Dune restoration in northern Chatham Island

A trial to enhance nesting opportunities for Chatham Island oystercatchers (*Haematopus chathamensis*)

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Abstract

In northern Chatham Island, nesting opportunities for the Chatham Island oystercatcher (*Haematopus chathamensis*) are affected by ongoing modification of the dune ecosystem resulting from stock grazing and the continued spread of introduced marram (*Ammophila arenaria*) grass. Marram creates steep dunes and narrow beaches that result in oystercatchers nesting close to the high tide mark, where nests are at risk of being washed away by high seas. A long-term solution to the degradation of breeding habitat and the need for translocating nests was trialled in 2001–05 at two sites, Mairangi Creek and Tioriori, using dune restoration techniques. These techniques included control of marram and other weed species, creation of extra open space for nesting, and revegetation of foredune areas with native species. The resident pair of oystercatchers at Mairangi Creek nested successfully within the restoration site in 2002 after floods and high seas cut away the previous nesting area on the beach. The new nesting area was outside the reach of normal storm-generated waves. In subsequent years, oystercatchers at Mairangi Creek nested on a newly accumulating beach crest in front of the restoration site within the storm zone. At Tioriori, the resident pair nested progressively further inland during the restoration period. A gradual accumulation of sand ensured that the nests were relatively safe from being washed away by wind-generated waves. Although the sample size of oystercatchers in this trial was small, the results indicate that dune restoration provides more nesting habitat for shorebirds while also benefiting threatened plant communities of the Chatham Islands. This approach has application elsewhere in New Zealand dune systems.

Keywords: Chatham Islands, Chatham Island oystercatcher, *Haematopus chathamensis,* breeding habitat, marram (*Ammophila arenaria*), dune restoration.

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1. Introduction

1.1 Chatham Island dunes

The Chatham Islands are situated approximately 800 km east of mainland New Zealand (44°S 176°30′W). Much of the northern coastline of the main island—Chatham Island (Rekohu)—has sandy beaches and extensive dune systems. A study by McFadgen (1994) indicates that, historically, dunes in these areas extended much further inland than the currently active dune areas (Fig. 1), and that modern dune sands are derived from older reworked dunes, with the quantity of sand available for dune building diminishing over time as sand has become locked up in stable dunes. McFadgen (1994) identified four distinct phases of dune building during the Holocene that have given rise to the present dune systems: Te Onean Depositional Episode (c. 5000–2200 years BP), Okawan Depositional Episode (c. 2200–450 years BP), Kekerionean Depositional Episode (c. 450–150 years BP) and Waitangian Depositional Episode (c. 150 years BP to present).

Dune building periods on the Chatham Islands appear to have been unrelated to sea level change, tectonic activity or cultural influence, but may be related to coastal erosion initiated by storms (McFadgen 1994). For example, severe northeasterly storms in 1985 caused active dune erosion along all northeast- to east-facing beaches on the northern Chatham Island coast (AD, pers. obs.). The foredunes along the northern Chatham Island coast still show evidence of this erosion today, although foredunes have since begun rebuilding.

The original pre-European vegetation of the Chatham Islands dunes was low forest dominated by Chatham Island akeake (*Olearia traversiorum*[1]) and Chatham Island māpou (*Myrsine chathamica*). Prior to the arrival of Europeans, open dune areas were confined to a relatively narrow foredune where a diverse plant community of endemic shrubs, megaherbs, sand tussock (*Austrofestuca littoralis*) and the sand sedge pīngao (*Desmoschoenus spiralis*) grew. Pīngao was the most common and widespread plant of the more open dunes.

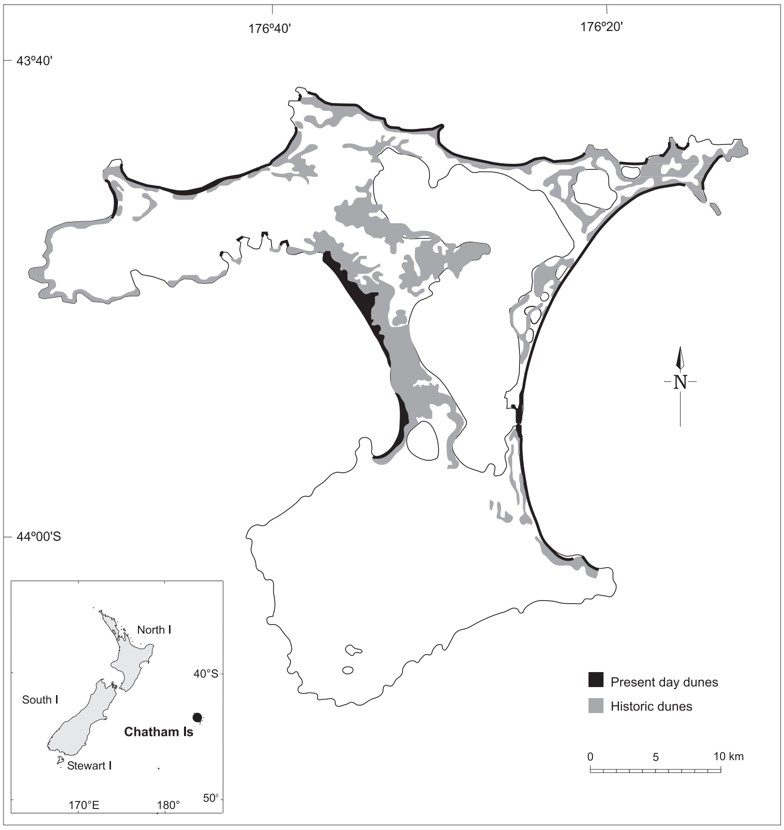

Figure 1. Probable extent of historic dunes in northern Chatham Island (based on sand-derived soils (Wright 1959) and present-day distribution of active dunes).

The original inhabitants of the Chatham Islands—Moriori—brought about only minor change to the natural vegetation of the dunes after their arrival about 500 years ago (King 1989). The dunes were key locations for settlement by Moriori, and both Moriori and Māori (who arrived in 1835) used the dunes as burial sites. European settlers brought farm stock to the islands in 1841, and farming became more widespread over the following 40 years. From the mid-1880s, more intensive grazing and clearing of forest led to a rapid change in dune vegetation and morphology.

[1] We follow the taxonomy outlined in Heenan et al. (2008).

Stock rapidly spread over the dunes, overgrazing and trampling the vegetation, destroying the forest understory and eliminating the megaherb ground cover on open dunes. This prevented the regeneration of dune forest that had previously stabilised the reardunes.

The botanist Leonard Cockayne visited the Chatham Islands in 1901. His account of this visit (Cockayne 1902) provided the earliest and most comprehensive description of the vegetation communities of the islands; although, by 1901, introduced stock had already altered the original vegetation in many places. Cockayne (1902) noted; with respect to the Chatham Islands dune system:

> … *in its primitive state it might well have received the name of Myosotidium* [Chatham Island forget-me-not, *Myosotidium hortensium*] *formation. Just above high-water mark, where the great masses of kelp accumulate, right up to the junction of the shore and dune, on to the dunes themselves, and into the open part of the Myrsine* [māpou] – *Olearia* [akeake] *scrub formerly extend great clumps and patches of this truly magnificent plant.*

However, he lamented the effects of farm animals, observing that:

> … *the long line of this plant* [forget-me-not] *on the seas-shore, with its huge shining green leaves and great heads of blue flowers, is lost to the world for ever.*

Grazing of the dune vegetation and clearance of rear dune forest significantly increased the area of open sand and the newly mobile sand dunes inundated remaining coastal forest and pasture areas. This suggests that farming may have been an important cultural influence in the Waitangian Depositional Episode over the last 150 years (c.f. McFadgen 1994). In the late 1880s, the settlers became concerned about the sand rapidly encroaching onto their farmland and began planting marram (European beach grass, *Ammophila arenaria*), a sand-binding grass introduced from Europe, to halt this process. Marram quickly spread through the Chatham Islands and by the 1950s it was widespread (Alfred 'Bunty' Preece, pers. comm.). Due to the vigorous growth of marram, and the concurrent effects of stock, much of the native vegetation on the more active dunes in the Chatham Islands was replaced with marrram. Native dune vegetation became increasingly rare, and a number of endemic dune plants became threatened with extinction. Sand tussock, once abundant, has all but disappeared from the islands because of its palatability to farm animals and competition from marram.

Figure 2. Marram (*Ammophila arenaria*)-covered foredune showing the older established dune and scarp (right) with younger incipient foredune (seaward), Mairangi Beach, Wharekauri, northern Chatham Island. *Photo: Peter Moore, 1 May 2006.*

Marram has now been present for over 100 years in the Chatham Islands, and its spread and the associated consolidation (progradation) of the dunes has continued throughout this period. The vigorous growth of marram, combined with episodes of storm erosion and sand deposition, has resulted in steep dune profiles and narrow beach frontages (Fig. 2). These narrow beaches are often swept by storm surges and high tides. The formerly extensive akeake dune forests are visible today mainly as dead and dying trees (Fig. 3). Remants of the original dune vegetation communities can be found only in a few less-disturbed areas of present-day dunes; for example, at Kaingaroa in the northeast of Chatham Island, where stock have been excluded from the dunes for over 30 years (Table 1; Davis & Moore 2001).

Figure 3. Surviving and dead remnant Chatham Island akeake (*Olearia traversiorum*) trees on dunes at Mairangi Beach, Wharekauri, northern Chatham Island. *Photo: Peter Moore, 12 February 2001.*

Table 1. Dune vegetation at Kaingaroa, illustrating one of the few natural dune vegetation sequences remaining in the Chatham Islands (Davis & Moore 2001).

DUNE POSITION	CHARACTERISTIC SPECIES
Strand (high tide mark to the start of the dunes)	Atriplex (*Atriplex billardierei*)
Foredune slope	Pīngao (*Desmoschoenus spiralis*) Chatham Island sow thistle (*Embergeria grandifolia*)
Foredune ridge top/dune crest	Pīngao (mixed with introduced marram (*Ammophila arenaria*)) Chatham Island forget-me-not (*Myosotidium hortensium*) (present in low numbers) Chatham Island sow thistle (*Embergeria grandifolia*) Chatham Island geranium (*Geranium traversii*) *Lobelia arenaria* Bidibidi (*Acaena* spp.)
Hollow behind foredune	Sand daphne (*Pimelea villosa*) Dune mingimingi (*Leucopogon* aff. *parviflorus*)* Sand coprosma (*Coprosma acerosa*) Euphorbia (*Euphorbia glauca*) Knobby clubrush (*Ficinia nodosa*) Sand wind grass (*Lachnagrostis billardierei*) Bidibidi (*Acaena* spp.)
Reardunes	Dieffenbach's hebe (*Hebe dieffenbachii*) Chatham Island corokia (*Corokia macrocarpa*) Chatham Island akeake (*Olearia traversiorum*) New Zealand spinach (*Tetragonia tetragonioides*) Pōhuehue (*Muehlenbeckia australis*) Chatham Island flax (*Phormium* aff. *tenax*) (present in dune hollows, in low numbers)
Reardunes—furthest inland	Kopi (*Corynocarpus laevigatus*) Chatham Island akeake (*Olearia traversiorum*) Chatham Island māpou (*Myrsine chathamica*) Chatham Island māhoe (*Melicytus chathamicus*) Chatham Island lancewood (*Pseudopanax chathamicus*) Kawakawa (*Macropiper excelsum*)

* We follow the usage of Miskelly (2008), based on recommended usage by Peter de Lange (Department of Conservation), for name combinations: dune mingimingi = *Leucopogon parviflorus*; Chatham Island mingimingi = *Coprosma propinqua* var. *martinii* (the latter is also known as swamp karamu).

1.2 Chatham Island oystercatcher

The Chatham Island oystercatcher (tōrea, *Haematopus chathamensis*) is an endangered species with a high risk of extinction because of its very small population (Birdlife International 2008). The species is ranked by New Zealand's Department of Conservation (DOC) as Nationally Critical, making it a high priority for conservation management (Miskelly et al. 2008).

Like other oystercatcher species, Chatham Island oystercatchers tend to nest on open ground between the high tide mark and dune vegetation. This allows the birds to easily defend their coastal feeding and breeding territories from neighbouring oystercatchers, and to see any approaching predators, to which the birds respond by temporarily leaving the nest and relying on camouflage of the eggs for their protection.

1.2.1 Problems facing Chatham Island oystercatchers

Flooding of nests, particularly by storm seas, is one of the main causes of egg loss for oystercatchers and other shorebirds around the world (Hockey 1996). For many species, for example the hooded plover (*Thinornis rubricollis*) and pied oystercatcher (*Haematopus* *longirostris*) in Australia (Park 1994), American oystercatcher (*Haematopus palliatus*) in Chile (Barrios 2004) and snowy plover (*Charadrius alexadrinus*) in Oregon, USA (Moore 2000; US Fish & Wildlife Service 2001), this has been exacerbated by introduced grasses with strong sand-binding properties that change the morphology of foredunes (e.g. Heyligers 1985) and reduce the available nesting habitat for shorebirds.

For Chatham Island oystercatchers, the areas available for nesting in front of the densely vegetated marram-covered dunes are now limited in extent and often swept by wind-generated waves and high tides (Figs 4 & 5). Some wider beaches occur in northern Chatham Island, and these can offer safer nest sites; but even wide beaches are sometimes subject to storm surges sweeping up to (Fig. 6) or over the foredunes.

The lack of safe nest sites appears to be one of the main factors limiting the population size of oystercatchers (Best 1987; Davis 1988; Aikman et al. 2001; Schmechel 2001; Schmechel & Paterson 2005; Moore 2008), along with predation of eggs and chicks by introduced predators, particularly feral cats (Moore & Reid 2009). Storm events also reduce productivity of oystercatchers, and in some years c. 40–50% of egg losses are caused by storm surges and very high tides (Moore & Reid 2009).

Figure 4. A narrow beach at the east end of Tioriori, northern Chatham Island, and the dense thicket of marram (*Ammophila arenaria*) on the dune offer limited nesting opportunities for Chatham Island oystercatchers (*Haematopus chathamensis*). Note the small alcove of cleared marram for translocation of a nest. *Photo: Rex Williams, 2001 breeding season.*

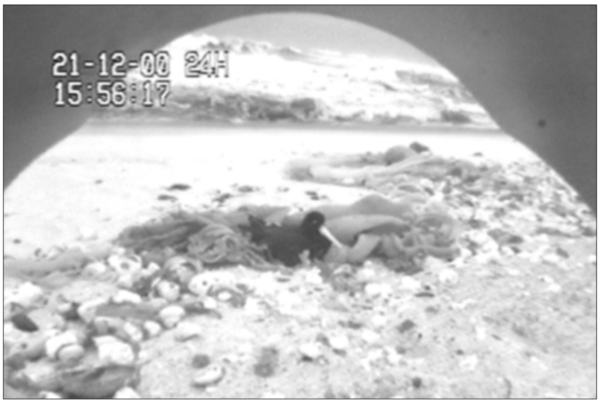

Figure 5. A Chatham Island oystercatcher (*Haematopus chathamensis*) nest amongst high tide debris about to be swept away by a wave. *Photo: Peter Moore, from time-lapse video, 21 December 2000.*

Figure 6. A Chatham Island oystercatcher (*Haematopus chathamensis*) nest (indicated by an arrow) on a wide beach at Paritu, northern Chatham Island, is vulnerable to storm surges that sweep up the gentle beach profile. *Photo: Rex Williams, 2001 breeding season.*

1.2.2 Addressing the problems

To address the problems facing Chatham Island oystercatchers, a recovery plan was developed (Aikman et al. 2001). This plan has two overarching goals:

- **10-year goal:** Improve productivity and adult survivorship to increase the total population to > 250 (mature) individuals (to change the species' IUCN conservation ranking from Endangered to Vulnerable)[2]
- **Long-term goal:** Restore the natural coastal ecology so that minimal management is required to maintain a population of > 250 (mature) individuals

10-year goal

Intensive management combining three general techniques (predator control, stock exclusion and translocation of nests to areas above the high tide mark) (Moore et al. 2001; Moore 2009) was carried out with the aim of achieving the 10-year goal by improving average productivity to 1.0 chicks per pair per year, compared with the unmanaged average of 0.37 (Moore & Reid 2009). From 1998 to 2004, two sites covering 16 km of northern Chatham Island coastline (Wharekauri and Maunganui) were managed for oystercatchers. Initially there were 16 pairs of oystercatchers nesting along the two stretches of coastline. Following the implementation of intensive management actions, increased production of juveniles and breeding recruitment contributed to a population increase of 144 to 316 birds (Moore 2008).

Long-term goal

While translocating oystercatcher nests to areas above the high tide mark and creating alcoves of cleared marram improves the breeding success of Chatham Island oystercatchers (Moore et al. 2001; Moore 2009), this requires intensive management throughout the breeding season every year and does nothing to improve nesting habitat in the long term. Restoring dunes to their natural shape and vegetation cover has shown some promise for improving nesting habitat for shorebirds in other places (e.g. US Fish & Wildlife Service 1996; Powell 1998; Powell & Collier 2000; Colwell et al. 2008; Lauten et al. 2008), and it was suggested that the longer term oystercatcher recovery goal (Aikman et al. 2001) could be achieved by restoring dunes to a more natural profile and vegetation type (Moore 2000). Native herbs and grasses tend to have a more sparse cover and form low hummocks and a gently sloping foredune. It was hypothesised that recreating this pattern would allow shorebirds such as oystercatchers to nest further inland from the high tide mark.

A trial to enhance nesting opportunities for oystercatchers by restoring native vegetation communities within dunes on northern Chatham Island was undertaken between 2001 and 2005 at two restoration sites (Mairangi Creek and Tioriori) within the two oystercatcher management areas (Wharekauri and Maunganui). Because coastal areas were populated historically by Moriori, and modern dunes contain their middens and burial sites, it was not appropriate to use mechanical methods such as bulldozing to make the dune profile changes needed. Hence, any changes could only occur as a result of changing the vegetation composition. The plan for restoration work (Davis & Moore 2001) was circulated to the Chatham Island community and imi/iwi groups for comment and approval. Once this was obtained, restoration work commenced in April 2001. In this report we describe the methods and results of this trial and make recommendations for future management of dunes in the Chatham Islands to improve the oystercatcher population status and biodiversity values of the dunes generally.

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[2] Aikman et al. (2001) refer to 'individuals' but the Chatham Island Oystercatcher Recovery Group interprets the goal as > 250 mature individuals in line with IUCN rankings (C. Miskelly, Museum of New Zealand *Te Papa Tongarewa*, pers. comm.).

2. Methods

2.1 Study areas

Two sites were chosen for dune restoration within the oystercatcher management areas of northern Chatham Island: Mairangi Creek (Wharekauri) and Tioriori (Maunganui) (Fig. 7). Each site had all, or most, of the following favourable characteristics:

- At least one breeding pair of oystercatchers occupied a territory in the area.
- The beach was narrow, and storm surges and high tides periodically washed over the nesting area into the dunes; hence, restoration would likely benefit the resident oystercatchers.
- Grazing animals were excluded.
- There was good access for restoration work.
- The sites would not require a lot of weed control, apart from marram—i.e. there were few weeds already present and a limited source of invading weeds from adjacent farmland (N.B. this was less true for Mairangi Creek).
- The sites were relatively sheltered and flat. This would reduce the likelihood of serious erosion or destabilisation and resultant wind-blown sand affecting fences and neighbouring farmland.
- Restoration of the areas was acceptable to local landowners.
- The sites were acceptable to imi/iwi as they had no, or few, cultural sites that would be affected by a change in dune morphology.

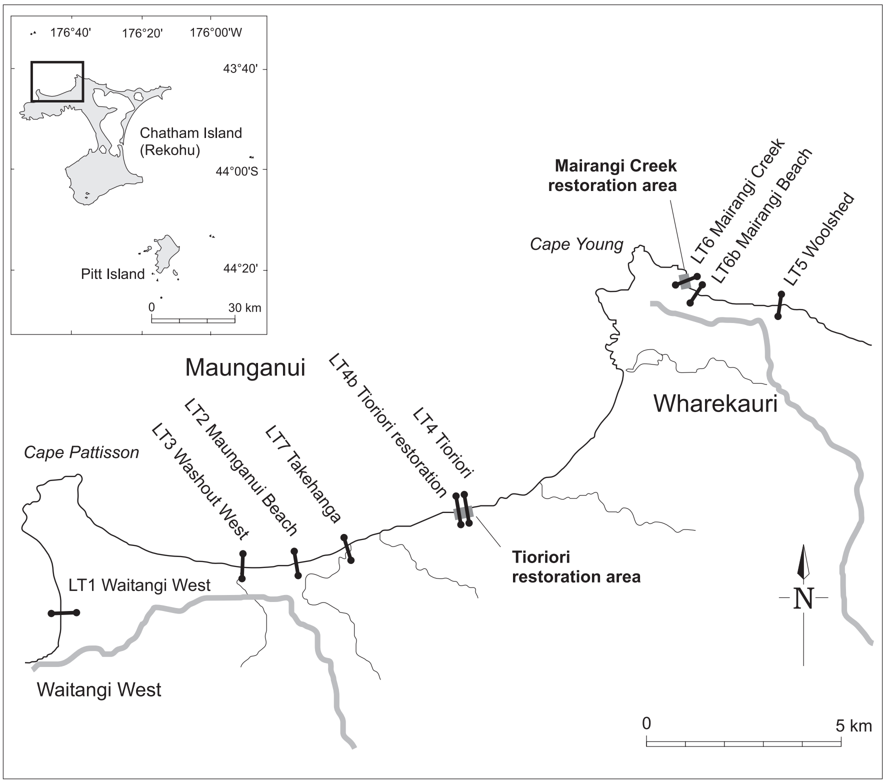


Figure 7. Location of Mairangi Creek and Tioriori restoration sites and dune profile monitoring transects, northern Chatham Island.

The Mairangi Creek restoration site (Figs 8 & 9) was a narrow (c. 30–50 m wide) dune within a Crown-owned marginal strip reserve. The inland side was separated from Wharekauri farm by a permanent stock fence. The eastern edge was a small unnamed stream referred to here as 'Mairangi Creek' because of its proximity to Mairangi Road. The northwest curve of the beach finished at a small rocky headland. The dune was low and relatively flat, probably because of erosion by the meandering stream and the partial shelter provided by the curve of the headland. The first 20 m seaward of the fence was largely vegetated by introduced pasture grasses, and the next 30 m by a thick cover of marram. An annual growth of introduced sea rocket (*Cakile edentula* var. *edentula*) built up each summer on the beach edge of the dune.

The initial 'core' restoration area at Mairangi Creek in 2001 comprised a section of dune measuring approximately 50 m × 40 m (2000 m^2, Areas 1–2 in Fig. 8; Fig. 9). A southeast extension (Area 3) approximately 30 m × 40 m (1200 m^2) and a northwest extension (Areas 4–6) 80 m × 40 m (3200 m^2) were progressively restored from 2002 (Fig. 8).

The Tioriori restoration site (Figs 10 & 11) was a narrow (c. 50 m wide) dune on private land. The inland side was separated from farmland by a permanent stock-proof fence built to protect the oystercatcher nesting area. To the west, the site was bounded by Tahatika Creek. As for the previous site, the dune was low and relatively flat, probably because of erosion by the meandering stream. The small dune had a thick cover of marram and a mix of native herbs such as bidibidi (*Acaena* spp.), shore lobelia (*Lobelia anceps*) and sand daphne (*Pimelea villosa*). A sparse cover of sand carex (*Carex pumila*) occurred in patches of more open sand near the beach front.

The initial 'core' restoration area at Tioriori in 2001 comprised a section of dune measuring approximately 50 m × 50 m (2500 m^2) (Areas 1–2 in Fig 10; Fig. 11). Western and eastern extensions comprising sections of dune measuring approximately 30 m × 35 m (1050 m^2) and 30 m × 50 m (1500 m^2), respectively, were progressively restored from 2002 (Areas 3–4 on Fig. 10).

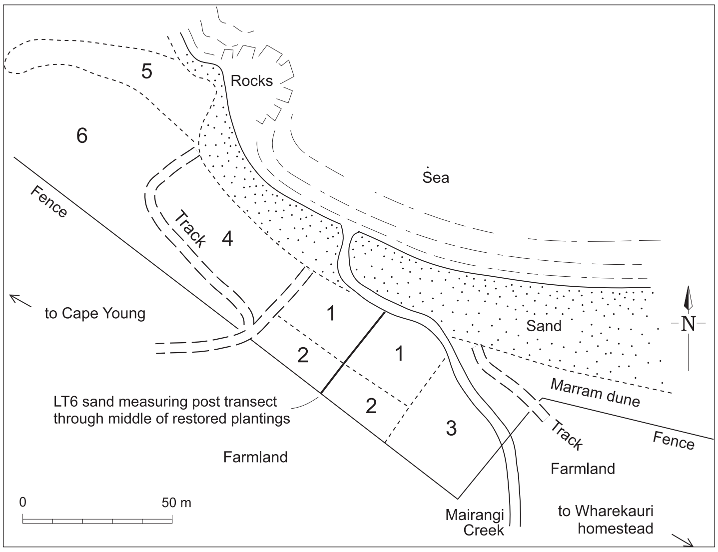


Figure 8. Diagram of Mairangi Creek restoration site, northern Chatham Island, showing numbered planting areas.

Key: Planted areas

1. Core area: pīngao (*Desmoschoenus spiralis*) and megaherbs (Chatham Island sow thistle (*Embergeria grandifolia*), Chatham Island forget-me-not (*Myosotidium hortensium*) and euphorbia (*Euphorbia glauca*)) with sand coprosma (*Coprosma acerosa*) and sand daphne (*Pimelea villosa*) on landward edge.
2. Core area: Chatham Island akeake (*Olearia traversiorum*) and Chatham Island flax (*Phormium* aff. *tenax*) in damper ground planted amongst introduced pasture grasses.
3. Extension area: Chatham Island flax in damper ground and Chatham Island akeake planted amongst introduced pasture grasses.
4. Extension area: pīngao and megaherbs (Chatham Island sow thistle, Chatham Island forget-me-not, euphorbia) with scattered Dieffenbach's hebe (*Hebe dieffenbachii*), Chatham Island corokia (*Corokia macrocarpa*), sand coprosma and sand daphne on the landward side and akeake on the seaward side of the track.
5. Extension area: pīngao and megaherbs (Chatham Island sow thistle, Chatham Island forget-me-not and euphorbia).
6. Extension area: Chatham Island akeake planted amongst introduced pasture grasses

Total planted area: 6400 m^2.

Figure 9. Mairangi Creek restoration site (Area 1, looking northwest), northern Chatham Island, before spraying and removal of marram (*Ammophila arenaria*). Sea rocket (*Cakile edentula* var. *edentula*) can be seen to the right. *Photo: Peter Moore, 28 December 2000.*

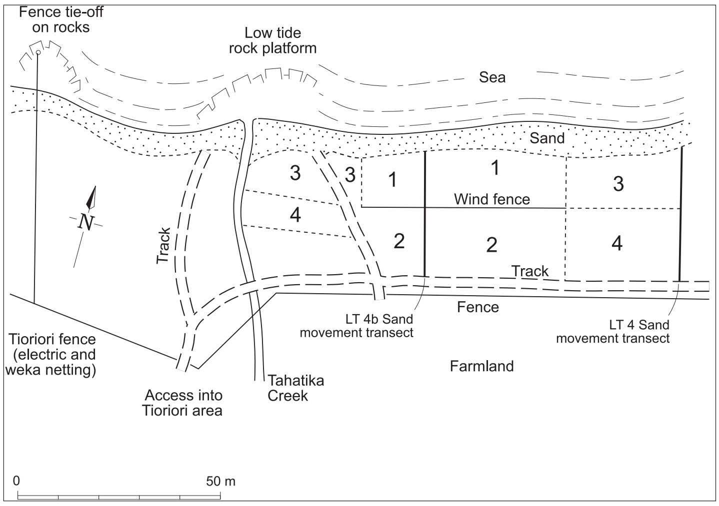


Figure 10. Diagram of Tioriori restoration site, northern Chatham Island, showing numbered planting areas.

Key: Planted areas

1. Core area: pīngao (*Desmoschoenus spiralis*) on the seaward edge, megaherbs (Chatham Island sow thistle (*Embergeria grandifolia*), Chatham Island forget-me-not (*Myosotidium hortensium*) and euphorbia (*Euphorbia glauca*)) on the landward side, and scattered sand daphne (*Pimelea villosa*) and sand coprosma (*Coprosma acerosa*) among the megaherbs.
2. Core area: Chatham Island akeake (*Olearia traversiorum*) and scattered Chatham Island corokia (*Corokia macrocarpa*) and Dieffenbach's hebe (*Hebe dieffenbachii*) on the seaward side.
3. West and east extension areas: pīngao on the seaward edge, megaherbs (Chatham Island sow thistle, Chatham Island forget-me-not and euphorbia) on the landward side.
4. Extension area: Chatham Island akeake and marram (*Ammophila arenaria*), planted amongst introduced pasture grasses.

Total planted area: 5050 m^2

Figure 11. Thicket of marram (*Ammophila arenaria*) at Tioriori restoration site, northern Chatham Island, before spraying. *Photo: Peter Moore, 29 April 2001.*

2.2 Restoration

2.2.1 Marram control and clearing ground

The initial spraying of marram occurred in autumn (April) 2001 in preparation for planting the following spring. At Mairangi Creek, where very little native vegetation was present, the dense marram growth was carpet-sprayed in Areas 1 and 2 with the general herbicide Roundup Extra® (Table 2). At Tioriori, where there were more native dune plants amongst the marram, the grass-specific herbicide Gallant® was used. The herbicides were mixed at a concentration recommended for hardy grasses such as pampas; i.e. 270 mL herbicide plus 75 mL surfactant (Pulse® for Roundup® and Uptake® for Gallant®) mixed with water for each 15 L knapsack sprayer, or 1 L herbicide plus 250 mL surfactant for each 60 L tank on an ATV (all terrain vehicle) spray unit. Coloured dye was used to show where the spray had been applied.

Table 2. Type and volume of herbicides used to control marram (*Ammophila arenaria*) and other weeds at the dune restoration sites in northern Catham Island 2001–05.

SITE	HERBICIDE TYPE	UNDILUTED VOLUME (L)
Mairangi Creek	Gallant®	8.5
Mairangi Creek	Roundup Extra®	9.5
Tioriori	Gallant®	7.0
Tioriori	Roundup Extra®	6.0

Spraying in April 2001 concentrated on the thick zones of marram in Area 1 of both sites. Within these areas, swaths approximately 50 m long by 15 m wide were sprayed. Spraying was carried out 6 months before planting was due to start (Table 3) to ensure that there was sufficient time for the marram to die. However, the thick thatch prevented the spray from reaching all the marram, so dead material was cleared with a scrub bar in September 2001 and any live marram remaining was spot-sprayed with a second application of herbicide several days before planting started in October 2001. Once marram was eliminated from the core restoration areas (particularly Area 1 at each site; Figs 8 & 10) and native dune plants were planted and established, it was possible to progressively enlarge the restoration areas. At both restoration sites, marram was sparser in the extended areas (Areas 3–6 at Mairangi Creek and 3–4 at Tioriori) and the dead thatch generally did not need clearing with a scrub bar. Where the dead marram was dense in these areas it was manually removed to open up the area for planting. Introduced pasture grass was spot-sprayed, and at the northwest extension of the Mairangi Creek restoration site, circles of grass were cleared with a scrub bar. The western and eastern extensions at Tioriori and the southeast extension at Mairangi Creek were sprayed in April 2002, and the northwest extension at Mairangi Creek was sprayed in October 2002, 6 months in advance of planting for those particular sectors of the restoration areas.

To eliminate regrowth, seedlings and invasion around the edges of the trial areas, localised spot-spraying of marram, using knap-sack sprayers, continued at both trial sites. This was carried out in both autumn and spring for the 3 years following initial spraying (2002, 2003 and 2004; Table 3). Both Roundup Extra® and Gallant® herbicides were used, but the latter was preferred within established plantings. The Mairangi Creek site had a denser and greater area of marram-covered dunes than Tioriori, and this is reflected in the volume of herbicide used (Table 2) and the time spent spraying and removing dead marram (Table 3).

Table 3. Approximate number of person hours used to restore dunes at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05. N.B. Times did not include travel time to the areas.

RESTORATION ACTIVITY	PERSON HOURS PER FIELD TRIP								TOTAL
	APRIL 2001	SEP 2001 – JAN 2002	APR 2002	OCT 2002	APR 2003	OCT–DEC 2003	APR 2004	APR 2005	
Mairangi Creek									
Spraying	24	4	20	12	12	9	3	0	**84.0**
Clearing ground		20	8	6	6	0	21	0	**61.0**
Planting		28	30	16	25	0	71	2	**172.0**
Weeding		34	3	8	8	27	0	12	**92.0**
Vegetation monitoring		4	4	6	24	24	5	29	**96.0**
Total	**24**	**86**	**65**	**48**	**75**	**60**	**100**	**43**	**505.0**
Tioriori									
Spraying	24	No data	24	12	12	14.5	3	0	**89.5**
Clearing ground		28	8	12	0	0	0	0	**48.0**
Planting		29	38	52	25	0	4	0	**148.0**
Weeding		4	1	8	0	2.5	0	0	**15.5**
Vegetation monitoring		4	4	24	24	24	11	27	**118.0**
Total	**24**	**60**	**75**	**108**	**61**	**41**	**18**	**27**	**419.0**

Figure 12. A wind fence along the dune at Tioriori restoration site, northern Chatham Island, was designed to prevent sand blowing inland once the marram (*Ammophila arenaria*) was removed. *Photo: Peter Moore, 29 April 2001.*

2.2.2 Controlling sand movement

It was anticipated that the Tioriori site might be more prone to sand movement than the Mairangi Creek site, as sand had already built up on parts of the Tioriori fence before the start of the project. To prevent wind-blown sand becoming a problem for the stock fence or adjacent farmland once the marram was removed, a wind-cloth fence was built in September 2001 along the middle of the core area between Areas 1 and 2 (Fig. 12).

2.2.3 Seed collection and propagation

Plants for revegetation were sourced from seed collected from various sites in northern Chatham Island (Appendix 1) at least 1 year before they were required for planting out. Seed was collected from Chatham Island akeake and māpou, Chatham Island corokia (*Corokia macrocarpa*), Dieffenbach's hebe (*Hebe dieffenbachii*), forget-me-not, euphorbia (*Euphorbia glauca*), Chatham Island sow thistle (*Embergeria grandifolia*), sand daphne, sand coprosma (*Coprosma acerosa*), dune mingimingi (*Leucopogon* aff. *parviflorus*), *Lobelia arenaria*, pīngao and knobby clubrush (*Ficinia nodosa*). Plants were raised in the DOC nurseries at Motukarara, Canterbury, and at Te One, Chatham Island. Akeake and pīngao were grown in root trainers, megaherbs such as sow thistle, forget-me-not and euphorbia were grown in PB3 planter bags or smaller pots, and shrubs such as corokia, sand daphne, sand coprosma and hebe were grown in smaller pots.

Figure 13. Amanda Baird planting pīngao (*Desmoschoenus spiralis*) at Tioriori restoration site, northern Chatham Island. *Photo: Peter Moore, 19 September 2001.*

2.2.4 Planting

Planting was carried out in either autumn (April/May) or spring (September/October) (Fig. 13). In total, 5479 akeake, 696 shrubs, 798 megaherbs and 2714 pīngao from nursery-raised stock were planted at both restoration sites (Appendix 2). Planting was progressive, initially concentrating on the core areas, then moving out to the extended areas. The progressive sequence of planting is indicated by the area numbers (Areas 1–6) and the key in Figs 8 and 10, and the spread of planting activities through the study is shown in Table 3 and Appendix 3. While most plants were planted in new areas, some were used to replace those that had died (Appendix 3). In addition to nursery-raised seedlings, Chatham Island flax, atriplex (*Atriplex billardierei*), knobby clubrush, *Carex virgata* and New Zealand spinach (*Tetragonia tetragonioides*) were transplanted into the study areas from the wild, and seeds of akeake, sow thistle, forget-me-not, euphorbia, knobby clubrush and *Lobelia arenaria* were sowed directly into the sand in several small plots at the two study sites. At both sites, the toe of the foredune was not planted or only sparsely planted to provide areas for oystercatchers to nest inland from the high tide mark and the reach of storm surges. Kelp and driftwood were spread about these areas to provide microhabitat features to attract the birds and provide shelter for their nests.

The pattern of planting at the sites emulated a natural vegetation succession, although the area available was constrained by the proximity of the fence to the shoreline. Flax was planted along the boundary fence to create a dense barrier to any inland movement of sand and provide some shelter for akeake plantings. Wetter areas of the Mairangi Creek site were also planted with flax.

Native plants including *Lobelia arenaria,* sand daphne and sand carex were already present at Tioriori. Once marram was removed, these plants had an opportunity to spread. A small number of atriplex plants were planted at the strand line in front of the foredune at Tioriori. Pīngao was planted on the seaward edge of the active foredune. A megaherb zone of sow thistle and forget-me-not was planted inland of the pīngao, followed by a zone of euphorbia. Pīngao was planted at a density of c. 0.6 plants/m^2. The megaherbs were planted about 1 m apart (1 plant/ m^2) in clusters, with 5–6 plants per cluster, and clusters were c. 3–4 m apart. Small numbers of Dieffenbach's speargrass (*Aciphylla dieffenbachii*) were planted at both sites, as the species may have been present in the past. Knobby clubrush, *Carex virgata* and New Zealand spinach were planted at Mairangi Creek within the megaherb zone. A shrub zone comprising sand coprosma and sand daphne backed by corokia and hebe was planted between the active front slope and the back of the foredune, which was more stable. Shrubs were planted in groups of 3–5 plants at a density of 0.5–1.0 plants/m^2, or in a narrow band between the megaherbs and trees. The back of the foredune was planted with akeake 0.7 m apart (1.4 plants/m^2). Because of the high survival of akeake in these areas, lower density planting, 1 m apart (1 plant/m^2), was used in the extension zones.

2.2.5 Fertiliser use

Approximately 75 kg (3 × 25 kg bags) of Magamp® slow-release fertiliser was used at Mairangi Creek and Tioriori to fertilise all plants at the time of planting. The pīngao and megaherb plantings were fertilised with an additional 40 kg bag of urea fertiliser (20 kg at each site) during the other subsequent planting periods (Table 3). Dead marram and other grasses were used to mulch around the trees and shrubs at the time of planting to improve moisture retention and provide shelter.

2.2.6 Controlling other weeds and releasing plantings

The removal of marram from the trial sites, particularly at Mairangi Creek, opened up the areas to invasion by broadleaf weeds, introduced grasses and thistles from the adjacent farmland. In the spring following marram removal, weeds had to be cleared from around new plantings until the native plants became established. This required hand-weeding or spraying of larger infestations with Gallant® or Roundup Extra® to prevent seed set from these invasive weeds. Weed control was carried out sporadically, as required, until the completion of the trial in 2005, with most effort occurring in the first 2 years and focused on the more open ground in the pīngao and megaherb planting areas.

From 2002 to 2004 in late summer at Mairangi Creek, sea rocket was cleared by hand from the beach to limit the number of plants maturing to seeding stage. Later in the project, hand pulling was supplemented by spraying of both live and pulled plants with Roundup Extra®. Small quantities of sea rocket at Tioriori were hand pulled.

In addition to weed control, repairs to fences and gates, and liaison with the landowners were required at both restoration sites to limit the number of stock incursions.

2.2.7 Monitoring plant survival and growth

The survival and growth of the plants at Mairangi Creek and Tioriori were monitored for 5 years from the start of planting in spring 2001 until autumn 2005. The date, number and average size of plant species was recorded, and their survival and growth rate was measured every 6 months from April 2002 to May 2004, and 12 months later in April 2005. Maximum height and breadth of plants were measured in situ (i.e. the leaves were not extended or spread out). Because of an oversight, plants were not measured when they were planted out. Therfore, a surrogate measurement was used based on typical size of seedlings at the Chatham Island nursery. Autumn measurements were taken in April (except May 2004). Spring measurements were taken either in September or October.

During the trial, the methodology for recording plant survival and growth changed. For the first 18 months of monitoring (October 2001 to April 2003), survivorship within the core area (Areas 1 and 2) at both sites was determined by a total count of all species as numbers of plants were relatively small. To obtain growth rates, measurements were made from a representative range of plants within an area, the sample size varying between 5 and 30 depending on the number of individuals of a species planted. However, these methods proved unreliable, as grass growth obscured many plants and the number of plants had increased substantially.

Therefore, from April to September 2003, quadrats were established to record survival of akeake and pīngao. Three 9 m^2 quadrats were established in pīngao at both sites, and four 25 m^2 quadrats were established in akeake at Mairangi Creek and three at Tioriori. Individual plants of less-numerous species were counted. Euphorbia at Tioriori grew into continuous patches, and as individual plants could not be distinguished, the total area occupied was measured. Samples of individual pīngao, akeake and other species were marked with metal tags to record growth rates. Tags were relocated using a metal detector, but this method was not 100% reliable, as some tags were obscured by grass, the growth of plants themselves and, in the pīngao zones, accumulation of sand that buried the tags. Sample sizes varied from 20 to 40 individuals measured per planting area for species planted in large numbers and 5 to 15 for species with lower numbers (e.g. sand coprosma and sand daphne). Growth measurements included the in situ height and breadth of each plant. As the trial progressed and more areas and species were planted, the monitored sample size was increased. Survival and growth rates were determined by combining all the measurements taken over the full period of the trial.

2.2.8 Resources needed for dune restoration

The amount of effort used to restore the trial areas was estimated (Table 3). This estimate did not include background field work before the study (Davis & Moore 2001) or collection of seeds and propagation of plants in the nurseries. In total, 505 person hours were spent on restoring the Mairangi Creek site and 419 hours at Tioriori (Table 3). The largest proportion of time was spent on planting activities. The main difference between the two sites was that Mairangi Creek required more weeding to control infestations of pasture weeds and sea rocket.

2.3 Dune profile monitoring

To gain an understanding of the direction, rate and quantity of sand movement on the northern Chatham Island dunes, nine marked transects were established in foredunes. Two transects were established in the dune restoration sites to determine whether replacement of marram with native vegetation would change the shape of the dune or create more space for oystercatcher nesting.

Transects were selected to represent a range of dune profile types along the northern beaches at Wharekauri, Maunganui and Waitangi West. Permission to establish line transects on private land was obtained from landowners. Transects extended from the strand line (above high tide mark) inland to the end of the active foredune (usually at a fenceline where it abutted the farmland or reached a dune hollow or meandering stream). They were marked with 1.5 m-long wooden stakes (hammered into the sand to a depth of about 0.9–1.0 m) at the boundary of each significant change in dune slope. This meant placing a stake on a dune crest, then the next stake at the base of the dune hollow, then on the next dune crest, and so on. The stakes were numbered sequentially using an indelible black marker pen. A baseline profile for each transect (including the beach in front of the marker stakes) was measured with a surveyor's dumpy level in February 2001. The profile of the beach in front of each transect was re-surveyed in April 2003 or May 2004. The height of each stake was measured regularly to determine whether erosion or accumulation of sand had occurred along the transect. Measurements were taken three times per summer for 3 years (September, December, February or April; 2000–03), twice for 1 year (December 2003 and May 2004) then annually for 2 years (April 2005, 2006).

Stakes were pulled up or replaced if they were close to being buried by accumulating sand, so that about 1 m of the stake was again protruding above the sand surface. Similarly, if stakes became dislodged or broken by people, vehicles, stock or erosion, they were replaced as close as possible to their original position and depth. Stakes that were washed away were not replaced. These events were noted on the recording sheet, so that sand accumulation figures could be adjusted accordingly. Photopoints were established at the front of each transect and a set of photographs repeated on each measurement date.

2.4 Oystercatcher nests

The position of oystercatcher nests on the beach profile in relation to the high tide mark was measured using a surveyor's dumpy level on 14–15 February 2001 and 3–5 January 2002. Thirty-one nests were surveyed at a variety of beaches in northern Chatham Island, including 21 at the restoration sites and other parts of the oystercatcher management areas at Wharekauri and Maunganui (section 1.2.2), and 10 nests at other areas (Paritu, Ohira Bay, Whangamoe Point, Waitangi West and Matarakau) (Moore 2009). The high tide level in February 2001 was close to mean high water springs (MHWS, calculated for Waitangi, Chatham Island, from data in the New Zealand nautical almanac, 2001, 2002–03). The high tides in January 2002 were 0.146 m higher than MHWS, and that figure was used as an offset to estimate nest positions on the beach profile in relation to MHWS. Positions of nests during two breeding seasons (2000 and 2001) at the dune restoration sites were measured by the above survey (N.B. except when calendar months are used, the year refers to oystercatcher breeding season, e.g. 2000 refers to the 2000–01 breeding season). For four other seasons (1999, 2002–04), nest positions were estimated by pacing metres in relation to the high tide mark, the nearest dune vegetation and the proximity to the dune profile transect posts. Some nests were moved away from high tide, as part of nest management to protect them from storm seas (Moore 2009)—the original positions of these nests, relative to their final positions, were estimated based on the cumulative number of metres they were moved during the breeding season. Photographs of nest positions were also taken.

3. Results

3.1 Effectiveness of marram removal and weed control

The general herbicide Roundup Extra® and the grass-specific herbicide Gallant® appeared to be equally effective at killing marram. Blanket spraying of the core area at each site in April 2001 resulted in the death of more than 95% of the existing marram, and because Gallant® was used at Tioriori, a number of existing native plant species there survived and spread. Clearing the dead marram with a scrub bar opened up the ground for planting and made any live marram more visible so that it could be spot-sprayed before planting commenced in October 2001. The ground was not cleared in the extension areas that were subsequently sprayed. This made the initial control of marram regrowth in the extension areas more difficult, as live growth was hidden amongst the dead marram tussocks. Similarly, where pasture grass was spot sprayed or a planting circle was cleared with a scrub bar, plants were more quickly smothered by grass regrowth than in areas that had been completely sprayed and cleared before planting. Nevertheless, ongoing spraying of marram, hand weeding and releasing of seedlings generally allowed the new plants to grow above their competitors. Gallant® was the preferred herbicide for use during the control period, as it was less likely to harm to the established plantings. However, it was also possible to use Roundup® in calm conditions when the weeds being controlled were a safe distance away from the native plants (N.B. great care is required to prevent spray from drifting onto sensitive plants).

Marram vigorously recolonised the restored areas at the study sites, and seedlings appeared on the beach/foredune interface, presumably growing from a combination of rhizome fragments left in the sand or seed dispersal from nearby unrestored dunes.

The Mairangi Creek restoration site was far weedier than Tioriori, and broadleaf weeds, introduced grasses and thistles invaded from the adjacent farmland. Sea rocket invaded the area from plants that first took hold and seeded on the beach/foredune interface. Weed competition and smothering by grasses undoubtedly slowed the growth and affected the survival of the native plants at Mairangi Creek; knobby clubrush, *Carex virgata*, megaherbs, and small shrubs such as sand daphne and sand coprosma were particularly affected by this. Periodic hand pulling and spraying of introduced grass was required at both trial sites until the native plants became well established.

At the start of the trial, sea rocket was a major weed problem at the front of the dune at Mairangi Creek but was largely absent at Tioriori. This species is dispersed laterally along the coast by wave action, but also sets copious amounts of seed that germinate locally. Sporadic hand pulling efforts at Mairangi Creek in late summer 2002–04 were not sufficient to eliminate it from the area. One problem with this weed was that its seedpods continued to mature after the plants were pulled and piled up. Spraying the piles of pulled weeds combined with more frequent hand pulling greatly reduced the quantity of sea rocket present in the area in 2005. Smaller numbers of sea rocket plants had established at Tioriori by spring 2003, and these were hand pulled. By 2005, only a few plants were present at Tioriori.

3.2 Plant survival and growth

Plant survival and growth varied widely between species and sites (Table 4; Appendices 4 & 5). Generally, plant survival was lower at Mairangi Creek than at Tioriori because of erosion of the front slope of the dune at Mairangi, caused by the combined effects of stream floods and high seas, wet conditions in winter (especially 2002), invasion of introduced pasture grasses and weeds, and incursions by sheep that grazed the plants.

Sheep browsed Mairangi Creek at least three times for periods of up to a week before they were removed. All species and most individual plants recovered from this browsing. Where the megaherbs had been browsed heavily, herbaceous weeds (including sea rocket) invaded the more open ground and worsened the existing weed problem. Cattle got into the Tioriori site at least twice, but were quickly removed. These incursions resulted in only minor browse on akeake and a small number of plants knocked over.

The following text describes the survival of different species in approximate order of dune succession sequence from beach to forest.

Table 4. Survival of plantings at the Mairangi Creek and Tioriori restoration sites 2001–05.

SPECIES	MAIRANGI CREEK		TIORIORI	
	PERCENTAGE SURVIVAL OF PLANTS	NUMBER OF PLANTS SURVIVING	PERCENTAGE SURVIVAL OF PLANTS	NUMBER OF PLANTS SURVIVING
Atriplex (*Atriplex billardierei*) transplants	Not planted	–	0.0	0
Pīngao (*Desmoschoenus spiralis*)	30.6	262	100.0	1984
Dieffenbach's speargrass (*Aciphylla dieffenbachii*)	80.0	4	83.3	10
Carex virgata transplants	0.0	0	Not planted	–
Knobby clubrush (*Ficinia nodosa*) transplants	0.0	0	Not planted	–
Chatham Island forget-me-not (*Myosotidium hortensium*)	55.1	103	100.0	62
Chatham Island sow thistle (*Embergeria grandifolia*)	23.5	42	53.6	37
Euphorbia (*Euphorbia glauca*)	8.7	24	100.0	83
Sand coprosma (*Coprosma acerosa*)	3.8	3	100.0	42
Sand coprosma cuttings	0.0	0	0.0	0
Sand daphne (*Pimelea villosa*)	6.7	6	No data	No data
Sand daphne cuttings	0.0	0	0.0	0
Chatham Island corokia (*Corokia macrocarpa*)	16.7	34	91.7	165
Dieffenbach's hebe (*Hebe dieffenbachii*)	57.4	27	100.0	20
Chatham Island akeake (*Olearia traversiorum*)	61.9	1724	64.1	1733
Chatham Island flax transplants (*Phormium* aff. *tenax*)	72.1	316	49.4	84

3.2.1 Atriplex

The transplanted atriplex at Tioriori did not survive, for unknown reasons, although small numbers of self-introduced individuals were noted during the study.

3.2.2 Pīngao

Pīngao grew well at both restoration sites. However, less than a third of plants survived at Mairangi, where flooding of the stream and storm waves in winter severely eroded the foredune, cutting away most of the pīngao zone. Some plants also died when introduced pasture grasses and weeds overcrowded the pīngao and consolidated the sand.

Pīngao plants were initially taller than they were wide (Figs 14–16). After 6 months, most plants showed little gain in height, but larger gains in breadth, usually because one or more runners had grown out from the original plant (Figs 17 & 18). In the core area at Mairangi Creek, individual pīngao plants grew rapidly in breadth in their first and second years (to 1.5 m wide), after which their expansion levelled off. Pīngao planted in the northwest extension at Mairangi grew more slowly (Fig. 14; Appendix 5). Mature plants fruited and produced seed. Conditions at Tioriori remained suitable for pīngao throughout the study, as shown by the survival of all plants, although plants did not gain significant breadth until the third year after planting (Fig. 15; Appendix 5). Sand accumulated around the plants, but very few weeds or other competitors entered the site. Native sand carex spread over bare sand in front of and through the pīngao zone, but this had little effect on pīngao, as the carex leaves were short and sparse in cover, and the growth was seasonal, dying back over winter.

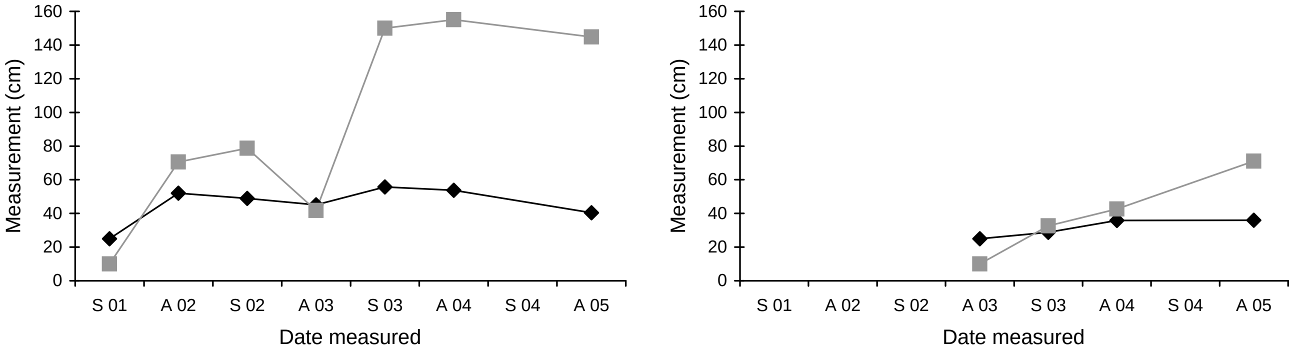


Figure 14. Mean dimensions and growth of pīngao (*Desmoschoenus spiralis*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek dune restoration site, northern Chatham Island; Core Area 1 (left) was planted in 2001 and northwest Extension Area 4 (right) was planted in 2003. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement of each series was an estimate based on nursery stock sizes.)

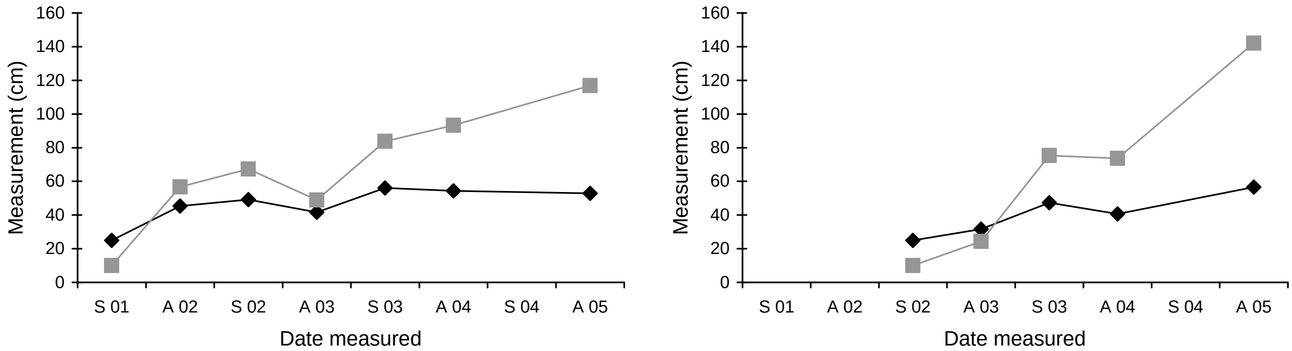


Figure 15. Mean dimensions and growth of pīngao (*Desmoschoenus spiralis*) measured at approximately six-month intervals in spring (S) and autumn (A) at Tioriori dune restoration site, northern Chatham Island; Core Areas 1 (left) were planted in 2001 and Extension Areas 3 (right) were planted in 2002. Black diamonds represent height in centimetres, grey squares represent breadth.

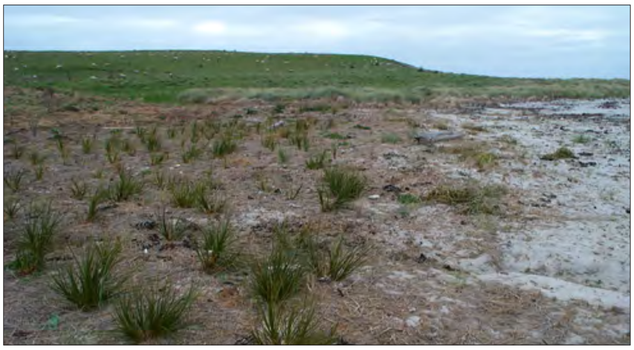


Figure 16. Seven-month old pīngao (*Desmoschoenus spiralis*) at Mairangi Creek restoration site, northern Chatham Island. *Photo: Peter Moore, 20 April 2002.*

Figure 17. Pīngao (*Desmoschoenus spiralis*) and Chatham Island forget-me-not (*Myosotidium hortensium*) at Mairangi Creek restoration site, northern Chatham Island. *Photo: Peter Moore, 1 May 2004.*

Figure 18. Pīngao (*Desmoschoenus spiralis*) runners at the eastern extension of the Tioriori restoration site, northern Chatham Island, 2.5 years after planting. *Photo: Peter Moore, 17 April 2005.*

3.2.3 Other sedges

Carex virgata and knobby clubrush transplanted to Mairangi Creek did not survive, possibly because of encroachment of grasses.

3.2.4 Dieffenbach's speargrass

Speargrass plants had high survival rates at both sites, although only a small number of them were planted (Appendices 3 & 4).

3.2.5 Chatham Island forget-me-not

Only half of the forget-me-nots planted at Mairangi Creek survived (Table 4) because of stock grazing, encroachment of grasses (Fig. 19) and erosion of the foredune; however, a follow-up visit in 2007 showed the species had recovered and was rapidly expanding in numbers (AD, pers. obs.). In contrast, all forget-me-nots survived at Tioriori (Table 4).

Figure 19. Chatham Island akeake (*Olearia traversiorum*) and Chatham Island forget-me-not (*Myosotidium hortensium*) growing amongst pasture grasses and weeds at Mairangi Creek restoration site, northern Chatham Island. *Photo: Peter Moore, 14 April 2005.*

Overall, forget-me-nots at Mairangi Creek increased in average breadth and tuberous root mass, but average height decreased (Fig. 20). Size fluctuation related to the large growth spurt the plants experienced before flowering in spring, which was followed by a die back in winter. The high moisture levels and seaweed washed up at Mairangi Creek appeared favourable for growth of forget-me-nots, and plants became luxuriant and fruited copiously (Fig. 21). However, many of these plants were lost during erosion of the foredune. The plants in the northwest extension at Mairangi Creek showed a more steady increase in size (Fig. 20; Appendix 5), as did the monitored plants at Tioriori (Fig. 22).

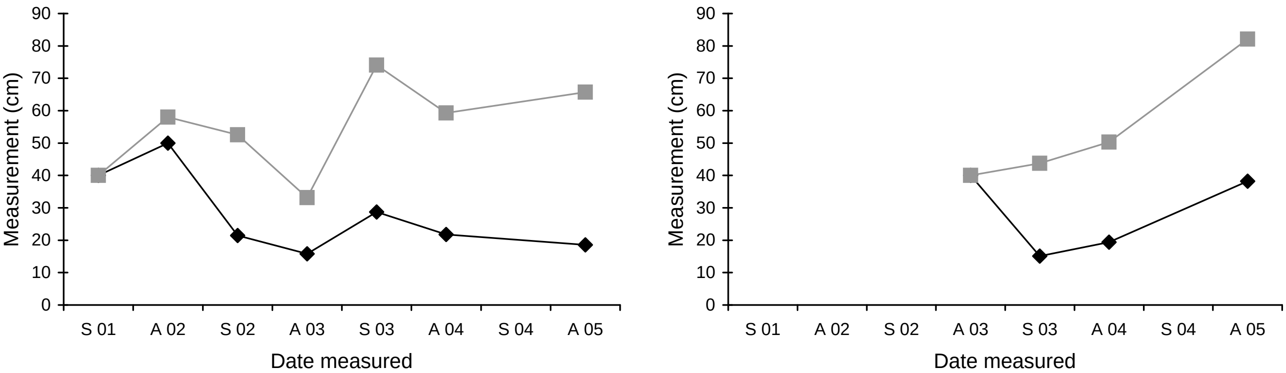


Figure 20. Mean dimensions and growth of Chatham Island forget-me-not (*Myosotidium hortensium*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek restoration site, northern Chatham Island; Core Area 1 (left) was planted in 2001 and northwest Extension Area 4 (right) was planted in 2003. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

Figure 21. Two-year-old Chatham Island forget-me-not (*Myosotidium hortensium*) at Mairangi Creek restoration site, northern Chatham Island. *Photo: Peter Moore, December 2003.*

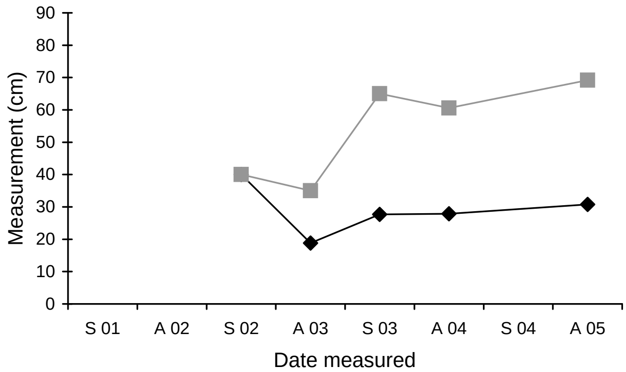


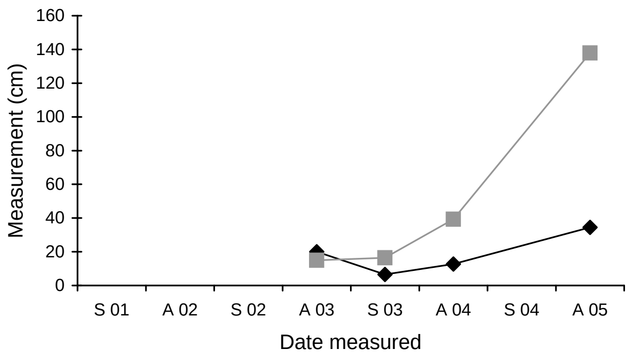
Figure 22. Dimensions and growth of Chatham Island forget-me-not (*Myosotidium hortensium*) measured at approximately six-month intervals in spring (S) and autumn (A) at Tioriori restoration site, northern Chatham Island; Core Area 1 was planted in 2002. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

3.2.6 Chatham Island sow thistle

Survival of sow thistle was low at Mairangi Creek because of stock grazing, weed encroachment and erosion of the foredune (Table 4). However, recovery was noted in a follow-up visit in 2007 (AD, pers. obs.). Although the situation was better at Tioriori, half the plants there died for unknown reasons (Table 4).

Growth data for sow thistle were only available from Mairangi Creek, as it was not planted at Tioriori until the last year of the trial. Sow thistle plants were initially slow to grow, but after 12 months accelerated greatly in breadth (Fig. 23). Sow thistles do not die down to the same extent as forget-me-nots, but the plants' large tuberous roots enable them to recover quickly if damaged by storm waves, wind or stock browsing. During one sheep incursion at Mairangi Creek, sow thistles were browsed down to ground level.

Figure 23. Mean dimensions and growth of Chatham Island sow thistle (*Embergeria grandifolia*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek restoration site, northern Chatham Island. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)



3.2.7 Euphorbia

Euphorbia plants did very poorly at Mairangi Creek, with only 9% of them surviving, probably because of intermittent stock grazing, wet conditions in winter and storm seas washing into the dunes. In contrast, there was remarkably high survival of euphorbia plants at Tioriori (Table 4).

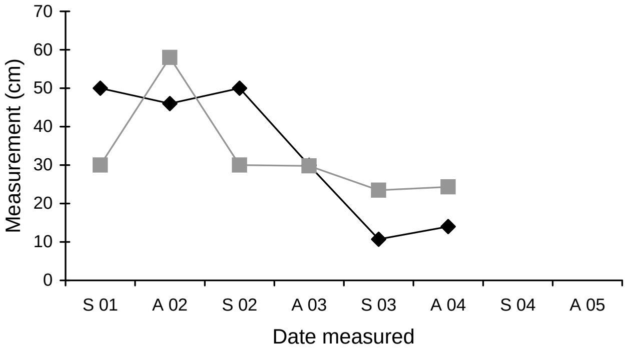
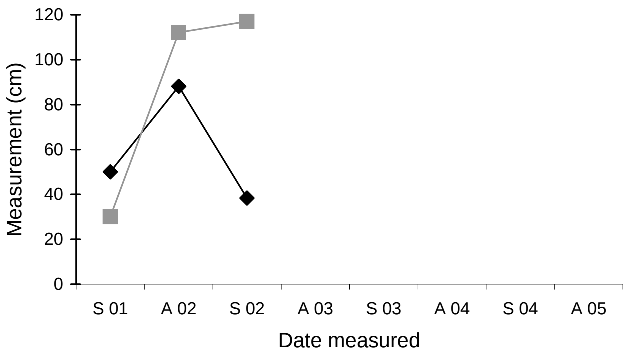


Figure 24. Mean dimensions and growth of euphorbia (*Euphorbia glauca*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek restoration site, northern Chatham Island; Core Area 1 was planted in 2001. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

Euphorbia plants at Mairangi Creek declined in size during the study, particularly in height (Fig. 24). In contrast, euphorbia at Tioriori showed a rapid expansion in breadth, sending out runners that took root and soon formed a continous cover (Figs 25–27). The apparent decline in breadth at the monitored sites (Fig. 25) was due to difficulties in measuring and identifying individual plants as they spread out. Hence, plants in the core area at Tiorori were not measured after April 2003. By 2005, the area occupied by euphorbia at Tioriori was 313 m^2.



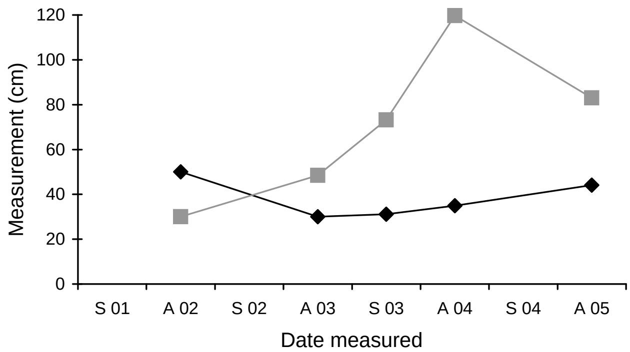


Figure 25. Mean dimensions and growth rates of euphorbia (*Euphorbia glauca*) measured at approximately six-month intervals in spring (S) and autumn (A) at Tioriori restoration site, northern Chatham Island; Core Area 1 (left) was planted in 2001 and Combined Areas (right) were planted in 2002. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

Figure 26. Cleared ground and recently planted euphorbia (*Euphorbia glauca*) at Tioriori restoration site, northern Chatham Island. *Photo: Peter Moore, 20 September 2001.*

Figure 27. A carpet of euphorbia (*Euphorbia glauca*), 3.5 years after planting, between the pīngao (*Desmoschoenus spiralis*) (right foreground) and Chatham Island akeake (*Olearia traversiorum*) (background) at Tioriori restoration site, northern Chatham Island. *Photo: Peter Moore, 18 April 2005.*

3.2.8 Chatham Island corokia

Only 17% of monitored corokia plants survived at Mairangi Creek (Table 4) and the surviving plants remained small (Fig. 28). The plants tended to be heavily grazed during the occasional stock incursions and sea swells also washed into the shrub zone. In contrast, almost all plants survived at Tioriori (Table 4) and there was slow but steady growth after the first 6 months (Fig. 28).

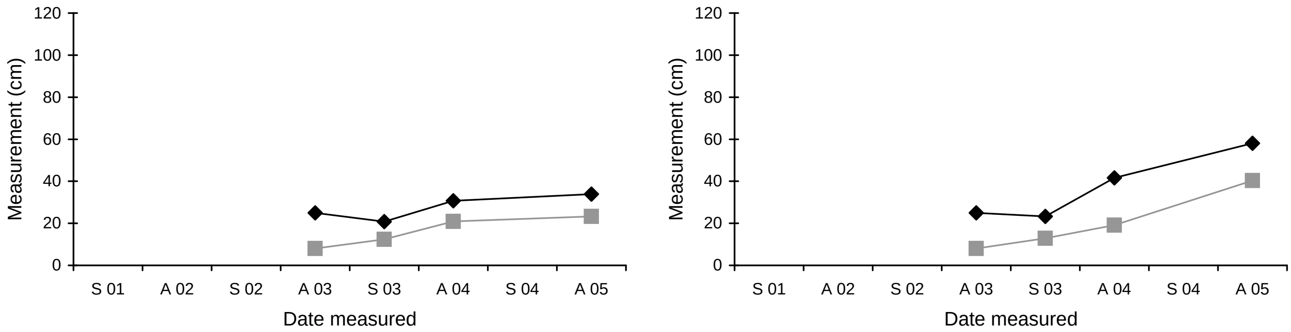


Figure 28. Mean dimensions and growth of Chatham Island corokia (*Corokia macrocarpa*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek (left) and Tioriori (right) restoration sites, northern Chatham Island. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

3.2.9 Dieffenbach's hebe

Nearly half of the hebes died at Mairangi Creek, probably for the same reasons that affected corokia. Hebes were heavily browsed during one sheep incursion at Mairangi Creek. They were the slowest of the browsed species to recover, and several plants died directly from browsing. Ironically, the plants that did survive had grown quite large by 1 year of age (Fig. 29; Appendix 5). The more benign conditions at Tioriori allowed all individuals to survive the trial (Table 4), yet they did not grow as large as the Mairangi Creek plants (Fig. 29).

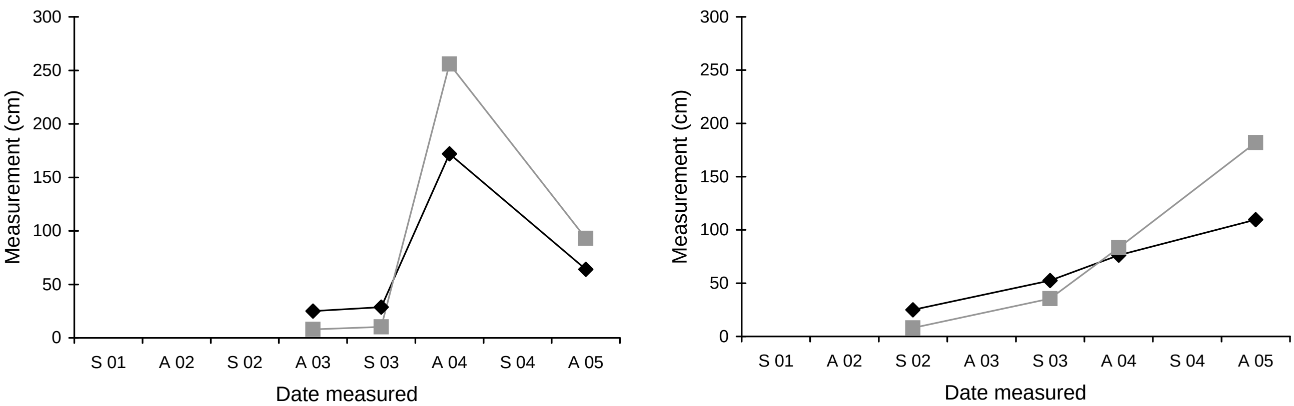


Figure 29. Mean dimensions and growth of Dieffenbach's hebe (*Hebe dieffenbachii*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek (left) and Tioriori (right) restoration sites, northern Chatham Island. Black diamonds represent height, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

3.2.10 Sand coprosma and sand daphne

Sand coprosma and sand daphne also had very low survival rates at Mairangi Creek (Table 4), probably because of smothering by invading pasture grasses. Survival of sand daphne was not recorded at Tioriori because of the rapid expansion of self-established as well as the planted individuals, but it appeared to be high. Sand daphne plants showed rapid growth at Tioriori in their second year, whereas Mairangi plants remained small (Fig. 30). Sand coprosma also grew steadily at Tioriori, particularly in breadth (Fig. 31). Growth of sand coprosma at Mairangi Creek was not measured due to the difficulty of finding surviving plants. Some cuttings from wild sand coprosma and sand daphne were planted directly into the sand at both restoration sites, but none survived.

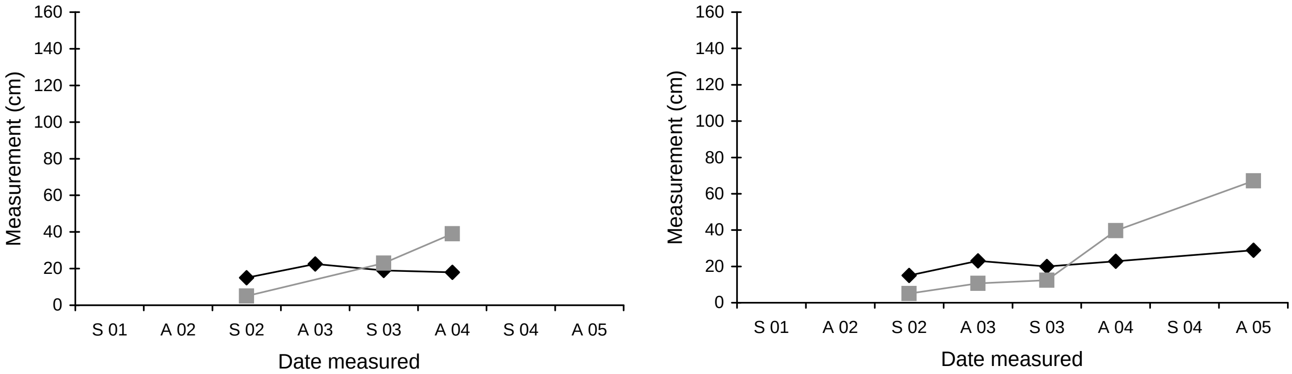


Figure 30. Mean dimensions and growth of sand daphne (*Pimelea villosa*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek (above) and Tioriori (below) restoration sites, northern Chatham Island. Black diamonds represent height, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

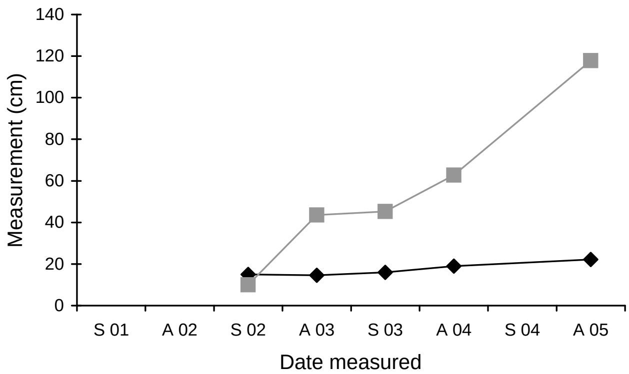
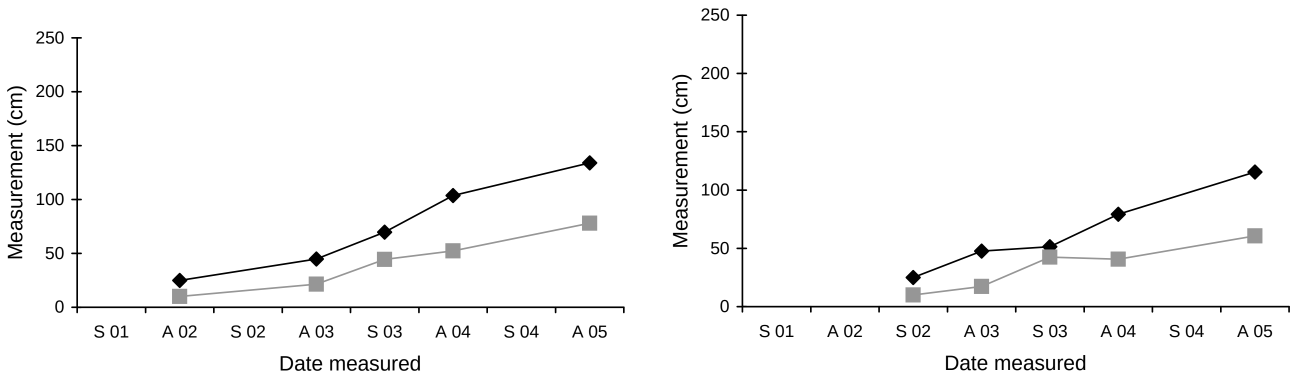


Figure 31. Mean dimensions and growth of sand coprosma (*Coprosma acerosa*) measured at approximately six-month intervals in spring (S) and autumn (A) at Tioriori restoration site, northern Chatham Island. Black diamonds represent height, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

3.2.11 Chatham Island akeake

Akeake survivorship was similar at the two sites, with over 60% of plants surviving after 4 years (Table 4). Losses at Mairangi Creek were mostly attributable to wet conditions in winter 2002 that caused some of the plantings to be flooded, smothering by pasture grasses and browsing during stock incursions. At Tioriori, smothering by grasses was probably the main cause of losses.

Akeake trees grew steadily throughout the trial, but their growth accelerated after the first year of establishment, with plants nearly doubling in height annually (Figs 32–33). Damp conditions at Mairangi and smothering by grass inhibited growth of akeake so that plants had reached only c. 1–1.3 m height by 2–3 years of age (Fig. 32; Appendix 5). At the core area of Tioriori, where akeake were planted at high density, growth was spectacular and the trees formed a continuous canopy within 2 years (Figs 34–36). By 18 months after planting, the plants were about 1 m high and by 3 years of age they were 2.5 m high and almost 1 m in breadth. The lower density plantings at the extension areas at Tioriori grew more slowly and were 1.5 m tall by 2.5 years of age (Appendix 5).



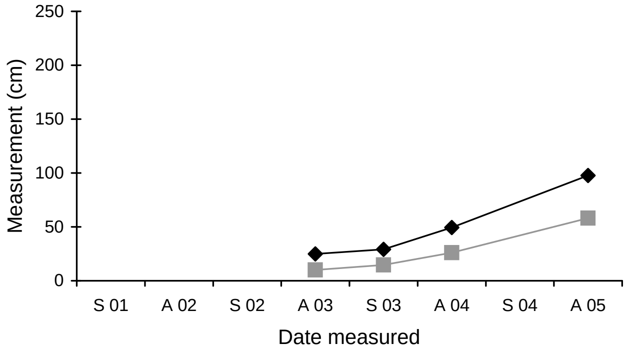


Figure 32. Mean dimensions and growth of Chatham Island akeake (*Olearia traversiorum*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek restoration site, northern Chatham Island; Core Area 2 (top left) and southeast Extension Area 3 (top right) were planted in 2002, and northwest Extension Area 4 (bottom left) was planted in 2003. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

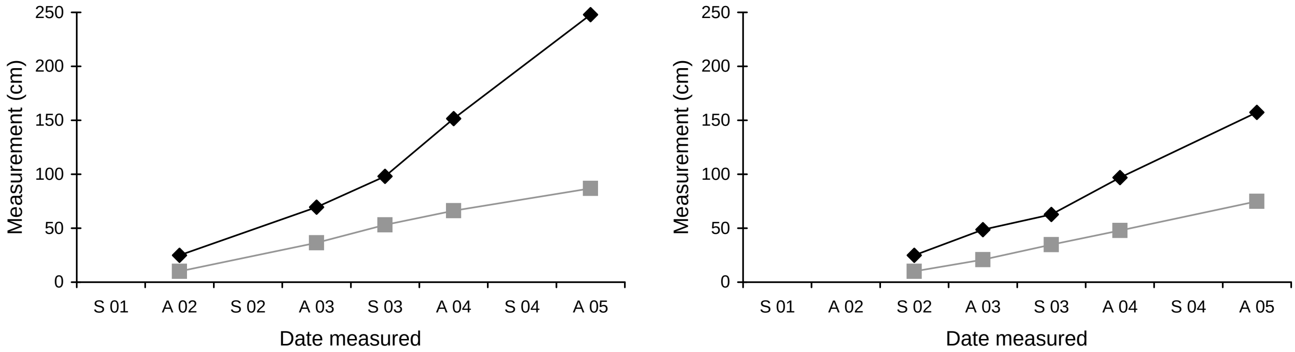


Figure 33. Mean dimensions and growth of Chatham Island akeake (*Olearia traversiorum*) measured at approximately six-month intervals in spring (S) and autumn (A) at Tioriori restoration site, northern Chatham Island; Core Area 2 (left) and Extension Areas 4 (right) were planted in 2002. Black diamonds represent height, grey squares represent breadth. (N.B. the first measurement was an estimate based on nursery stock sizes.)

Figure 34. Six-month-old Chatham Island akeake (*Olearia traversiorum*) planted behind the foredune at Tioriori restoration site, northern Chatham Island. *Photo: Peter Moore, 8 October 2002.*

Figure 35. One-year-old Chatham Island akeake *(Olearia traversiorum*) amongst rank grasses at Tioriori restoration site, northern Chatham Island. Photo: *Peter Moore, 8 April 2003.*

Figure 36. Two-year-old Chatham Island akeake (*Olearia traversiorum*) behind the foredune at Tioriori restoration site, northern Chatham Island. *Photo: Peter Moore, 6 May 2004.*

3.2.12 Chatham Island flax transplants

Flax, particularly the transplants from the wild, survived better and grew faster at Mairangi Creek than at Tioriori, probably due to the wetter conditions at the former area. Flax at Tioriori did not begin to increase in height or breadth until the second summer after planting (Fig. 37).

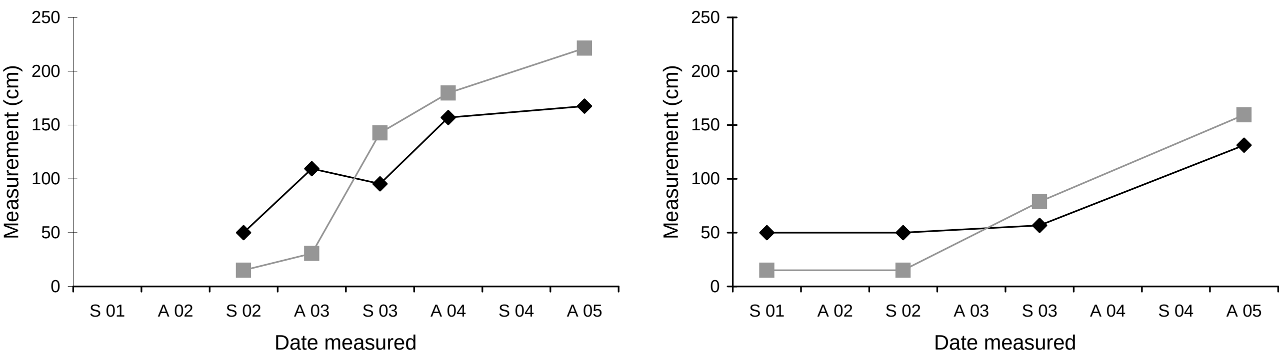


Figure 37. Mean dimensions and growth of Chatham Island flax (*Phormium* aff. *tenax*) measured at approximately six-month intervals in spring (S) and autumn (A) at Mairangi Creek (left) and Tioriori (right) restoration sites, northern Chatham Island. Black diamonds represent height in centimetres, grey squares represent breadth. (N.B. the first measurement was an estimate.)

3.2.13 Direct seeding

The seeds of most species that were sowed directly in the restoration sites failed to germinate (Appendix 6). However, a few sow thistle plants germinated and the forget-me-not established during the main restoration trial fruited and produced considerable numbers of seedlings. Competition from introduced pasture grasses may have been a factor in suppressing germination of akeake and the shrub species.

3.3 Dune profiles

There was considerable variation in morphology between dunes monitored in northern Chatham Island, including the inland extent, height and overall shape (Appendix 7: Figs. A7.1–A7.9). Four sites (Waitangi West, Maunganui Beach, Takehanga and Woolshed; Figs A7.1, 3, 4 & 9) had relatively wide beaches and foredunes, extending 90–120 m inland to a dune hollow, stream or farmland, but with dune heights that varied from 2.5 m to 10 m (Appendix 7). Mairangi Beach (Fig. A7.8) was a narrow (< 60 m) but relatively tall (8 m) foredune ending at farmland. The remaining four sites (Washout West, Tioriori restoration site, Tioriori and Mairangi Creek) were narrow (< 60 m) and short (2–5 m) foredunes (Appendix 7). Mairangi Creek and Takehanga had very gentle (c. 2°) sloped profiles at the front of the foredune, five sites were more gentle to moderate (6–12°) in slope, and two sites (Maunganui Beach and Mairangi Beach) were steep (31–33°). Main periods of sand erosion and accumulation are summarised in Table 5.

The nine monitored sites in northern Chatham Island showed different cycles of erosion and accumulation over the 6 years of the study, but most change occurred on the beach frontage and the beginning of the foredune, with very little change in the vegetated dune itself (Table 5). Cycles of erosion and accumulation were short (1–2 years) at some sites (e.g. Waitangi West) and medium term (2–3 years) at others (Maunganui Beach, Takehanga, and Tioriori and Mairangi Creek restoration sites). Other sites showed gradual accumulation of sand over 5–6 years (e.g. Washout West, Tioriori, Mairangi Beach and Woolshed). The western sites (Waitangi West to Tioriori) tended to show changes of ± 0.5 m, but Wharekauri sites (Mairangi Creek to Woolshed) showed changes of up to 1.7 m (Table 5).

Table 5. Dune profile changes in northern Chatham Island 2000–05.

DUNE TRANSECT	CHANGES AT THE FRONT OF THE FOREDUNE	CHANGES FURTHER INLAND ON FOREDUNE
Waitangi West	Lost 0.5 m of sand 2000 Gained sand by 2002 Lost sand 2003	No change
Washout West	Gained 0.53 m of sand 2000–05	No change
Maunganui Beach	Gained 0.53 m of sand 2000–02 Lost 0.29 m of sand by 2005	No change
Takehanga	Lost 0.2 m of sand 2000–01 Erosion at front 2003 Gained 0.46 m of sand by 2005	Gained 0.3–1.0 m of sand at mid-dune humps 30–60 m from high tide mark, no change further inland
Tioriori	Gained 0.55 m of sand	No change
Tioriori restoration site	Gained 0.56 m of sand 2000–03 Lost 0.25 m of sand by 2005	No change
Mairangi Creek restoration site	Lost 0.4–0.7 m of sand 2000–01 Gained 0.5 m of sand by 2003	No change
Mairangi Beach	Gained 0.83 m of sand 2000–04 Erosion in front 2005	No change
Woolshed	Gained 1.7 m of sand 2000–05	No change

3.3.1 Mairangi Beach profile and vegetation changes

Figures 38–42 provide details of the change in beach profile and expansion of marram at Mairangi Beach over the study period. This dune was chosen as an example of a dune with a steep-faced escarpment in an unrestored area, as opposed to the more gentle profiles at the restoration sites. At this site at the beginning of the study there was a small incipient foredune with a sparse cover of young marram in front of an old steep erosion scarp on the main foredune that was vegetated with thick mature marram. The photograph series shows the marram consolidating and spreading towards the high tide mark and sand accumulating in a new foredune (seen as the hump at post 2; Fig. 42). By April 2005, a new scarp had formed by wave action at the position of the first transect post (Fig. 41).

Figure 38. Dune transect LT6b at Mairangi Beach, northern Chatham Island, showing the first two posts and young marram (*Ammophila arenaria*) colonising the beach in front of a steep dune scarp. *Photo: Peter Moore, 28 December 2000*.

Figure 39. Dune transect LT6b at Mairangi Beach, northern Chatham Island, showing the first two posts becoming obscured by the encroaching marram (*Ammophila arenaria*) colonising the beach. *Photo: Peter Moore, 26 December 2001.*

Figure 40. Dune transect LT6b at Mairangi Beach, northern Chatham Island, showing the first two posts becoming further obscured by the encroaching marram (*Ammophila arenaria*) colonising the beach. *Photo: Peter Moore, 5 April 2003*.

Figure 41. Dune transect LT6b at Mairangi Beach, northern Chatham Island, with the first two posts completely obscured by the marram (*Ammophila arenaria*) and new escarpment forming from wave action. *Photo: Peter Moore, 15 April 2005.*

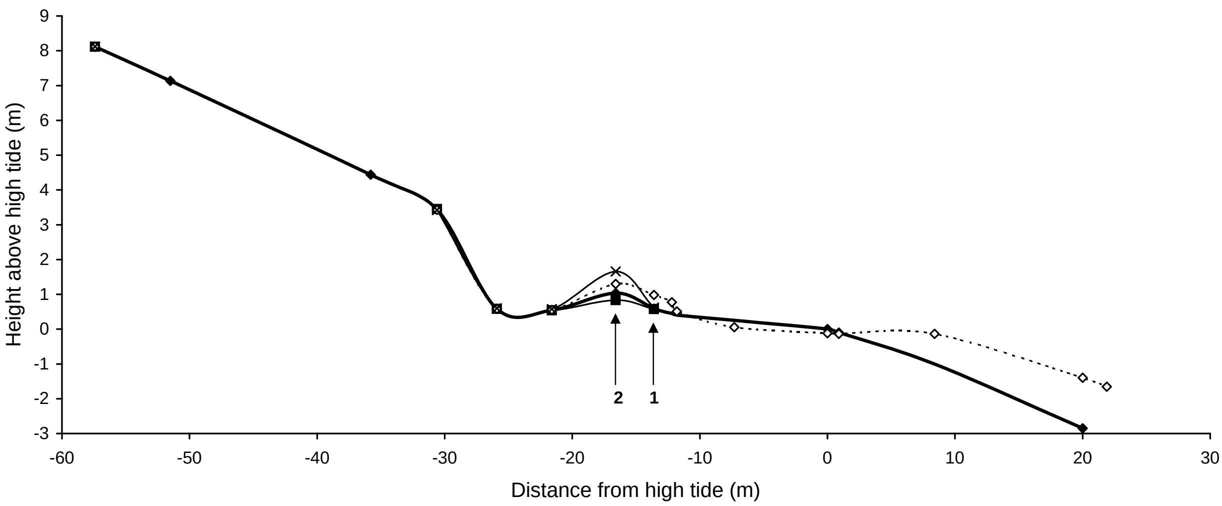


Figure 42. Dune profile changes at Mairangi Beach transect (LT6b), northern Chatham Island, as seen from an eastern perspective and measured by surveyor's level in February 2001 (closed diamonds) and April 2003 (open diamonds), and post height in December 2001 (closed squares) and April 2005 (crosses) (vertical scale exaggerated; position of posts 1 and 2 indicated for comparison with views in Figs 38–41).

3.3.2 Mairangi Creek restoration site dune profile and vegetation changes

The pattern of change in beach profile at Mairangi Creek is shown in Figs 43–48. In 2000, the beach sloped gently into a foredune of dense marram. Clearance of marram and activities associated with planting did not alter the dune profile. However, during the restoration of native vegetation, the beach front was eroded by the combined action of the stream and the sea. This occurred mainly in the winters of 2001 and 2002, and resulted in a steep bank approximately 0.7 m high (Fig. 45). Erosion of the bank continued over the next 2 years, although a beach crest built up in front of the stream (Fig. 48). By April 2006, marram was recolonising the new sand in front of the restoration site following spraying of marram regrowth in 2005 (Fig. 47).

Figure 43. Mairangi Creek dune transect (LT6), northern Chatham Island, showing the first two posts, extensive marram (*Ammophila arenaria*) in the background and sea rocket (*Cakile edentula* var. *edentula*) in the foreground, before restoration began. *Photo: Peter Moore, 28 December 2000*.

Figure 44. Mairangi Creek dune transect (LT6), northern Chatham Island, showing the first two posts after restoration began and foreground erosion. Young pīngao are visible around and behind post 2. *Photo: Peter Moore, 20 April 2002*.

Figure 45. Mairangi Creek dune transect (LT6), northern Chatham Island, showing the fourth post after erosion of the dune front by the stream and high seas in winter 2002 had removed the first three posts. The vegetation is a mixture of maturing pīngao and invading sea rocket. *Photo: Peter Moore, 29 December 2002.*

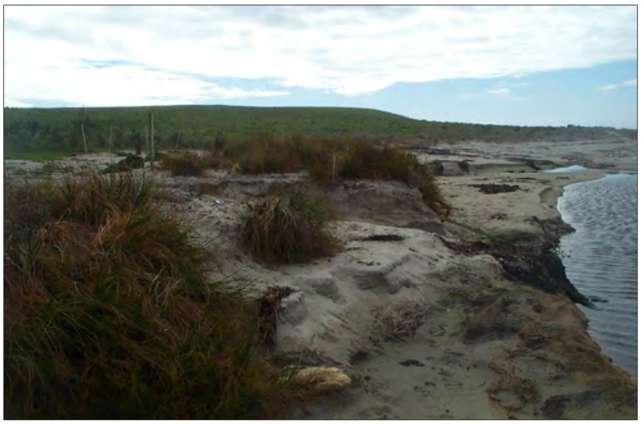


Figure 46. Mairangi Creek dune transect (LT6), northern Chatham Island, showing the fourth post, continued erosion of the dune front and maturing pīngao. *Photo: Peter Moore, 1 May 2004.*

Figure 47. Mairangi Creek dune transect (LT6), northern Chatham Island, showing further erosion of the pīngao (*Desmoschoenus spiralis*) zone (post 4 is now missing) and a return of marram (*Ammophila arenaria*) on the beach front amongst the seaweed, after the previous spraying of marram regrowth in 2005. *Photo: Peter Moore, 1 May 2006.*

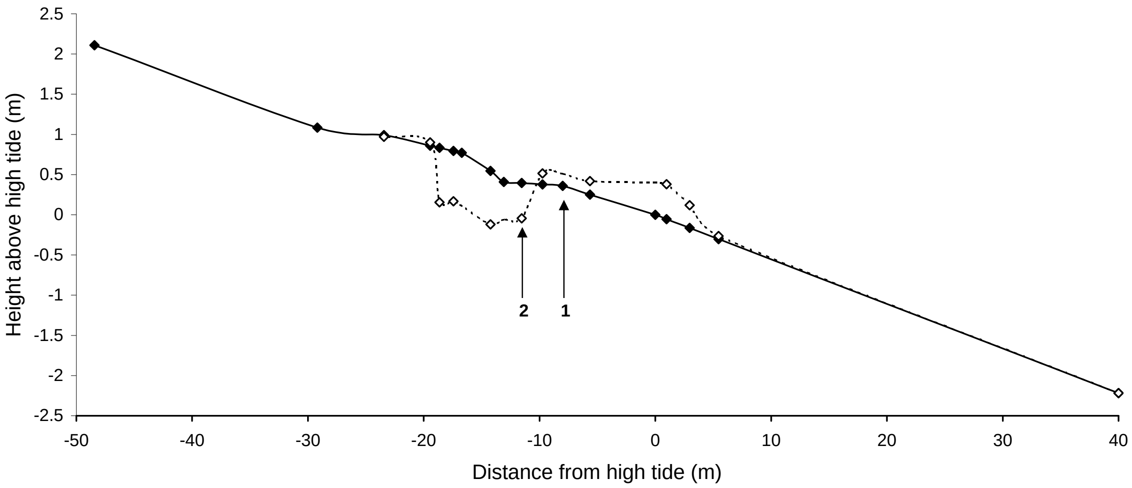


Figure 48. Dune profile changes at Mairangi Creek transect (LT6), northern Chatham Island, as seen from an eastern perspective and measured by surveyor's level in February 2001 (closed diamonds) and May 2004 (open diamonds) (vertical scale exaggerated; positions of posts 1 and 2 indicated for comparison with views in Figs 43–47).

3.3.3 Tioriori dune restoration site profile and vegetation changes

The change in beach profile at Tioriori restoration site is shown in Figs 49–54. In 2000, the beach sloped gently into the foredune. Sand carex spread over the site once marram was removed, and over the next 3 years there was a slow accumulation of sand (Figs 52 & 54). In the final 2 years of monitoring, the beach slowly eroded again (Fig. 53).

Figure 49. Tioriori dune transect (LT4b), northern Chatham Island, showing the first two posts at the edge of dense marram (*Ammophila arenaria*) and patches of native sand carex (*Carex pumila*) before restoration began. *Photo: Peter Moore, 29 April 2001*.

Figure 50. Tioriori dune transect (LT4b), northern Chatham Island, after restoration, showing the absence of marram (*Ammophila arenaria*) and the spread of sand carex (*Carex pumila*). *Photo: Peter Moore, 28 December 2002.*

Figure 51. Tioriori dune transect (LT4b), northern Chatham Island, showing the summer growth of sand carex *(Carex pumila)* seaward of the first post. *Photo: Peter Moore, 8 April 2003.*

Figure 52. Tioriori dune transect (LT4b), northern Chatham Island, showing the autumn die-off of sand carex (*Carex pumila*) and an accumulation of sand at post 1. *Photo: Peter Moore, 2 May 2004*.

Figure 53. Tioriori dune transect (LT4b), northern Chatham Island, showing a loss of sand at post 1 in the previous 12 months, patches of atriplex (*Atriplex billardierei*) in the foreground and a consolidation of native vegetation in the foredune. *Photo: Peter Moore, 17 April 2005*.

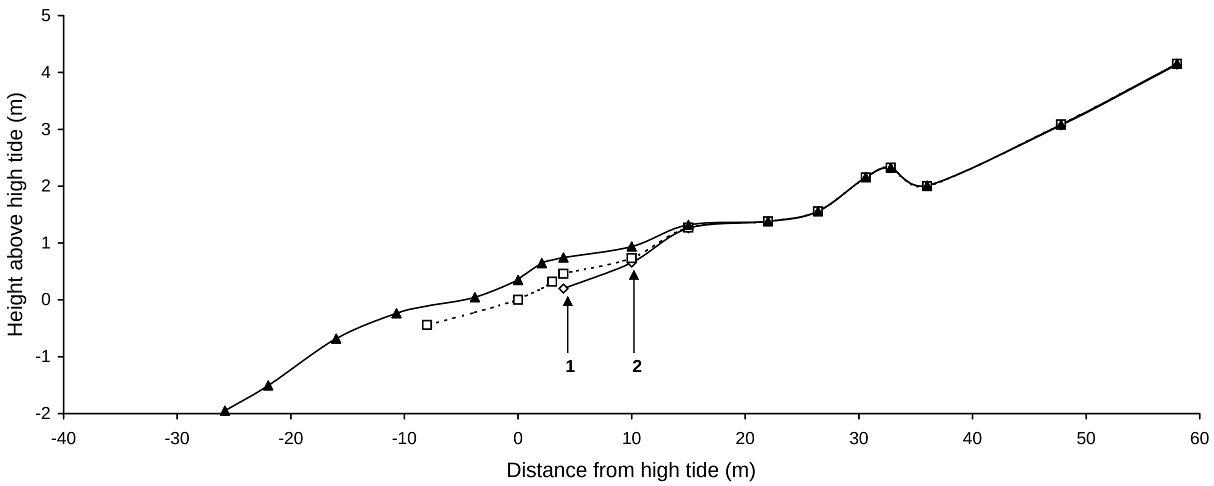


Figure 54. Dune profile changes at Tioriori transect (LT4b), northern Chatham Island, as seen from a western perspective and measured by post height in April 2001 (open diamonds), and surveyor's level in April 2003 (open squares) and May 2004 (closed triangles) (vertical scale exaggerated; position of posts 1 and 2 indicated by arrows for comparison with views in Figs 49–53).

3.4 Oystercatcher nests

3.4.1 Position of nests on beach profile

The two areas of northern Chatham Island (Wharekauri and Maunganui) that were managed for oystercatchers (predator control, stock exclusion and translocation of nests to areas above the high tide mark) (Moore et al. 2001; Moore 2009) had relatively narrow beaches. Other beaches in northern Chatham Island (Paritu, Ohira Bay, Whangamoe Point, Waitangi West and Matarakau) were approximately twice as wide and tall in profile as the managed beaches (Table 6). A sample of oystercatcher nest locations recorded in 2000 and 2001 were, on average, only 8.5 m (range –5.9 to 31.3 m; Table 6) from the high tide mark (MHWS), and the majority were less than 16 m from MHWS (Fig. 55). On average, the managed nests were 0.39 m (range –0.20 to 1.26 m) in elevation above MHWS. Consequently, nests were vulnerable to overwash by the sea resulting from relatively small changes in tide level, winds pushing waves over the beach terrace or storm swells sweeping into the dunes. Managers translocated 11–23 of the more vulnerable nests per year to reduce the chance of them being washed away (Moore 2009). For example, nine of the measured sample of 21 nests were translocated. Five of these were originally below the high tide mark (on the day of measurement), including four below MHWS (Table 6; Fig. 56). Moving the nine nests an average of 11 m further inland raised them, on average, to elevations more than 1 m higher than MHWS (range 0.22 to 2.06 m).

Table 6. Relative distance of nests and dune vegetation from the high tide mark (mean high water springs) in managed and unmanaged oystercatcher areas of northern Chatham Island 2000–01, and nine of the managed nests that were translocated away from the high tide mark.

	NEST POSITION IN RELATION TO THE HIGH TIDE MARK				DUNE VEGETATION POSITION IN RELATION TO THE HIGH TIDE MARK				
	DISTANCE		HEIGHT		DISTANCE		HEIGHT		*n*
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	
Unmanaged area	22.3	10.7	1.94	2.5	35.2	22.4	2.52	1.55	10
Managed area	8.5	8.9	0.39	0.39	16.2	12.1	1.14	0.96	21
Original nest site	5.2	8.0	0.16	0.34	15.5	11.45	1.22	1.26	9
Translocated nest site	16.7	9.7	1.08	0.7	15.5	11.45	1.22	1.26	9

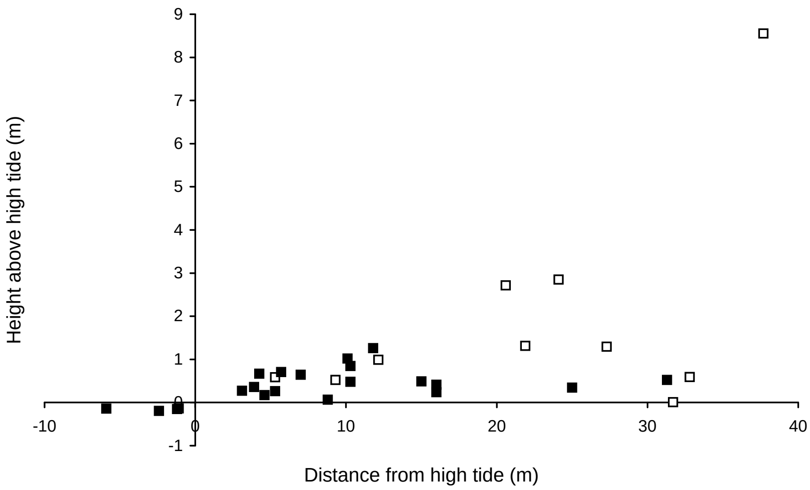


Figure 55. Distance and elevation from the high tide mark (MHWS) of 10 Chatham Island oystercatcher (*Haematopus chathamensis*) nests in unmanaged areas (Paritu, Ohira Bay, Whangamoe Point, Waitangi West, Matarakau; open squares) and 21 nests in managed areas (Wharekauri, Maunganui; dark squares), northern Chatham Island, in 2000 and 2001.

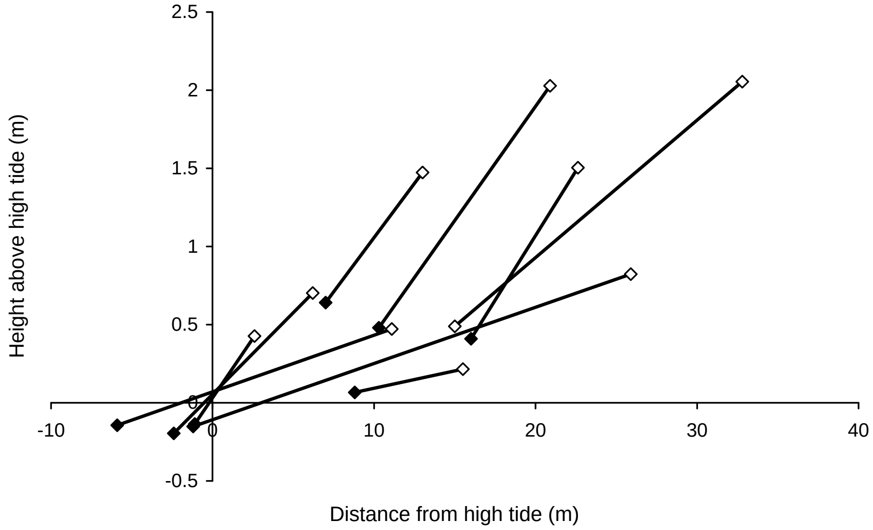


Figure 56. Distance and elevation from the high tide mark (MHWS) of nine Chatham Island oystercatcher (*Haematopus chathamensis*) nests in managed areas (Wharekauri, Maunganui) in 2000 and 2001, northern Chatham Island; original nest sites (closed diamonds) are connected to translocated nest sites (open diamonds). Note that four of the original nest sites were below MHWS.

3.4.2 Reponses of oystercatchers to dune restoration

Mairangi Creek restoration site

Dune restoration was trialled as a long-term alternative to seasonally translocating nests above the high tide mark. At Mairangi Creek in years prior to dune restoration the resident pair of oystercatchers chose to nest in a car tyre platform that was placed in their territories on the beach. This platform and the nest on it was gradually dragged further up the beach closer to the marram and into comparative safety from sea wash (nests were moved 4 m in 1999 and 3 m into a cleared alcove in 2000). In September 2001, restoration of Mairangi Creek began (clearing of dead marram and planting of native species) and a car tyre platform was placed close to the edge of the sprayed marram, but not moved once the birds laid in it in mid-October 2001 (Fig. 57). This nest was approximately 22 m inland and 0.64 m in elevation above the high tide mark (MHWS), so it was relatively safe from high seas. The approximate positions of the original nest sites within the storm tide zone on the beach over the period 1999–2001 are shown schematically in Fig. 58. One chick fledged per year during the three respective breeding seasons.

Figure 57. Chatham Island oystercatcher (*Haematopus chathamensis*) nest on a car tyre platform (with a time-lapse video camera beside it on the left) on the beach at Mairangi Creek restoration site, northern Chatham Island. *Photo: Peter Moore, 26 October 2001.*

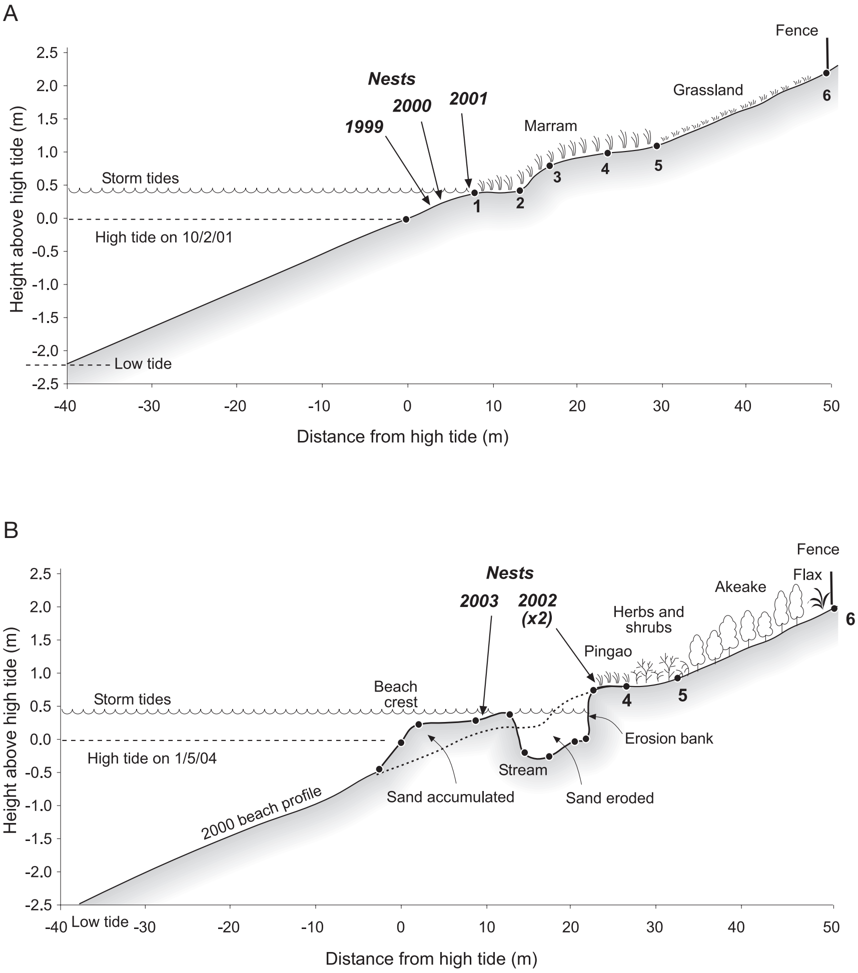


Figure 58. Approximate original positions of Chatham Island oystercatcher (*Haematopus chathamensis*) nests on the Mairangi Creek restoration site dune profile, northern Chatham Island, in 1999, 2000 and 2001 before dune restoration (A), and in 2002 and 2003 after dune restoration (B). Numbers on the profile indicate the positions of dune transect posts and black points indicate the positions used to measure the profile by survey level.

In winter 2002, high creek levels and seas eroded much of the beach at Mairangi Creek. The following spring, the car tyre platform was not put out, to encourage the oystercatchers to choose their own nest site. The birds laid their eggs in mid-October 2002 in a nest above the erosion scarp within the restoration site (Figs 59 & 60). Although the nest was close to the bank, it was 0.75 m above high tide. The nest failed (one egg disappeared and the other was infertile) and a second clutch was laid nearby (Fig. 61) that fledged two chicks. The approximate position of these two nests on the dune profile is shown in Fig. 58.

Erosion of the pīngao and megaherb zones at the site continued in 2003, as the creek cut laterally across the nesting area. At the same time, a new beach crest (0.3 m above MHWS) built up on the seaward side of the creek and the oystercatcher pair laid eggs on the crest rather than within the restoration site (Figs 58 & 62). Consequently, the new nest site was relatively vulnerable to storm tides compared with the nest site chosen in 2002. The chicks and one of the adults disappeared, apparently from dog predation after people had a picnic in the area. In subsequent years, two neighbouring oystercatcher pairs divided up the Mairangi Creek territory, nesting on the beach or beach crest at either end of the restoration site. In 2004, one pair failed (the chick from the first nest failed after human disturbance and the second clutch disappeared) and the second pair fledged a chick (the first nest was washed away by high seas).

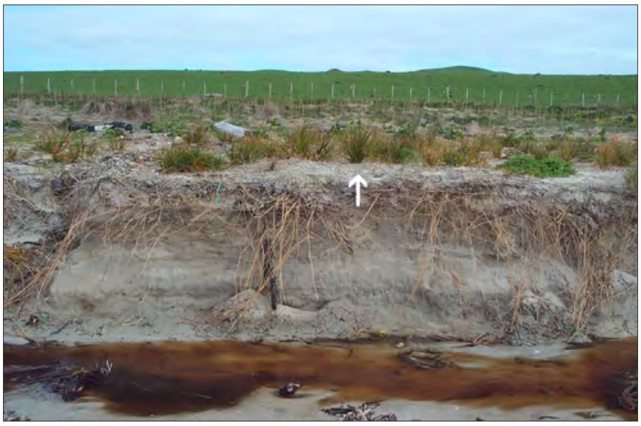


Figure 59. Chatham Island oystercatcher (*Haematopus chathamensis*) nest site (arrow) above a recent erosion scarp at the edge of Mairangi Creek restoration site, northern Chatham Island, in 2002. Note the old rhizomes of marram (*Ammophila arenaria*) visible in the bank. *Photo: Rex Williams, October 2002.*

Figure 60. Chatham Island oystercatcher (*Haematopus chathamensis*) nest beside a young pīngao (*Desmoschoenus spiralis*) plant at Mairangi Creek restoration site, northern Chatham Island. *Photo: Rex Williams, October 2002.*

Figure 61. A second clutch of eggs laid by the Mairangi Creek Chatham Island oystercatcher (*Haematopus chathamensis*) pair in a patch of Chatham Island celery (*Apium prostratum* subsp. *denticulatum*) at Mairangi Creek restoration site, northern Chatham Island. *Photo: Rex Williams, December 2002.*

Figure 62. Site of Chatham Island oystercatcher (*Haematopus chathamensis*) nest (indicated by the arrow) on the beach crest in front of the Mairangi Creek restoration site, northern Chatham Island. *Photo: Rex Williams, 2003 breeding season*.

Tioriori restoration site

In 1999–2000, prior to the start of dune restoration, the resident pair of oystercatchers at Tioriori nested on the beach within the storm zone and their eggs were moved 2–6 m inland from the high tide mark as part of DOC's Chatham Island oystercatcher management programme. In 2001, the birds laid eggs in front of the newly established restoration site, close to the high tide mark and only 0.07 m in elevation above MHWS. The eggs were moved c. 8 m up the beach (Figs 63 & 64), a change in elevation of 0.15 m. The pair successfully raised 2–3 chicks per year during 1999–2001.

In 2002, a sparse carpet of sand carex had spread over the area that had been cleared of marram at the Tioriori restoration site. The birds nested at the edge of this zone (Figs 63, 65 & 66), a position that was 5–10 m further inland from where they previously nested, but which was still vulnerable to storm tides. Nevertheless, the pair successfully raised two chicks. Over the next 2 years, 0.55 m of sand accumulated into a shallow ridge over the sand carex zone and the birds nested further up the beach (Figs 63 & 67), approximately 10–15 m further inland than during 1999–2001, and 0.5–0.8 m in elevation above the high tide mark. Consequently, the nests in 2002–04 were less vulnerable to the sea (Fig. 63). The pair continued to raise two chicks per year in the three seasons after dune restoration work commenced.

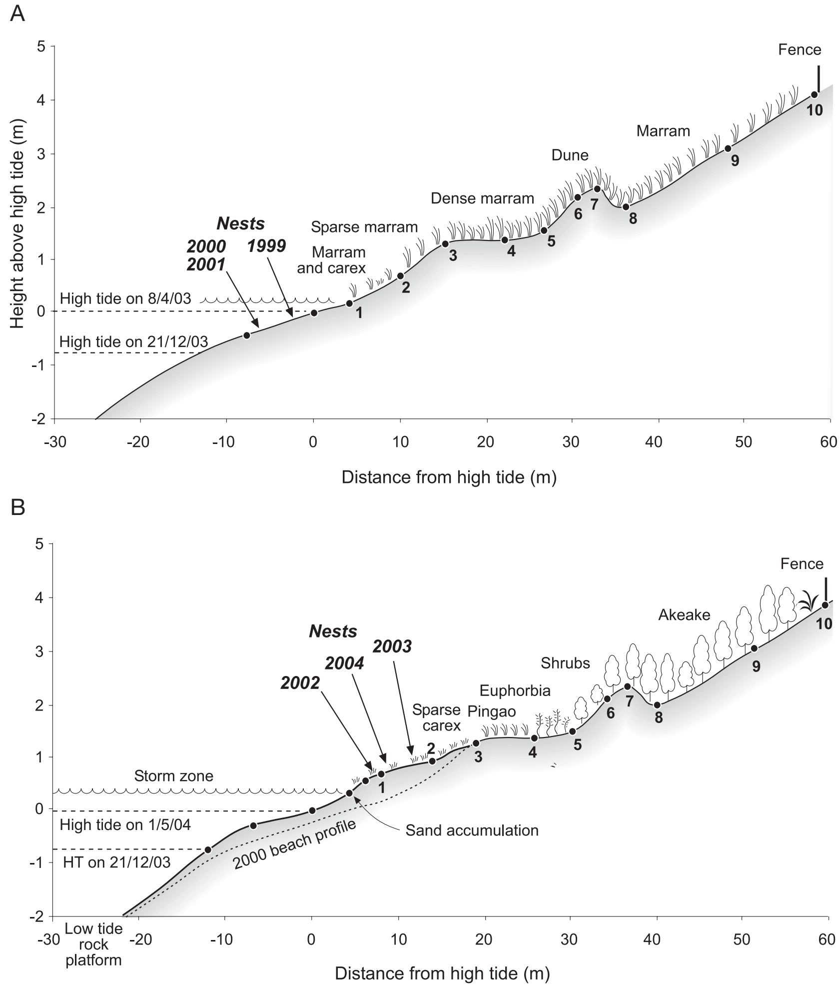


Figure 63. Approximate original positions of Chatham Island oystercatcher (*Haematopus chathamensis*) nests on the Tioriori restoration site dune profile, northern Chatham Island, during 1999–2001 before dune restoration (A) and during 2002–04 after dune restoration (B). Numbers on the profile indicate the positions of dune transect posts, and black points indicate the positions used to measure the profile by survey level.

Figure 64. A Chatham Island oystercatcher (*Haematopus chathamensis*) nest moved approximately 8 m from its original site to a position safer from high tides at Tioriori restoration site, northern Chatham Island. Nest sites indicated by arrows. *Photo: Rex Williams, 2001 breeding season.*

Figure 65. Chatham Island oystercatcher (*Haematopus chathamensis*) nest site (indicated by arrow) in 2002, amongst native sand carex (*Carex pumila*) that spread over bare sand after marram (*Ammophila arenaria*) was removed in 2001 at Tioriori restoration site, northern Chatham Island. *Photo: Rex Williams, 2002 breeding season.*

Figure 66. Chatham Island oystercatcher (*Haematopus chathamensis*) nest amongst native sand carex (*Carex pumila*) at Tioriori restoration site, northern Chatham Island. *Photo: Rex Williams, 2002 breeding season*.

Figure 67. Chatham Island oystercatcher (*Haematopus chathamensis*) nest site (indicated by arrow) on a mound at the edge of the Tioriori restoration site, northern Chatham Island. *Photo: Rex Williams, 2003 breeding season.*

4. Discussion

4.1 Restoring native vegetation to Chatham Island dunes

The dune restoration trials on Chatham Island demonstrated that changing a modified dune system dominated by marram grass to one with a more natural community of native plants was feasible, and provided some indication of the effort involved in doing this. The end result mimicked a natural dune vegetation sequence, similar to that described by Cockayne (1902), and provided more nesting habitat for oystercatchers.

The two trial sites were selected for their low dune profiles, to lessen the amount of sand that could mobilise and threaten adjoining farmland after removal of vegetative cover. Similarly, the wind fence at Tioriori was another safeguard against sand mobilisation. As it turned out, the establishment of new plants (and invasion of grasses and weeds at Mairangi Creek) was rapid and the precautions against sand movement were not needed. This has also been the experience in more exposed dune sites that have been restored to native vegetation on the New Zealand mainland (AD & MB, pers. obs.).

The herbicides Gallant® and Roundup Extra® were used to spray marram, and both appeared to work equally well in spring and autumn and have a comparable effect on marram. Gallant® had the advantage of not affecting native plants but was more expensive than Roundup®. Applying herbicide using hand guns and tanks mounted on ATVs was found to be a more time-efficient method than using knapsacks. Survival and growth rates of plants were higher when there was blanket spraying of marram, followed by removal of dead thatch, as occurred in the core planting areas. The removal of dead marram thatch allowed any live marram that remained underneath, or any regrowth, to be identified and spot-sprayed. In some of the extension areas, the dead marram was left intact and some plants regrew despite repeated spraying. Marram grass seedlings were observed establishing at the front of the dunes in both sites for the duration of the trial, possibly growing from fragments of runners remaining in the sand as well as seeds from marram adjacent to the trial sites. Restoration of small sites, such as those in this study, would require regular marram control, particularly at the front of the foredune where open space and sparse native vegetation provides room for reinvasion. Alternatively, a longer period of marram control before the restoration of native plants commenced might reduce the amount of ongoing control required.

The removal of introduced pasture grasses followed by ongoing control likely resulted in higher survival and growth rates in plantings of shrubs and akeake than just spot-spraying. Farmland in close proximity to the trial sites provided weed sources, particularly at Mairangi Creek, where neighbouring thistles and pasture weeds were more prevalent and wet conditions in winter inhibited growth of native dune plants. Furthermore, at the start of the trial, sea rocket was already present at Mairangi Creek and the restoration work created more open space in front of the foredune that was ideal for its spread. Although easily pulled by hand, the plants set copious seeds and a concerted effort was required to reduce the infestation to more manageable levels towards the end of the trial. Annual spraying of sea rocket, or volunteer weeding days, might be required to prevent this species taking over the open spaces at Mairangi Creek.

Most native plant seeds were collected for propagation 2 years before planting, although akeake, pīngao, sow thistle and forget-me-not can be collected the year before planting out. In contrast, shrubs, particularly corokia, required more than 2 years for propagation and raising in the nursery because of their slow growth. Consequently, the numbers of shrubs available for planting was lower than initially planned, with the result that they were planted out later and at low density, probably contributing to a poorer establishment of the shrub zone. Transplanting cuttings or root stock from wild plants to the trial sites was successful for flax, as has been found for other restoration projects in mainland New Zealand (AD, pers. obs.), but unsuccessful for other plants. Similarly, direct seeding was successful for sow-thistle; however, a range of other species failed to establish from direct seeding. These species may need to be raised in a nursery before they can be successfully established in a new area. Forget-me-not is potentially a species that can be sown as seed, since numerous seedlings were produced from self-sown seed during the restoration trial.

Although we did not test the effectiveness of fertiliser application during the study, previous research has shown that it can improve growth rates and survival (Bergin & Kimberley 1999), because dunes are often low in phosphate. Megaherbs, for example, do well where they gain marine-derived nutrients from salt spray and rotting seaweed (AD, pers. obs.) as well as inputs from breeding seabirds and mammals (Meurk et al. 1994; Norton et al. 1997; Erskine et al. 1998; Mitchell et al. 1999), and mammal carcasses (C. Miskelly, Museum of New Zealand *Te Papa Tongarewa*, pers. comm.). Stock incursions and browsing at Mairangi Creek caused considerable damage to megaherbs, shrubs and young akeake. Even relatively short incursions of a few days set back the establishment of native plants, illustrating their vulnerability to browsing.

The lower rate of survival of akeake seedlings at Mairangi Creek was due to wet conditions in winter months and associated poor drainage in the core area. In this respect, the area is not typical of most of the steeper dunes of the Chatham Islands. The drier conditions and 0.7 m spacing between akeake plants at Tioriori resulted in rapid growth and canopy closure within 2 years of planting, which then reduced the space available for weed (including marram) reinvasion. This growth rate was faster than that observed for akeake planted elsewhere on Chatham Island dunes, most of which which had wider planting spaces (about 1.5 m) (AD, pers. obs.). Thinning of akeake at the trial sites may be required in the future to allow other canopy species such as māpou, Chatham Island mahoe (*Melicytus chathamicus)* and kawakawa (*Macropiper excelsum*) to be planted, and for other dune forest plants to self-establish.

The rapid growth and high survival rate of the megaherbs, except for euphorbia at the Mairangi site, meant that they were providing good cover within 2 years. Although losses of megaherbs occurred at both trial sites for various reasons, their fast growth rates enabled them to mature, produce seed and spread in subsequent years. This was particularly evident for euphorbia, which spread widely at Tioriori, and, similarly, sow thistle at Mairangi. The pīngao also created cover at the front of the dune by sending out long runners, and by fruiting, potentially establishing its own seed source. Protecting existing native plants enabled self-establishment of sand daphne and sand carex at Tioriori, and *Lobelia arenaria* and native convolvulus (*Calystegia sepium* subsp. *roseata*) at Mairangi Creek, without any need to supplement their spread.

A number of the species that successfully established at the trial sites are threatened (such as forget-me-not, euphorbia and sow thistle). Small numbers of the threatened Dieffenbach's speargrass were planted at both sites to see if the species could survive in dune habitat (it generally occurs on coastal cliffs, particularly on seabird islands, of the Chatham Islands, although one large female plant was found growing in dunes south of Kahuitara Point on Pitt Island in February 2007—C. Miskelly, Museum of New Zealand *Te Papa Tongarewa*, pers. comm.). The initial high survival rate of this species in our planting trial could indicate that dunes were formerly habitat for speargrass. Further opportunities to increase the biodiversity of the trial sites remain—by establishing atriplex and sand tussock, for example.

The trial restoration project required a relatively small labour effort over 4 years (less than 200 hours per ha per year) for site preparation (spraying, clearing and fencing), planting (9070 plants/ha) and maintenance to transform the two 0.5–0.64 ha sites to a cover of native vegetation. The resources required to restore larger areas (the 16 km oystercatcher management zone, for example) would probably be less per hectare than for the trial sites, since greater efficiencies of scale could be achieved for site preparation, plant raising and maintenance (AD & MB, pers. obs.; Bellingham 2009).

A number of dune management projects in New Zealand and in other countries (e.g. US Fish &Wildlife Service 2001; Barrios 2004) have used earthmoving machinery to remove marram and reshape dune profiles. However, this method may pose a greater risk of subsequent dune erosion and large-scale sand movement than a more gradual replacement of exotic vegetation with native species. The challenge for the latter method is keeping marram out of the restored areas in the long term. Recent checks of the restoration sites on the Chatham Islands have identified some relatively minor instances of re-establishment of marram amongst the native dune vegetation since 2005. This suggests that occasional maintenance work by the Chatham Area Office of DOC has been sufficient to prevent marram re-invasion of the sites. Larger areas restored to native dune vegetation would have relatively low long-term maintenance costs per hectare because of smaller edge effects.

4.2 The role of marram in modifying dune profiles

Marram was deliberately planted in several parts of the world, including New Zealand, Australia, South Africa, Chile, The Falkland Islands and North America to form or stabilise dune systems (Wiedemann & Pickart 1996, 2004; Hertling & Lubke 1999; Hilton et al. 2005). Marram has been particularly invasive in New Zealand and on the west coast of North America. This is because the latitudinal range (34°–54°) and climate (temperate, with wet winters; Wiedemann & Pickart 2004) of these areas are similar to those of the natural range of the grass in Europe. In the USA and New Zealand, marram was introduced in the late 1800s as a sand stabiliser. It then spread widely, reducing the prevalence of active dune systems and almost completely replacing dunes' native plant communities (Pickart 1997; Hilton et al. 2005, 2006). In New Zealand, the area of active dunes reduced by 70% during the 20th Century as a result of marram establishment, followed by planting of commercial forests, farming and development. The spread of marram has continued in more remote southern beaches in recent decades (Hilton et al. 2006). Several factors may give marram a competitive advantage over native plants. Marram sprouts readily from rhizome fragments, and because these are tolerant of immersion in sea water, they readily resprout when they are washed ashore following transport along coasts during storms (Aptekar & Rejmanek 2000; Hilton et al. 2005). Marram develops vigorous root and rhizome systems that are stimulated by sand accumulation, and its dense growth habit enables it to out-compete native plants. It is also more tolerant of periods of drought (Dixon et al. 2004), and appears to have few natural enemies (such as specialised pathogenic nematodes; Beckstead & Parker 2003; van der Putten et al. 2005) in its host countries. Before the establishment of marram, foredunes were typically discontinuous, low (2–3 m), irregularly shaped hummocks that were sparsely vegetated (Hilton et al. 2005, 2006). For example, in the Manawatu area of the lower North Island, pīngao-covered dunes typically had slopes of 8°–14°, and were only 3 m high because the sparse vegetation did not trap much sand (Esler 1970). In contrast, marram establishment has resulted in steep and regularly shaped dunes, typically with 24°–28° slopes and heights > 6 m (Esler 1970). At Mason Bay, Stewart Island/Rakiura, marram establishment resulted in the creation of a single continuous foredune and displacement of the native pīngao and sand tussock over a 20-year period (1958–1978, Hilton et al. 2005). The steep dune shape encourages the accumulation of sand at the dune front and increases erosion in the lee, and because marram is far more tolerant of burial by sand and erosion during storms, the native plants gradually die out (Hilton et al. 2005, 2006). In turn, the rear of the dune and the dune hollow is deprived of mobile sand which encourages the formation of dense vegetation that further stabilises the dune (Pickart 1997; US Fish & Wildlife Service 2001). The consequence of marram invasion is a narrow wave-swept beach and no open sand behind the foredune in which shorebirds can nest (US Fish & Wildlife Service 2001). Furthermore, the presence of marram depresses sand dune arthropod populations, and reduces the potential food supply for shorebirds (Slobodchikoff & Doyen 1977).

Monitoring dune profiles during our study provided a unique opportunity to observe changes in sand and vegetation at the beach front and dunes of northern Chatham Island. Cycles of erosion and sand deposition differed between sites, most gaining and/or losing around 0.5 m depth of sand (and up to 1.7 m) at the front of the foredune over a 6-year period. The monitored site at Mairangi Beach (Figs 38–41) provides a graphic example of how quickly marram can invade bare sand accumulated in front of an erosion scarp. Within 3 years, marram consolidated a new foredune with a thicket of vegetation. A new dune scarp soon began to form as a result of wave action. These observations confirm the role that marram has played in the shaping of northern Chatham Island dunes, as it has in other parts of New Zealand, since its introduction in the late 1800s to stabilise dunes. However, not all of the marram-dominated dunes in our study were steep and tall. The tallest (Mairangi Beach and Maunganui Beach) were 8–10 m foredunes with slopes of > 30°, and were perhaps most similar to the marram-dominated dunes described by Esler (1970) and Hilton et al. (2005). These sites were probably the most exposed of the sites monitored in our study because of their position in the centre of long sweeping beaches. The other dunes at our study sites were of variable height (2–5 m) and slope (2°–20°), and were closer to streams or promontories. Nevertheless, all the dunes were dominated by marram.

The dune restoration sites on Chatham Island were chosen for their low profile, so there would be less chance of sand being destabilised after removal of marram. Their low dune height meant that these sites were more likely to maintain their profile during the restoration process. This appeared to be true at Tioriori, where a modest accumulation of sand occurred, followed by gradual erosion on the dune front, thus maintaining a gentle profile, but with more open ground and sparser vegetation. This subtle change in dune morphology created safer sites for oystercatcher nesting. This was in contrast to the wave-cut scarps at the sites vegetated by marram.

The situation differed at the Mairangi Creek restoration site, which was severely eroded by winter floods and wave action, forming a steep bank beside the stream. Evidently the stream outlet has shaped the profile of the foredune in this area over the years, keeping it low by periodically meandering parallel to the dune and cutting sand away. Nevertheless, open ground inland of the scarp was created for oystercatcher nesting during the restoration process, and a new marram-free beach crest formed during the next phase of sand accumulation.

We were unable to trial dune restoration on steeper marram-covered dunes to see if their steep profile could be reduced by replacement with native vegetation, as the risk that sand would mobilise and cover nearby fences and farmland was thought to be too high. These steeper dunes could be reshaped by mechanical means before expansion of restoration along the coast, but this is unlikely to be an option because of the potential for damage to Moriori burial sites. Programmes in other countries have successfully recreated open nesting habitat for shorebirds by flattening dunes to create a shelf that is safe from tidal wash (US Fish & Wildlife Service 2001). Reshaping dune profiles by changing vegetation may be less intrusive on Moriori cultural sites, and poses less risk of large-scale erosion.

4.3 Restoring shorebird nesting habitat

The areas of northern Chatham Island that were managed for oystercatchers in 1998–2004 (Maunganui/Wharekauri) tend to have narrow beaches, making the birds' nests vulnerable to sea wash. Prior to vegetation restoration at Mairangi Creek and Tioriori, nests had been translocated by managers up the beach profile to sites that were safer from wave action. The restoration trials showed that nest positions could be influenced by creating more space for nests at the front of the foredune. Although birds still tended to nest relatively close to the high tide mark, the nest sites were outside the normal storm zone and therefore less vulnerable to sea wash. At Mairangi Creek, the resident oystercatcher pair nested within the restoration site in 2002. Storm seas had cut into the foredune, which formerly had a dense thicket of marram, and without restoration the oystercatchers would have had no choice but to nest on the wave-swept beach. In the years following the restoration trial, the pairs in this area used a newly accumulating beach crest in front of the dune for nesting. Although this meant the benefit of restoration was less apparent in these years, controlling the spread of marram meant it was probable that more space for breeding was maintained. Success in manipulating oystercatcher nesting was more sustained at Tioriori. The resident pair nested further inland from high tide during the 3 years of restoration work than they did before marram was removed, at the edge of a dune slope vegetated by a sparse cover of sand carex. In subsequent years the dune front remained open and sparsely vegetated, and a small ridge of sand accumulated, which further safeguarded the birds' nesting positions from wave action. These outcomes indicate that the oystercatchers' nesting attempts were aided by restoration efforts.

Marram removal alone is an option for creating more nesting space for oystercatchers; for example, alcoves (10 m^2) can be created in marram-covered foredunes for nests to be translocated into (Moore 2009). However, if such clearance work was expanded to a larger scale, destabilised sand could cover the stock fences and cover neighbouring farmland. Also, it is necessary to hand-pull and/or spray the reinvading marram once or twice a year, particularly if only a marginal strip of marram is removed. In contrast, a fully restored length of coastline, with a cover of native plants and no neighbouring marram, would only require periodic spot spraying of any invading marram plants. Furthermore, vegetation restoration would not only benefit oystercatchers, but would also help to re-establish threatened coastal plant communities, which would have follow-on benefits to other animals that depend on them.

In the long term, dune restoration is a more desirable alternative to intensive, direct management of oystercatcher breeding such as translocation of nests. After the initial cost of restoration, maintaining restored areas is more economically sustainable than labour-intensive management of individual nests, and restoration continues to provide benefits during periods of no management. Although predators, particularly feral cats, appear to be the primary threat to oystercatchers on the Chatham Islands, c. 40–50% of egg losses are caused by the sea during years with stormier weather (Moore & Reid 2009). The removal of marram and restoration of native dune vegetation will enable oystercatchers to nest further inland away from wave action than they do in the presence of marram-covered foredunes.

Oystercatchers, like other beach-nesting shorebirds, prefer to nest in areas of sparse vegetation that provide some protection while also allowing them a good view of their surroundings for territorial defence and observing potential threats. This sort of habitat, which has also been described for pīngao-dominated dunes elsewhere in New Zealand (e.g. Esler 1970; Hilton et al. 2005), was probably typical of the original native dune vegetation of the Chatham Islands. The spread of sand carex over the front of the foredune at Tioriori illustrated what a more natural vegetation cover might have looked like in the past. This vegetation allowed a slow build up of sand in a gentle crest, rather than the steeper profile typical of marram-covered dunes, and the sparse cover was suitable for oystercatchers to nest in.

An important requirement for successful dune revegetation efforts—stock exclusion—further benefits breeding oystercatchers by preventing eggs or chicks from being trampled, and stock from harassing incubating adults sitting on nests.

Although the extent of the restoration in this trial was relatively small, it does indicate that, even on a small scale, this kind of project can be of benefit to threatened shorebird species. Our results suggest that the extra space provided by marram removal was the key for birds nesting further inland. The maintenance of a gentle dune profile at Tioriri allowed a modest accumulation of sand, which raised the nesting area above high tide. A small change in beach profile can make the difference between inundation and safety at high tide or during storm tides, as the severity of wave action varies greatly, depending on the magnitude of storms, timing of the lunar cycle and the wind direction. Instead of physically managing the positions of oystercatcher nests by progressively moving them inland or laterally to higher ground, dune restoration allows the birds to choose their own sites in safe habitat. For example, nine nests that were moved an average of 11 m inland in the managed areas (Wharekauri and Maunganui) gained 1 m in elevation. Similar results were obtained at the restoration sites (Mairangi Creek and Tioriori) without direct manipulation. At Tioriori, birds nested 5–15 m further inland than previously, gaining an extra 0.5–0.8 m height above high tide. Greater benefits could be made if restoration and nest translocation were combined, since more space would be available for moving nests, and birds tend to return to sites where they have previously nested successfully (Moore 2009). Without the option of bulldozing steep dunes level to create shorebird habitat (as has been done for snowy plover; US Fish & Wildlife Service 2001), small ledges at the toe of restored steep foredunes on the Chatham Islands would have to be kept free of vegetation to provide nesting sites for oystercatchers.

Sea level rise, coastal erosion and the incidence of extreme storm events have accelerated as a result of climate change brought about by human activities. While the average sea level rise over the last 3000 years has been estimated at 0.1–0.2 mm per year, it has been 1–2 mm/year during the 20th Century (Church et al. 2001). Sea level rise is expected to continue to increase in the future—a rise of 0.05–0.11 m is projected by 2100 (Nicholls et al. 2007). This is likely to have major effects on shorebird intertidal feeding habitat (Galbraith et al. 2002). Egg losses caused by the sea are likely to be an increasing phenomenon (Weston 2003; Rounds et al. 2004; Boettcher et al. 2007), and beach-nesting species will need to adapt or move inland if they are to continue to breed successfully. In modified habitats (such as dunes vegetated with introduced marram), these species will struggle to survive unless provided with alternative habitats, such as restored native dunes. The current state of dunes on the Chatham Islands—which generally comprise a narrow (c. 50 m wide) foredune between the high tide mark and farmland—does not offer much flexibility for habitat management in the face of rising sea levels. Nevertheless, the DOC Chatham Island Area Office began preliminary work in 2005 to gradually extend the restoration of northern Chatham Island dunes. The plantings at Tioriori have been consolidated and extended to the northeast, and plans for future work include spraying of marram in oystercatcher habitat at Wharekauri and, potentially, initiating restoration at Manganui (subject to landowner permission), where fencing parallel to the coast has recently been completed (J. Clarkson, DOC, pers. comm.). In the long term, restoration of dune vegetation may have to expand inland as the rise in sea level impacts the current narrow strip of currently protected land.

Our findings are consistent with the positive effects of dune restoration reported for yellow-eyed penguin (*Megadyptes antipodes*) (D. McFarlane, Yellow-Eyed Penguin Trust, pers. comm.), snowy plovers (Powell & Collier 2000; Colwell et al. 2008; Lauten et al. 2008), piping plovers (*Charadrius melodus*) (Flemming et al. 1992; US Fish & Wildlife Service 1996; Cohen et al. 2008, 2009) and California least terns (*Sterna antillarum*), and are applicable to a range of New Zealand shorebirds and coastal species, such as New Zealand dotterel (Cumming 1991), white-fronted terns (*Sterna striata*), Caspian terns (*S. caspia*), variable oystercatcher (*Haematopus unicolor*), white-flippered penguins (*Eudyptula minor albosignata*) and black-billed gulls (*Larus bulleri*) (Christchurch City Council 2000; Grove 2003).

5. Conclusions

Over the past 100 years, the extensive dunelands of the Chatham Islands have been modified from a diverse native ecosystem to one dominated by marram grass. Dune restoration in northern Chatham Island was shown to increase the amount of available breeding habitat for Chatham Island oystercatchers. Two trial sites were transformed over 4 years from a monoculture of introduced marram to a more natural sequence of native dune plants. During this transformation there were no negative consequences, such as mobilisation of sand or exposure of Moriori cultural sites. An understanding of the habitat requirements of the dune plants, adapting management of the sites to local conditions and weed control, were elements in the successful establishment of native species. Newly created open ground and sparse vegetation on the front slope of the foredune were utilised by the local breeding oystercatchers, which, particularly at one site, nested further inland from the high tide mark than they had done previously. This reduced the risk of nests being washed away by high seas and removed the need to translocate nests to higher ground. Dune restoration presents a longer term alternative to intensive direct management of shorebird nests to minimise flooding by storm seas. Safer nesting habitat is created for shorebirds while also benefiting threatened coastal dune ecosystems, an approach that has application for other coastal areas of New Zealand.

6. Recommendations

The methods outlined in this report present guidelines for extending dune restoration on the Chatham Islands and also to other parts of New Zealand. The following steps are recommended for future dune restoration efforts:

1. Identify what the original dune vegetation was likely to have been, to determine the communities to be re-established.
2. Determine the sequence, pattern and density of planting.
3. Plant across the entire dune system (as in this trial), removing all of the exotic vegetation and replanting a strip across the entire dune. This may be more difficult on wide dune systems.
4. Allow sufficient time for site preparation, collection of seed stock and plant rearing. Prepare an area that will not exceed the plant supply for the following 2 years. This will reduce the likelihood of weed reinvasion and excessive sand mobilisation.
5. Remove marram before planting. The more thorough the initial removal of marram, the fewer the resources required to eliminate it from the site. It is far more difficult and labour intensive to remove marram once native plants are establishing. Marram removal requires:
    a. Herbicide application (although mechanical removal may be an alternative in areas that have no cultural significance and where young seedlings can be removed by hand pulling, provided all root material is removed);
    b. Suitable spraying conditions (calm and fine weather), which means schedules must be flexible, particularly for the Chatham Islands, where windy days are prevalent.
    c. Ensuring that any sand mobilisation on steeper dunes does not inundate native plantings in the back of the dunes or farm fences (by installing wind fences, for example).
6. Thoroughly remove of all other weeds and introduced pasture grasses prior to planting. This is essential for reducing the need for intensive hand-weeding during the native plants' establishment period.

7. Plant appropriate species in the zones where they will thrive, and protect existing native plants by reducing competing weeds and allowing them to self-establish. Ensure there is adequate plant stock to compensate for plant losses and for the introduction of later-phase species.
8. Fertilise plantings with a slow-release fertiliser at the time of planting and top-dress with fertiliser in subsequent years. Using fertilisers that are available naturally at restoration sites (e.g. seaweed) can help establish coastal herbs such as forget-me-not and sow thistles.
9. Exclude stock to prevent them from browsing the native vegetation, especially megaherbs. Even occasional access by stock can set back plantings by several years, as stock target the new plants, which may then be smothered by introduced pasture grasses and other weeds before they can recover from the browsing. Control of rabbits and hares is essential for dune restoration at mainland New Zealand sites to succeed, as they can remove all pīngao seedlings and severely browse shrubs and trees (AD & MB, pers. obs.).
10. Maintain the site to prevent marram regrowing from rhizome fragments, and from reseeding and rhizome growth into the restoration site from neighbouring areas of marram. Close proximity of farmland to restoration sites provides weed sources, making weed control essential, particularly during the plant establishment phase.
11. Plan for long-term maintenance of the dune restoration site. The minimum requirements are stock exclusion and control of marram reinvasion. On Stewart Island/Rakiura, 7 years of site maintenance was required to significantly reduce the risk of marram reinvasion (M. Hilton, University of Otago, pers. comm.). Control of other weeds may also be required; although, as the plantings establish, this is likely to be needed only in the active part of the dune where bare sand persists. To increase the benefits of restoration, once a good cover of native vegetation has established, plant diversity can be increased by planting other threatened and secondary species.
12. In the future, translocation of oystercatcher nests into newly opened dune areas may achieve greater nesting success than leaving the birds to choose their own sites. Pairs that have successfully hatched young are more likely to choose the same site in the following breeding season, and since the species has shown a high tolerance of nest movement, translocation may increase the benefits of restoration of breeding habitat.
13. The vegetative cover of the front slope of the foredune may need to be opened up periodically, regardless of the vegetation growing there, to maintain optimal nesting habitat for oystercatchers. The most favourable period for nesting is likely to be the early part of restoration, when there is plentiful open space, sparse vegetation and small seedling plants. The restored sites may gradually stabilise with time, so every 5 years or so the dune front may need to be cleared of vegetation.

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Appendix 1

Locations and dates of seed collection

Location and dates of seed collection of plant species used at dune restoration trial sites at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05. SR = Scenic Reserve; Hapupu NHR = J.M. Barker (Hapupu) National Historic Reserve.

SPECIES	LOCATION OF SEED COLLECTION	DATE OF SEED COLLECTION (2002)	PURPOSE OF COLLECTION
Sand coprosma	Ocean Mail	5 Apr	Nursery propagation
Chatham Island corokia	Harold Pierce SR	12 Mar	Nursery propagation
	Kaingaroa Harbour	18 Mar	Nursery propagation
Pīngao	Waitangi West	7 Mar	Nursery propagation
Chatham Island sow thistle	Waitangi West	12 Mar	Nursery propagation
	Kaingaroa Harbour	18 Mar	Nursery propagation
	Kaingaroa Harbour	5 Apr	Direct sowing
Dieffenbach's hebe	Kaingaroa Harbour	1 Mar	Nursery propagation
	Kaingaroa Harbour	5 Apr	Nursery propagation
Knobby clubrush	Kaingaroa settlement	5 Apr	Direct sowing
Dune mingimingi	Harold Pierce SR	12 Mar*	Nursery propagation
Chatham Island forget-me-not	West of Kaingaroa	12 Mar	Nursery propagation
	Kaingaroa settlement	5 Apr	Direct sowing
Chatham Island māpou	Harold Pierce SR	12 Mar	Nursery propagation
	Hapupu NHR	12 Mar	Nursery propagation
Chatham Island akeake	Harold-Peirce SR	12 Mar	Nursery propagation
Sand daphne	Harold Pierce SR	12 Mar	Nursery propagation
	Kaingaroa Harbour	5 Apr*	Nursery propagation
Lobelia arenaria	Kaingaroa Harbour	5 Apr	Direct sowing

* Only a few seeds only collected

Appendix 2

Seed sources of plants used for dune restoration

Seed sources of plants used at dune restoration trial sites at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05. PB3 = planter bags, RTH = root trainers (Hilson); SR = Scenic Reserve.

MAIRANGI CREEK				TIORIORI			
SPECIES	SIZE/GRADE	SOURCE LOCATION	NUMBER PLANTED	SPECIES	SIZE/GRADE	SOURCE LOCATION	NUMBER PLANTED
September 2001 plantings							
Chatham Island flax transplants	Cuttings—root material (c. 0.5 m tall)	Ocean Mail	58	Chatham Island flax transplants	Cuttings—root material (c. 0.5 m tall)	Ocean Mail	50
Euphorbia	PB3	Henga SR	15	Euphorbia	PB3	Kaingaroa Harbour	40
Pīngao	PB3	Kaingaroa Harbour	63	Pīngao	PB3	Waitangi West	149
Pīngao	Pot	Kaingaroa Harbour	154	Pīngao	Pot	Waitangi West	315
Knobby clubrush	Cuttings—root material	Mairangi Beach	15				
Chatham Island forget-me-not	PB3	Henga SR	73				
New Zealand spinach	Cuttings—root material	Mairangi Beach	5				
Sand daphne	Cuttings (c. 50% with root material)	Mairangi Beach	66				
Carex virgata	Cuttings—root material	Mairangi Creek	80				
April 2002 plantings							
Chatham Island akeake	RTH	Tangepu, Ocean Mail	1200	Chatham Island akeake	RTH	Tangepu	1300
Sand coprosma	Transplants—cuttings	Mairangi	16	Atriplex	Transplants—cuttings	Tioriori	2
Sand daphne	Transplants—cuttings	Mairangi	4				
October 2002 plantings							
Chatham Island akeake	RTH	Ocean Mail	250	Chatham Island akeake	RTH	Ocean Mail	1295
Chatham Island flax transplants	Transplants	Ocean Mail	380	Chatham Island flax transplants	Transplants	Ocean Mail	120
Sand coprosma	Pot	Ocean Mail	5	Sand coprosma	Pot	Ocean Mail	8
Sand daphne	Pot	Ocean Mail	29	Sand daphne	Pot	Ocean Mail	16
Euphorbia	PB3	Kaingaroa	18	Euphorbia	PB3	Kaingaroa	62
Chatham Island forget-me-not	PB3	Kaingaroa	89	Chatham Island forget-me-not	PB3	Kaingaroa	42
Pīngao	RTH & Pots	Kaingaroa	138	Pīngao	RTH & Pots	Waitangi West (2/3), Kaingaroa (1/3)	1394

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Appendix 2 continued

MAIRANGI CREEK				TIORIORI			
SPECIES	SIZE/GRADE	SOURCE LOCATION	NUMBER PLANTED	SPECIES	SIZE/GRADE	SOURCE LOCATION	NUMBER PLANTED
April 2003 plantings							
Chatham Island akeake	RTH	Ocean Mail	360	Chatham Island akeake	RTH	Ocean Mail	80
Chatham Island corokia	Pots	Ocean Mail	192	Chatham Island corokia	Pot	Ocean Mail	180
Dieffenbach's hebe	Pot	Ocean Mail	23	Dieffenbach's hebe	Pot	Ocean Mail	18
Euphorbia	Pots & PB3	Kaingaroa	106				
Chatham Island forget-me-not	PB3	Kaingaroa	10				
Chatham Island sow thistle	PB3	Kaingaroa	90				
Pīngao	RTH, Pots, PB3	Kaingaroa	232				
April 2004 plantings							
Chatham Island akeake	RTH	No data	976	Chatham Island akeake	RTH	Tangepu, Ocean Mail	28
Chatham Island corokia	Pot	No data	12	Sand coprosma	Pot	No data	34
Chatham Island sow thistle	PB3	No data	89	Chatham Island sow thistle	PB3	No data	69
Dieffenbach's speargrass	PB3	No data	5	Dieffenbach's speargrass	PB3	No data	12
Sand coprosma	Pot	No data	75				
Sand daphne	Pot	No data	60				
Chatham Island forget-me-not	PB3	No data	15				
Euphorbia	PB3	No data	136				
Pīngao	RTH, Pot	No data	270				
April 2005 plantings							
Dieffenbach's hebe	PB3	No data	24				

Appendix 3

Species and plants numbers used in dune restoration

Species and plant numbers used at dune restoration trial sites at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05.

TRIAL SITE	PLANT SPECIES	AREA	ZONE	NUMBER OF PLANTS						
				OCT 2001	APR 2002	OCT 2002	APR 2003	MAY 2004	APR 2005	TOTAL PLANTED
Mairangi Creek	Chatham Island akeake	Core area	2		1200					
		Southeast extension	3			250				
		Northwest extension	4				360	400		
		Northwest extension	6					576		
		All areas								2786
	Chatham Island flax transplants	Fenceline core area	2	58						
		Core area and southeast extension	2, 3			380				
		All areas								438
	Chatham Island corokia	Core area and extensions	2, 3, 4				192	12		204
	Dieffenbach's hebe	Core area and extensions	2, 3, 4				23		24	47
	Sand coprosma cuttings	Core area	2		16					
	Sand coprosma	Core area	2			5		45		
		Northwest extension	4					30		
		All areas								96
	Sand daphne cuttings	Core area	2		4	29		26		
		Northwest extension	4					34		
		All areas								93
	Carex virgata transplants	Core area	1	80						80
	Knobby clubrush transplants	Core area	1	15						15
	Euphorbia	Core area	2	15		18		70		
		Northwest extension	4				106	25		
			5					41		
		All areas								275
	Chatham Island sow thistle	Core area, northwest extension	1, 4				90			
		Core area	1					23		
		Northwest extension	4					52		
			5					14		
		All areas								179

Continued on next page

Appendix 3 continued

TRIAL SITE	PLANT SPECIES	AREA	ZONE	NUMBER OF PLANTS						
				OCT 2001	APR 2002	OCT 2002	APR 2003	MAY 2004	APR 2005	TOTAL PLANTED
	Dieffenbach's speargrass	Northwest extension	4					5		5
	Chatham Island forget-me-not	Core area	1	73		89				
		Northwest extension	4				10	8		
			5					7		
		All areas								114
	Pīngao	Core area	1	217						
		Northwest extension				138				
			4				232	24		
			5					246		
		All areas								857
Tioriori	Chatham Island akeake	Core area	2		1300			14		
		Extensions	4			1295	80	14		
		All areas								2689
	Chatham Island flax transplants	Fenceline core area	2	50						
		Western extension	4			120				
		All areas								170
	Chatham Island corokia	Core area, extensions	2, 4				180			180
	Dieffenbach's hebe	Core area, extensions	2, 4				18			18
	Sand coprosma	Core area, extensions	1, 3			8		34		42
	Sand daphne	Core area, extensions	1, 3			16				16
	Euphorbia	Core area	1	40						
		Core area, extensions	1, 3			42				
		All areas								82
	Chatham Island sow thistle	Core area	1					31		
		Western extension	3					38		
		All areas								69
	Dieffenbach's speargrass	Core area	1					12		12
	Chatham Island forget-me-not	Core area, extensions	1, 3			62				62
	Pīngao	Core area	1	463						
		Extensions	3			1394				
		Allareas								1857
Total Mairangi	**All species**									**5189**
Total Tioriori	**All species**									**5197**
Grand total	**All species**									**10386**

Appendix 4

Survival of plants at dune restoration trial sites

Survival of plants at dune restoration trial sites at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05.

SITE	SPECIES	2001–02		2002–03		2003–04		2005		GRAND TOTAL PLANTED
		TOTAL PLANTED	TOTAL LIVE PLANTS APR 2002	TOTAL PLANTED	TOTAL LIVE PLANTS APR 2003	TOTAL PLANTED	TOTAL LIVE PLANTS APR 2004	TOTAL PLANTED	TOTAL LIVE PLANTS APR 2005	
Mairangi Creek	Chatham Island akeake	1200	1200	610	1294	976	2063	0	1724	2786
	Chatham Island flax transplants	58	54	380	No data	0	321	0	316	438
	Chatham Island corokia	0	0	192	192	12	133	0	34	204
	Dieffenbach's hebe	0	0	23	23	0	6	24	27	47
	Carex virgata transplants	80	16	0	0	0	0	0	0	80
	Knobby clubrush transplants	15	15	0	11	0	No data	0	No data	15
	Sand coprosma	0	0	5	0	75	75	0	3	80
	Sand coprosma cuttings	16	16	0	0	0	0	0	0	16
	Sand daphne	0	0	29	14	60	61	0	6	89
	Sand daphne cuttings	4	4	0	0	0	0	0	0	4
	Euphorbia	15	12	124	136	136	175	0	24	275
	Chatham Island sow thistle	0	0	90	90	89	109	0	42	179
	Dieffenbach's speargrass	0	0	0	0	5	5	0	4	5
	Chatham Island forget-me-not	73	55	99	100	15	120	0	103	187
	Pīngao	217	195	370	382	270	560	0	262	857
Tioriori	Chatham Island akeake	1300	1300	1375	2582	28	2146	0	1733	2703
	Chatham Island flax transplants	50	40	120	No data	0	77	0	84	170
	Chatham Island corokia	0	0	180	180	0	132	0	165	180
	Dieffenbach's hebe	0	0	18	18	0	18	0	20	18
	Sand coprosma	0	0	8	5	34	35	0	42	42
	Sand daphne	0	0	16	19	0	22	0	No data	16
	Euphorbia	40	39	42	182 m^2	0	No data	0	313 m^2	82
	Chatham Island sow thistle	0	0	0	0	69	69	0	37	69
	Dieffenbach's speargrass	0	0	0	0	12	12	0	10	12
	Chatham Island forget-me-not	0	0	62	69	0	61	0	62	62
	pīngao	463	320	1394	2276	0	2016	0	1984	1857

Appendix 5

Growth of plants at dune restoration trial sites

Growth of plants at dune restoration trial sites at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05.

TRIAL SITE	PLANT	AREA	AREA NO.	DATE PLANTED	DATE MEASURED	MEAN HEIGHT (cm)	SD	MEAN BREADTH (cm) (WIDEST EXTENT)	SD	NO. PLANTS MEASURED
Mairangi Creek	Chatham Island akeake	Core area	2	Apr 2002	Apr 2002	25.0	NA	10.0	NA	30
					Apr 2003	44.8	14.2	21.5	10.8	20
					Sep 2003	69.8	16.8	44.4	9.5	30
					May 2004	103.7	26.3	52.3	13.0	30
						133.9	28.0	78.0	18.6	29
		Southeast extension	3	Oct 2002	Oct 2002	25.0	NA	10.0	NA	20
					Apr 2003	47.7	10.1	17.4	6.1	20
					Sep 2003	51.3	11.0	42.5	13.8	30
					May 2004	79.2	22.8	40.7	20.0	25
						115.4	28.9	60.6	19.4	24
		Northwest extension	4	Apr 2003	Apr 2003	25.0	NA	10.0	NA	20
					Sep 2003	29.2	7.6	14.7	3.1	20
					May 2004	49.4	15.7	26.0	10.5	20
						97.8	29.1	58.2	22.7	17
	Chatham Island flax transplants	Core area Fenceline	2	Oct 2001	Oct 2002	50.0	NA	15.0	NA	20
					Apr 2003	109.5	20.4	30.7	8.7	20
					Sep 2003	95.4	15.8	142.7	21.7	30
					May 2004	157.0	24.0	179.7	24.4	30
						167.5	18.0	221.3	34.9	30
		Core area, eastern extension	2, 3	Oct 2002	Oct 2002	30.0	NA	15.0	NA	20
		All areas	2	Oct 2002	Apr 2003	65.1	13.2	11.0	3.5	20
	Chatham Island corokia	Core area and extensions	2, 3, 4	Apr 2003	Apr 2003	25.0	NA	8.0	NA	20
		Southeast extension	3	Apr 2003	Sep 2003	20.8	5.0	12.4	3.4	30
					May 2004	30.7	9.3	21.0	8.4	22
						33.9	11.7	23.3	5.5	10
	Dieffenbach's hebe	Core area and extensions	2, 3, 4	Apr 2003	Apr 2003	25.0	NA	8.0	NA	20
					Sep 2003	28.8	5.6	10.3	3.8	15
					May 2004	172.0	92.3	256.0	55.9	5
						64.0	NA	93.0	NA	1

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Appendix 5 continued

TRIAL SITE	PLANT	AREA	AREA NO.	DATE PLANTED	DATE MEASURED	MEAN HEIGHT (cm)	SD	MEAN BREADTH (cm) (WIDEST EXTENT)	SD	NO. PLANTS MEASURED
Mairangi Creek	Sand coprosma	Core area	2	Oct 2002	Oct 2002	15.0	NA	10.0	NA	5
			1		Sep 2003	NA	NA	NA	NA	0
	Sand daphne	Core area	2	Oct 2002	Oct 2002	15.0	NA	5.0	NA	20
					Apr 2003	22.6	7.4	NA	NA	14
			1		Sep 2003	19.0	4.6	23.0	13.9	4
					May 2004	18.0	2.3	39.0	1.2	4
					Apr 2005	NA	NA	NA	NA	0
	Carex virgata transplants	Core area	1	Oct 2001	Oct 2001	35.0	NA	10.0	NA	15
	Knobby clubrush transplants	Core area	1	Oct 2001	Oct 2001	30.0	NA	15.0	NA	15
					Apr 2003	35.3	20.6	26.5	15.1	11
	Euphorbia	Core area	2	Oct 2001	Oct 2001	50.0	NA	30.0	NA	15
					Apr 2002	46.0	8.9	58.0	14.8	5
				Oct 2002	Oct 2002	50.0	NA	30.0	NA	10
				Oct 2001, Oct 2002	Apr 2003	29.9	10.8	29.8	20.0	29
			1, 4	Oct 2001, Oct 2002	Sep 2003	10.7	4.7	23.4	15.9	16
					May 2004	14.0	2.6	24.3	12.9	3
					Apr 2005	NA	NA	NA	NA	0
		Northwest extension	4	Apr 2003	Apr 2003	50.0	NA	30.0	NA	30
					Sep 2003	32.1	9.2	30.1	13.7	30
					May 2004	28.9	11.1	51.6	32.9	25
					Apr 2005	31.0	2.9	105.3	39.2	4
	Chatham Island sow thistle	Core area, northwest extension	1, 4	Apr 2003	Apr 2003	20.0	NA	15.0	NA	30
					Sep 2003	6.5	2.2	16.5	5.9	30
					May 2004	12.7	4.9	39.3	23.7	10
					Apr 2005	34.4	20.3	137.9	83.1	9
	Chatham Island forget-me-not	Core area	1	Oct 2001	Oct 2001	40.0	NA	40.0	NA	30
					Apr 2002	50.0	NA	58.0	4.5	5
					Oct 2002	21.5	10.4	52.5	18.9	15
					Apr 2003	15.8	8.1	33.1	21.9	30
				Oct 2002	Oct 2002	40.0	NA	40.0	NA	30

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Appendix 5 continued

TRIAL SITE	PLANT	AREA	AREA NO.	DATE PLANTED	DATE MEASURED	MEAN HEIGHT (cm)	SD	MEAN BREADTH (cm) (WIDEST EXTENT)	SD	NO. PLANTS MEASURED
				Oct 2001, Oct 2002	Sep 2003	28.7	12.7	74.1	30.2	30
					May 04	21.8	12.3	59.3	26.9	26
					Apr 2005	18.6	9.2	65.7	34.8	22
		Northwest extension	4	Apr 2003	Apr 2003	40.0	NA	40.0	NA	10
					Sep 2003	15.1	3.3	43.8	11.2	13
					May 2004	19.4	5.9	50.3	16.0	10
					Apr 2005	38.2	11.8	82.1	20.7	10
	Pīngao	Core area	1	Oct 2001	Oct 2001	25.0	NA	10.0	NA	30
					Apr 2002	52.0	14.0	70.5	33.3	20
					Oct 2002	48.9	11.1	129.6	236.5	20
					Apr 2003	45.1	11.0	41.8	29.3	29
					Sep 2003	55.8	14.0	149.9	42.2	30
					May 2004	53.8	10.9	155.0	43.8	22
					Apr 2005	40.4	2.9	144.8	50.5	5
		Northwest extension	4	Oct 2002	Oct 2002	25.0	NA	10.0	NA	30
				Apr 2003	Apr 2003	25.0	NA	10.0	NA	30
					Sept 2003	28.7	7.7	32.6	11.6	30
					May 2004	35.8	9.7	42.6	13.7	19
					Apr 2005	36.0	NA	71.0	NA	1
Tioriori	Chatham Island akeake	Core area	2	Apr 2002	Apr 2002	25.0	NA	10.0	NA	30
					Apr 2003	69.6	24.8	36.5	7.9	20
					Sep 2003	98.1	21.5	53.1	13.9	29
					May 2004	151.5	30.0	66.2	17.3	30
					Apr 2005	248.0	34.3	86.8	19.8	30
				Oct 2002	Oct 2002	25.0	NA	10.0	NA	20
		Western and eastern extensions		Oct 2002	Oct 2002	25.0	NA	10.0	NA	20
					Apr 2003	48.7	12.7	20.9	9.3	40
		Eastern extension	4	Oct 2002	Sep 2003	62.8	11.9	34.7	11.9	30
					May 2004	96.9	19.7	47.8	13.2	25
					Apr 2005	157.4	36.4	75.0	24.2	26
				Apr 2003	Apr 2003	55.4	10.7	21.9	10.9	20

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Appendix 5 continued

TRIAL SITE	PLANT	AREA	AREA NO.	DATE PLANTED	DATE MEASURED	MEAN HEIGHT (cm)	SD	MEAN BREADTH (cm) (WIDEST EXTENT)	SD	NO. PLANTS MEASURED
	Chatham Island flax transplants	Along fenceline		Oct 2001	Oct 2001	50.0	NA	15.0	NA	30
		Core area			Oct 2002	50.0	NA	15.0	NA	30
					Sep 2003	56.7	26.7	78.7	45.3	30
					Apr 2005	131.2	48.1	159.5	73.0	21
		Western extension		Oct 2002	Oct 2002	50.0	NA	15.0	NA	30
	Corokia	Core area and extensions		Apr 2003	Apr 2003	25.0	NA	8.0	NA	30
		Core area	2	Apr 2003	Sep 2003	23.3	7.1	12.8	3.3	30
					May 2004	41.6	10.5	19.2	7.1	28
					Apr 2005	58.0	14.5	40.3	12.4	27
	Dieffenbach's hebe	Core area and extensions		Apr 2003	Oct 2002	25.0	NA	8.0	NA	15
		Core area	2	Apr 2003	Sep 2003	52.5	14.4	35.5	10.9	15
					May 2004	76.4	17.7	83.2	15.2	14
					Apr 2005	109.7	17.0	182.1	39.9	15
	Sand coprosma	Core area and extensions		Oct 2002	Oct 2002	15.0	NA	10.0	NA	8
					Apr 2003	14.6	5.5	43.6	7.2	5
		Core area	Area 1	Oct 2002	Sep 2003	16.0	9.8	45.3	15.7	7
					May 2004	19.0	2.7	62.8	15.1	4
					Apr 2005	22.2	4.8	117.8	20.3	6
	Sand daphne	Core area and extensions		Oct 2002	Oct 2002	15.0	NA	5.0	NA	15
					Apr 2003	23.0	7.2	10.6	8.2	19
		core area	Area 1	Oct 2002	Sep 2003	20.0	7.0	12.4	7.6	14
					May 2004	22.9	3.8	39.7	20.7	7
					Apr 2005	28.9	7.1	67.2	27.0	13
	Euphorbia	Core area		Oct 2001	Oct 2001	50.0	NA	30.0	NA	30

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Appendix 5 continued

TRIAL SITE	PLANT	AREA	AREA NO.	DATE PLANTED	DATE MEASURED	MEAN HEIGHT (cm)	SD	MEAN BREADTH (cm) (WIDEST EXTENT)	SD	NO. PLANTS MEASURED
	Euphorbia	Core area		Oct 2001	Oct 2002	38.4	10.0	117	26.2	10
					Apr 2003	30.1	6.6	48.5	16.9	20
		Core area, western and eastern extensions		Oct 2002	Apr 2002	50.0	NA	30.0	NA	30
						30.1	6.6	48.5	16.9	20
		All areas	3b	Oct 2002	Sep 2003	31.1	9.0	73.2	37.3	30
					May 2004	35.0	14.6	119.7	76.0	25
					Apr 2005	44.1	22.9	83.0	51.2	18
	Chatham Island forget-me-not	Core area and extensions		Oct 2002	Oct 2002	40.0	NA	40.0	NA	20
		Core area	1	Oct 2002	Apr 2003	18.9	5.8	35.0	12.5	20
					Sep 2003	27.7	7.9	65.0	18.7	30
					May 2004	27.9	8.9	60.6	18.6	28
					Apr 2005	30.8	9.5	69.2	19.4	17
	Pīngao	Core area	1	Oct 2001	Oct 2001	25.0	NA	10.0	NA	30
					Apr 2002	45.3	9.2	56.7	14.5	20
					Oct 2002	49.2	11.9	67.4	21.2	20
					Apr 2003	41.6	12.0	49.0	26.8	20
					Sep 2003	56.1	10.4	83.8	32.6	30
					May 2004	54.4	13.4	93.3	38.2	26
					Apr 2005	52.9	11.3	116.9	47.7	13
		Western and eastern extensions		Oct 2002	Oct 2002	25.0	NA	10.0	NA	30
		Western extension	1	Oct 2002	Apr 2003	31.7	8.5	24.3	7.6	15
					Sep 2003	47.3	10.9	75.4	28.8	30
					May 2004	40.6	10.5	73.6	33.5	23
						56.6	8.0	142.1	44.4	9

Appendix 6

Direct seeding trials at dune restoration trial sites

Direct seeding trials at dune restoration trial sites at Mairangi Creek and Tioriori, northern Chatham Island, 2001–05.

TRIAL SITE	SPECIES	SIZE OF PLOT	DATE SOWN	PLOT NO.	PRESENCE OF SEEDLINGS OCT 2002	NO. OF SEEDLINGS OCT 2002	PRESENCE OF SEEDLINGS APR 2003	NO. OF SEEDLINGS APR 2003	PRESENCE OF SEEDLINGS OCT 2003	NO. OF SEEDLINGS OCT 2003	PRESENCE OF SEEDLINGS APR 2004	NO. OF SEEDLINGS APR 2004	PRESENCE OF SEEDLINGS APR 2005	NO. OF SEEDLINGS APR 2005
Mairangi Creek	Chatham Island forget-me-not	0.4 m diameter	Apr 2002	1	Yes	2–12	No data	No data	No	0	No	0	No	0
				2	Yes	2–12	No data	No data	No	0	No	0	No	0
				3	Yes	2–12	No data	No data	No	0	No	0	No	0
				4	Yes	2–12	No data	No data	Yes	9	Yes	9	No	0
				5	Yes	2–12	No data	No data	No	0	Yes	5	No	0
			Apr 2003	6			No data	No data	No	0	No	0	No	0
				7			No data	No data	No	0	No	0	No	0
				8			No data	No data	No	0	No	0	No	0
				9			No data	No data	Yes	20	Yes	20	No	0
				10			No data	No data	Yes	11	Yes	11	Yes	4
				11			No data	No data	No	0	No	0	No	0
				12			No data	No data	Yes	4	Yes	4	No	0
				13			No data	No data	Yes	2	No	0	No	0
				14			No data	No data	Yes	25	Yes	2	No	0
				15			No data	No data	No	0	Yes	25	Yes	4
				16			No data	no data	Yes	0	No	0	No	0
				17			No data	No data	Yes	4	Yes	4	No	0
				18			No data	No data	No	0	No	0	No	0
	Chatham Island sow thistle	0.4 m diameter	Apr 2002	1	No	0	No data	No data	No	0	No	0	No	0
				2	No	0	No data	No data	No	0	No	0	No	0
				3	no	0	No data	No data	No	0	No	0	No	0
				4	No	0	No data	No data	No	0	No	0	Yes	1
				5	No	0	No data	No data	No	0	No	0	Yes	1
			Apr 2003	6					No	0	No	0	No	0
				7					No	0	No	0	No	0
				8					No	0	No	0	No	0
				9					No	0	No	0	No data	No data
				10					No data	No data	No data	No data	No data	No data
				11					No data	No data	No data	No data	No data	No data
				12					No data	No data	No data	No data	No data	No data
				13					No data	No data	No data	No data	No data	No data
				14					No data	No data	No data	No data	No data	No data

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Appendix 6 continued

TRIAL SITE	SPECIES	SIZE OF PLOT	DATE SOWN	PLOT NO.	PRESENCE OF SEEDLINGS OCT 2002	NO. OF SEEDLINGS OCT 2002	PRESENCE OF SEEDLINGS APR 2003	NO. OF SEEDLINGS APR 2003	PRESENCE OF SEEDLINGS OCT 2003	NO. OF SEEDLINGS OCT 2003	PRESENCE OF SEEDLINGS APR 2004	NO. OF SEEDLINGS APR 2004	PRESENCE OF SEEDLINGS APR 2005	NO. OF SEEDLINGS APR 2005
	Euphorbia	0.4 m diameter	Apr 2003	1					No	0	No	0	No	0
				2					No	0	No	0	No	0
				3					No	0	No	0	No	0
				4					No	0	No	0	No	0
	Lobelia arenaria	Seed broadcasted	Apr 2002	NA	No	0	No data	No data	No data	No data	No data	No data	No data	No data
	Knobby clubrush	Seed broadcasted	Apr 2002	NA	No	0	No data	No data	No data	No data	No data	No data	No data	No data
	Chatham Island akeake	2 m^2	Apr 2003	1					No	0	No	0	No	0
				2					No	0	No	0	No	0
				3					No	0	No	0	no	0
				4					No	0	No	0	No	0
				5					No	0	No	0	No	0
Tioriori	Chatham Island forget-me-not	0.4 m diameter	Apr 2002	1	Yes	18	No	0	Yes	100	No	0		
				2	Yes	0	No	0	No	0	No	0		
				3	No	6	No	0	No	0	No	0		
				4	No	0	No	0	No	0	No	0		
			Apr 2003	5					Yes	1	Yes	1		
				6					Yes	106	No	0		
				7					Yes	130	Yes	1		
				8					Yes	120	Yes	1		
	Chatham Island sow thistle	0.4 m diameter	Apr 2002	1	No	0	No	0	No	0	No	0		
				2	No	0	No	0	No	0	No	0		
				3	No	0	No	0	No	0	No	0		
				4	No	0	No	0	No	0	No	0		
				5	No	0	No	0	No	0	No	0		

Appendix 7

Dune profiles in northern Chatham Island

Dune profiles in northern Chatham Island as measured by surveyor's dumpy level in February 2001 (Figs A7.1–A7.9). Location of profiles is shown in Fig. 7.

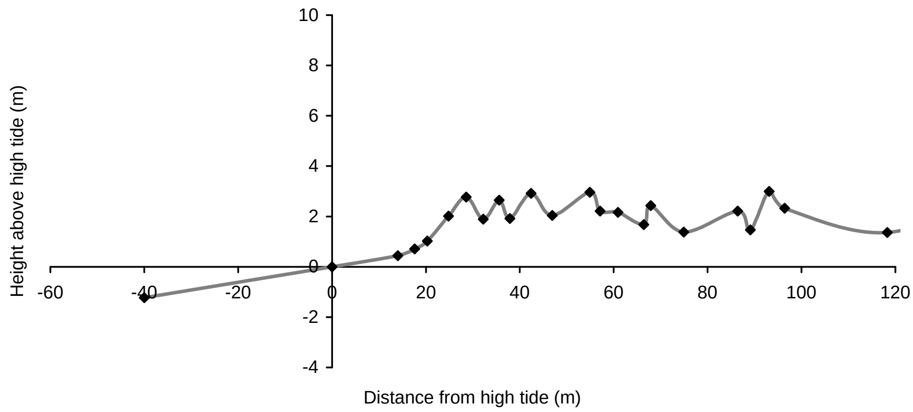

Figure A7.1. Waitangi West dune profile (LT1), northern Chatham Island (vertical scale exaggerated).

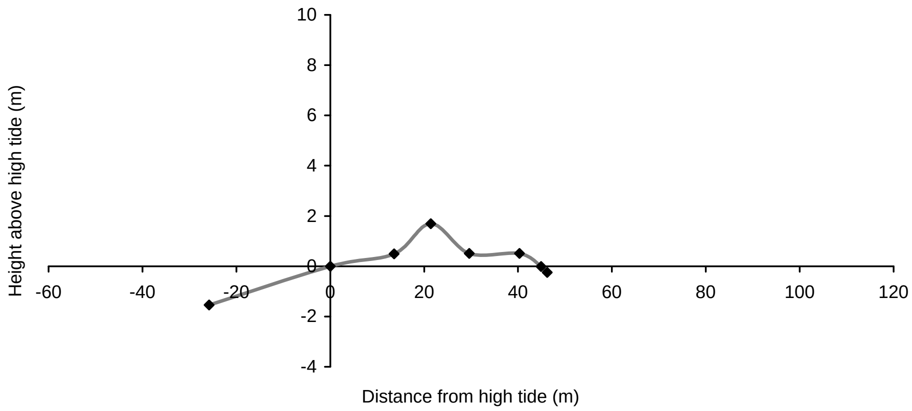

Figure A7.2. Washout West dune profile (LT3), Maunganui, northern Chatham Island (vertical scale exaggerated).

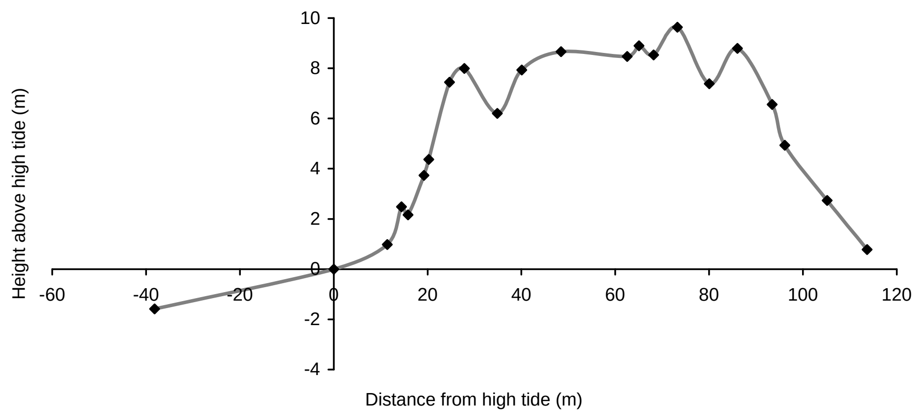

Figure A7.3. Maunganui Beach dune profile (LT2), Maunganui, northern Chatham Island (vertical scale exaggerated).

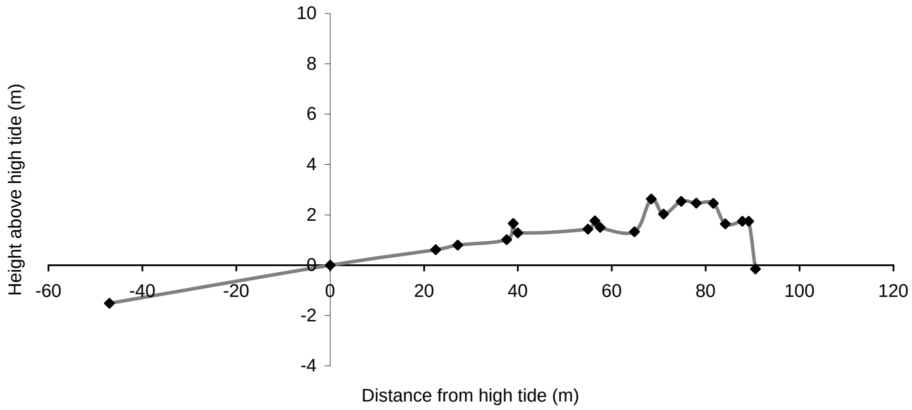

Figure A7.4. Takehanga dune profile (LT7), Maunganui, northern Chatham Island (vertical scale exaggerated).

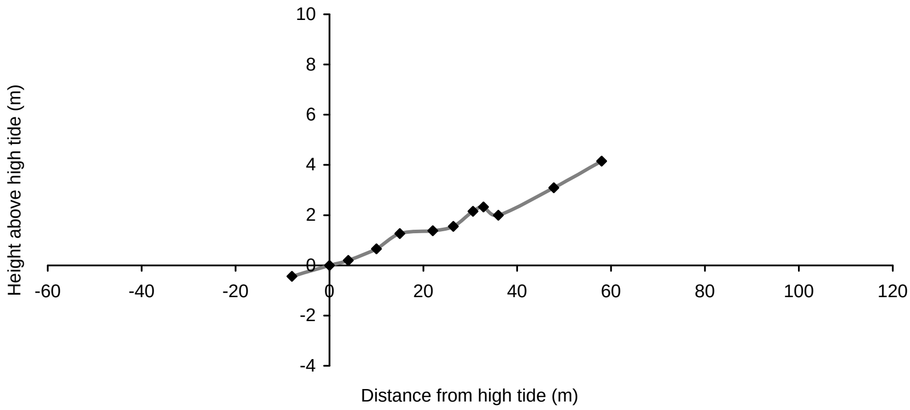

Figure A7.5. Tioriori restoration area dune profile (LT4b), Maunganui, northern Chatham Island (vertical scale exaggerated).

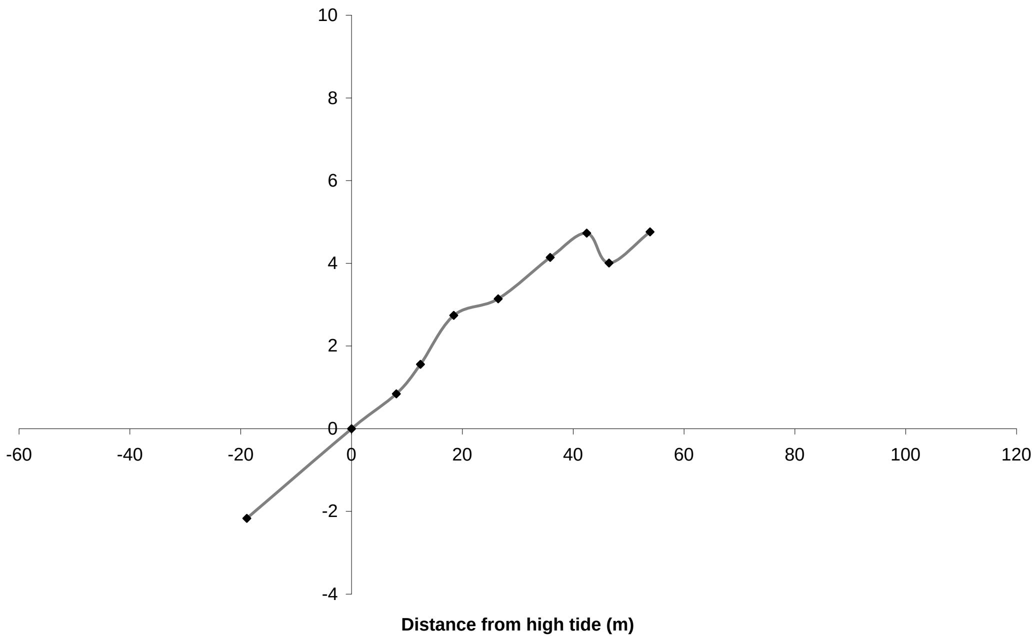

Figure A7.6. Tioriori dune profile (LT4), Maunganui, northern Chatham Island (vertical scale exaggerated).

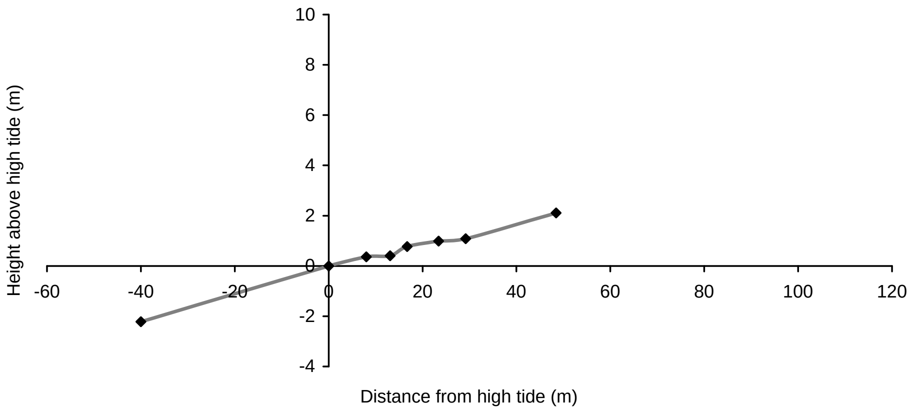

Figure A7.5. Mairangi Creek restoration area dune profile (LT6), Wharekauri, northern Chatham Island (vertical scale exaggerated).

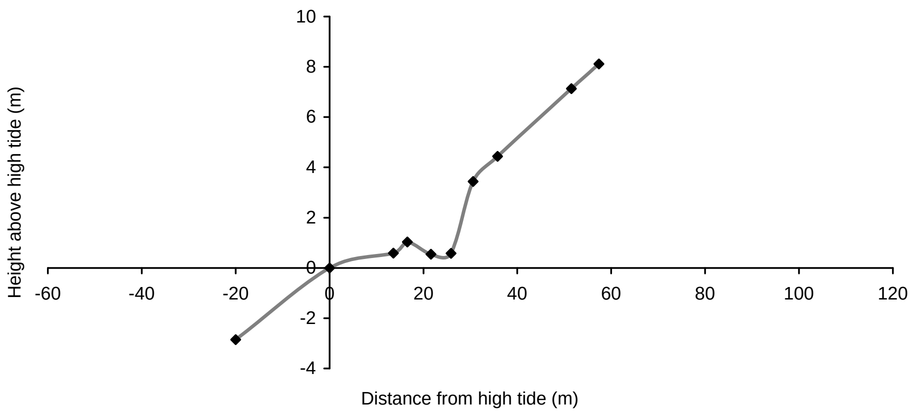

Figure A7.6. Mairangi Beach dune profile (LT6b), Wharekauri, northern Chatham Island (vertical scale exaggerated).

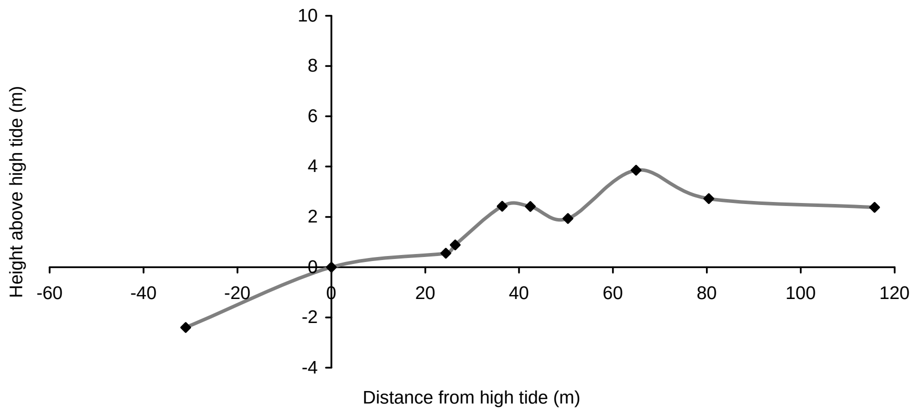

Figure A7.9. Woolshed dune profile (LT5), Wharekauri, northern Chatham Island (vertical scale exaggerated).