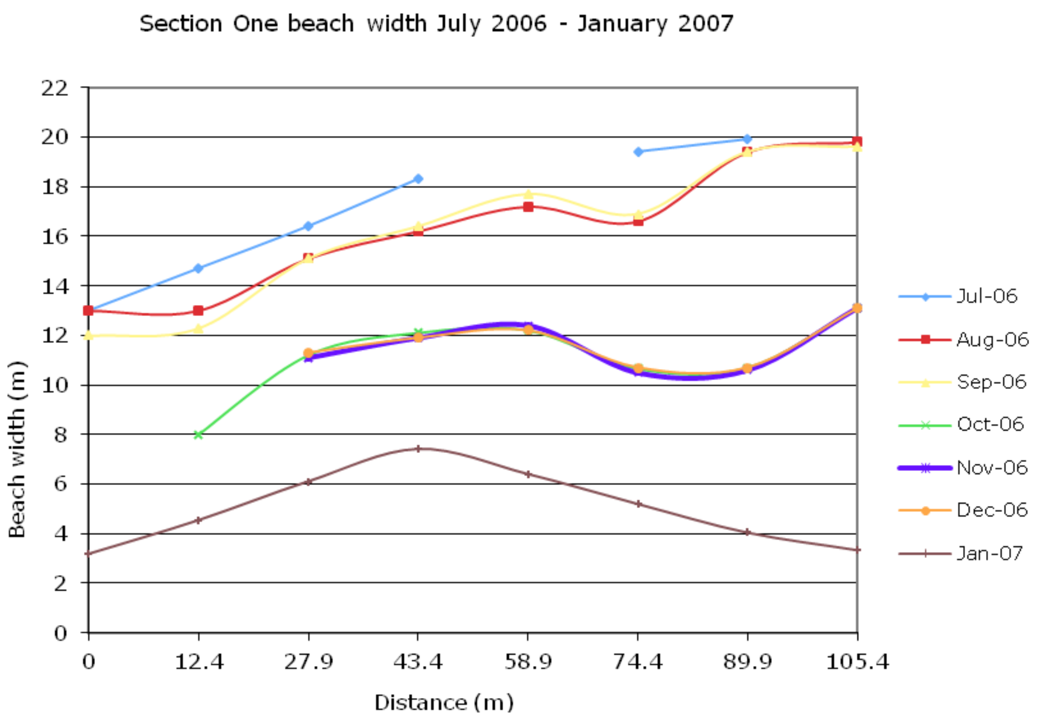
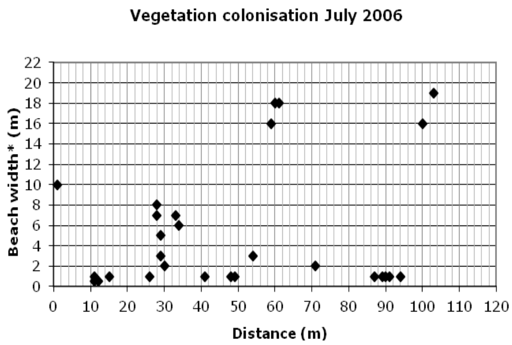


Figure 6.6. Beach width, Section One, July 2006 - January 2007. 'Beach width' is the area between the most seaward edge of the emplaced sand and the most landward edge of the emplaced sand at the backing drift fence ('0'). 'Distance (m)' represents the intervals across the beach at which width was measured. Note: missing data points represent blow-outs or areas of disturbance where an estimation of width could not be made.

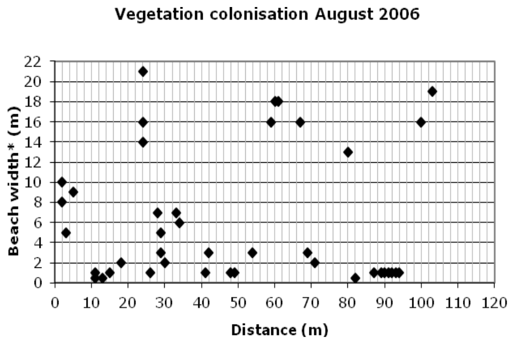
6.3.1.2 Vegetation colonisation

The colonisation behaviour of *Thinopyrum junceiforme* in Section One between July 2006 and January 2007 is shown in Figure 6.7 a-g. In the first month of monitoring, July, a total of 28 plants were recorded in Section One. The number of plants increased to 41 in the second month of monitoring in August. While three plants recorded in July were not found in August, an additional 16 new plants were recorded. In the following month of September there was another increase in the number of plants recorded, and at 47 was the maximum number of plants found in any month. Eight new plants were recorded, and the loss of one from the previous month was noted, in this period. October saw a large

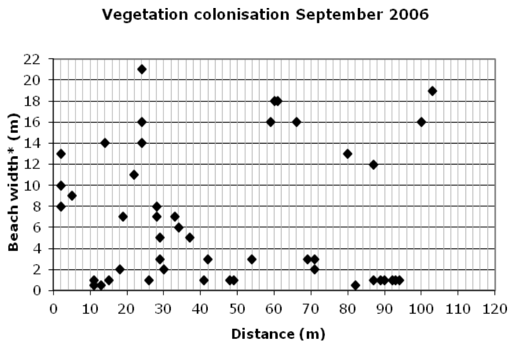
6.7a. July 2006



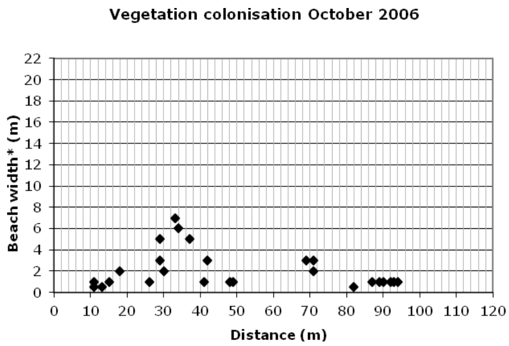
6.7b. August 2006



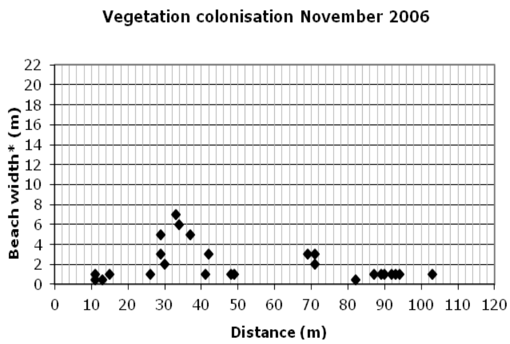
6.7c. September 2006



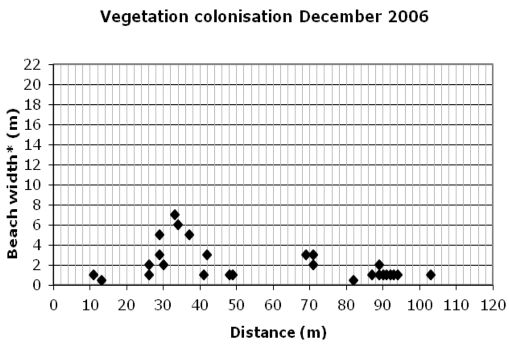
6.7d. October 2006



6.7e. November 2006



6.7f. December 2006



6.7g. January 2007

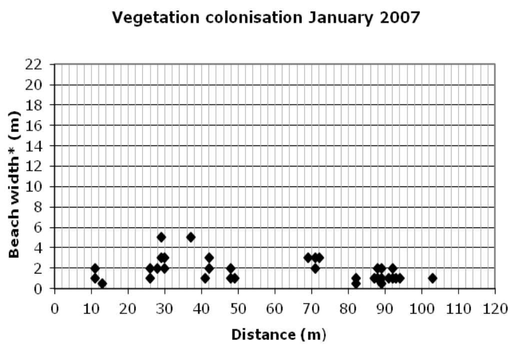


Figure 6.7 a-g. Vegetation colonisation, Section One, July 2006 – January 2007. Beach width axis scaling is identical for comparative purposes. See Figure 6.6 for actual widths

Note: 'Distance m' represents the area monitored across the beach between walkways. 'Beach width' is the area between the most seaward edge of the emplaced sand and the most landward edge of the emplaced sand at the backing drift fence ('0').

decrease in the number of plants recorded with a loss of 21 plants. As in October, 26 plants were also recorded in November. This included the loss of one plant from October and the addition of one new plant. December recorded 27 plants, losing two plants from the previous month and gaining three new plants. The final month of monitoring, January 2007, recorded an increase in plants recorded in Section One to 35. Three plants were lost from the previous month, and 11 new plants were noted during this period.

6.3.2 Section Two

6.3.2.1 Beach width

Beach width for Section Two is shown in Figure 6.8. The figure shows that maximum beach width for Section Two occurs in the first three months of monitoring (July, August and September). Beach width during this period remained relatively constant with an average of between 13.38-13.82 m. Subsequent to the first three months of monitoring, erosion was experienced resulting in a reduction of beach width by around 5.15 m between September and October 2006. The months of October, November and December remained relatively constant with new average widths of between 8.28 - 8.73 m (Figure 6.8). A subsequent period of erosion was recorded in January, with average beach width dropping to 3.75 m – a loss of almost 5 m between the final two months of monitoring (Figure 6.8).

6.3.2.2 Vegetation colonisation

The colonisation behaviour of *Thinopyrum junceiforme* in Section Two between July 2006 and January 2007 is shown in Figure 6.9 a-g. During the first two months of monitoring, 22 plants were recorded in July and August (Figure 6.9). Nearly all (21) of these plants were common to both months, except one plant from July was not recorded in August, and in August a new plant was recorded. In the third month of monitoring, September, all plants previously recorded in August were present, but an additional three plants, and thus a total of 25 plants, were recorded. October reported a slight reduction in the number of plants recorded at 22. While this obviously involved the loss of plants previously recorded, one new plant was still recorded over this period. November recorded a slight increase in plants present with 24 plants noted, including three previously unrecorded plants. In December 26 plants were recorded, and included 4 plants previously unrecorded and the loss of 2 plants from the previous month. The final month of monitoring, January 2007, recorded the highest number of plants over the entire monitoring period at 28, which included 3 new plants and one the loss of one plant from the previous month.

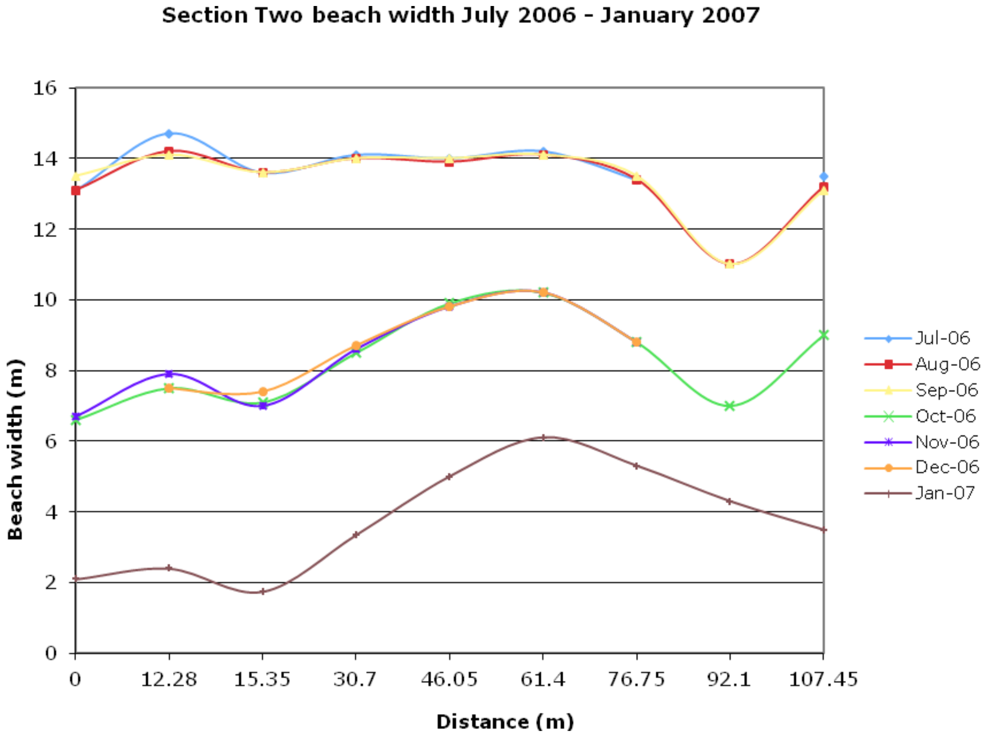


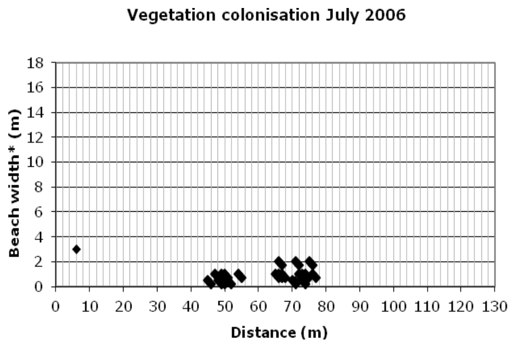
Figure 6.8. Beach width, Section Two, July 2006 - January 2007. 'Beach width' is the area between the most seaward edge of the emplaced sand and the most landward edge of the emplaced sand at the backing drift fence ('0'). 'Distance (m)' represents the intervals across the beach at which width was measured. Note: missing data points represent blow-outs or areas of disturbance where an estimation of width could not be made.

6.3.3 Section Three

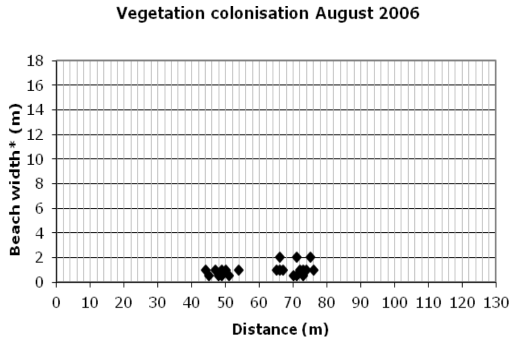
6.3.3.1 Beach width

Beach width for Section Three for the period July 2006 – January 2007 is shown in Figure 6.10. Figure 6.10 shows that the maximum beach width for Section Three occurs in the first three months of monitoring (July, August and September). Beach width during this period remained relatively constant with an average between 13.93-14.39 m. However, following this period, a significant period of erosion was experienced resulting in a reduction of beach width. The beach was eroded by over half its original size with around 7.36 m sand lost from the beach between September and October 2006. The months of October, November and December remained relatively constant with new average widths of between 6.55 - 6.96 m (Figure 6.10). Subsequently, another period of erosion occurred resulting in the loss of almost 5 m of sand, leaving the beach in Section Three with an average width of 2.09 m in January 2007 (Figure 6.10).

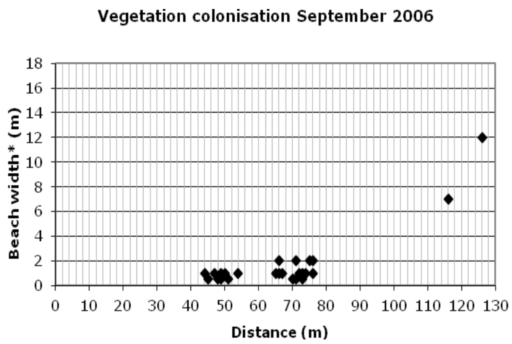
6.9a. July 2006



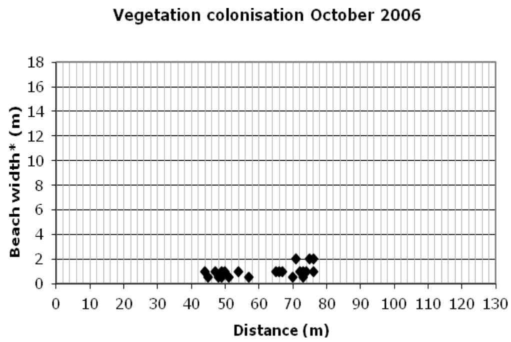
6.9b. August 2006



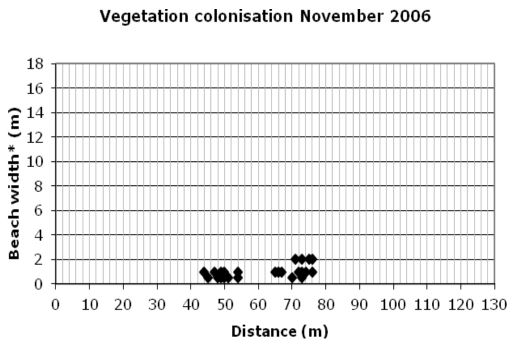
6.9c. September 2006



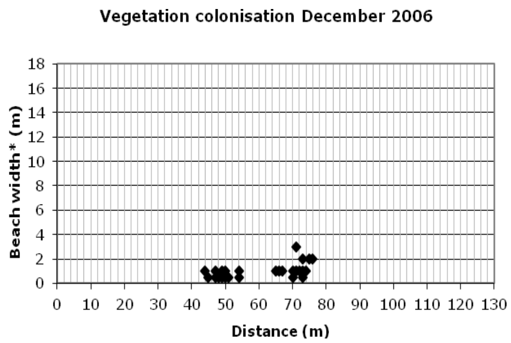
6.9d. October 2006



6.9e. November 2006



6.9f. December 2006



6.9g. January 2007

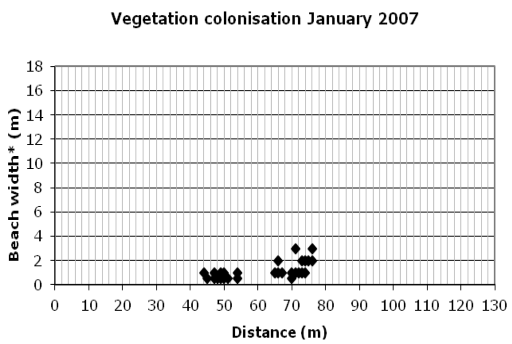


Figure 6.9 a-g. Vegetation colonisation, Section Two, July 2006 – January 2007. Beach width axis scaling is identical for comparative purposes. See Figure 6.8 for actual widths.

*See Note for Figure 6.7 regarding distance and beach width.

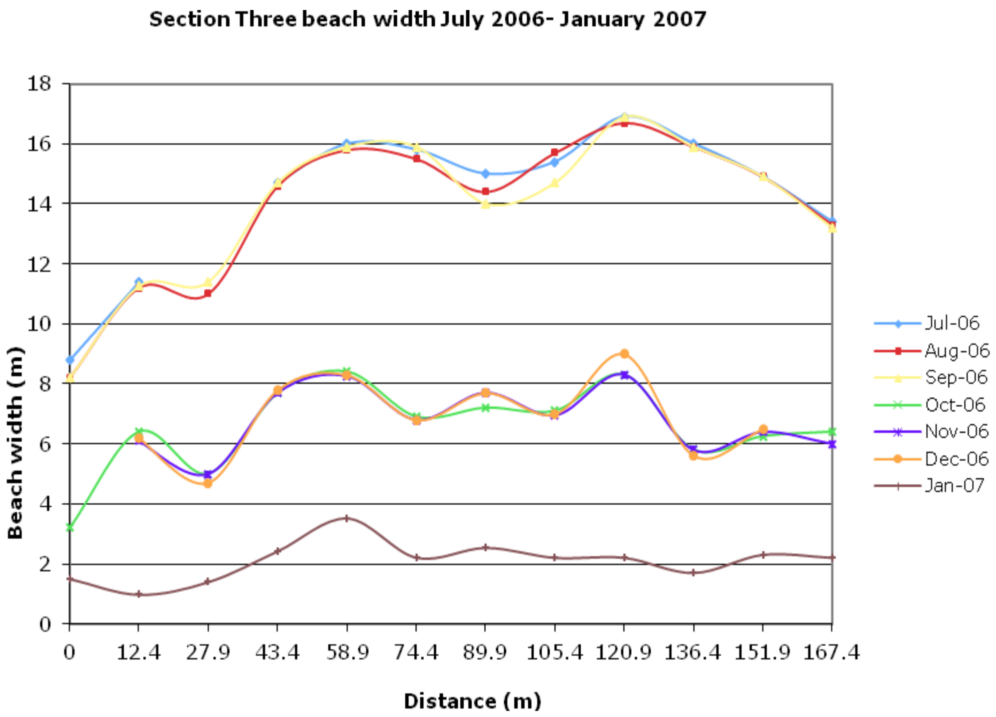
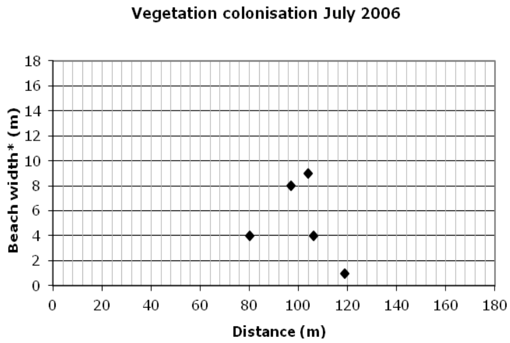


Figure 6.10. Beach width, Section Three, July 2006 - January 2007. 'Beach width' is the area between the most seaward edge of the emplaced sand and the most landward edge of the emplaced sand at the backing drift fence ('0'). 'Distance (m)' represents the intervals across the beach at which width was measured. Note: missing data points represent blow-outs or areas of disturbance where an estimation of width could not be made.

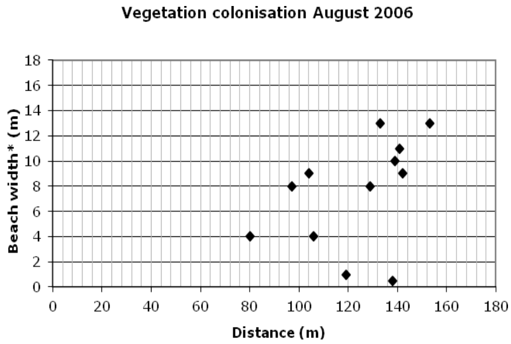
6.3.3.2 Vegetation colonisation

Figures 6.11 a-g shows the colonisation behaviour of *Thinopyrum junceiforme* in Section Three between July 2006 and January 2007. The figure shows that during the first month of monitoring in July, only 5 plants were recorded. In August an additional 7 plants had colonised Section Three, with a total of 12 plants recorded. In September, a total of 15 plants was recorded, comprising the original 5 plants from July and 6 of the 7 new plants recorded in August. Consequently, a total of 4 new plants had colonised the area in the third month of monitoring. In October, a dramatic reduction in the number of plants colonising Section Three was recorded with only three plants remaining. In November and December, the total number of plants recorded dropped to two (both originally recorded in July), and in January only one plant (again, originally from July) remained in Section Three (Figure 6.11g).

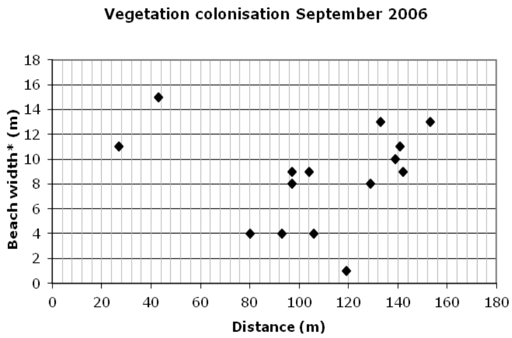
6.11a. July 2006



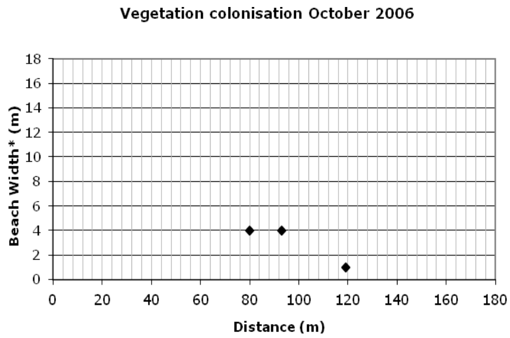
6.11b. August 2006



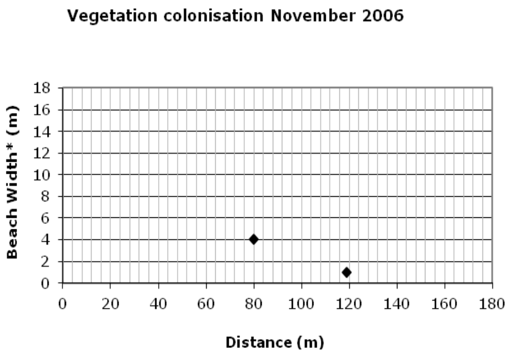
6.11c. September 2006



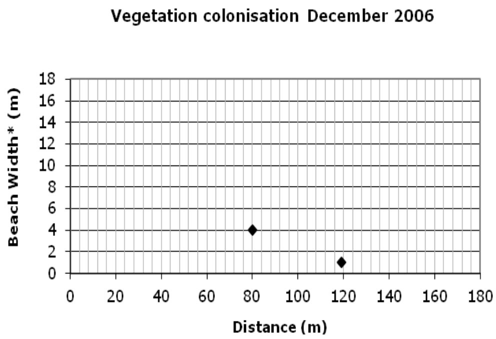
6.11d. October 2006



6.11e. November 2006



6.11f. December 2006



6.11g. January 2007

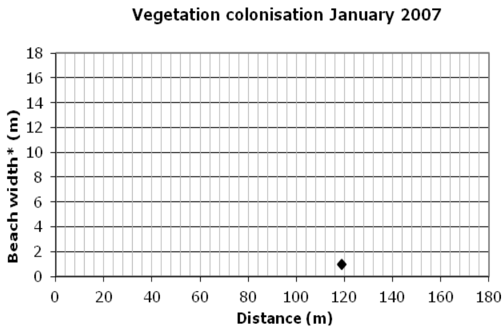


Figure 6.11 a-g. Vegetation colonisation, Section Three, July 2006 – January 2007. Beach width axis scaling is identical for comparative purposes. See Figure 6.10 for actual widths.

*See Note for Figure 6.7 regarding distance and beach width.

6.4 DISCUSSION

6.4.1 Site comparison of beach width

Each section of the study area displayed similar behaviour in terms of beach width. Maximum beach widths were recorded for all sections in the first three months of monitoring. During this time widths were relatively stable with little fluctuation between the three months for Sections Two and Three, while Section One experienced some fluctuation between July and the subsequent two months. Subsequent to this period, an erosional event during October significantly reduced the width of the beach in each section: over 7 m for Section Three, and over 5 m for Sections One and Two. On 4th and 12th October fronts producing gale force north west winds were recorded in South Australia and it is possible the erosion recorded in the study area was related to one of these events (BOM 2006).

Beach width for the months of October, November and December remained relatively constant for all sections. However, monitoring in late January revealed all sections had undergone another period of erosion, with beach widths being eroded by an average of almost 5 m for Sections Two and Three, and over 6.5 m for Section One. It is possible that this erosion related to a low off the south of South Australia on 20th January 2007 which in a combination with strong winds and an expected high tide caused the stranding of vehicles on the beach in the south of the state between Kingston and Salt Creek (BOM 2007, Riches & Zed 2007).

Average beach widths remaining at the termination of the study in January 2007 were 5.03 m, 3.75 m, and 2.09 m, for Sections One, Two and Three, respectively. In some areas, a steep scarp remained (Figure 6.12).

Figure 6.12. Steep scarp remaining at the end of the study in January 2007. Source: Photograph by the author.

6.4.2 Site comparison of vegetation colonisation

Results were more varied between the three sections of the study area for vegetation (*Thinopyrum junceiforme*) colonisation. Most clearly, the sections varied in terms of actual plant numbers, with Section Three, the largest site, recording the lowest numbers of plants. This section recorded an average of 5.7 plants per month compared with 24.24 plants per month for Section Two and 32.85 plants per month for Section One. The only explanation for this difference is that Section Three is in closer proximity to local beach amenities than the other sections, perhaps resulting in higher visitor usage, and consequently a higher potential for destruction of colonising plants. Certainly, uprooted desiccated plants were noted on occasion (Figure 6.13). Supporting this, Section One, recording the highest number of plants per month, was located the greatest distance from the beach amenities.

Variation in *Thinopyrum junceiforme* distribution over the study site was also noted during the study. In Section Three, *T. junceiforme* plants were distributed widely over the beach over the first three months of monitoring, between 0 – 15 m across the width of the beach, and between 27-153 m along the beach. Similarly, in Section One, plants were also distributed widely over the beach during the first three months of monitoring, occurring between 0-21 m across the width of the beach, and between 1-103 m along the beach. In comparison to these two sections, plants colonising Section Two were not as widely distributed over the site. Excluding three outliers, they appeared clustered between 44-

76 m along the beach, and within three metres of the drift fencing. This distribution was subsequently important in the survival of the plant.

Figure 6.13. Uprooted, desiccated plant in the study area. Source: Photograph by the author.

In Sections One and Three, a steady increase in plant colonisation occurred over the first three months of monitoring, peaking in the first month of spring in September. In October, these sections experienced a dramatic decrease in plant numbers that was clearly related to the erosion of the beach described earlier. While the new beach widths were relatively constant between October and December, no additional colonisation took place in Section Three and only a few new plants were recorded in Section One. In contrast to the other sections, Section Two experienced only a slight reduction in plant numbers in October, when two outliers were removed by the erosional event. Clearly, plant losses were affected by a combination of *Thinopyrum junceiforme* distribution and extent of erosion, during October. In January, the beach width of all sections was again substantially reduced due to an erosional event. However, unlike the previous event in October dramatic reductions in plant numbers were not associated with this event. Moreover, increases in plant numbers were recorded in Section One and Section Two, with numbers of colonising plants in the latter section in January exceeding plant numbers in each previous month.

In January, when the study was terminated, surviving *Thinopyrum junceiforme* plants were those clustered along the drift fence in Sections One and Two.

6.4.3 The regenerative potential of *Thinopyrum junceiforme* rhizomes

Between July 2006 and January 2007 *Thinopyrum junceiforme* colonised a section of beach on the Adelaide metropolitan coast that had been supplemented with 25 000 m^3 of sand containing *T. junceiforme* rhizome fragments (Figure 6.2). The transportation of sand containing *T. junceiforme* rhizomes fragments to the study area at Henley Beach South somewhat replicated a naturally occurring process according to the literature. In this study rhizomes were fragmented and transported to a new location by machinery, while under natural conditions rhizomes are usually broken during periods of erosion, and then transported to new sites by the sea or wind (Nicholson 1952 p. 83).

Once fragmentation, transportation and emplacement had occurred, rhizome fragments of variable length were observed to produce roots and shoots (Figures 6.14 & 6.15) as they would under natural conditions when fragmentation from the parent plant by erosion overcomes the inhibitory effect of the apical bud (Nicholson 1952 p. 82). As noted earlier (Chapter Two), not all nodes on fragmented rhizomes produce both roots and shoots, with some only producing either one (Nicholson 1952 p. 83, 84), which may compromise survival. Therefore Harris and Davy (1986b) suggested that it is the multi-noded rhizomes that have the greatest chance of survival. While a study of rhizome fragment nodes and shoot/root production was not undertaken in this research, limited excavation indicated the presence of many multi-noded rhizomes, such as that shown in Figure 6.13a. Consequently, while it cannot be quantified, the presence of many multi-noded rhizomes may have been important in the plants survival.

Parallels can be drawn between the current study and experiments associated with seasonality of *Thinopyrum junceiforme* rhizome regenerative potential, that is, the production of plant parts ‘leading to a new individual’ (Harris & Davy 1986b p. 1060). As mentioned earlier, the regenerative ability of *T. junceiforme* is best ‘in late winter-early spring’ (Harris & Davy 1986b p. 1060). During the warmer seasons regenerative potential may decline due to the redistribution of nutrients away from rhizomes (Harris 1982 p. 178). These results are consistent with results in sections one and three in the current study, which achieved highest results (greatest numbers of *T. junceiforme* plants) in late winter (August) and early spring (September).

Figure 6.14. *Thinopyrum junceiforme* rhizome fragment with development of multiple roots and shoots, July 2006. Source: Photograph by the author.

Figure 6.15. *Thinopyrum junceiforme* rhizome fragment with root and shoot development, July 2006. Source: Photograph by the author.

Thinopyrum junceiforme survival during the study may have also been influenced by the seasonality of artificial sand emplacement. The sand had been deposited at the study site in March, in autumn, and monitoring commenced in mid winter. It is possible that the cooler, wetter months of autumn and winter enabled the survival of more plants than if the sand had been deposited at another time, such as summer, when rhizome fragments may have been subject to hotter, drier conditions with an increased likelihood of desiccation and death. An increase in visitors to the beach during the hotter months may have also compromised the survival of rhizomes.

Thinopyrum junceiforme survival was also dramatically affected by erosion. Highest losses were in those areas where plants were widely distributed across the beach, in contrast to lower losses where plants were clustered near the drift fencing in the most landward parts of the study area. In Harris's (1982 p. 52) study of strandline and foredune populations of *T. junceiforme*, he found that survival in the strandline was 'rare' due to 'violent and unpredictable accretion and erosion' (Harris 1982 p. 54). While the area monitored in the current study did not comprise a strandline and foredune as such, some parallels can be drawn between Harris's strandline plants and the plants colonising areas further down the beach in the current study, all of which had been lost by the end of the monitoring period. In contrast, surviving *T. junceiforme* plants were those clustered along the drift fence in two of the three areas monitored.

There is little doubt that sand replenishment has assisted in the spread of *Thinopyrum junceiforme* on the metropolitan coast. It somewhat replicates a natural process involving fragmentation and transportation of fragmented rhizomes to new locations where they may produce new individuals if conditions are conducive to their survival. While natural processes may subsequently cause the removal of both plants and sand, reflecting the ongoing need for sand replenishment of this coast, some plants clearly survive, as demonstrated by the widespread occurrence of *T. junceiforme* along the metropolitan coast.

6.5 SUMMARY

Thinopyrum junceiforme rhizomes, fragmented and transported by machinery to a new location along the metropolitan Adelaide coastline, produced roots and shoots as they would under natural conditions. Seasonal conditions appeared to be important in regard to the regenerative potential of rhizomes. The presence of many multi-noded *T. junceiforme* rhizome fragments may have also been important in survival. Sand replenishment has assisted in the spread of the plant to new areas, with a number of established plants remaining at the end of the monitoring period. Ultimately, monitoring indicated that the decline in many colonising *T. junceiforme* plants was associated with the natural process of erosion.

CHAPTER 7. THE IMPACT OF *THINOPYRUM JUNCEIFORME* ON THE ECOLOGY AND GEOMORPHOLOGY OF THE YOUNGHUSBAND PENINSULA

….Ninety miles of coastal lakes
Below the Murray's mouth;
Bounded to the seaward
By Young Husband's long and thin
Peninsula of sandhills
Where the ocean thunders in,
Releasing pent-up energy,
In booming sound and spray
That rolls across my surface
On every stormy day….
(From 'Cry of the Coorong' Rob England 1993)

This chapter documents the distribution, rate of spread, and dune forms created by *Thinopyrum junceiforme* on the Younghusband Peninsula, to assist in determining its impact on the ecology and geomorphology of the barrier.

7.1 BACKGROUND

7.1.1 Geomorphological setting

Younghusband Peninsula occurs in the nationally and internationally significant Coorong National Park in South Australia (see Chapter Two, Figure 2.3). The peninsula is a Holocene coastal sand barrier formed over the last 6-7,000 years, along with the flanking spit of Sir Richard Peninsula when sea level stabilised following post glacial sea level rise associated with the last glacial maximum (Bourman et al. 2000, Bourman & Murray-Wallace 1991). The double reversed spits separate the ocean from the Holocene River Murray estuary and flank the River Murray mouth which probably resulted from fluvial breaching of the coastal barrier system, although marine processes are also important in maintaining the river mouth (Bourman & Murray-Wallace 1991).

Sir Richard and Younghusband peninsulas are modern analogues of a series of older dune barriers located on the coastal plain to the south east of the River Murray estuary (Belperio et al. 1996; Bourman et al. 2000). Preserved by a calcrete capping, the older barriers have been interpreted as former shorelines associated with Quaternary sea level changes (Harvey

1981; Belperio et al. 1996; Bourman et al. 2000), although tectonism has resulted in the modification of their configuration (see Belperio 1995; Belperio et al. 1996; Sprigg 1952, 1959; Harvey 1981).

The sediment contributing to the development of the spits comprises a mix of marine shells and Last glacial Maximum ‘desert dune’ sands (Bourman 1997; Bourman et al. 2000). On Younghusband Peninsula these sediments partly overlay a calcreted barrier formed approximately 80-100,000 years BP (von der Borch 1974; Harvey 1981; Bourman et al. 2000), while a small area of calcareous sediments are present, back barrier lagoon facies and washover fans provide the foundations for Sir Richard Peninsula (Bourman & Murray-Wallace 1991; Bourman et al. 2000).

Sir Richard Peninsula is approximately 10 km long and up to 1 km wide, with dunes up to approximately 25 m high. In contrast, Younghusband Peninsula and the back barrier Coorong lagoon are approximately 100 km long. The Coorong lagoon narrows south of Salt Creek, eventually becoming ephemeral, and the peninsula becomes attached to the mainland (NP&WS 1984). Backed by a series of ephemeral lakes the dune complex continues to the southeast for another 40-50 km. The peninsula is up to 3 km wide (NP&WS 1984) and sand dunes can extend up to 30-40 m above sea level (Belperio 1995; Belperio et al. 1996).

7.1.2 Climate and tides

At the regional level, climate in the study area is classed as ‘mesothermal with a marked summer drought’ and is characterised by a north to south rainfall gradient (Gilbertson 1977 p. 5, Short & Hesp 1980 p. 22). Meteorological data from Meningie (BOM 2011a) and Cape Jaffa (BOM 2011b), at the northern and southern extremes of the study area, should be interpreted bearing in mind the influence of their position in relation to their exposure to the coast. Mean maximum annual temperatures range from 20.8^{o}C at Meningie to 19.2^{o}C at Cape Jaffa, with a mean minimum annual temperature of 10.2^{o}C for both locations. Annual rainfall is 468.4 mm for Meningie and 492.2 mm for Cape Jaffa, with the highest rainfalls occurring in June and July for Meningie and Cape Jaffa, respectively. Mean annual 9 am and 3 pm wind speeds are 10.8 km/hr and 13.9 km/hr for Meningie and 26.2 km/hr (9 am) and 33.1 km/hr (3 pm) for Cape Jaffa, and clearly reflect their varying positions on the coast.

The peninsula is located in a microtidal environment, experiencing a tidal range (mean high water springs) of 0.8 m at Victor Harbor (Ports Corp South Australia 2001).

7.1.3 Morphodynamics of the study area

Short and Hesp (1980) undertook a morphodynamic survey of the coast of the South East Coast Protection District which they divided into three provinces. It is Province One, or the 190 km section of coast between the River Murray mouth and Cape Jaffa, that is of most relevance to the study area. Province One, according to Short and Hesp (1980 p. 31) 'represents a classic example of spatial variation in nearshore wave energy and beach surfzone morphology controlling the evolution, extent and nature of the entire coast zone'. In this province a gradual decline in the offshore gradient causes a progressive decrease in wave breaker energy 'to the degree that it is non existant between 168 and 190 km' (Short & Hesp 1980 p. 31). The decrease in wave breaker energy along this part of the coast has resulted in the subdivision of Province one into Coorong I, Coorong II, Coorong III and Lacapede Bay by Short and Hesp (1980). Only the first two (Coorong I and Coorong II) are relevant to the study area as Coorong III and Lacapede Bay occur further to the south east.

The first 100 km of the Younghusband Peninsula commencing from the River Murray mouth (Coorong I) is a zone of high wave energy characterised by low gradient 'relatively stable' dissipative beaches with a relatively consistent fine grain size (Short & Hesp 1980 p. 45, 114). However, there are exceptions where the gradient steepens and grain size becomes coarser (Short & Hesp 1980 p. 34). The proportion of calcium carbonate in beach sediments increases in distance from the River Murray mouth (Short & Hesp 1980). Foredunes are 'moderately stable' (p. 14) although there are areas where the frontal dune is erosional and unstable or not present at all, and incipient foredunes may fill the 'gaps' (Short & Hesp 1980 p. 39). Short and Hesp (1980 p. 114, 172) suggest that substantial foredune erosion may occur 1 in 10 or 1 in 20 years. In this section of coast there are transgressive dunes (p. 39, 172), blowouts that may be 'revegetated at the mouths' (p. 39), parabolic dunes, transverse dunes and dune ridges, which may occur in deflation zones (Short & Hesp 1980 p. 43, 172).

The next section of coast along the Younghusband Peninsula is Short and Hesps' (1980) Coorong II (100-145 km) sub province, which experiences a decrease in off shore gradient and wave breaker energy from the preceding section (p. 173). This section of coast is characterised by 'pronounced spatial – temporal variations in beach morphology' (p. 45) and is described as comprising the 'most unstable dune region along Younghusband Peninsula' (p. 49). Initially, the coast in this section exhibits an increase in grain size resulting in a narrow 'steeper reflective beach', although this is followed by the presence of finer grained low carbonate sediment on the lower beach and coarser grained sediment higher in carbonate on the upper beach-foredune (p. 47). Dunes in the area are described as 'highly erosional' or 'unstable or non existent' along with 'extensive unstable transgressive dune sheets' (Short & Hesp 1980 p. 44, 45). Beach ridges may intermittently occur in deflation basins in some areas, and transverse dunes are 'less well developed' in this area compared to Coorong I (p. 39). Occasionally, incipient foredunes form on storm cusps (p. 173). Another characteristic of this section of coast is that the inner bar attaches to the shoreline numerous times producing 'horns' between which are narrow embayments (p. 45). These features, which may be 'temporally and spatially dynamic', are associated with rips and a high 'potential for erosion' (p. 45). In Coorong II, significant foredune erosion may occur around every 3-5 years, influenced by the 'narrowness of reflective beaches and rips in storms' (Short & Hesp 1980 p. 173).

7.1.4 Vegetation of the Younghusband Peninsula

7.1.4.1 Vegetation surveys

The vegetation of the Younghusband Peninsula, including the alien species component, has been described in a number of vegetation surveys. According to Noye (1974) one of the earliest accounts of the vegetation was by Sutton (1925) for the northern part of Younghusband Peninsula (Cleland & Lothian 1958 p. 44). The objective of Sutton's visit to the Coorong was to observe birds (Sutton 1925 p. 75), but a list of 70 plants was also 'prepared' by Cleland, one of the expedition members, because 'the kind of vegetation and its distribution is such an important factor in bird life…' (Sutton 1925 p. 84). Over 30 years later Cleland and Lothian (1958) visited an area 'opposite Lampard Point' (This is likely to be Lamberts Point opposite Dodds Landing on the northern Younghusband Peninsula). According to the authors, the list prepared earlier in 1925 'would hold good to-day' (Cleland & Lothian 1958 p. 44), although the 1958 survey contributed an additional 18 species (Cleland & Lothian 1958 p. 44). This included a number of alien species including Marram Grass which they observed was 'still actively spreading' (Cleland & Lothian 1958 p. 43). Vegetation descriptions on the southern part of the peninsula were provided by Correll (1963), as noted by Noye (1974) in his discussion of the vegetation, and by Wollaston (1974) who provided a brief overview of the vegetation of the barrier and the mainland shore.

Further surveys were undertaken in the 1970s by the South Australian government's Ecological Survey Unit, which had 'been involved in the survey of the natural resources of The Coorong for a number of years' (Douglas et al. 1982 np), and by Mowling and Taylor (1977) and Alcock and Symon (1977) for the Nature Conservation Society of SA inc. (NCSSA) Annual Survey in the southern Coorong/lower Younghusband Peninsula. Alcock and Symon (1977) collected nearly 260 plant species in the area with 92 of these being alien species, including *Euphorbia paralias,* which they noted was '…spreading rapidly along the South Australian foredunes' (p. 25). Just over 30% of the alien species comprised grasses (p. 25). The authors suggested that the large number of alien plants in the area was due to '…introductions and disturbance of the habitat which has continued from the early pioneering days' (Alcock & Symon 1977 p. 29).

Detailed descriptions of the vegetation of Younghusband Peninsula were provided by Douglas et al. (1982) of the Remote Sensing Applications Branch (formerly the Ecological Survey Unit, mentioned above). According to these authors 242 plant species were recorded of which 77, or just over 30%, were alien species (Douglas et al. 1982 p. 2). They noted the 'extensive' planting of Marram grass and its effects on the native *Spinifex hirsutus* (np). They observed that it was 'widespread on the peninsula' and suggested that 'all occurrences were possibly intentionally introduced' (Douglas et al. 1982 p. 3). They also commented on the alien Sea Spurge which grew with much vigour '..on the foredunes and has seriously altered the nature of these communities' (Douglas et al. 1982 np). The alien African Boxthorn (*Lycium ferrocissimum*) was also observed as being 'widespread on the consolidated dunes on the Peninsula' (p. 3). The work of Douglas et al. (1982) was used in the 1984 Coorong National Park and Game Reserve Draft Management Plan.

In the 1990s a vegetation survey of the South Australian coastline, including the Coorong area (encompassing the area from Goolwa to Cape Jaffa), was undertaken by Oppermann (1999) for the Biological Survey of South Australia. Data analysis identified a number of prevalent alien species encountered during the survey(s) including *Thinopyrum junceiforme*. The 96 alien species listed were those occurring in more than 10 quadrats and included *Lycium ferocissimum* (242 quadrats), *Euphorbia paralias* (144 quadrats), *Cakile maritma* subsp. *maritima* (137 quadrats), *Ammophila arenaria* (30 quadrats) and also *T.*

junceiforme (listed under the synonym *Elymus farctus*) which was recorded in 16 quadrats (p. 61), with most recorded in the Coorong region (p. 281). *L. ferocissimum* was considered the 'dominant pest plant along the whole of the coastline' (p. 213). *E. paralias*, *C. maritma* subsp. *maritima* and *T. junceiforme* were classed as cosmopolitan plants (p. 213), and it was concluded that neither of the former two appeared '..to be preventing the establishment of native species' (p. 61). Marram grass was also 'not considered a problem' because it was thought it had not spread from the areas in which it had been planted (Oppermann 1999 p. 213).

Other vegetation studies in the area included those specifically focussing on *Thinopyrum junceiforme* in or near the study area such as that of Harvey et al. (2003), as discussed in Chapter One. More recently, along the South East coast, between the River Murray mouth and the Victorian border, a weed survey was undertaken for the production of *The Limestone Coast and Coorong Coastal Action Plan* (Caton et al. 2011). As indicated in Chapter three, nearly 40 specimens of *T. junceiforme* were collected from this area during the survey.

Other studies near to the study area in which *Thinopyrum junceiforme* was identified include that of Hilton and Harvey (2002) on nearby Sir Richard Peninsula as discussed in Chapter One, and that of Carruthers (1991) and James (2004) on the former flood tidal delta of Bird Island in the River Murray mouth estuary. The study of Mavrinac (1986) actually focussed on *T. junceiforme* but he was unable to visit the Younghusband Peninsula. Instead he undertook surveys at Blackford and Butcher Gap drains south of the Coorong National Park near Kingston SE, as well as at Normanville and on the Metropolitan coast, at sites where he had identified the presence of the plant.

7.1.4.2 Floristic communities

Of the 52 floristic communities identified in the Coastal Dune and Clifftop vegetation survey of South Australia (Oppermann 1999), 7 groups were found in the Coorong region (Table 7.1). The three most common groups were the *Olearia axillaris/Leucopogon parviflorus* and *Leucopogon parviflorus/Olearia axillaris* Shrublands and *Spinifex sericeus/Euphorbia paralias* grasslands (Shrublands).

Table 7.1. Floristic communities identified in the Coorong region by Oppermann (1999). *There was a total of 175 quadrats in the Coorong region.

Note: In the analysis of floristic data, the results of other surveys were also used including the South East Coast Survey (survey # 4), which was undertaken for the Biological Survey of South Australia between 1982-1987 and which included the study area.

Floristic communities of the Coorong Region	**Total Quadrats SA**	**Coorong Quadrats ***
Spinifex sericeus/Euphorbia paralias grasslands (Shrublands)	42	11
Olearia axillaris/Leucopogon parviflorus Shrublands	65	47
Leucopogon parviflorus/ Olearia axillaris Shrublands	150	24
Atriplex cinerea Shrublands	20	1
Olearia axillaris/tetragonia implexicoma Shrublands	42	4
Olearia axillaris/Rhagodia candolleana subsp. *candolleana* Shrublands	64	3
Eucalyptus diversifolia/Clematis microphylla Mallees	37	2

Detailed vegetation mapping by Douglas et al. (1982) indicates that the foredune of the Younghusband Peninsula comprised a low shrubland or tussock grassland community. The tussock grassland community, comprising *Spinifex sericeus* and *Austrofestuca littoralis,* was described at that time as being the pioneering vegetation involved in dune stabilisation and was present on much of the northern peninsula (to Parnka Point). The low shrubland foredune community comprised *Ozothamnus turbinatus*/*Olearia axillaris* with *Spinifex sericeus*, with other species including the introduced *Euphorbia paralias*. Vegetation maps by Douglas et al. (1982) in NP&W (1984), show the low shrubland community to be more prevalent south of Parnka Point on the peninsula.

7.2 Methods

7.2.1 Site selection and location

The Younghusband Peninsula is a dynamic coastal environment, historically characterised by sand drift. Matthew Flinders' observation of the Younghusband Peninsula in 1802 was of 'a low sandy shore topped with hummocks of almost bare sand' (Flinders 1802). It was later described in 1866 by the South Australian Gazetteer as '..a tract of land composed principally of sandy drift..' (Whitworth 1866 p. 287). Sutton (1925 pp. 84-85), on a bird observation expedition on the peninsula, referred to the 'shifting white sand' that smothered the vegetation, and attributed it to human activities. However, others such as

Cleland and Lothian (1958) suggested that the 'bare dunes' occurred regardless of the activities of humans. Gilbertson (1981) suggested that climatic/oceanographic fluctuations were probably responsible for changes in stability along the peninsula in pre-European times. Impacts have also been caused by pre-European Aboriginal burning and European pastoral activities but they are thought to be 'minor' in comparison to the damage caused by four wheel drives (Gilbertson 1981). Similarly, Short and Hesp (1980) believed that the dunes of the South East (including Younghusband Peninsula) have been 'naturally' unstable over the last few thousand years. However, anthropogenic impacts, in the form of rabbits and grazing have been responsible for dune instability in the South East over the last century (Short & Hesp 1980). Short and Hesp (1980 pp. 9-10) considered that these impacts 'are no longer their former threat' and have suggested that four wheel drives, pedestrians and wind and wave erosion, were the foremost '..threat to dunes..'.

However, the Younghusband Peninsula may now face a new and very different type of threat. The potential threat that *Thinopyrum junceiforme* presents to the geomorphology and ecology of the peninsula represents an antithesis to the concerns of dune instability as it is proposed that this plant promotes 'stability' in the landscape. Commenting on the use of introduced species to stabilise dunes in the area, Douglas et al. (1982) suggested that it is factors such as sand movement and dune erosion and reconstruction that were responsible for the 'dynamic nature' of many vegetation communities on the Younghusband Peninsula. For these reasons the Younghusband Peninsula was selected for the purpose of undertaking investigations on *T. junceiforme*.

A Department of Environment and Heritage (DEH) Permit to Undertake Scientific Research was obtained to undertake all fieldwork in the Coorong National Park.

7.2.2 Selection of survey sites

A total of 14 survey sites were located at 10 km intervals along the length of the Younghusband Peninsula between the River Murray mouth and southern boundary of the Coorong National Park (Figure 7.1). The locations of most survey sites was influenced by pre-existing markers installed (every 10 km) along the foredune, and, which on most occasions were associated with survey marks located further inland. Transects commenced at 42 Mile Crossing, where the '0' km transect was placed. A further eleven transects were undertaken to the north, with the 110 km Transect being closest to the River Murray mouth. An additional two transects were located to the south of the '0' km Transect. To clearly distinguish between the 10 and 20 km Transects located immediately to the north and immediately to the south of the 0 km Transect at 42 Mile Crossing, these transects are henceforth denoted in the text with an ‘n’ (north) and ‘s’ (south), respectively.

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Figure 7.1. Survey sites located at 10 km intervals along the length of the Younghusband Peninsula. Source: Base map derived from Commonwealth of Australia (1982).

7.2.3 Surveying

The same method used in the seasonal ecological monitoring of *Thinopyrum junceiforme* (Chapter Two), the belt transect method (Kent & Coker 1992), was utilised for this part of the research. It involved the use of a transect line along which 1 m^2 quadrats were contiguously placed (Kent & Coker 1992), using a collapsible plastic square with extendable legs. A similar method was used previously by James (2004) to record coastal dune vegetation in the River Murray mouth estuary of South Australia.

Surveys were undertaken at systematic intervals every 10 km along the peninsula. At each 10 km marker, a transect was established by laying out a measuring tape perpendicular to the coast. The start point of each transect was the approximate position of the last high tide on the beach. From this point the transect extended landwards, over the backbeach and foredune and terminated either at the existing survey mark, or alternatively, the highest ground in the vicinity or where there was an obvious change in topography. While the focus of analysis (see below) was the most exposed seaward quadrats, transects extended inland for two reasons: firstly, to assist in determining the distance that *T. junceiforme* could colonise inland, and also, to assist in calculating rates of spread. Consequently, transects along the Younghusband Peninsula ranged between a maximum length of 86 m (86 quadrats) in Transect 10 km and a minimum length of 40 m (40 quadrats) in Transect 110 km, in the northern most part of the peninsula.

7.2.4 Data collection

Data collection involved recording sand surface relief, plant composition and cover in each per $1m^2$ quadrat which were placed along transects which ran from the high tide mark to an arbitrary point in the dunes. Estimates of cover were made using the same technique and cover classes utilised in the seasonal ecological monitoring of *Thinopyrum junceiforme* (Chapter Two). Observations were made of dune form and *T. junceiforme* colonisation along the length of the barrier.

7.2.5 Analysis

7.2.5.1 Vegetation Analysis

As *Thinopyrum junceiforme* is primarily a coloniser of the strandline and foredune areas (Chapter Two) vegetation analysis in this chapter was applied to the data obtained from the 'high exposure zone', that is, the most exposed, seaward areas exposed to the types of coastal stresses described in Chapter Two. In this research, the high exposure zone extended from the high tide line inland across the backshore and into the foredune area. For each transect, the first ten vegetated quadrats encountered in this area were selected for analysis.

Vegetation analysis employed the Sorensen Coefficient to compare similarity between transects along the length of the peninsula, over the high exposure zone. The dissimilarity measure was also applied. The coefficient was also used to determine the 'tendencies of association' between *T. junceiforme* and other species recorded on the Younghusband Peninsula in the high exposure zone. The Chi-square test was employed to clarify the association between *T. junceiforme* and the native foredune coloniser *Spinifex sericeus*.

7.2.5.2 Dune form and *Thinopyrum junceiforme* colonisation

Nicholson (1952) described how *Thinopyrum junceiforme* contributes to the formation of incipient dunes (Chapter Two). In this chapter observations of dune form/ *T. junceiforme* colonisation were made along the length of the Younghusband Peninsula, noting the morphology and possible mode of incipient dune formation. According to Hesp (1983, 2002) three distinct incipient dune morphologies may be observed: ramps, terraces and ridges, which may result from factors including inherited morphology, accretion rates and plant density, height and growth rates. Four modes of incipient dune formation are distinguished by Hesp (1984, 1989). Type 1a incipient foredunes result from 'sand deposition within, and in the lee of discrete plants', the plants may be annuals or perennials, germinating from seed deposited on the backshore by the wind or found in the debris line (also referred to as wrack line or drift line, or the 'swash limit' where 'drift materials such as logs, vegetative matter and rubbish are commonly deposited by waves' (Hesp 2000 p. 28); 'plant fragments' derived from erosion may also 'act as the nucleii' for these dunes (Hesp 1984 p. 71, Hesp 1989 p. 182). Type 1b incipient foredunes differ from the Type 1a dunes as they form by sand deposition 'within discrete *zones* of seedlings' (my emphasis) on the backshore (Hesp 1984 p. 76, Hesp 1989 p. 185).

Type 2a incipient foredunes are initiated by sand deposition within 'laterally continuous (alongshore) zones colonised by perennial seedlings' germinating from seed deposited by the wind or in the debris line (Hesp 1984 p. 76,77, Hesp 1989 p. 186). In contrast, Type 2b incipient dunes are formed by rhizome/stolon 'colonisation of the immediate seaward backshore zone'; usually from a 'landward source' such as the foredune (Hesp 1984 p. 80, Hesp 1989 p. 188). Hilton and Konlechner (2011) proposed that an addition be made to Hesp's (1984, 1989) classification. They suggest that a 'Type 3' incipient foredune, initiated by marine–dispersed rhizome, based on their observations of *Ammophila arenaria*, be included in the scheme. While Hesp (1984, 1989) clearly recognised that 'plant fragments' may play a role in the formation of incipient dunes (see Type 1a above), a category that emphasises the role of marine dispersed individual rhizome fragments and/ or the 'massive tangles of rhizome' observed by Hilton and Konlechner (2011), seems valid.

7.2.5.3 Rate of spread

The rate of spread of alien species has been calculated elsewhere by analysis of aerial photographs from different time periods (eg. Buell et al. 1995, Hilton et al. 2005). In this research an alternative approach was taken by using herbarium records and survey transect data to calculate the rate of spread of *Thinopyrum junceiforme* along the Younghusband Peninsula. The timeframe for the rate of spread was from 1986 (first herbarium record for the Younghusband Peninsula) and 2007 (surveying undertaken along the peninsula). The extent of colonisation was calculated by dividing the length of the peninsula surveyed (130 km) by the average distance the plant extended inland (30 m), and converting this to hectares. Of course some degree of caution is required with this method of estimation as the precise extent of colonisation in 1986 is unknown, the colonisation inland is an average, and at two locations along the peninsula colonisation was zero.

7.3 RESULTS

7.3.1 Vegetation on Younghusband Peninsula

7.3.1.1 Introduction

Thinopyrum junceiforme is primarily a coloniser of the strand and foredune, thus, attention was primarily focussed on the relationships between vegetation occurring in this high exposure zone of each transect (n=14), although, the extent of the colonisation of *T. junceiforme* inland, as determined by transects that extended into the backdune area for variable distances, are discussed later. Appendix 5 provides a full list of all species found along the Younghusband Peninsula during surveys.

The high exposure zone of the Younghusband Peninsula varied, sometimes considerably, in relation to the distance between the high tide line and the first line of vegetation (Figures 7.2 and 7.3). The relief of the backshore (Figure 7.3) also was variable. The figures illustrate that the southern part of Younghusband Peninsula at Transects 10 km (s) and 20 km (s) exhibited the shortest distance between the high tide line and the first line of vegetation, with short, sloping backshores measuring 8 m. In contrast to these transects, Transects 0 km (42 Mile Crossing) and 10 km (n) exhibited the greatest distance between the high tide line and the first line of vegetation - 46 m at Transect 10 km (n) and 33 m for the 0 km (42 Mile Crossing) Transect. The average distance between the high tide line and first line of vegetation for all transects was 17.92 m. For Transect 10 km (n), the backshore was relatively flat, but the 0 km Transect displayed the most dramatic variation in this area of all the transects; certainly, the area was characterised by eroded beach cusps and the 42 Mile Crossing beach access point was nearby.

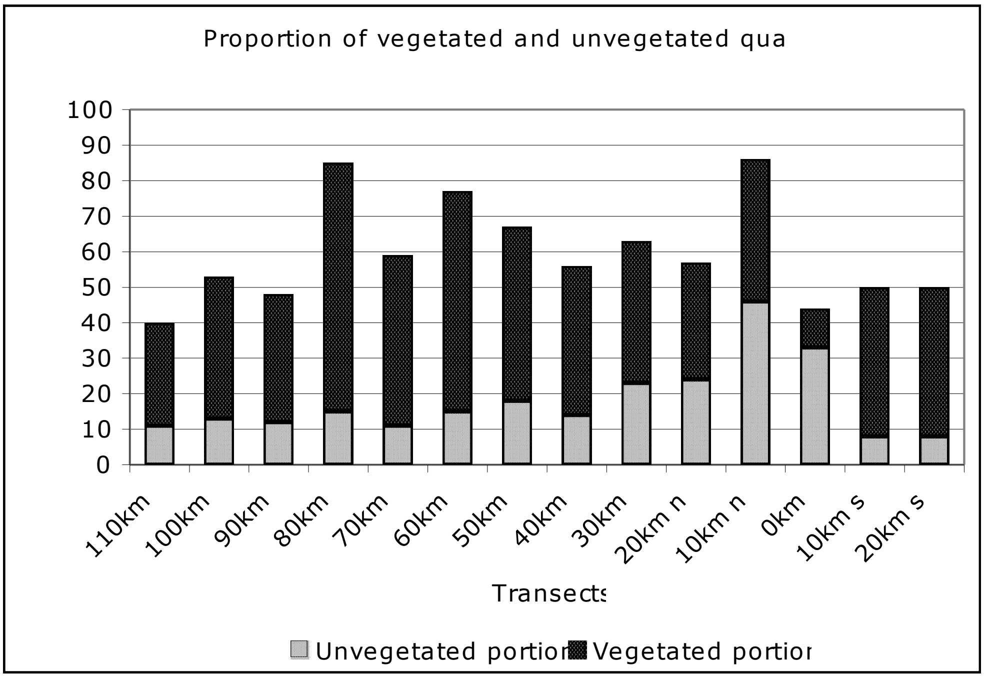

Figure 7.2. Distance between the high tide line and first line of vegetation (unvegetated portion) of transects along the Younghusband Peninsula. Vegetated portion represents the distance transects extended inland to record the extent of *Thinopyrum junceiforme* colonisation in the backdune area of the peninsula. Transect 110 km is nearest to the River Murray mouth and Transect 20 km s is nearest to the southern boundary of the Coorong National Park.

7.3.1.2 Vegetation composition of the high exposure zone

In the high exposure zone along the Younghusband Peninsula, 18 plant species were recorded (Figure 7.4). Most species were recorded in Transect 30 km (*n*=12). The least number of species was recorded at transect 70 km with only one species, *Thinopyrum junceiforme,* being present. No species occurred in every transect in the high exposure zone, although the native *Spinifex sericeus* was recorded in most transects (*n*=13). Also recording a high presence was *T. junceiforme* (*n*=12) and *Euphorbia paralias* (*n*=11). The remaining species recorded in the high exposure zone, *Carpobrotus rossii, Ficinia nodosa, Exocarpos syrticola, Olearia axillaris, Stackhousia spathulata, Pimelea serpyllifolia* subsp. *serpyllifolia, Senecio* species.[1], *Myoporum insulare, Rhagodia candolleana* subsp. *candolleana, Leucophyta brownii, Apium prostratum* var. *prostratum, Ozothamnus turbinatus, Lotus australis, Limonium binervosum* and *Cakile maritima* subsp. *maritima,* occurred in 5 or less transects (Figure 7.4).

[1] Originally identified as *Senecio lautus*

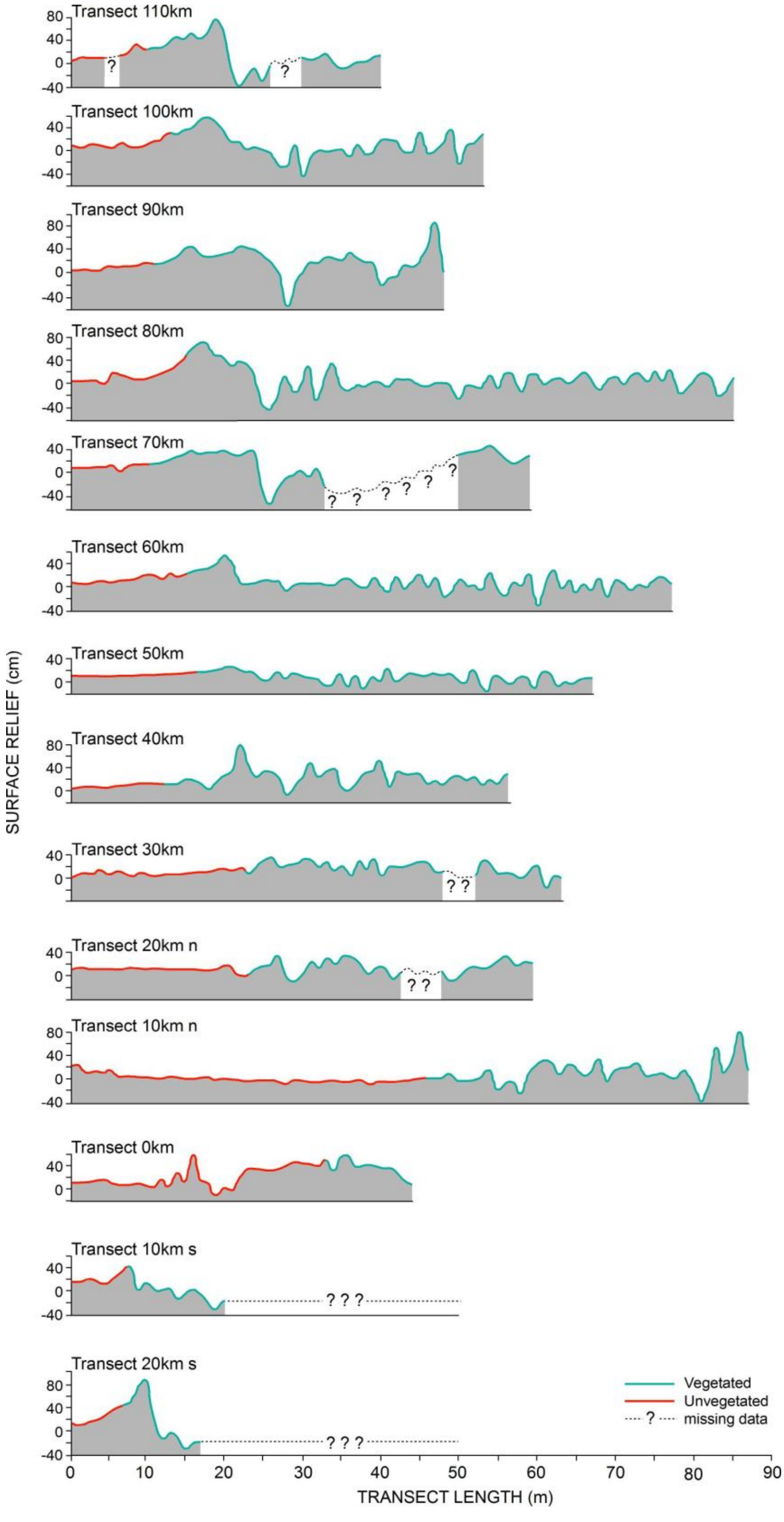

Figure 7.3. Diagrammatic representation of transects along Younghusband Peninsula. Gaps in the data represent locations in which the horizon could not be sited using the surveying instrument.

						Transects								
Species	110	100	90	80	70	60	50	40	30	20 n	10 n	0	10 s	20 s
SS	■	■	■	■		■	■	■	■	■	■	■	■	■
TJ	■	■	■	■	■	■	■	■	■		■		■	■
EP			■	■		■	■	■	■	■	■	■	■	■
CR							■	■	■	■			■	
FN							■		■	■			■	■
ES									■	■	■			
OA									■		■			■
SSp									■					■
PSsS									■				■	
Sspp									■	■				
MI										■			■	
RCsC													■	
LB									■					
APvP									■					
OT										■				
LA										■				
LB										■				
CMsM												■		

Figure 7.4. Plant species occurring in the high exposure zone of each transect along the Younghusband Peninsula. Species: *SS - S. sericeus, TJ - T. junceiforme, EP - E. paralias, CR - C. rossii, IN - F. nodosa, ES - E. syrticola, OA - O. axillaris, SSp - S. spathulata, PSsS - P. serpyllifolia* subsp. *serpyllifolia, Sspp – S. species, MI - M. insulare, RCsC - R. candolleana* subsp. *candolleana, LB - L. brownii, APvP - A. prostratum* var. *prostratum, OT - O. turbinatus, LA - L. australis, LB - L. binervosum, CMsM - C. maritima* subsp. *maritima.*

7.3.1.3 Similarity/dissimilarity between transects in the high exposure zone

Figure 7.4 shows that with the exception of the 0 km Transect, transects along the northern section of the peninsula, to the north of the 50 km Transect, namely Transects 60, 70, 80, 90, 100 and 110 km, appeared to contain fewer plant species in the high exposure zone than the other transects. Three or fewer plants were recorded in these northern transects which comprised variably the native *Spinifex sericeus*, and *Euphorbia paralias* and *Thinopyrum junceiforme*. To compare the compositional similarity of all of the transects in the high exposure zone the Sorensen Coefficient was used (see Kent & Coker 1992). The dissimilarity measure was also applied.

Analysis reveals that the transects that were most similar occurred north of the 50 km Transect, with the most similar transects being Transects 110 and 100 km, and the 90, 80 and 60 km Transects (Figure 7.5). These northern transects were characterised by a lower number of species (with the exception of the 0 km Transect at 42 Mile Crossing) and comprised various combinations of similar species (*Spinifex sericeus, Euphorbia paralias* and *Thinopyrum junceiforme)* (Figure 7.4).

T	110	100	90	80	70	60	50	40	30	20 n	10 n	0	10 s	20 s
110		50.00	44.44	44.44	40.00	44.44	36.36	40.00	22.22	15.38	36.36	28.57	28.57	33.33
100	50.00		44.44	44.44	40.00	44.44	36.36	40.00	22.22	15.38	36.36	28.57	28.57	33.33
90	44.44	44.44		50.00	33.33	50.00	42.85	46.15	28.57	23.52	42.85	40.00	35.29	40.00
80	44.44	44.44	50.00		33.33	50.00	42.85	46.15	28.57	23.52	42.85	40.00	35.29	40.00
70	40.00	40.00	33.33	33.33		33.33	25.00	28.57	13.33	0	25.00	0	18.18	22.22
60	44.44	44.44	50.00	50.00	33.33		42.85	46.15	28.57	23.52	42.85	40.00	35.29	40.00
50	36.36	36.36	42.85	42.85	25.00	42.85		47.05	37.03	34.78	37.5	33.33	43.47	42.10
40	40.00	40.00	46.15	46.15	28.57	46.15	47.05		33.33	30.00	40.00	36.36	40.00	37.5
30	22.22	22.22	28.57	28.57	13.33	28.57	37.03	33.33		35.29	37.03	21.05	37.5	40.00
20 n	15.38	15.38	23.52	23.52	0	23.52	34.78	30.00	35.29		28.57	23.52	35.71	27.27
10 n	36.36	36.36	42.85	42.85	25.00	42.85	37.5	40.00	37.03	28.57		33.33	31.57	42.10
0	28.57	28.57	40.00	40.00	0	40.00	33.33	36.36	21.05	23.52	33.33		26.66	30.76
10 s	28.57	28.57	35.29	35.29	18.18	35.29	43.47	40.00	37.5	35.71	31.57	26.66		36.36
20 s	33.33	33.33	40.00	40.00	22.22	40.00	42.10	37.5	40.00	27.27	42.10	30.76	36.36	

Figure 7.5. Similarity matrix of transects (‘T’) in the high exposure zone along the Younghusband Peninsula using the Sorensen Coefficient. Values in percent. Highest values (%) are highlighted.

After applying the Sorensen dissimilarity measure, results indicated that the most dissimilar transects (100%) were the 20 km and 70 km Transects, and the 0 and 70 km Transects (Figure 7.6). This clearly reflects the fact that the 70 km Transect comprised only *Thinopyrum junceiforme* and no other species, whereas Transects 20 km and 0 km were the only two transects in which *T. junceiforme* was not recorded in the high exposure zone. Transects 70 km and 30 km were also highly dissimilar (86.66%) reflecting the fact that the former transect comprised the least number of species (one) of all the transects, and the latter comprised the maximum (twelve), with only one species in common, *T. junceiforme.*

T	110	100	90	80	70	60	50	40	30	20 n	10 n	0	10 s	20 s
110		50.00	55.55	55.55	60.00	55.55	63.63	60.00	77.77	84.61	63.63	71.42	71.42	66.66
100	50.00		55.55	55.55	60.00	55.55	63.63	60.00	77.77	84.61	63.63	71.42	71.42	66.66
90	55.55	55.55		50.00	66.66	50.00	57.14	53.84	71.42	76.47	57.14	60.00	64.70	60.00
80	55.55	55.55	50.00		66.66	50.00	57.14	53.84	71.42	76.47	57.14	60.00	64.70	60.00
70	60.00	60.00	66.66	66.66		66.66	75.00	71.42	86.66	100	75.00	100	81.81	77.77
60	55.55	55.55	50.00	50.00	66.66		57.14	53.84	71.42	76.47	57.14	60.00	64.70	60.00
50	63.63	63.63	57.14	57.14	75.00	57.14		52.94	62.96	65.21	62.5	66.66	56.52	57.89
40	60.60	60.60	53.84	53.84	71.42	53.84	52.94		66.66	70.00	60.00	63.63	60.00	62.5
30	77.77	77.77	71.42	71.42	86.66	71.42	62.96	66.66		64.70	62.96	78.94	62.5	60.00
20 n	84.61	84.61	76.47	76.47	100	76.47	65.21	70.00	64.70		71.42	76.47	64.28	72.72
10 n	63.63	63.63	57.14	57.14	75.00	57.14	62.5	60.00	62.96	71.42		66.66	68.42	57.89
0	71.42	71.42	60.00	60.00	100	60.00	66.66	63.63	78.94	76.47	66.66		73.33	69.23
10 s	71.42	71.42	64.70	64.70	81.81	64.70	56.52	60.00	62.5	64.28	68.42	73.33		63.63
20 s	66.66	66.66	60.00	60.00	77.77	60.00	57.89	62.5	60.00	72.72	57.89	69.23	63.63	

Figure 7.6. Dissimilarity matrix of transects ('T') in the high exposure zone along the Younghusband Peninsula using the Sorensen Coefficient. Values in percent. Highest values (%) are highlighted.

7.3.1.4 Association between *Thinopyrum junceiforme* and other species recorded in the high exposure zone

The Sorensen Coefficient was then used to determine 'tendencies of association' between *Thinopyrum junceiforme* and all other plant species recorded in each transect in the high exposure zone. Of the 17 species examined, results indicated that *T. junceiforme* had the closest association with *Spinifex sericeus*, at nearly 90% (Figure 7.7). It was also somewhat closely associated with *Euphorbia paralias* at nearly 80%. Tendencies of association with 11 of the remaining species were under 50%: for *Carpobrotus rossi* and *Ficinia nodosa* it was just over 47%, and for *Olearia axillaris*, 40% (Figure 7.7). Tendencies of association for both *Stackhousia spathulata* and *Pimelea serpyllifolia* subsp. *serpyllifolia* were just over 28%. Lower tendencies of association were found with *Senecio* species and *Myoporum insulare* (14.28%) because while these plants were recorded in 2 transects, they were only recorded in 1 transect in which *T. junceiforme* occurred. Alternatively, *Rhagodia candolleana* subsp. *candolleana*, *Leucophyta brownii* and *Apium prostratum* var. *prostratum* were recorded in only 1 transect, but one in which *T. junceiforme* occurred, thus their slightly higher tendency of association (15.38%) than the previous two species. There were no tendencies of association with the remaining species simply because these species occurred in transects in which *T. junceiforme* did not occur.

Species	*Tendency of association with T. junceiforme (%)*
S. sericeus	88.00
E. paralias	78.26
C. rossii	47.05
F. nodosa	47.05
E. syrticola	26.66
O. axillaris	40.00
S. spathulata	28.57
P. serpyllifolia subsp. *serpyllifolia*	28.57
S species	14.28
M. insulare	14.28
R. candolleana subsp. *candolleana*	15.38
L. brownii	15.38
A. prostratum var. *prostratum*	15.38
O. turbinatus	0
L. australis	0
L. binervosum	0
C. maritima subsp. *maritima*	0

Figure 7.7. Tendencies of association between *T. junceiforme* and other species recorded in each transect along the Younghusband Peninsula.

7.3.1.5 Association between *Thinopyrum junceiforme* and *Spinifex sericeus*

Given the high degree of association between *Thinopyrum junceiforme* and *Spinifex sericeus*, and the importance of *S. sericeus* as a native coastal foredune coloniser, a more detailed examination of the tendency of association between the two species was undertaken. While presence/absence per transect was useful to achieve an initial idea of *T. junceiforme's* tendencies of association with other species, it was a very coarse approach. Consequently, the Sorensen Coefficient was used to determine 'tendencies of association' between *T. junceiforme* and *S. sericeus* in each quadrat (*n*=10) per transect in the high exposure zone to provide a more detailed overview.

Results indicate tendencies of association between *Thinopyrum junceiforme* and *Spinifex sericeus* ranged between 75.00 % and 0 (Figure 7.8). The highest tendencies of association (75.00%) occurred in two Transects, 80 and 50 km, while the lowest (0) occurred in Transects 70 km, 20 km (n), 10 km (n), and 0 km. The zero values are explained by the fact that *S. sericeus* was not recorded in Transect 70 (in the high exposure zone) and *T.*

junceiforme was not recorded in 20 km (n) and 0 km. They both occurred in 10 km (n), but never in the same quadrat.

					S_s *T.junceiforme* %									
Transects	110	100	90	80	70	60	50	40	30	20 n	10 n	0	10 s	20 s
S. sericeus	33.33	46.15	46.15	75.00	0	66.66	75.00	33.33	66.66	0	0	0	66.66	57.14

Figure 7.8. Tendencies of association between *Thinopyrum junceiforme* and *Spinifex sericeus* in the high exposure zone.

These results are made clearer in Figure 7.9, which shows the distribution of *Thinopyrum junceiforme* and *Spinifex sericeus* in the first 10 quadrats of the high exposure zone in each transect along the Younghusband Peninsula. Figure 7.9 also shows that with few exceptions (Transect 10 km (n)), in the transects in which both *T. junceiforme* and *S. sericeus* occur, *T. junceiforme* always occupies the most seaward quadrat(s) and generally, with few exceptions, *S. sericeus* is absent from these quadrat(s). On average, *S. sericeus* was absent from the first 5 quadrats of each transect in the high exposure zone (Figure 7.9).

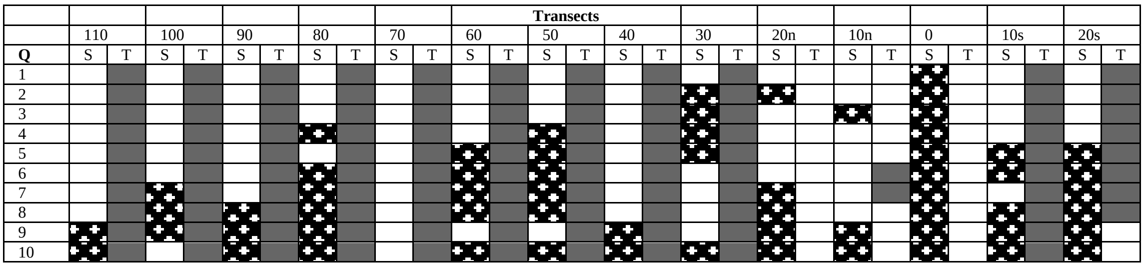

Figure 7.9. Distribution of *Thinopyrum junceiforme* and *Spinifex sericeus* in the high exposure zone quadrats (*n*=10) in each transect along the Younghusband Peninsula. *Thinopyrum junceiforme* =T, quadrats in solid colour, *Spinifex sericeus* = S, hashed quadrats, Q = quadrats

To further clarify the association between *Thinopyrum junceiforme* and *Spinifex sericeus* the Chi-square test, using the Yates correction and employing a 2 x 2 contingency table, was used (see Kent & Coker 1992). A significant association was revealed; $x^2 = 9.52$, df = 1, p = 0.0025.[2] However, as the expected frequency (47.92) exceeded the observed frequency (41), the result was a negative association. In almost half (69) of the quadrats

[2] Or $x^2 = 8.28$, df =1, p = 0.005 without the Yates correction.

analysed (*n* = 140), *T. junceiforme* occurred alone, while *S. sericeus* occurred alone in 20. They occurred jointly in only just under 30 % of quadrats.

7.3.1.6 Distribution of *Thinopyrum junceiforme* in other parts of the dune system

Results show *T. junceiforme* is prominent in the high exposure zone of the Younghusband Peninsula. However, analysis of the transect data show that it is not limited to this area and it can also be found colonising parts of the backdune environment. In the surveys undertaken in this research *T. junceiforme* was found extending inland as far as 65 m in Transect 80 (Figure 7.10). In other transects it also extended a significant distance inland: to 49 m in Transect 50, and 47 m in Transects 60 and 70 (Figure 7.10). In such locations *T. junceiforme* cover was always low, recording values of 1 or less frequently, 2 (Figure 7.10). It can also be observed that cover in the first quadrat of 11 of the 12 transects in which *Thinopyrum junceiforme* occurred was also low, usually 1, less frequently 2, and it was completely absent in the first 5 quadrats of Transect 10 km (Figure 7.10).

7.3.2 Dune form and *Thinopyrum junceiforme* colonisation

In this section observations of dune form/ *T. junceiforme* colonisation were made along the length of the Younghusband Peninsula, noting the morphology (Hesp 1983, 2002) and possible mode of incipient dune formation (Hesp 1984, 1989). Some general observations on dune form and *T. junceiforme* colonisation along the Younghusband Peninsula are first presented.

7.3.2.1 General observations of dune form/*Thinopyrum junceiforme* colonisation along Younghusband Peninsula

Thinopyrum junceiforme colonisation is relatively continuous along the Younghusband Peninsula. However, in some locations *T. junceiforme* was sparsely continuous, to sparse, patchy and intermittent and difficult to detect (eg. 42 Mile Crossing to Tea Tree Crossing) (Figure 7.11). In some places the plant was not present at all (Figure 7.12) and in other areas both *T. junceiforme* and the foredune appeared to be largely non existent (Figure 7.13). *T. junceiforme* also occurred variously in occasional thick or dense pockets (eg. 40 – 50 km), substantial thick continuous sections (eg. 70 – 110 km +) or few, thick semi-continuous sections (eg. 32 Mile Crossing – 28 Mile Crossing). It occupied variously the backbeach, dune base/toes, dune stoss slope and crest, and at times extended into the backdune area.

	Transects													
Q	110	100	90	80	70	60	50	40	30	20 n	10 n	0	10 s	20 s
1	1	1	1	2	1	1	2	1	1		0		1	1
2	2	3	2	3	1	1	2	2	1		0		3	1
3	2	2	3	3	1	1	3	2	1		0		3	1
4	3	2	2	4	2	2	3	2	1		0		3	1
5	4	2	2	3	2	3	2	2	1		0		2	1
6	3	5	2	3	2	2	2	2	1		1		2	1
7	3	3	2	3	2	2	1	2	1		1		2	1
8	3	2	1	3	3	1	2	2	1		0		2	1
9	4	3	1	3	2	1	2	2	1		0		2	
10	3	3	2	2	3	1	2	2	1		0		1	
11	2	3	2	1	4	1	2	2	1		0		1	
12	2	2	2	1	3	1	2	1	1		0		0	
13	1	2	1	1	3	1	2	1	1		0		1	
14	1	3	2	1	2	1	1	1	1		1		0	
15	1	3	1	1	1	1	2	1	1		1		0	
16	1	2	0	1	2	1	1	1	1		1		1	
17	1	2	1	1	1	1	1	2	1		1		0	
18	2	1	1	1	2	1	1	2	2		0		1	
19	2	1	1	1	1	1	1		1		0		0	
20	2	1	1	1	1	1	1		1		1		1	
21	2	1	1	1	1	0	2		1		0		1	
22	2	1	0	0	1	1	1		0		1		1	
23	3	1	0	1	1	0	1		1		0		1	
24	2	1	0	1	1	0	1		1		0		1	
25	1	1	1	0	0	1	1		1		0		1	
26	1	1	1	1	1	1	1				1		1	
27	1	1	1	1	1	1	1				0		0	
28	1	1	1	1	1	1	1				1		0	
29	2	1	1	1	1	1	1						0	
30		0	1	1	0	1	0						0	
31		0		0	1	1	0						0	
32		1		0	1	1	0						0	
33				0	1	1	0						0	
34				1	0	1	0						0	
35				0	1	0	0						0	
36				0	0	0	0						0	
37				0	1	0	0						1	
38				0	1	0	0						1	
39				0	1	1	0						0	
40				1	1	1	0						1	
41				0	1	0	0						1	
42				0	1	1	0						1	
43				0	1	0	0							
44				1	1	1	0							
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46				0	1	1	1							
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64				0										
65				1										

Figure 7.10. Presence of *Thinopyrum junceiforme* – all vegetated quadrats. It was absent in Transects 20 km (n) and 0 km. In the remaining transects ‘0’ represents *T. junceiforme’s* absence in quadrats (Q) between the first and last noted specimen in each transect. Cover values: 1 = less than 5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75% and 5 = greater than 75%.

Flowering appeared limited to the very south (eg. Wreck Crossing – southern Coorong National Park boundary) and the very north (eg. 110 km +) of the peninsula (Figure 7.11).

As shown in Figure 7.11 there are variations in the mode of dune form/*Thinopyrum junceiforme* colonisation along the length of the peninsula. Variation is not only spatial but temporal too, particularly in the southern section of the study area due to major erosional events that appear to occur more frequently than in the northern section (Short & Hesp 1980). A number of underlying factors, such as wind conditions (eg. Heyligers 1985) and original dune morphology, beach type and sand supply may influence the high exposure zone of the Younghusband Peninsula.

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Figure 7.11. Variations in the mode of dune form/*Thinopyrum junceiforme* colonisation along the length of the peninsula. Source: Base map derived from Commonwealth of Australia (1982).

Figure 7.12. In some locations along the peninsula *Thinopyrum junceiforme* was absent from the foredune. Source: Photograph by the author.

Figure 7.13. In some locations along the peninsula both *Thinopyrum junceiforme* and the foredune appeared to be largely non-existent. Source: Photograph by the author.

7.3.2.2 Specific observations of dune form/*Thinopyrum junceiforme* colonisation along Younghusband Peninsula

i. Colonisation by *Thinopyrum junceiforme* in 'ribbon-like strips'.

Thinopyrum junceiforme colonises long stretches of the Younghusband Peninsula in what initially appears to be ribbon-like strips. It is the alongshore continuity of *T. junceiforme* colonisation, whether it be sparse or dense, that gives this impression. The areas to which the ‘ribbon-like strip’ title is applied were generally confined to the upper backbeach, base of dunes/dune toes, and lower slopes, but sometimes extended up onto the upper parts of seaward slopes (but see ii below). Ramp morphologies (Hesp 2002) could be observed on seaward slopes, bases/toes of dunes and upper backbeach where *T. junceiforme* had colonised (Figure 7.14), probably initially via seedlings and/ or rhizome fragments and subsequently, by lateral rhizome growth. Seaward growth of rhizomes from a landward source (incipient dune type 2b) was not a consideration in these areas (for example, see Figure 7.14) although it was observed in other areas (see iv below).

Figure 7.14. *Thinopyrum junceiforme* incipient foredune displaying ramp morphology. Source: Photograph by the author.

ii. Colonisation of the stoss slopes of erosional dunes.

In many locations *Thinopyrum junceiforme* was observed colonising the stoss slopes of existing erosional dunes along the peninsula (eg. Wreck Crossing to 28 Mile Crossing) (Figure 7.11). In these areas *T. junceiforme* formed a series of discontinuous incipient foredunes, with parallels to the situation described by Hilton et al. (2006), but contrasts to the areas of ‘ribbon-like strips’ (above) which were more continuous alongshore. These ‘ramp incipient foredunes’ have clearly formed on ‘inherited seaward sloping surfaces’ (Hesp 1983 p. 335), probably from *T. junceiforme* growth ‘on a scarp fill or at the base of a foredune scarp’ (Hesp 1983 p. 335). This growth would follow deposition of seed or rhizome fragments as these areas were not generally characterised by a landward source of *T. junceiforme.* Figure 7.15 illustrates a *T. junceiforme* ramp formed on scarp fill amongst erosional dunes and an outcrop of aeolian-calcarenite on the northern part of the peninsula.

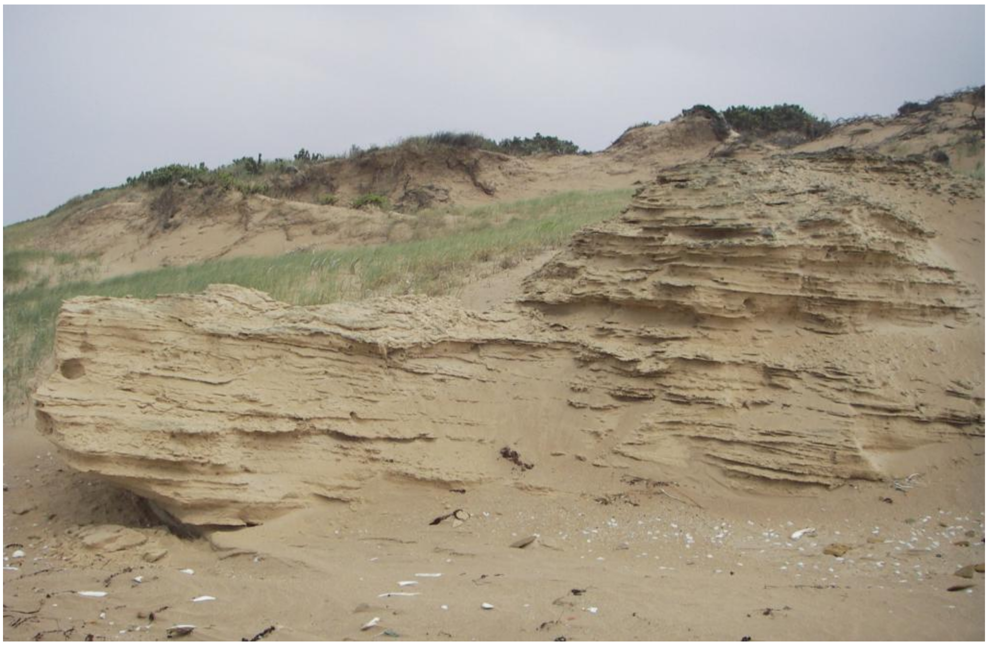

Figure 7.15. *Thinopyrum junceiforme* ramp formed on scarp fill amongst erosional dunes and an outcrop of aeolian-calcarenite on the northern part of the peninsula. Source: Photograph by the author.

iii. Large scale and small scale low, broad mound-like dunes formed by *Thinopyrum junceiforme.*

In a number of areas along the Younghusband Peninsula *T. junceiforme* is associated with low, broad mound-like dunes displaying a terrace morphology (eg. Between the Murray Mouth and 80 km) (Figure 7.11). Probably initiated by seedling and/or rhizome fragment colonisation of the backshore, they are laterally extensive and continuous alongshore (Figure 7.16) and may be found abutting the older (former) established foredune (Figure 7.17). Predominantly, *T. junceiforme* forms a monoculture on these dunes but colonisation by the native *Spinifex sericeus* is apparent in some areas (Figure 7.17). Similar, smaller scale features were also present along the peninsula (Figure 7.18).

Figure 7.16. Laterally extensive and continuous *Thinopyrum junceiforme* dune near the River Murray mouth. Source: Photograph by the author.

Figure 7.17. Laterally extensive and continuous *Thinopyrum junceiforme* dune abutting former foredune (top right of photograph). Source: Photograph by the author.

Figure 7.18. Small scale low, broad mound-like dunes formed by *Thinopyrum junceiforme* along the Younghusband Peninsula. Source: Photograph by the author.

iv. Seaward growth by *Thinopyrum junceiforme* from landward populations.

Hesp's (1984, 1989) incipient foredune type 2b relates, as indicated above, to seaward colonisation by rhizomes or stolons usually from existing landward populations. Colonisation of the backbeach from the adjacent foredune was noted at a number of locations along the peninsula (Figure 7.19). In such areas plants are susceptible to inundation during storms (Figure 7.20). The potential for seaward growth from a landward source 'particularly following major dune scarping' (Short & Hesp 1980 p. 221) was observed following storm activity resulting in major foredune erosion and exposure of rhizomes on the very northern part of the Younghusband Peninsula (Figure 7.21).

Figure 7.19. Seaward colonisation by *Thinopyrum junceiforme*. Source: Photograph by the author.

Figure 7.20. Inundation of *Thinopyrum junceiforme* on the backbeach. Source: Photograph by the author.

Figure 7.21. *Thinopyrum junceiforme* rhizomes exposed by erosion on the northern Younghusband Peninsula. Source: Photograph by the author.

v. Colonisation across mouths of dune blowouts

Thinopyrum junceiforme was observed colonising entrances of dune blowouts (eg. between 28 Mile Crossing and 42 Mile Crossing - see Figure 7.11). During their study Short and Hesp (1980 p. 43) observed that a number of blowouts had been 'revegetated' across their mouths, and noted the formation of type 1a incipient foredunes across the blowouts (p. 41). According to Hesp (1984) *Cakile* sp. 'are the most common plants involved' (p. 72) but require invasion by perennial species such as *Spinifex* to survive (Hesp 1989 p. 185). Certainly, type 1a incipient foredunes initiated by *Cakile* sp. can be seen seaward of the *T. junceiforme* revegetated blowout mouth in Figure 7.22. Hence, it could be postulated that *T. junceiforme* has subsequently invaded type 1a incipient foredunes initiated by *Cakile* sp. in the blowout entrance. Initially, it was thought that because the dune does not display a hummocky (inherited) topography and appears to be a relatively continuous and smooth ridge, that this may not be the case. However, Hesp (1984 p. 75) reported the development of a 'low hummocky terrace' into a 'subtle asymmetric ridge' between 1976-1980, following initiation by *Cakile edentula* and subsequent invasion by *Spinifex sericeus*. Alternatively, incipient dune initiation in this area by *T. junceiforme* alone is entirely possible.

In many cases the dune vegetation either side of the blowouts was not *Thinopyrum junceiforme* (but see below) and consequently seed and/or rhizome fragments must have been transported and deposited in these locations, subsequently resulting in incipient dune formation. Given the smooth topography, it suggests that colonies of seedlings (incipient dune type 2a, Hesp 1984, 1989) or stranded rhizomes (Hilton & Konlechner 2011) and not discrete plants (incipient dune type 1a, Hesp 1984, 1989) initiated the dune. In other cases, it appears that *T. junceiforme* has colonised each side of the blowout entrance and may be in the process of 'filling the gap' via lateral extension of rhizomes (Figure 7.23).

Figure 7.22. *Thinopyrum junceiforme* colonising across blowout entrance. Note the type 1a incipient foredunes initiated by *Cakile* sp. seaward of the revegetated blowout entrance. Source: Photograph by the author.

Figure 7.23. *Thinopyrum junceiforme* colonising either side of blowout entrance. Source: Photograph by the author.

vi. Hummocky dune topography.

At the River Murray mouth hummocky *Thinopyrum junceiforme* dune topography was observed (Figure 7.24). Hummocky dune topography may be associated with incipient foredune type 1a and coalescence may result in 'low hummocky terraces' or 'semi-continuous foredune ridges' (Hesp 1984 p. 76, Hesp 1989 p. 185). *T. junceiforme* dunes may also display this morphology under increased wind conditions (Heyligers 1985).

Figure 7.24. Hummocky *Thinopyrum junceiforme* dune topography near the River Murray mouth, northern Younghusband Peninsula. Source: Photograph by the author.

7.3.3 Rate of *Thinopyrum junceiforme* colonisation on Younghusband Peninsula

Herbarium records first record the presence of *Thinopyrum junceiforme* on the Younghusband Peninsula in 1986. Surveys undertaken for this research in 2007 demonstrate that in just over two decades the grass has colonised much of the 130 km length of the coastal barrier surveyed. The width of *T. junceiforme* colonisation across the coastal dunes, or the distance that it extended inland, was on average 30 m. Consequently, it was calculated that along the Younghusband Peninsula *T. junceiforme* has colonised approximately 390 hectares in just over 20 years.

7.4 Discussion

7.4.1 Rate of *Thinopyrum junceiforme* spread along Younghusband Peninsula

Vegetation surveys undertaken along the length of the Younghusband Peninsula indicated that *Thinopyrum junceiforme* was recorded at most locations along the length of the peninsula. Only a few gaps were noted in the plant's distribution: It was not recorded in the 0 km Transect near 42 Mile Crossing nor the Transect at 20 km north of 42 Mile Crossing.

Its presence was also low, compared to other sites, in the 10 km north of 42 Mile Crossing Transect, which was located between the former two transects. Consequently there was a 20 km stretch of coast along the peninsula where the presence of *T. junceiforme* was tenuous, and conditions were less conducive to its colonisation, at least in the vicinity of the transects, and this should be taken into consideration in terms of the estimated rate of colonisation.

It was cautiously estimated that *T. junceiforme* has colonised approximately 390 hectares of the Younghusband Peninsula in just over 20 years (1986-2007). How does this compare to the spread of other introduced species? The comprehensive study of Hilton et al. (2005) who monitored the spread of Marram grass in Mason Bay on Stewart Island, which lies off the coast of New Zealand's South Island, was examined for comparative purposes. According to Hilton et al. (2005), whose calculations were based on aerial photograph analysis and the use of density classes, Marram grass in this location spread from 1.4 ha in 1958 to 74.9 ha in 1998, or thus, 73.5 ha in 40 years. While not directly comparable due to differences in the method of analysis, Marram grass has been spreading at approximately 1.875 hectares a year (over 40 years) on Stewart Island, whereas on Younghusband Peninsula *T. junceiforme* appears to be spreading at a much faster rate of 18.571 ha a year (over 21 years). Moreover, while Marram grass was deliberately planted for stabilisation purposes in Mason Bay (Hilton et al. 2005), the spread along the Younghusband Peninsula has been by natural dispersal from other areas. The limits to its spread are the extent to which *T. junceiforme* can extend inland. Marram grass was found to have extended in 'dense patches' 'up to 750 m inland' between 1958-1998 (Hilton et al. 2005), while the average extent of colonisation inland of *T. junceiforme* was 30 m, although it was found extending inland as far as 65 m in Transect 80, although its cover was low. A decline in vigour of *T. junceiforme* with distance from the sea has been attributed to a 'freshening of soil water' (Heyligers 1985 p. 31) or 'dwindling nutrient availability' (Heyligers 2006 p. 580). Certainly, Meijering (1964) suggests that with a reduction in the salt content of soil water 'stunted' plants may result and Marram grass becomes dominant. Alternatively, Nicholson (1952) suggested that it is the presence of Marram grass that plays a role in the decline of *T. junceiforme*, inland.

7.4.2 Dune form and *Thinopyrum junceiforme* colonisation

Observations in the high exposure zone along the peninsula reveal incipient dune formation by *T. junceiforme* via a number of possible modes (Hesp 1984, 1989) including seaward colonisation from a landward source (Type 2b) and the colonisation of Type 1a incipient dunes formed by *Cakile* sp. Colonisation occurred in various locations: on the backbeach, and dune toe and seaward slope of the foredunes and across the mouths of blowouts. A number of morphologies: ramps, terraces and ridges (Hesp 2002), were also recognised. On the Younghusband Peninsula a variety of dune forms/*T. junceiforme* colonisation occurs, as confirmed by Mavrinac (1986 p. 60) who commented that the morphology of dunes colonised by *T. junceiforme* in the areas he surveyed to be not as 'similar' as he expected. These forms illustrate not only the versatility of *T. junceiforme* but also variations in factors such as pre-existing morphology, wind conditions and plant growth.

An interesting artefact of analysis relates to the 20 km stretch of coast along the peninsula where the presence of *T. junceiforme* was tenuous. As mentioned above it was not recorded in the 0 km Transect nor the 20 km (n) Transect and its presence was very low in the 10 km (n) Transect. These three transects also recorded the widest back beaches, between the high tide mark and first line of vegetation, with 24 m, 46 m and 33 m for Transects 20 km (n)[3], 10 km (n) and 0 km, respectively. Thus, it appears that *T. junceiforme* had a low or no presence in the three transects with the widest beach width between the high tide line and first line of vegetation. The issue of beach width is important in regard to habitat for shorebirds, and Hilton and Harvey (2002) and Rudman (2003) have commented on the potential impact of *Thinopyrum junceiforme* on birds such as the hooded plover (*Thinornis rubricollis*), by reducing beach width and consequently, shore bird habitat (Hilton & Harvey 2002 p. 188). The hooded plover, which is endemic to Australia, occurs in the 'Near Threatened' category in the 2008 IUCN Red List (Birdlife International 2008). According to Buick and Paton (1989) in the Coorong region these birds nest on the beach landward of the high tide mark near to the base (usually within 6 m) of the foredune.

In wider sections of beach, such as at 20 km (n), 0 km and 10 km (n), it would be assumed that nesting plovers would be less likely to suffer from the impact of vehicles driving along the beach, and have a wider area of habitat from which to select suitable nesting sites. On the other hand, transects with short or narrow beach widths, and consequently, those with higher levels of *Thinopyrum junceiforme* colonisation, would probably have a greater

[3] But it should be noted that Transect 30 km recorded a beach width of 23 m and *T. junceiforme* occurred in all quadrats in the high exposure zone.

impact on nesting shore bird habitat. Relatively narrow beach widths of only 8 m were recorded for Transects 10 km and 20 km, and Transects 110 and 70 km recorded a maximum width of 11 m. Transects 90 km and 100 km also recorded narrow beach widths of 12 m and 13 m respectively. While Buick and Paton (1989) found that the highest density of vehicle tracks occurred within only 10 m of the foredune, and that most nesting occurred within 6 m of the dunes, there is little doubt that the narrower sections of beach provide less choice in nesting site selection, as well as limiting the area for vehicles to travel, thereby increasing the chances of nest destruction by vehicles. However, beach closures north of Tea Tree Crossing in the Coorong National Park between October 24 and December 24 would afford some protection from the impact of vehicles.

Observations in the high exposure zone have shown that *T. junceiforme* modifies the environment of the Younghusband Peninsula by colonising pre-existing dunes and by forming new dunes. In some cases *T. junceiforme* mimics the activities of native species, for example, by invasion of incipient dune type 1a in the mouths of blowouts, as per *Spinifex sericeus*. In other cases its colonisation technique is unique and alien to the environment of the peninsula, such as the way in which it forms low, broad continuous dunes bearing a monoculture or the way it colonises the seaward slopes of otherwise sparsely vegetated pre-existing dunes. The mode of colonisation of *T. junceiforme* not only affects the natural character of the dune environment of the Younghusband Peninsula, but also has implications for its native vegetation.

7.4.3 *Thinopyrum junceiforme* in the high exposure zone along the Younghusband Peninsula

Results indicated that *Thinopyrum junceiforme*, along with the native *Spinifex sericeus*, and the alien *Euphorbia paralias*, were the most common plants found along most of the Younghusband Peninsula in the high exposure zone. Certainly, the latter two species comprise the *S. sericeus/E. paralias* grassland (shrubland) community, one of seven floristic groups identified by Oppermann (1999) in the Coorong. A tussock grassland community comprising *S. sericeus* and *A. littoralis* was once described by Douglas et al. (1982) as the dominant community on the majority of the frontal dunes between the River Murray mouth and Parnka Point. However, results from the current research indicate that *A. littoralis* was not recorded in any transect in the high exposure zone. As indicated earlier, Douglas et al. (1982) commented that *E. paralias* was growing with much vigour on the peninsula and suggested it had ‘seriously altered the nature’ of the foredune communities. Thus, whether the absence of *A. littoralis* in the high exposure zone was caused by *T. junceiforme* colonisation, or *T. junceiforme* and *E. paralias* in combination, or some other factor, is not conclusively known but nonetheless indicates a significant change in the species composition of the tussock grassland community of the Younghusband Peninsula foredune, at least between the River Murray mouth and Parnka Point, during the last 25 years.

Hilton and Harvey (2002) discussed the displacement of native foredune species such as *Spinifex sericeus* by *Thinopyrum junceiforme* due to factors such as the higher tolerance to salinity of *T. junceiforme*. Certainly, previous studies indicate that *T. junceiforme* has a considerable tolerance of salinity, both in terms of salt spray and soil or root salinity (Sykes & Wilson 1988, 1989). *S. sericeus*, on the other hand, is less tolerant to salinity and requires fresh soil water (Heyligers 1985). Other mechanisms for displacement may relate to the monospecific growth of Sea wheat-grass (in closer proximity to the sea) (Hilton & Harvey 2002). In some locations the effects of the monospecific growth of *T. junceiforme* may be dependant upon its degree of cover: in Tasmania, in locations where *T. junceiforme* is sparse, the native grass '…appears to maintain its dominance on foredunes…' (Rudman 2003 p. 8).

While initially it appeared that *Thinopyrum junceiforme* and *Spinifex sericeus* had a strong association (88%), this may be due to both plants having a wide distribution along the peninsula in the high exposure zone. Certainly, a closer look at the quadrat level revealed this close relationship was less apparent. The Chi-square test revealed a significant but negative association between the two plants. In almost half (69) of the 140 quadrats analysed, *T. junceiforme* occurred alone, while *S. sericeus* occurred alone in 20. They occurred jointly in only just under 30 % of quadrats.

With few exceptions, in the transects in which both *Thinopyrum junceiforme* and *Spinifex sericeus* occurred, *T. junceiforme* always occupied the most seaward quadrat(s) and generally, with few exceptions, *S. sericeus* was absent from the first few quadrat(s) of each transect. Similar results have been found in previous studies such as the one of Mavrinac (1986). According to Hilton and Harvey (2002), the dichotomy in the spatial distribution of *T. junceiforme* and *S. sericeus* on dunes may relate to the relative tolerance of each species to salinity, and may explain the results of the surveys undertaken in this research. The ability of *T. junceiforme* to form new monospecific dunes seaward of existing dunes, resulting potentially in the exclusion of native species like *S. Sericeus* may also be a contributing factor.

The widespread occurrence of *Spinifex sericeus* along the Younghusband Peninsula in the high exposure zone does not suggest that *T. junceiforme* has yet had a significant impact on the plant at this stage. Research indicates there are many modes by which *T. junceiforme* colonises along the Younghusband Peninsula, and as a consequence it may limit the movement of sand. By promoting stability in a usually dynamic environment there may be ongoing implications for *S. sericeus,* which responds positively to sand deposition (Maze & Whalley 1992).

While *Spinifex sericeus* still appears prevalent along the peninsula *T. junceiforme* has clearly impacted on the natural character of the vegetation community originally characterising the dunes of the barrier and *T. junceiforme,* not *S. sericeus,* is now the primary pioneer coloniser.

7.5 SUMMARY

Thinopyrum junceiforme has become established along most of the length of the Younghusband Peninsula where it is prevalent in the high exposure zone. It not only colonises existing dunes, but forms its own continuous dunes seaward of the established dunes. In areas where it has low or no presence, beach width is widest, where *T. junceiforme* is more prevalent, narrower widths were recorded, providing a more limited area for nesting site selection by shorebirds.

By virtue of its presence *Thinopyrum junceiforme* has changed the composition of vegetation communities on the Younghusband Peninsula. Along with *Euphorbia paralias* it may have contributed to the decline in *Austrofestuca littoralis,* which had formed part of the pioneering tussock grassland community on the barrier. The comparative distribution of *T. junceiforme* and *Spinifex sericeus* along the peninsula suggests a pattern of zonation reflecting environmental preferences, although the monoculture formed by *T. junceiforme* in some areas may contribute to this dichotomy. Moreover, *S. sericeus* has now been displaced as the primary pioneer coloniser by *T. junceiforme*. While *S. sericeus* still appears to be widespread along the barrier, there may be implications for the vigour of its growth due to *T. junceiforme's* affect on sand mobility.

Consequently, *Thinopyrum junceiforme* has altered both the geomorphology and ecology along the Younghusband Peninsula.

CHAPTER 8. CONCLUSIONS

In the introductory chapter to this thesis a number of questions were posed based on gaps in the existing research on *Thinopyrum junceiforme*. These questions were grouped under the following headings: the Spatial and Temporal dimensions of invasion, Awareness of the plant, Dispersal, and Impact. The acronym STADI is a convenient summary of these fundamental issues. In addressing these questions, this chapter presents a STADI model of invasion for *T. junceiforme* along the south eastern Australian coastline (Figure 8.1). This is followed by some concluding comments and opportunities for further research.

8.1 A STADI MODEL OF INVASION FOR *THINOPYRUM JUNCEIFORME* ALONG THE SOUTH EASTERN AUSTRALIAN COASTLINE

Spatial and **T**emporal dimensions of invasion

The first specimen of *T. junceiforme* was collected from Victoria nearly 90 years ago in 1923. The plant was probably initially accidentally introduced via ballast, in a voyage from Europe over a distance of over 11,500 nautical miles (Figure 8.1a). Hence, it overcame a major geographical barrier assisted *accidentally* by humans (Richardson et al. 2000). Subsequently, *deliberate* importations by the CSIR and CSIRO also facilitated the introduction of *T. junceiforme* into Australia. Sand stabilisation trials by the Soil Conservation Authority (SCA) contributed to the spread of the plant locally. However, drift card and bottle studies reveal a number of potential pathways for the natural dispersal of the plant between the south eastern states of Victoria, Tasmania and South Australia (Figure 8.1a), which form part of an 'invasion hotspot' (O'Donnell et al. 2012), to which *most* species of the genus *Thinopyrum* in Australia appear to be confined.

From its first point of arrival in Victoria, *Thinopyrum junceiforme* was subsequently recorded 25 years later, 319 km away in Tasmania (Rocky Cape) and from there it took 35 years to reach South Australia at Long Beach, 672 km away. Alternatively, if the plant dispersed from Victoria to South Australia it took 6 decades to travel the 430 km between these two states (Figure 8.1a). *T. junceiforme* has produced 'self sustaining populations' at locations some distance away from its initial point of arrival, and its spread along the south eastern Australian coastline spectacularly exceeds scales of invasion found in the literature (Richardson et al. 2000). Hence, *T. junceiforme* may be considered to be an invasive species in Australia.

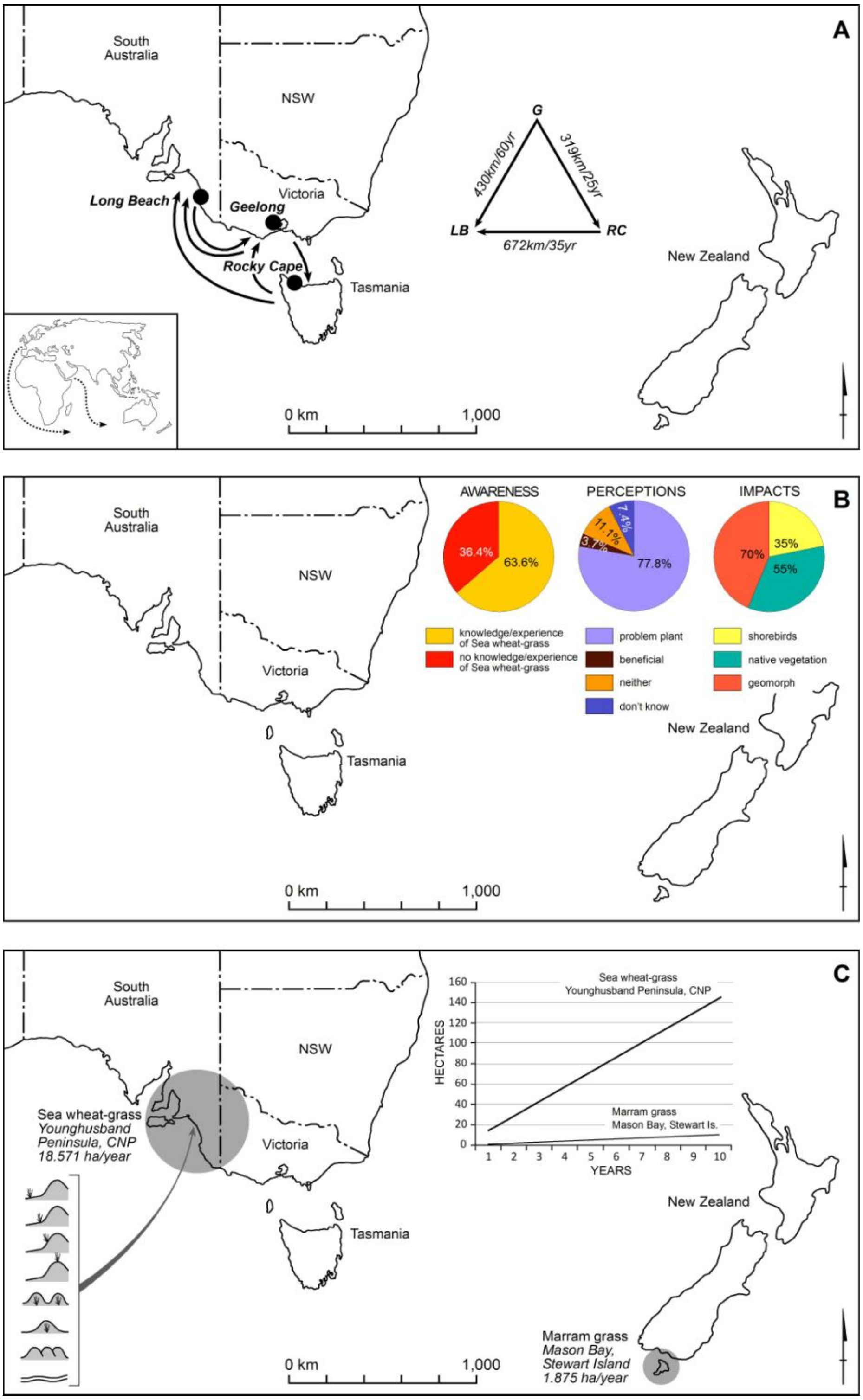

Figure 8.1. A STADI model of invasion for *Thinopyrum junceiforme* along the south eastern Australian coastline.

Awareness

While a plethora of research exists for Marram grass, comparatively little is available on *T. junceiforme,* as a search of the Web of Knowledge database demonstrated (Chapter Four).

In Australia, aside from the astute observations of Petrus Heyligers (Heyligers 1985) and the work of Mavrinac (1986) the plant received little attention until more recent publications appeared (eg. Hilton & Harvey 2002, Harvey et al. 2003, Hilton et al. 2006, 2007, Rudman 2003). Despite the appearance of these more recent publications, it seemed that the plant largely went unnoticed as it spread along the south eastern Australian coastline.

However, contrary to expectations, the Sea wheat-grass survey indicated that over half of all respondents either knew of or had direct experience of Sea wheat-grass (Figure 8.1b)! Moreover, most respondents held negative perceptions of Sea wheat-grass (Figure 8.1b), with three clear themes emerging from their responses: impacts on shorebirds, impacts on native vegetation, and impacts on coastal geomorphology and beach-dune processes (Figure 8.1b). Thus, *T. junceiforme* was not totally overlooked as it spread along the coast, and a level of awareness of the plant is present. It does not have the status of some other coastal weeds, but its profile is not as low as originally thought. Instead of a lack of awareness perhaps a more important point identified in the research was the lack of information available about the plant, with suggestions that the current research on *T. junceiforme* should be shared for management purposes.

Dispersal

Thinopyrum junceiforme seeds (as florets) can float on seawater for up to 21 days under calm conditions. However, they demonstrate a limited tolerance to turbulent conditions and will sink, as suggested by Darwin (1859). Most importantly, whether *T. junceiforme* seeds sink or remain afloat, they tend not to germinate in seawater. Contrary to perceptions that this may indicate a poor tolerance to salinity (Nicholson 1952), the ability to delay germination may increase the plant's potential for establishment (Guja et al. 2010), and is one of three important requirements in oceanic hydrochory according to Ridley (1930). Following prolonged submersion in seawater, *T. junceiforme* demonstrates a high germination rate, reflecting its ability to 'resist the action of salt' (Ridley 1930 p. 242).

Thus, while turbulent oceanic conditions may restrict the ability of *T. junceiforme* seeds to float, the capacity to germinate well subsequent to prolonged immersion suggests the existence of mechanisms that provide a significant advantage to the plant's survival, establishment and spread.

Thinopyrum junceiforme rhizome fragments offer an alterative, and by some reports the principal way in which the plant may spread (Nicholson 1952), although the probability of a *T. junceiforme* plant arising from seed or rhizome fragments has been found to be similar (Harris & Davy 1986a). In this study, rhizome fragments of *T. junceiforme*, fragmented and transported with sand by machinery to a new location along the metropolitan Adelaide coastline for sand replenishment purposes, commenced to produce roots and shoots as they would under natural conditions, fragmented and transported to new sites by the ocean.

It is likely that the timing of artificial sand emplacement played a crucial role in rhizome regeneration on the metropolitan coast, but the presence of many multi-noded *T. junceiforme* rhizome fragments may have also been important, as suggested in the literature (Harris & Davy 1986b). Beach replenishment activities appear to be assisting in the dispersal of *T. junceiforme,* but the survival of establishing plants on the more seaward sections of the beach is associated with the natural process of erosion.

Probably the most revealing factor regarding the dispersal potential of *T. junceiforme* does not come from experiments or field observations in this research, but from the fact that it survived and was able to establish on Australian shores following a voyage from Europe taking perhaps 35-40 days, over 11,500 nautical miles, in ships' ballast (Figure 8.1 a).

Impact

Thinopyrum junceiforme has become established along much of the length of the Younghusband Peninsula where it appears to be spreading at a rate of 18.571 ha a year, which is much faster than rate of spread of Marram grass on Stewart Island (Figure 8.1c).

Observations along the high exposure zone of the peninsula reveal that not only does *Thinopyrum junceiforme* colonise existing dunes but also forms new dunes seaward of the established dunes (Figure 8.1c). Incipient dune formation by *T. junceiforme* occurs by a number of possible modes including seaward extension of rhizomes (Hesp 1984, 1989) and a number of morphologies: ramps, terraces and ridges (Hesp 2002) were recognised. Observations confirm the ability of *T. junceiforme* to stabilise sand as suggested in the literature (Heyligers 1985, Hilton & Harvey 2002, Mavrinac 1986) and in questionnaire responses. As a consequence of its widespread dune building along the Younghusband Peninsula *T. junceiforme* may limit the movement of sand and promote stability in a usually dynamic environment, which in turn has implications for the vegetation communities on the barrier.

By virtue of its presence *Thinopyrum junceiforme* has changed the composition of vegetation communities in the high exposure zone along the Younghusband Peninsula. Along with *Euphorbia paralias* it may have contributed to the decline in *Austrofestuca littoralis,* which had formed part of the pioneering tussock grassland community on the barrier (Douglas et al. 1982). The comparative distribution of *T. junceiforme* and *Spinifex sericeus* along the peninsula suggests a pattern of zonation related in part to their relative tolerances to salinity, as suggested in the literature (Hilton & Harvey 2002). The ability of *T. junceiforme* to form new monospecific dunes seaward of existing dunes may also have contributed to this dichotomy. Consequently, the presence of *T. junceiforme* has resulted in the displacement of *S. Sericeus* as the primary pioneer coloniser along the Younghusband Peninsula. While *S. sericeus* still appears to be widespread along the barrier, there may be further implications for the vigour of its growth due to the capacity of *T. junceiforme* to inhibit sand mobility.

Finally, *Thinopyrum junceiforme* has impacted upon both the geomorphology and ecology of the Younghusband Peninsula and hence it falls into the 'sand stabiliser' category of transformer species (Richardson et al. 2000) as proposed in the introduction to this thesis.

8.2 Concluding comments and opportunities for further research

At the beginning of this research project attention was initially focussed on the potential impact of *Thinopyrum junceiforme* on the Younghusband Peninsula. However, a dearth of data available on the plant dictated that a more comprehensive study be undertaken, resulting ultimately in the STADI model of invasion (Figure 8.1).

In the presentation of the STADI model this thesis provides evidence of the invasiveness of the alien plant *Thinopyrum junceiforme* in Australia. Using a case study focussing on the Younghusband Peninsula in South Australia, the rapidity of *T. junceiforme* colonisation was revealed. It also demonstrated the mechanisms by which *T. junceiforme* modifies coastal ecosystems, and hence impacts on the ecology and geomorphology of such ecosystems. Knowledge of these impacts was found to be prevalent amongst survey respondents, as was a greater level of awareness of *T. junceiforme* than expected. Although, a lack of general information available about the plant was identified.

In contrast to the case study on the Younghusband Peninsula, which documented the rapid spread of *Thinopyrum junceiforme* along that coast by natural means of dispersal, the case study on the Adelaide metropolitan coast revealed how coastal management practices *replicate* the natural processes involved in the dispersal of *T. junceiforme* by rhizome fragments. Investigations into the dispersal of *T. junceiforme* by seed revealed a survival mechanism that enables the plant to establish following submergence in the ocean for extended periods.

The results of this research, in combination with pre-existing research on the considerable salinity tolerance of *T. junceiforme*, and its ability to cope with burial, means that a formidable invader is well established on Australian shores.

To expand on the model of invasion presented in this research, probably the main opportunity for further research is investigating the buoyancy capacity of *T. junceiforme* rhizomes fragments, and their post-buoyancy viability, as has been undertaken for Marram grass in a number of investigations including Knevel (2001) and more recently Konlechner and Hilton (2009). Such investigations would provide valuable data contributing to the overall assessment of the dispersal ability of *T. junceiforme* when combined with the results from this research which investigated the buoyancy and post buoyancy viability of *T. junceiforme* seeds.

Another opportunity for further research relates to the management of *T. junceiforme*. Many respondents to the *T. junceiforme* questionnaire thought that the alien grass should undergo control, with responses indicating that some control measures have already been undertaken. Consequently, further research to assess the results of such existing control measures and undertake further trials to determine the most effective methods of management of *T. junceiforme* should be undertaken. Nearly 30 years have passed since the potential impacts of *T. junceiforme* on coastal ecosystems in south eastern Australia were first recognised by Heyligers. The outcomes of this research demonstrate that *T. junceiforme* has since rapidly ‘transformed’ dynamic coastal ecosystems. Consequently, investigations regarding control should be undertaken sooner rather than later.

Appendix 1. Australian herbaria holding records of *Thinopyrum junceiforme* in 2005 [14 October 2005] according to the AVH.

Tasmanian Herbarium HO	Australian National Herbarium CANB/CBG**	National Herbarium of Victoria MEL	Queensland Herbarium BRI	State Herbarium of South Australia AD
114630	465877	116995	AQ0681051	994
309462	403752	225837	AQ0670353	984
309463	403737	1533986	AQ0626521	981
315143	407110	1581646	AQ0513278	988
400217	409910	1581647	AQ0379916	984
406457	409909	1590034	**5 records**	984
507235	405666	1590035		992
516968	322111	1590036		987
520214	488044	2015442		991
9 records	322098	2021938		992
	373058	2012939		992
	22476	2024573		990
	9001794	2026748		985
	13 records	2139652		990
		2139653		989
		1619300		998
		1617696		**16 records**
		2273417		
		2271710		
		2281851		
		2281852		
		2281393		
		23 records		

** CANB/CBG – CANB is the current herbarium code for the Australian National Herbarium which is comprised of an amalgamation of a series of herbarium collections. CBG is an earlier herbarium abbreviation for the Canberra Botanic Gardens which was later renamed the Australian National Botanic Gardens.

Appendix 2. Australian herbaria holding records of *Thinopyrum junceiforme* in 2010 [14 November 2010] according to the AVH.

Tasmanian Herbarium HO	Australian National Herbarium CANB/CBG	National Herbarium of Victoria MEL	Queensland Herbarium BRI	State Herbarium of South Australia AD	The National Herbarium of New South Wales NSW
538976	591755	647904A	AQ0513278	99838237	594376
101088	600193	626891A	AQ0681051	99432033	**1 record**
54421	488044	626850A	AQ0626521	99228061	
77017	322111	626849A	AQ0379916	99228060	
535019	373059	626848A	AQ0670353	99208077	
533387	373058	619679A	**5 records**	99151200	
533145	322098	594279A		99029269	
520214	465877	573225A		99029164	
114630	465878	2281852A		98910252	
309462	409910	2281851A		98801340	
315143	409909	2281393A		98706354	
516968	403711	2273418A		98518001	
39171	403737	2273417A		98450025	
113785	403695	2271710A		98439223	
507235	403752	225837A		98409214	
309463	407110	2139653A		98110134	
406457	22476	2139652A		187218	
400217	**17 records**	2026748A		187217	
18 records		2024573A		225097	
		2021939A		225098	
		2021938A		225848	
		2015442A		226856	
		1619300A		231456	
		1617696A		231356	
		1590036A		231273	
		1590035A		231284	
		1590034A		231291	
		1581647A		231306	
		1581646A		231309	
		1545259A		231340	
		1533986A		231454	
		116995A		231386	
		32 records		231538	
				231549	
				231555	
				231560	
				231507	
				231510	
				231513	
				231515	
				231554	

	231558
	231940
	231941
	231522
	231523
	231531
	231532
	231565
	231944
	231289
	231307
	231345
	231516
	231519
	231537
	231546
	231553
	231983
	231986
	231406
	61 records

Appendix 3. The spatial and temporal distribution of *Thinopyrum junceiforme* from herbarium records.

Source: Based primarily on data from Australia's Virtual Herbarium (AVH), but also supplemented with data from the Australian National Herbarium Specimen Information Register (ANHSIR) (http://www.anbg.gov.au/cgi-bin/anhsir), the Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/), and the Tasmanian Herbarium (HO), the Australian National Herbarium (CANB/CBG), the National Herbarium of Victoria (MEL), the State Herbarium of South Australia (AD), and the University of Melbourne Herbarium (MELU). Additional sources consulted, for example, in relation to the geographical location of specimens as many AVH entries indicated 'nearest locality not available'.

† records from MELU not databased on the AVH

new records from HO not databased on the AVH

Source institute	**Accession #**	**Collector/#**	**Collecting date**	**State**	**Near named place**	**Latitude**	**Longitude**
MELU	10,878	†A.C.Gates	1923	VIC	Geelong		np
MEL	2021939A	Black, R.A./s.n.	1933	VIC	Mentone, Melbourne	-37.83	145
MEL	626891A	Sonnenberg, E.J./s.n..	1933	VIC	Ricketts Point	-38	145
MEL	626849A	Sonnenberg, E.J../s.n.	1933	VIC	Ricketts Point	-38	145
MEL	2281393A	Sonnenberg, E.J../s.n.	1933	VIC	Ricketts Point nr Black Rock	-38	145
MEL	626848A	Willis, J.H. ./s.n.	1942	VIC	Swan Island nr Queenscliff	-38.17	144.67
MEL	2021938A	Willis, J.H. ./s.n.	1943	VIC	Altona, Seaholme area, Melbourne	-37.83	144.83
HO	39171	Willis, J.H. ./s.n.	1943	VIC	Altona, Seaholme area, Melbourne	-37.83	144.83
MEL	1533986A	Smith, R.V./ 43/94	1943	VIC	Along Williamstown Road (near ferry), West Port Melbourne.	-37.83	144.83
MEL	626850A	Muir, T.B./47	1957	VIC	San Remo, Western Port.	-38.5	145.33
MELU	10,876	†Sonnenberg, E.J.	1959	VIC	Queenscliff		np
MEL	573225A	Pearson, J.D.M./517	1963	VIC	Portsea Military Camp	-38.17	144.67
MELU	10,877	†Conner, D.	1964	VIC	Wilsons Promontory National Park		np
CBG	22476	Carroll, E.J. ./s.n.	1966	VIC	Balnarring, Mornington Peninsula	-38.33	145
MEL	1590036A	White, M.D. ./s.n.	1979	VIC	Mouth of Anglesea River.	-38.33	144.17
CANB	322111	Heyligers, P.C./80218	1980	VIC	Woolamai Beach	-38.5	145.17
MEL	1590034A	Heyligers, P.C./80218	1980	VIC	Woolamai Beach Phillip Island	-38.5	145.17

MEL	1590035A	Beauglehole, A.C./68940	1981	VIC	Bells Swamp Wildlife Reserve	-36.83	143.83
CANB	322098	Heyligers, P.C./81014	1981	VIC	Waratah Bay, mth of Shallow Inlet	-38.83	146.17
MEL	619679A	Heyligers, P.C./81014	1981	VIC	Waratah Bay, mth of Shallow Inlet	-38.83	146.17
MEL	1545259A	Yugovic, J.Z./152	1983	VIC	St Leonard/Port Arlington, Port Phillip Bay	-38.17	144.67
MEL	1581646A	Beauglehole, A.C./75891	1983	VIC	Waratah Bay - Shallow Inlet Coastal Reserve.	-38.67	146
MEL	1581647A	Beauglehole, A.C./75992	1983	VIC	Wilsons Promontory National Park.	-39	146.33
MEL	116995A	Brown, A.J./298	1988	VIC	Mordialloc Beach	-38	145
HO	114630	Brown, A.J./298	1988	VIC	Mordialloc Beach	-38	145
MEL	225837A	LeBreton, C. ./s.n.	1990	VIC	Sand Island off Swan Island, Queenscliff	-38.17	144.67
BRI	AQ0626521	Le Breton, C. ./s.n.	1990	VIC	Sand Island off Swan Island, Queenscliff	-38.17	144.67
MEL	2015442A	Clarke, I.C./2269	1993	VIC	Western Port Bay, Pelican Island.	-38.33	145.33
CANB	465877	Heyligers, P.C. /93027	1993	VIC	Sandspit off Shallow Inlet, nw of Wilsons Promontory	-38.83	146.17
CANB	465878	Heyligers, P.C. /93027	1993	VIC	Sandspit of Shallow Inlet, nw of Wilsons Promontory	-38.83	146.17
MEL	1619300A	Heyligers, P.C. /93027	1993	VIC	Sandspit of Shallow Inlet, nw of Wilsons Promontory	-38.83	146.17
HO	309462	Heyligers, P.C. /93027	1993	VIC	Sandspit of Shallow Inlet, nw of Wilsons Promontory	-38.83	146.17
MEL	2026748A	Paget, A./1150	1994	VIC	Sandy Point Foreshore	-38.67	146
MEL	2024573A	Walsh, N.G./3984	1994	VIC	Port Phillip Bay foreshore at McCrae, c. 0.5 km ENE from McCrae lighthouse.	-38.33	144.83
HO	315143	Walsh, N.G./3984	1994	VIC	Port Phillip Bay foreshore at McCrae, c. 0.5 km ENE from McCrae lighthouse.	-38.33	144.83
CANB	600193	Stajsic, V./3664	2004	VIC	Black Rock	-37.83	145
MEL	2281852A	Stajsic, V. ./3664	2004	VIC	Black Rock	-37.83	145
MEL	2281851A	Stajsic, V. ./3664	2004	VIC	Black Rock	-37.83	145
HO	538976	Stajsic, V. ./3664	2004	VIC	Black Rock	-37.83	145
AD	187218	Stajsic, V. ./3664	2004	VIC	Black Rock	-37.83	145
AD	187217	Stajsic, V. ./3664	2004	VIC	Black Rock	-37.83	145
MEL	2271710A	Clarke, I.C./3319	2004	VIC	Waratah Bay – foredune opposite S end of NS section of Fish Creek - Waratah Bay Road	-38.67	146
NSW	594376	Hosking, J.R./2556	2004	VIC	Sand dunes alongside Somers Yacht Club, Somers.	-38.33	145
CANB	591755	Hosking, J.R.2556	2004	VIC	Sand dunes alongside Somers Yacht Club, Somers.	-38.33	145
MEL	2273418A	Hosking, J.R., Stajsic, V./JRH2556	2004	VIC	Sand dunes alongside Somers Yacht Club, Somers.	-38.33	145

MEL	2273417A	Hosking, J.R., Stajsic, V./JRH2556	2004	VIC	Sand dunes alongside Somers Yacht Club, Somers.	-38.33	145
MEL	2139653A	Curtis, W.M. ./s.n.	1948	TAS	Rocky Cape, Black River Rd. Beach.	-40.67	145.5
MEL	2139652A	Curtis, W.M. ./s.n.	1948	TAS	Rocky Cape, Black River Rd. Beach.	-40.67	145.5
AD	98439223	Curtis, W.M. ./s.n.	1948	TAS	Rocky Cape, Black River Rd. Beach.	-40.67	145.5
HO	77017	Curtis, W.M. ./s.n.	1948	TAS	Rocky Cape, Black River Rd. Beach.	-40.83	145.33
BRI	AQ0379916	Curtis, W.M. ./s.n.	1948	TAS	Rocky Cape, Black River Rd. Beach.	-40.83	145.5
HO	101088	Morris, D.I. ./s.n.	1975	TAS	Whitemark Beach, Flinders Island	-40	148
AD	98801340	Morris, D.I. ./s.n.	1975	TAS	Whitemark Beach, Flinders Island	-40	148
AD	98110134	Whinray, J.S./1492	1975	TAS	Flinders Island, Whitemark Village	-40	148
CANB	488044	Whinray, J.S./2256	1975	TAS	Flinders Island, Whitemark Village	-40	148
MEL	594279A	Whinray, J.S./2204	1975	TAS	Flinders Island, Whitemark Village	-40	148
HO	535019	Allan, M. ./s.n.	1976	TAS	Flinders Island, nr Emita	-40	147.83
MEL	647904A	Morris, D.I./8210	1982	TAS	Whitemark Beach	-40	148
HO	54421	Morris, D.I./8210	1982	TAS	Whitemark Beach	-40	148
MEL	1617696A	Buchanan, A.M./8860	1986	TAS	W end of Green Hills Rd, Circular Head	-40.67	145.17
HO	406457	Buchanan, A.M./8860	1986	TAS	W end of Green Hills Rd, Circular Head	-40.67	145.17
AD	99432033	Buchanan, A.M./8860	1986	TAS	W end of Green Hills Rd, Circular Head	-40.67	145.17
HO	400217	Steane, D.F. ./s.n.	1992	TAS	Cape Portland	-40.67	147.83
CANB	409910	Heyligers, P.C./93007	1993	TAS	Three Mile Sand, c. 4 km north of Marrawah.	-40.83	144.83
HO	309463	Heyligers, P.C. /93007	1993	TAS	Three Mile Sand, c. 4 km north of Marrawah.	-40.83	144.67
CANB	409909	Heyligers, P.C./93002	1993	TAS	Bridport	-41	147.33
BRI	AQ0670353	Batianoff, G.N./980132	1998	TAS	Sisters Beach, north coast of Tasmania	-40.83	145.5
HO	507235	Rudman, T. ./s.n.	1999	TAS	Pats River, Whitemark Airport, Flinders Island	-40	148
HO	516968	Schahinger, R.B. ./s.n.	2001	TAS	c. 300m N of the mouth of Bottle Creek, 5 km S of Arthur River	-41	144.67
HO	520214	Buchanan, A.M./15977	2002	TAS	Somerset Beach	-41	145.67
HO	533387	Baker, M.L./1482	2005	TAS	Georgetown Coastal Reserve	-41	146.67
HO	533145	Baker, M.L./1429	2005	TAS	Beechford Coastal Reserve	-41	146.83
HO	550839	#Tyson, P.A./902	2008	TAS	West Cove, Erith Island	39 27 E	147 17 E
HO	559055	#Povey, A.	2010	TAS	Ulverstone East, W bank of Buttons Ck	41 9 S	146 11 E

AD	98409214	Heyligers, P.C./83007	1983	SA	Long Beach	-36.67	139.83
AD	98518001	Whibley, D.J.E./9719	1984	SA	Henley Beach	-34.83	138.33
HO	113785	Gibbons, P./543	1986	SA	Butcher Gap Conservation Pk	-36.83	139.67
AD	98706354	Gibbons, P./543	1986	SA	Butcher Gap Conservation Park	-36.83	139.67
CANB	403695	Heyligers, P.C./86013	1986	SA	Semaphore	-34.67	138.33
CANB	403752	Heyligers, P.C. /86013	1986	SA	Semaphore	-34.67	138.33
AD	99228061	Heyligers, P.C. /86013	1986	SA	Semaphore	-34.67	138.33
AD	99228060	Heyligers, P.C. /86013	1986	SA	Semaphore	-34.67	138.33
BRI	AQ0513278	Heyligers, P.C. /86013	1986	SA	Semaphore	-34.83	138.33
CANB	403711	Heyligers, P.C. /86023	1986	SA	Younghusband Peninsula, frontal dune southwest of old Cantara homestead.	-36.33	139.67
CANB	403737	Heyligers, P.C. /86023	1986	SA	Younghusband Peninsula, frontal dune southwest of old Cantara homestead.	-36.33	139.67
AD	99208077	Heyligers, P.C. /86023	1986	SA	Younghusband Peninsula, frontal dune southwest of old Cantara homestead.	-36.33	139.67
AD	99029164	Spooner, A.G./11908	1989	SA	West Beach	-34.83	138.5
CANB	407110	Heyligers, P.C./89163	1989	SA	Canunda National Park	-37.5	140.17
AD	99151200	Heyligers, P.C./89163	1989	SA	Canunda National Park	-37.5	140.17
AD	98910252	Bates, R./17463	1989	SA	Semaphore	-34.67	138.5
AD	99029269	Owen, Daniel./s.n.	1990	SA	Hindmarsh Island	-35.5	138.83
AD	99838237	Taylor, R./299	1998	SA	Surfers	-35.5	138.67
BRI	AQ0681051	Taylor, R./299	1998	SA	Surfers	-35.5	138.67
CANB	373059	Whibley, D.J.E./9719	2002	SA	Henley Beach, River Torrens Outlet. Near Military Road	-34.83	138.5
CANB	373058	Whibley, D.J.E./9719	2002	SA	Henley Beach, River Torrens Outlet. Near Military Road	-34.83	138.5
AD	226856	Brodie, C.J./450	2009	SA	Normanville	-35.33	138.17
AD	225097	Taylor, R.1171	2009	SA	Parsons Beach	-35.5	138.33
AD	225098	Taylor, R./1171	2009	SA	Parsons Beach	-35.5	138.33
AD	231507	Brodie, C.J./835	2009	SA	Kingston S.E.	-36.67	139.83
AD	231510	Brodie, C.J./838	2009	SA	Kingston S.E.	-36.83	139.83
AD	231513	Brodie, C.J./842	2009	SA	Cape Jaffa	-36.83	139.67
AD	231515	Brodie, C.J./841	2009	SA	Kingston S.E.	-36.83	139.67
AD	231516	Brodie, C.J./843	2009	SA	Cape Jaffa	-36.83	139.67

AD	231519	Brodie, C.J./845	2009	SA	Cape Jaffa	-36.83	139.67
AD	231940	Brodie, C.J./852	2009	SA	Bernouilli Conservation Park	-37	139.67
AD	231941	Brodie, C.J./852	2009	SA	Bernouilli Conservation Park	-37	139.67
AD	231522	Brodie, C.J./857	2009	SA	Thomas, Cape	-37	139.67
AD	231523	Brodie, C.J./855	2009	SA	Cadara Swamp	-37	139.67
AD	231532	Brodie, C.J./866	2009	SA	Long Beach	-37	139.67
AD	231944	Brodie, C.J./857	2009	SA	Thomas, Cape	-37	139.67
AD	231531	Brodie, C.J./868	2009	SA	Long Beach	-37	139.67
AD	231565	Brodie, C.J./873	2009	SA	Long Beach	-37	139.67
AD	231456	Brodie, C.J./619	2009	SA	Barker Knoll	-35.5	138.83
AD	231406	Brodie, C.J./615B	2009	SA	Barker Knoll	-35.5	138.83
AD	231356	Brodie, C.J./659	2009	SA	Coorong National Park	-36.33	139.67
AD	231983	Brodie, C.J./904	2009	SA	Granites, The	-36.5	139.83
AD	231986	Brodie, C.J./912	2009	SA	Coorong National Park	-36.33	139.67
AD	231273	Brodie, C.J./666	2009	SA	Piccaninnie Ponds	-38	140.83
AD	231284	Brodie, C.J./702	2009	SA	Nene Valley	-37.83	140.5
AD	231291	Brodie, C.J./685	2009	SA	Carpenter Rocks	-37.83	140.33
AD	231306	Brodie, C.J./689	2009	SA	Bucks Bay	-37.83	140.33
AD	231309	Brodie, C.J./698	2009	SA	Nene Valley	-37.83	140.33
AD	231289	Brodie, C.J./684	2009	SA	Douglas, Cape	-38	140.5
AD	231340	Brodie, C.J./715	2009	SA	Canunda National Park	-37.67	140.17
AD	231454	Brodie, C.J./714	2009	SA	Post Office Rock	-37.33	139.83
AD	231307	Brodie, C.J./709	2009	SA	Beachport	-37.33	139.83
AD	231345	Brodie, C.J./736	2009	SA	Oil Rig Square	-37.67	140.17
AD	225848	Brodie, C.J./240	2009	SA	North Haven	-34.67	138.33
AD	231386	Brodie, C.J./777B	2009	SA	Rivoli Bay	-37.5	140
AD	231538	Brodie, C.J./793	2009	SA	Little Dip Conservation Park	-37.17	139.67
AD	231549	Brodie, C.J./780	2009	SA	Nora Creina Bay	-37.17	139.83
AD	231537	Brodie, C.J./794	2009	SA	Robe	-37.17	139.67
AD	231546	Brodie, C.J./786	2009	SA	Little Dip Conservation Park	-37.17	139.67
AD	231555	Brodie, C.J./798B	2009	SA	Robe	-37	139.67
AD	231560	Brodie, C.J./797	2009	SA	Robe	-37	139.67
AD	231554	Brodie, C.J./808	2009	SA	Little Dip Conservation Park	-37.17	139.67

AD	231558	Brodie, C.J./799	2009	SA	Robe	-37	139.67
AD	231553	Brodie, C.J./804	2009	SA	Fox Beach	-37	139.67

Appendix 4. Sea wheat-grass survey 2008.

Sea-wheat grass survey 2008

A survey to collect your views on the introduced coastal grass Thinopyrum junceiforme

About me
My name is Kris James and I am a PhD candidate in Geographical & Environmental Studies at the University of Adelaide. My research focuses on the spread and potential impact of the introduced coastal grass Thinopyrum junceiforme or Sea-wheat grass (Synonyms Elymus farctus, Agropyron junceum/junceiforme).

About Sea-wheat Grass
Originally from Europe, Sea-wheat grass is a coastal coloniser of the upper beach and foredunes which has been collected in South Australia, Victoria and Tasmania. Spreading by both seed and rhizomes (Heyligers 1985, Harris and Davy 1986), Sea-wheat grass has the capacity to initiate dunes (Heyligers 2006) as well as colonising existing foredunes. It can tolerate high soil salinity and some inundation by tides (Heyligers 1985), and has been observed in situations too extreme for native dune grasses such as Austrofestuca littoralis and Spinifex sericeus (Heyligers 1985, Heyligers 2006).

The Survey
There is little information in the literature regarding Sea-wheat grass when compared with other introduced coastal plants such as Marram Grass. Consequently, I am seeking to compile knowledge of Sea-wheat grass from the wider coastal community and other interested parties, via participation in this short questionnaire.

I would like to know how many people work with or are familiar with Sea-wheat grass, and their perceptions of the plant. I believe that Sea-wheat grass largely "flies below the radar", so if potential participants are not familiar with the plant or it does not occur in their area, I encourage them to take part in the survey and let me know – this information is equally as important! All contributions will be valuable in building knowledge of Sea-wheat grass in southern Australia!

Please Note: Participation in this study is entirely voluntary, and strictly confidential. No individuals will be identified in the project report of which this survey forms part.

For further information please contact Kris James on: kris.james@adelaide.edu.au

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How to use the Survey
To move forward through the survey click on the 'next' button. To go back a page, click on the 'prev' button. When you have finished the survey click on the 'done' button. You may exit the survey at any time by clicking the 'Exit this Survey' button.

This survey is hosted by SurveyMonkey.

Sea-wheat grass survey 2008

About you

This section of the survey seeks to gather information about you for analytical purposes.

1. To which type of organisation do you belong? Please select a response by clicking on the relevant button.

- ◯ Community/Conservation/Environmental
- ◯ Government - Commonwealth
- ◯ Government - State
- ◯ Government - Local
- ◯ Industry/Private sector
- ◯ Research
- ◯ Education
- ◯ Landholder
- ◯ Student
- ◯ Individual
- ◯ Other

2. Which categories best describe your organisation's work (or your own research/work) - choose as many as applicable by clicking on the relevant boxes.

- ☐ Coastal conservation/rehabilitation/biodiversity
- ☐ Coastal maintenance/on ground works
- ☐ Coastal management/protection
- ☐ Natural Resources Management
- ☐ Weed management
- ☐ Policy/planning
- ☐ Tourism/recreation
- ☐ Cultural heritage
- ☐ Research
- ☐ other

3. If you are comfortable to do so, please provide the name of your organisation in the box below.

4. Which state do you live in? Use the drop-down menu to make your selection.

Sea-wheat grass survey 2008

Sea-wheat Grass

This section seeks to gather information about your views and opinions of Sea-wheat grass.

5. Do you know of Sea-wheat grass or have you had direct experience with Sea-wheat grass? Please select a response by clicking on the relevant button.

- ◯ I know of Sea-wheat grass
- ◯ I have had direct experience with Sea-wheat grass
- ◯ Neither of the above (Please go to question 16)

6. Does your knowledge /experience of Sea-wheat grass come from the plant growing in your state or region in which you work? Please select a response by clicking on the relevant button.

- ◯ Yes
- ◯ No (Please go to question 9)

7. If you answered 'yes' to the previous question, approximately how long has Sea-wheat grass been present in this area? Enter years in the box below - leave blank or enter 'don't know' if you are unsure.

8. How common would you estimate Sea-wheat grass is in this area? Please select a response by clicking on the relevant button.

◯ It is common/widespread ◯ It is limited in distribution ◯ Unsure

9. If Sea-wheat grass is not present in your area, please briefly explain how you have become aware of the plant. Please use the box below to type your answer.

10. In your opinion is Sea-wheat grass (Please select a response by clicking on the relevant button)

- ◯ A beneficial plant along the coast
- ◯ A problem plant along the coast (Please go to question 12)
- ◯ Neither of the above (Please go to question 13)
- ◯ Don't know (Please go to question 13)

Sea-wheat grass survey 2008

11. If you view Sea-wheat grass as a beneficial plant, please provide a brief statement as to why. Please use the box below to type your answer.

12. If you view Sea-wheat grass as a problem plant, please provide a brief statement as to why. Please use the box below to type your answer.

13. Are you aware if measures have been used to control Sea-wheat grass in your state or another area? Please select an answer by clicking on the relevant button.

- ○ Yes
- ○ No (Please go to question 15)

14. If you answered yes to the previous question, could you briefly provide details? Please use the box below to type your answer.

15. Do you believe Sea-wheat grass should undergo weed control in your state or another area? Please select a response by clicking on the relevant button.

- ○ Yes
- ○ No
- ○ Don't know

Sea-wheat grass survey 2008

Coastal Weed Management

This section seeks to briefly ascertain your perceptions on coastal weeds and coastal weed management.

16. In your opinion, what are the worst coastal weeds in your state or region in which you work? (Please list up to 4 weeds in the boxes provided below)

1.
2.
3.
4.

17. Today coastal areas may face a range of management issues, including for example, protection works, amenity and infrastructure maintenance, tourism and weed management. In your opinion, what are the most significant issues currently facing coastal areas? (Please list up to 4 issues in the boxes provided below)

1.
2.
3.
4.

18. In your opinion, what are the key policies, plans or guidelines influencing coastal weed management in your state or region in which you work (Please list up to 4 directives in the boxes provided below)

1.
2.
3.
4.

19. Any other comments you wish to make?

Thank you for completing this survey!

Appendix 5. Plant species recorded along Younghusband Peninsula during vegetation sampling. Nomenclature after State Herbarium of South Australia (2012). Common names from Bonney (2004) and Jessop and Toelken (1986). Asterisks indicate alien species.

Scientific name	**Common name**
Acacia longifolia subsp. *sophorae*	Coastal Wattle
* *Ammophila arenaria*	Marram grass
Apium protratum var *prostratum*	Sea celery
Austrofestuca littoralis	Coast fescue
Billardiera cymosa subsp. *cymosa*	Sweet apple-berry
* *Cakile maritima* subsp. *maritima*	Two-horned sea-rocket
Carpobrotus rossii	Ross's noon-flower, Angular pigface
Clematis microphylla	Small leaved clematis, Old mans beard
* *Euphorbia paralias*	Sea spurge
Exocarpos syrticola	Coast ballart, native cherry
Ficinia nodosa	Knobby club-rush
Lotus australis	Australian trefoil, austral trefoil
Leucophyta brownii	Cushion bush
Leucopogon parviflorus	Coastal bearded-heath, native currant
* *Limonium binervosum*	Dwarf sea-lavender
Nitraria billardierei	Nitre bush
Myoporum insulare	Native juniper, Common boobialla
Olearia axillaris	Coast daisy-bush
Ozothamnus turbinatus	Coast everlasting
Pelargonium australe	Austral (or native) storks bill
Pimelea serpyllifolia subsp. *serpyllifolia*	Thyme riceflower
Rhagodia candolleana subsp. *candolleana*	Seaberry saltbush
Senecio species[1]	Variable groundesel
Spinifex sericeus	Rolling spinifex, Hairy (or coastal) spinifex
Scaevola calendulacea	Dune fanflower
Scaevola crassifolia	Cushion fanflower
Stackhousia spathulata	Coast stackhousia
Tetragonia implexicoma	Bower spinach
* *Thinopyrum junceiforme*	Sand couch-grass, Sea wheat-grass
Threlkeldia diffusa	Coast bonefruit
Thistle species	-

[1] Originally identified as *Senecio lautus*

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