Enhancing the Ecological Health of Western Port

Mangrove Planting for Coastal Stabilisation 2010-2013
Final Report

Acknowledgements

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Summary

Seagrass populations in Western Port declined by around 70% in the late 1970's and early 1980's (Bulthuis, 1984). While many theories explaining this decline exist, there is general agreement that excessive sediment input to the bay has played a leading role (Melbourne Water, 2011). In particular, excess sediments which are resuspended by waves and daily tides reduce water quality and compromise the ability of seagrasses to photosynthesise in the turbid water. Additionally, the sediment that is dumped onto the bottom of the bay raises the level of seagrass habitat. This results in a higher likelihood of seagrass desiccation by longer exposure to hot weather when it coincides with very low tides. While some recovery of the seagrass meadows in Western Port has been observed in since the 1980's, there are still large areas which the plant has been unable to recolonise (Melbourne Water, 2011).

The large drains that were cut into the Koo Wee Rup Swamp from the mid-19th century are the source of much of the sediment (Wallbrink et al., 2003). Melbourne Water and other organisations have been attempting to reduce the impact of these drains through stormwater quality improvement, waterway stabilisation and revegetation programs in the catchments. However, coastal erosion is another large source of sediment to the bay which has not received as much attention. CSIRO estimated that as much as 32% of sediment entering the bay could be derived from a 9km stretch of eroding coastline in the northeast of the bay (Wallbrink et al., 2003) which is also adjacent to the part of the bay experiencing the most persistent seagrass loss. The Western Port Seagrass Partnership, in conjunction with the community, has attempted to grow seagrass at several locations and has also been trying to stabilise this part of the coastline by planting mangroves for a number of years. Besides their efforts and some ad hoc stabilisation attempts by adjacent landowners, there have been very few attempts to seriously address the problem. The remoteness of the site and the scale of the problem have meant that using

conventional engineering solutions (i.e. seawalls) would be prohibitively expensive. Additionally, the question of who is responsible for the management of this coastline remains unclear.

Melbourne Water has concern for the quality of the receiving waters in its jurisdiction, namely Port Phillip and Western Port and the Better Bays and Waterways strategy identified this issue as a priority. This allowed Melbourne Water to secure Victorian State Government funding to address the coastal erosion problem in Western Port using mangrove revegetation as a means to protect the coastline from the erosive forces of the tides and waves. This method of coastal stabilisation was seen as desirable because;

1. It has the potential to be substantially less expensive than conventional engineering stabilisation techniques, and
2. It has the potential to provide a long-term, self-sustaining and ecologically sound solution to coastal erosion in this part of the bay.

This project complements the work that the Western Port Seagrass Partnership had begun by trialling a range of mangrove revegetation approaches and undertaking assessments of works to identify the most effective methods. It also instigated some targeted studies in the field and nursery to determine improvements to the collection of seeds, growth in the nursery and survival in the environment. The report also hopes to provide a useful resource to those launching their own mangrove restoration programs as this information has the potential to be used more broadly.

1. Introduction

1.1 Background

Western Port is a large tidal bay located around 70km southeast of Melbourne, Victoria (Figure 1). Two large islands, French Island and Phillip Island exist within the bay along with a number of smaller islands. The bay was a former sunkland that was inundated during the Holocene period and now drains a catchment of around 3250 km2 (Dale, 1974). The major river systems draining into the bay are Cardinia and Yallock Creeks, the Bunyip, Lang Lang and Bass Rivers as well as a number of smaller waterways draining from the Mornington Peninsula and the islands. Agriculture is the major land use in the catchment, utilising around 70% of the land, and consists predominantly of horticulture, grazing and dairy farming (Wallbrink & Hancock, 2003). The remaining catchment area comprises remnant forests and reserves and increasing areas of urban and industrial development.

Figure 1: Western Port Bay, Victoria. Mangrove extent marked in red (Boon et al., 2011). Eroding Lang Lang Coast indicated by green arrow.

The bay covers an area of 680km2 which includes around 270km2 of intertidal mudflats. There is approximately 263km of coastline surrounding Western Port which is fringed in some areas by a band of 'grey' or 'white' mangrove trees growing in the intertidal zone (see figure 1 for distribution of mangroves). Mangroves currently do not occupy the eroding coastline in the northeast of bay (discussed further in Section 2). The mangrove fringe is generally less than 100m wide but in some areas can be up to 300m wide (Bird, 1986). In Victoria, mangroves grow at their southernmost global limit and only one species exists, the grey or white mangrove *Avicennia marina* var. *australasica*. The southernmost (and highest latitude globally) population exists at Corner Inlet (lat 38°54'S). The largest areas of mangroves in Victoria are found around the Nooramunga Islands and coastline with the next largest areas existing in Western Port (Boon et al., 2011).

On the landward edge of the mangrove fringe, large areas of diverse saltmarsh exist, dominated by Sarcocornia and Tecticornia species (Boon et al., 2011). In the bay itself, extensive seagrass meadows are important primary producers and also provide nursery, refuge and food for various marine organisms (Melbourne Water, 2011). Western Port is known as a very good example of a mangrove-saltmarsh-seagrass wetland complex in its biogeographic area and this satisfies one of the criterion that contributed to its classification as an internationally important wetland under the Ramsar Convention (Kellogg Brown & Root, 2010).

During the late 1970s, there was concern that the cover of seagrass meadows in Western Port was declining. An assessment in the early 1980s found that 70% of the seagrass that had existed in Western Port in 1973 had disappeared by 1984 (Bulthuis, 1984). A number of possible reasons for this reduction in seagrass were posed, including a reduction in light reaching the seagrass plants due to suspended sediments, the physical blanketing of seagrass by sediments, desiccation of exposed intertidal seagrass during very hot weather and very low tides, and industrial waste effects (May & Stephens, 1996). In 2001, an assessment of seagrass extent in Western Port indicated that there had been some recovery of seagrasses since the 1980's (Blake & Ball, 2001). The latest available seagrass mapping (2009) in Western Port shows that there has been some further recovery in some areas but also some decline in seagrasses around the Yaringa and Corinella segments of the bay (Melbourne Water, 2011).

CSIRO investigated sediment dynamics in Western Port and found that fine sediment in the bay was reworked daily by tidal and wave action causing high turbidity (Wallbrink et al., 2003). The clockwise transport of this sediment around the bay means that sediment resuspended in the northern sections can affect water quality in the eastern and southern parts of the bay. CSIRO also traced the origin of sediments in the bay and found that most sediment deposited in Western Port is derived from channel and gully erosion occurring in the Bunyip and Lang Lang River catchments. The sediment study also suggested that up to 32% of sediments originate from the eroding clay cliffs (see Figure 2) along the north-eastern coast around the Lang Lang River mouth (Wallbrink et al., 2003). The erosion of this coastline has probably been occurring for many centuries but could have been accelerated by the loss of seagrass which may have been mitigating wave energy. CSIRO was recommended that, despite the unlikely existence of mangroves historically in this area, replanting of mangroves to stabilise these eroding cliffs could help to reduce some of the possible causes of seagrass decline, particularly in the northern and eastern sections of the bay.

Figure 2: Example of erosion occurring along Lang Lang Coast in foreground with landholder attempts at stabilisation with concrete rubble in background.

1.2 The Project

CSIRO's recommendation to stabilise the eroding coastline was adopted in the Better Bays and Waterways strategy which was developed by Melbourne

Water and EPA Victoria as a water quality improvement plan for Port Phillip and Western Port (Melbourne Water & EPA, 2009). Specifically, the action appeared in the strategy as follows;

> **Marine Action 8.4**: Implement targeted re-establishment of shoreline vegetation, especially mangroves on Western Port shorelines identified as at risk of erosion, and monitor its effectiveness using water quality indicators and seagrass condition assessment to guide future investment (Melbourne Water & EPA, 2009).

In 2010, Melbourne Water applied for funding from the Department of Sustainability and Environment's (DSE now DEPI) Victorian Investment Framework (VIF) through the Port Phillip and Western Port Catchment Management Authority (PPWCMA) to satisfy Marine Action 8.4 from the Better Bays and Waterways Strategy. Funding was approved for 3 years.

The Western Port Seagrass Partnership (WPSP), led by Dr Tim Ealey, had already been undertaking mangrove revegetation projects along the Lang Lang Coast for several years. Their trial and error of different techniques had greatly advanced local knowledge of mangrove revegetation but their success in mangrove survival along the Lang Lang coast had been limited. Melbourne Water proposed a larger mangrove revegetation project that would work collaboratively with the WPSP and other relevant stakeholders. This project included a range of research projects that trialled and monitored various techniques of mangrove restoration and assessed environmental factors contributing to higher survival rates.

1.3 Project timeline

To provide a reference point for the reader as different activities and timeframes are discussed throughout the report, the major activities that were undertaken during the project in chronological order are given in Figure 3.

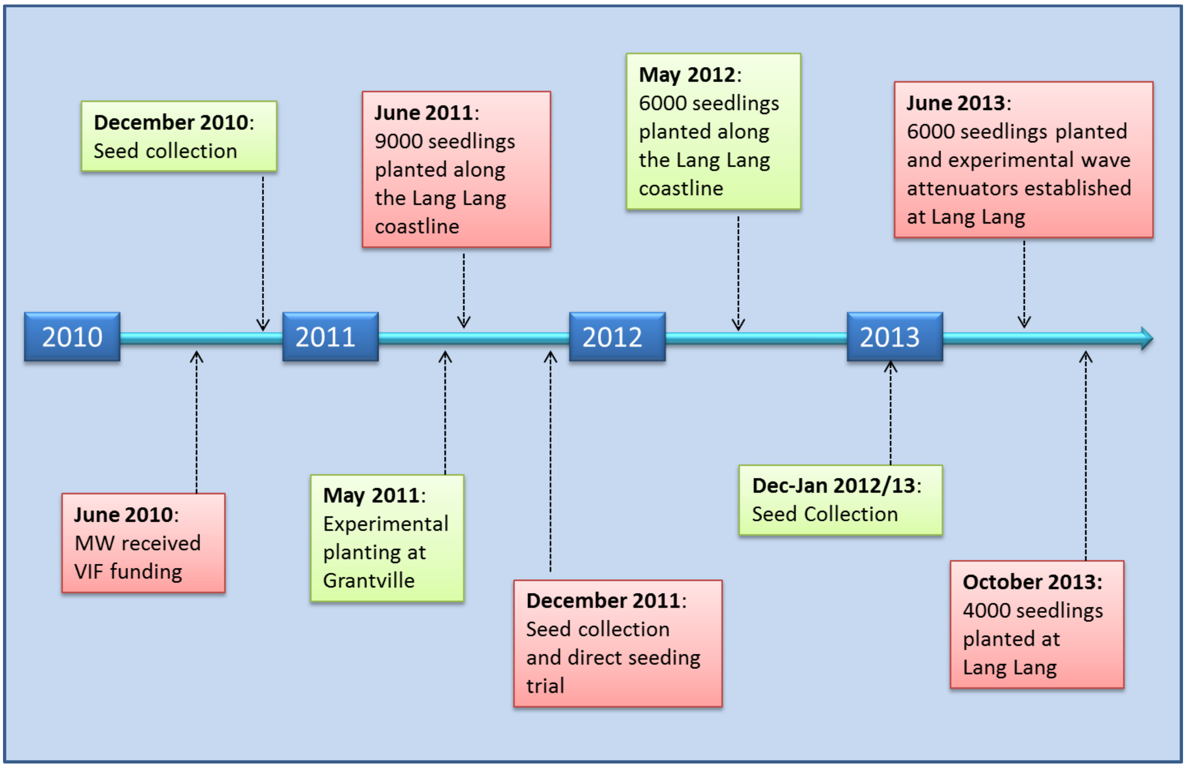


Figure 3: Melbourne Water Mangrove Restoration Project timeline

2. The Lang Lang Coast

The eroding section of the Lang Lang coastline stretches approximately 9km from the mouth of the Yallock Creek in the north to approximately 1km north of the Lang Lang caravan park in the south (see Figure 4). The coastal form in this part of the bay is a 1-2m receding cliff which largely consists of dark clay with high organic matter content indicative of former swamp deposits. The morphology of the cliff is generally crenulated, i.e. regular occurrence of jutting headlands and eroded coves as shown in Figure 4. The cliff is topped by saltmarsh and is backed by a 1-2m high levee for most of the 9km length. The levee has been breached by coastal erosion and landholders have attempted to stabilise the coastline with rubble (see Figure 2). This section of the report describes some of the relevant features of this coastline in more detail.

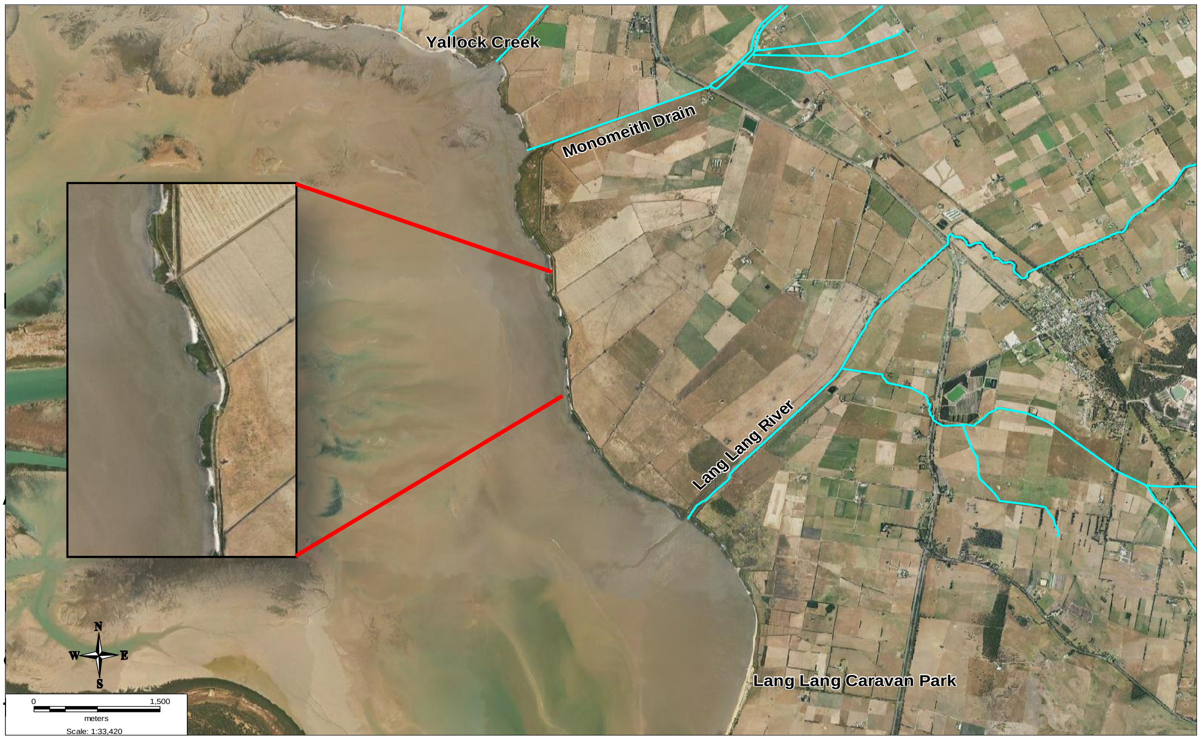


Figure 4: The Lang Lang Coast. Inlaid photo is close-up of typically crenulated length of the coastline.

2.1 Erosion

A few attempts have been made to estimate the rate of erosion from the Lang Lang coast. Gell (1974), Hurst (2012) and Tomkins and McLachlan (in prep.) analysed historical aerial photography and determined average rates of coastal retreat of between 0.29 and 1.47 m yr^{-1}. The WPSP also measured erosion at a number of sites and found an average rate of 0.84m yr^{-1} (Ealey 2010). This was translated into sediment yields to the bay of between 4.76 and 35 kt yr-1. The variation in sediment yield estimates are the result of differing assumptions made about average cliff height, total length of eroding coastline and bulk density of the soils.

Tomkins and McLachlan are also monitoring erosion in one of the eroding coves over 12 months (November 2012 to November 2013) to answer questions about erosion rates and processes (see figure 5). Some preliminary results from their investigation indicate that erosion is occurring in all parts of the eroding cliff’s profile (i.e. on the horizontal parts as well as the vertical parts) and that erosion is most rapid on the most vertical faces of the eroding cliff as well as on the headlands of the crenulated shoreline. They are due to present their findings to Melbourne Water in 2014.

Figure 5: Erosion monitoring (erosion pins arranged in a series of transects across erosion profile) being undertaken by Tomkins and McLachlan.

2.2 Sediments

Casual observations of sediments found along the Lang Lang coast indicate that they generally consist of dark, cohesive clays that are high in organic matter. The surface of the sediment is pitted by crab and polychaete burrows. Coarser sand banks and piles of small bivalve shells also exist and are reworked by tides so that they change position on a regular basis.

The sediment structure at the base of the eroding cliff (where mangrove planting occurs) varies along the length of the coast (see figure 6). In some areas there is a wide (2-50m) gently sloping bench consisting of similar firm, organic rich clays that are also found in the cliff. At the seaward edge of these benches there is a small drop-off (<50cm) into unconsolidated and very fine sediments that increase in depth with distance from the bench. In other areas the bench is absent and the cliff directly abuts these unconsolidated sediments. These areas generally correspond to headlands, but are also found along large lengths of the coastline.

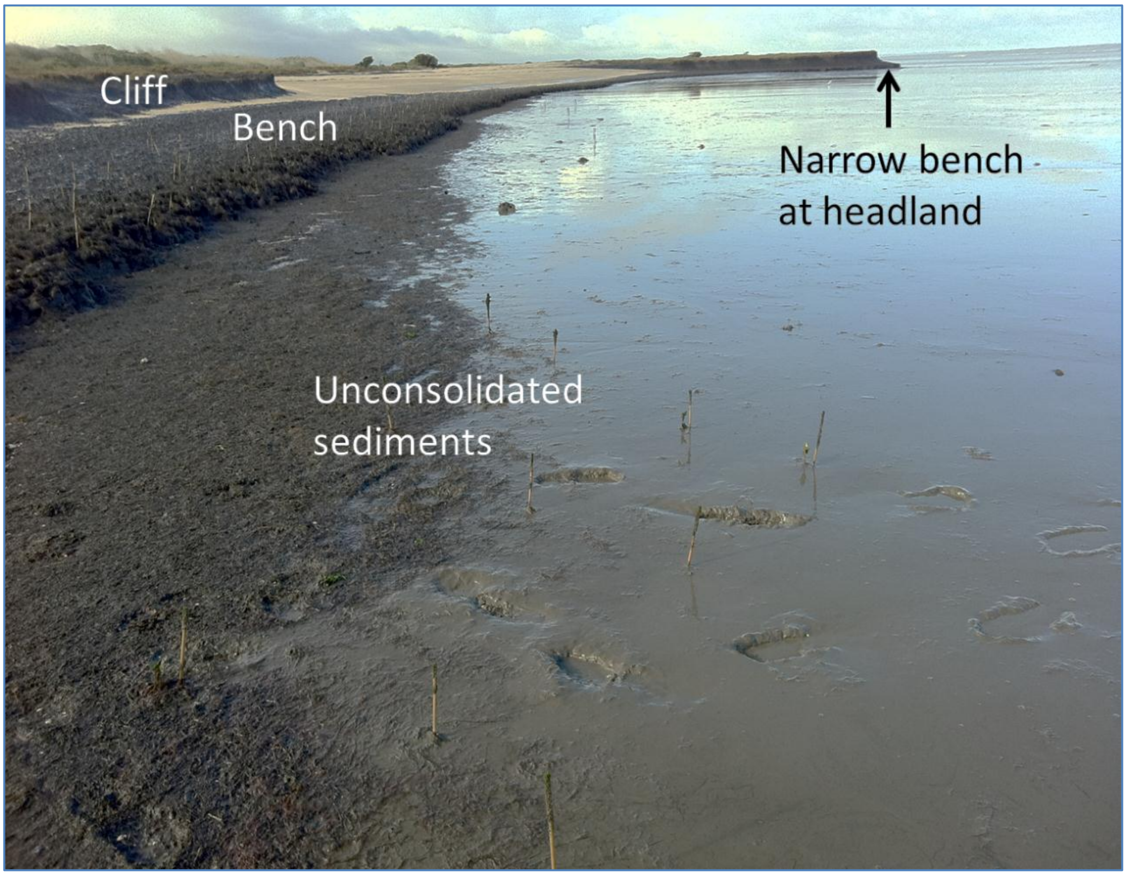


Figure 6: Typical cliff, bench, unconsolidated sediment arrangement at Lang Lang coast. The bench varies in width as indicated at headland in top right of picture.

Tomkins and McLachlan (in prep.) sampled the sediment profile of the eroding cliff and found a number of distinct layers. Generally though, sediments in the cliff and bench were found to be high in clay, low in dispersibility and had a low to moderate susceptibility to erosion. They also found erosion was more prevalent on the steeper parts of the cliff, and was probably enhanced by the animal burrows mentioned above.

Sediment sampling was also undertaken by this project in 2012 to investigate nutrient levels in the planting substrate at the Lang Lang coast compared with samples taken within nearby natural mangrove forests . This analysis did not point to any major differences between the sites although there were generally slightly higher levels of nutrients within the mangrove forest site (probably due to the extra organic matter derived from forest detritus).

2.3 Vegetation

The Lang Lang coastal mudflats are almost devoid of vegetation with only small mangroves found occasionally. There are however, a few mature mangroves found in more physically protected areas in the mouths of the Lang Lang River, Monomeith Drain and Yallock Outfall (see figure 7).

Figure 7: Mature mangroves at the mouth of the Monomeith Drain

Some naturally occurring mangroves can also be found in the drainage lines that flow through saltmarsh on the landward side of the eroding cliff (see Figure 8). These naturally occurring mangroves, along with observations of large numbers of propagules (seeds) beached along the Lang Lang coast indicates that natural mangrove regeneration in the area is unlikely to be limited by inadequate supply of propagules. However, *Avicennia* propagules require a period of low-energy water movement to enable root penetration into the soil and subsequent establishment (Balke et al., 2011). Given the Lang Lang coast's exposure to a long wave fetch (discussed below) it seems that mangroves are less likely to establish on the higher energy mudflats than the areas that are more protected from wave energy e.g. drain mouths or saltmarsh drainage lines.

Figure 8: Naturally recruited mangroves in saltmarsh drainage line

Although it appears that mangroves have not existed along the Lang Lang coastline since European colonisation (Smythe, 1842), tree roots can be found protruding from the eroding cliff and mudflat surface (see figure 9). The clustered arrangement of roots indicates that they are the remains of a former forest at that location. A sample of the roots was sent to the National Herbarium of Victoria for identification and it was confirmed through examination of preserved vascular tissue that they are *Avicennia* roots (Cantrill, 2012). A sample was subsequently sent to the Australian Nuclear Science and Technology Organisation (ANSTO) for radiocarbon dating that estimated that they are 9,695 years old +/- 50yrs. (ANSTO, 2012). Sea-levels at this time were likely to be much lower than they are today and this information may be useful for local geological studies. However, while interesting, the prehistoric existence of mangroves along the Lang Lang coast does not really tell us much about whether they will survive here today.

Figure 9: 10,000 year old mangrove root (left) and site where roots are located along the Lang Lang coast (right).

Between the top of the eroding cliff and the private farmland there exists a strip of saltmarsh that varies in width (2-250m). This saltmarsh is dominated by *Sarcocornia quinqueflora* (Beaded Glasswort), *Sueda australis* (Austral Seablite), *Atriplex paludosa* (Marsh Saltbush) and *Disphyma crassifolium* (Rounded Noon-flower). This area also contains the aforementioned levee, which runs parallel to the coast and was constructed to prevent seawater incursion into adjacent farmland (J. F. Bird, 1980). Saltmarsh species also grow on the levee and in the drains on the landward side of it, however these areas seem to be more susceptible to weed invasion (Phalaris spp., Lophopyrum ponticum etc.), probably due to lower salinities and closer proximity to agricultural activities.

2.4 Waves

The Lang Lang coast is exposed to the longest wave fetch in Western Port and wave heights of up to 0.5m have been modelled offshore in the area (Rennie, Boon, Womersley, & Lawry, 2011). Waves are mitigated by the expansive adjacent tidal flats but they are still larger than those modelled at Grantville and Jam Jerrup where mangroves currently exist.

2.5 Climate

Monthly climate statistics for Rhyll on the northern coast of Phillip Island are presented in Table 1.

Table 1: Mean monthly climate statistics for Rhyll for the period 1991 to 2013 (BOM, 2010)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
Mean maximum temperature (°C)	23.5	24.2	22.3	19.4	16.2	13.8	13.2	14.3	15.9	17.6	19.9	21.5	**18.5**
Mean minimum temperature (°C)	15.2	15.8	14.5	12.4	10.6	8.8	8.1	8.3	9.3	10.4	12.1	13.5	**11.6**
Mean number of days ≥ 35 °C	0.6	0.4	0.2	0	0	0	0	0	0	0	0.1	0.2	**1.5**
Mean number of days ≤ 2 °C	0.1	0.1	0.2	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.2	**1.8**
Mean number of days ≤ 0 °C	0	0	0	0	0.2	0.2	0.1	0	0.1	0.1	0.1	0	**0.8**
Mean rainfall (mm)	35.7	38.1	36.2	61.3	65.2	57.5	65.2	78.3	67.2	59.4	56.4	42.5	**665.9**
9am wind	20.0	19.1	19.8	18.8	20.9	20.0	22.5	22.1	24.0	19.9	18.7	19.6	**20.4**
3pm wind	25.4	24.2	23.8	20.9	23.1	22.6	24.1	24.8	25.9	22.4	23.7	25.0	23.8

Farrell and Ashton (1974) found that mangroves in Western Port only grow when average temperatures are above 21°C. They also found that very low (i.e. frosts) and very high temperatures also had detrimental effects on mangrove propagules and seedlings. Although there are very few days below 2O°C at Rhyll (on Phillip Island) which has a relatively stable marine climate, frosts are more likely in the northern parts of the bay due to cold air drainage through the former swamps found in the hinterland (Shapiro, 1974).

3. Raising Mangrove Seedlings

Propagation of *Avicennia marina* seedlings in a nursery is relatively easy and has seen success rates of 40-60% after planting in the field (Saenger, 1996). The Western Port Seagrass Partnership (WPSP) has experimented with various alternative revegetation techniques (direct seeding, transplanting etc.), however nursery propagated seedlings maintained the highest survival rates. The preferred approach of the WPSP involves the initial collection of propagules followed by treatment and planting in the nursery and finally, storage of the seedlings that emerge until they are ready to be planted in the field. This project aimed to refine mangrove propagation techniques in conjunction with the WPSP and the nursery and this chapter outlines how this was achieved.

3.1 Collecting propagules

The phenology of *Avicennia marina* was described by Duke (1990) who found that the timing of major reproductive events (budding, flowering and fruiting) varies with latitude. These events are much closer together nearer to the equator and the time between first bud emergence and fruit ripening is as little as 7 months. Conversely, at higher latitudes (such as at Western Port) this cycle can take as long as 17 months and means that not every tree produces fruit every year. This phenomenon has certainly been observed in Western Port over the life of the project where there was abundant fruiting across the bay in 2010/11 and a general absence of fruit the following year (2011/12), except in the mangroves around Grantville on the eastern shores of the bay. Once again in 2012/13 there was an abundance of fruit across the entire bay. This phenomenon has implications for the planning of mangrove revegetation projects in temperate areas.

Figure 10: Propagule collection – volunteer collectors (left) and *A. marina* propagules on a tree (right).

Collection of mangrove propagules for seedling propagation was generally undertaken by picking ripe propagules from trees. Propagule collection activities were often undertaken with help of volunteers (see Figure 10) who were told that ripe propagules were generally more easily detached from the tree and were identified by a change in colour from greenish to pale yellow and by cracks that may appear on the seedcoat (Hong, 1996). Seed collection started early in the season (beginning of December) with the assumption that earlier collection would allow a longer period of seedling growth in the nursery leading to larger seedlings for planting the following winter.

Collectors were also told to concentrate on collection of the larger propagules from trees (as opposed to picking up fallen seeds from the ground – although this was never discouraged by the WPSP). Little is known about the optimal approach to seed collection to enhance mangrove seedling survival. Consequently a trial was undertaken to test the effect of propagule size, collection method and collection time on survival and growth of nursery reared seedlings (see study summary in Box 1).

Box 1: The effect of propagule size, collection method and collection time on survival and growth of nursery raised mangrove seedlings

In Summer 2012/13 mangrove propagules were collected during three consecutive months (December, January and February) using two different collection methods (picking from tree and collecting fallen propagules from the ground). Propagules were split into four size classes based on weight (i.e. Small, Medium, Large and Extra Large) and sown into soil filled 600mL milk cartons. These were kept in baths that were flooded and drained with 30% seawater (10 PSU) on a daily cycle. Survival and growth of the seedlings was monitored until late April 2013. The seedlings grown during the experiment were planted in August 2013 and their growth and survival will be monitored for up to 12 months.

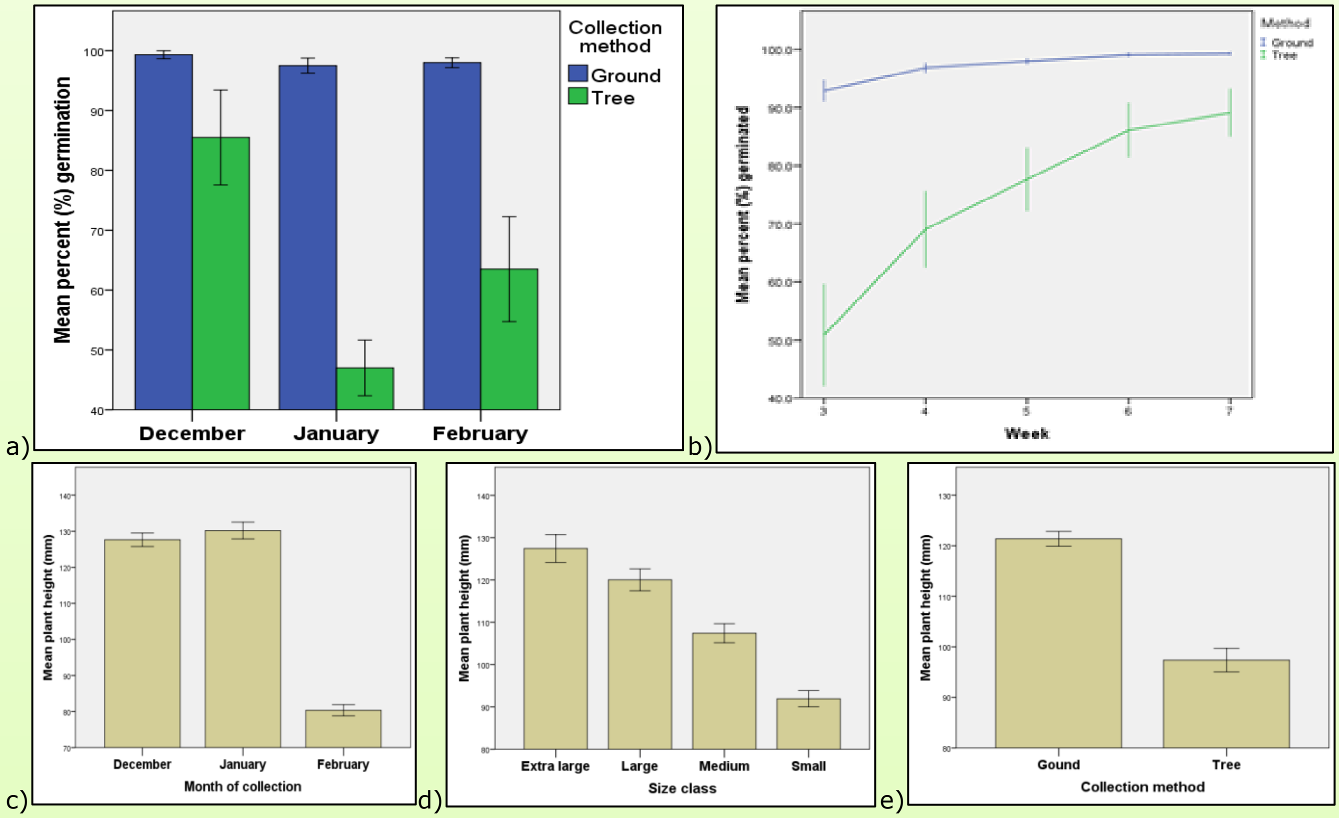


Figure 11: Propagule collection trial results.

Figure 11 displays results from monitoring from December 2012 to the 21st of April 2013. Total germination of propagules that were collected from the ground was high (>95%) for all collection months while germination was lower and more variable for those picked from the tree (a). Propagules collected from the ground germinated very quickly and over 95% had germinated by the 4th week after planting (b). Conversely, propagules picked from the tree took longer to germinate and did not reach maximum germination (85%) until the 7th week. Longer germination times by tree-picked propagules is probably a result of being under-ripe compared to those that had already fallen from the tree and may have left them more susceptible to death in the nursery by desiccation. Mean heights for December and January collected seedlings are significantly larger than those collected in February but not significantly different from each other (c). This indicates that if the plants are to be planted in autumn as per current methods, propagules don't need to be collected as early as December as those collected in January will result in similar sized plants. Results also showed that larger propagules result in taller seedlings (d) and that propagules collected from the ground will result in seedlings that are on average 20mm taller than those grown from tree-picked propagules (e). The experiment will continue with the planting of the seedlings near Grantville and further monitoring for 12 months to determine if the larger seedlings resulting from some treatments will translate to higher survival and growth in the field.

3.2 Growing seedlings in the nursery

Once collected, propagules are transported to the nursery and soaked for at least 24 hours to promote dehiscence (removal) of the pericarp (the slightly hairy covering of the propagule) which will float to the surface. It is important to change the water in which the propagules are soaked on a daily basis as pericarps appear to ferment after they are removed which results in the propagules becoming brown. Observations indicate that propagules which display some brown discoloration are less likely to germinate and produce healthy seedlings. It is also important to keep propagules moist and to avoid planting them on hot days as they tend to brown very quickly in the heat.

The seedling-raising technique originally developed by the WPSP involves planting propagules directly into 600ml milk cartons filled to ~5cm from the top with soil. The milk cartons are a convenient and cheap container that is biodegradable and thought to provide extra stability for young mangroves planted in the mudflats (see Figure 12). This stability is the result of the suction formed by the contact between the waxed side of the carton and the mud. A hole is drilled through the sides of the cartons to allow for root growth and water circulation before being filled with soil. Due to concerns about the cartons resulting in seedlings becoming 'root bound', the nursery investigated alternative containers during the 2012/13 growing season.

Figure 12: Mangrove seedling raised in 600ml milk carton planted directly into mud

A number soil types used in the milk cartons have also been trialled. Originally, the nursery’s own potting mix was used however this contained a lot of bark and other lighter material that tended to float out of the carton after planting. More recent use of a sandy loam soil has been more successful in retaining soil in the carton. It has been suggested that a single addition of a slow release fertiliser (i.e. osmocote) is beneficial (Saenger, 1996; Yates, Ashwath, & Midmore, 2002), however nutrient addition was not a focus of our trials.

Once the cartons have been filled, a single dehisced propagule is sown in each carton. Propagules are carefully pushed into the soil until they are about one third buried (see figure 13). The radicle (root structure), which is visible on the dehisced propagule (see figure 13), should be pointing downwards when sown to improve root establishment. WPSP have also allowed propagules to develop roots and shoots in trays of moist seagrass wrack before transferring the seedlings into the cartons. Care must be taken not to damage the delicate root structures when re-potting (Ealey, 2011).

Figure 13: Mangrove propagules sown in soil filled milk cartons (left) and dehisced propagules showing radicles with hairy tip which should be on the lower side when sown.

Studies have shown that *A. marina* seedlings grow most successfully when stored in water that is about 30% the salinity of standard seawater (~10 PSU) (Clough, 1984; Farrell & Ashton, 1974). During the first year of the project, seedlings were stored in plastic lined timber frames (see figure 14) that were filled and watered daily with 30% seawater. However, daily hand watering was time-consuming and it was difficult to maintain salinity in the baths. In response, the nursery produced a covered storage system where water that is kept at a stable salinity is stored in a central tank and pumped into a series of fibreglass baths (Figure 15). The baths are filled and drained on a daily cycle to mimic a diurnal tidal regime.

Figure 14: Old system of seedling storage. Plastic lined timber frames.

Figure 15: Tidal mangrove seedling storage system (central storage tank shown in inlay)

The new storage system was evaluated by monitoring the growth of 100 seedlings over two months, compared to 100 seedlings that were stored in the old timber frame storage system (discussed above) and another 100 seedlings that were watered with fresh water instead of 30% seawater. The monitoring found that germination was above 50% for the tidal system and much lower for the other two methods (a in Figure 16). It also showed that the tallest seedling

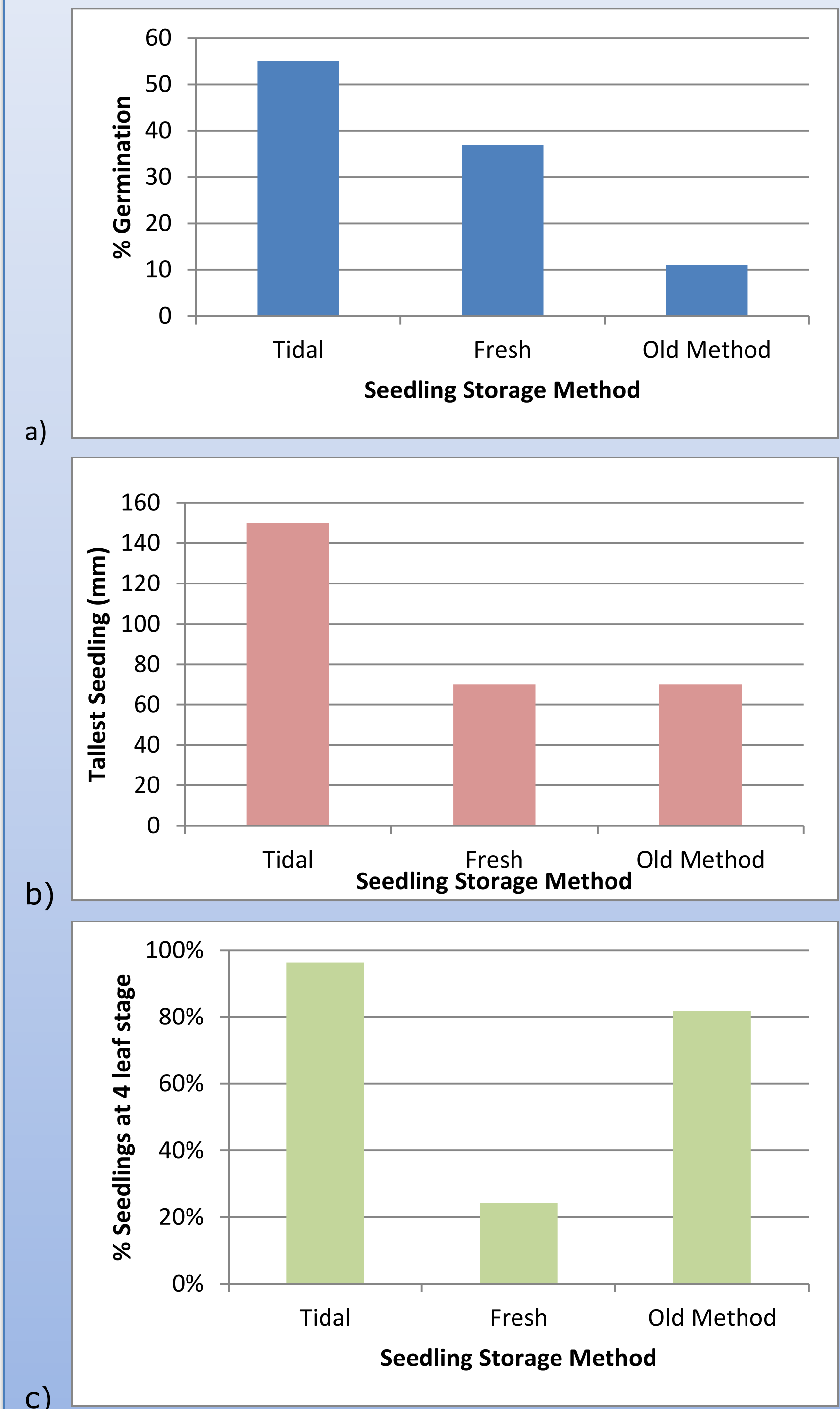


Figure 16: Comparisons of mangrove seedling storage systems (Tidal, Fresh Water Irrigated and old timber frame storage method). a) Germination rates between systems. b) Tallest seedling from each system. c) % of seedlings to reach 4-leaf stage of growth. Data provided by Couchman (2012).

from the tidal system was more than twice the size of any seedling grown in the other two storage systems (b) and that almost all plants grown in the tidal systems had reached the four leaf (two-pair) stage after two months (c). Only 20% of seedlings reached the four-leaf stage in the fresh water system which appears to inhibit leaf production more than the old storage method.

Another advantage of the tidal storage system is the cover that provides a 'hot-house' environment. A major reason for the covering is that in previous years, seedlings that were uncovered in the nursery were severely damaged by frost in late autumn. This experience resulted in a reluctance to store seedlings in the nursery over winter, as it was assumed that they would be less likely to be frost damaged after planting in the mudflats where low temperatures are moderated by the thermal mass of the bay. The covered storage system allowed some seedlings to be kept in the nursery over winter to be planted in spring (discussed in section 4 and 5).

The importance of allowing seedlings to grow as large as possible in the nursery is demonstrated from data collected as part of a concurrent planting experiment that was established in 2011 near Grantville (Figure 17). This experiment is explained further in Box 2, Section 5. Seedlings which were t aller, had a greater stem diameter and more pairs of leaves when planted were more likely to survive after planting.

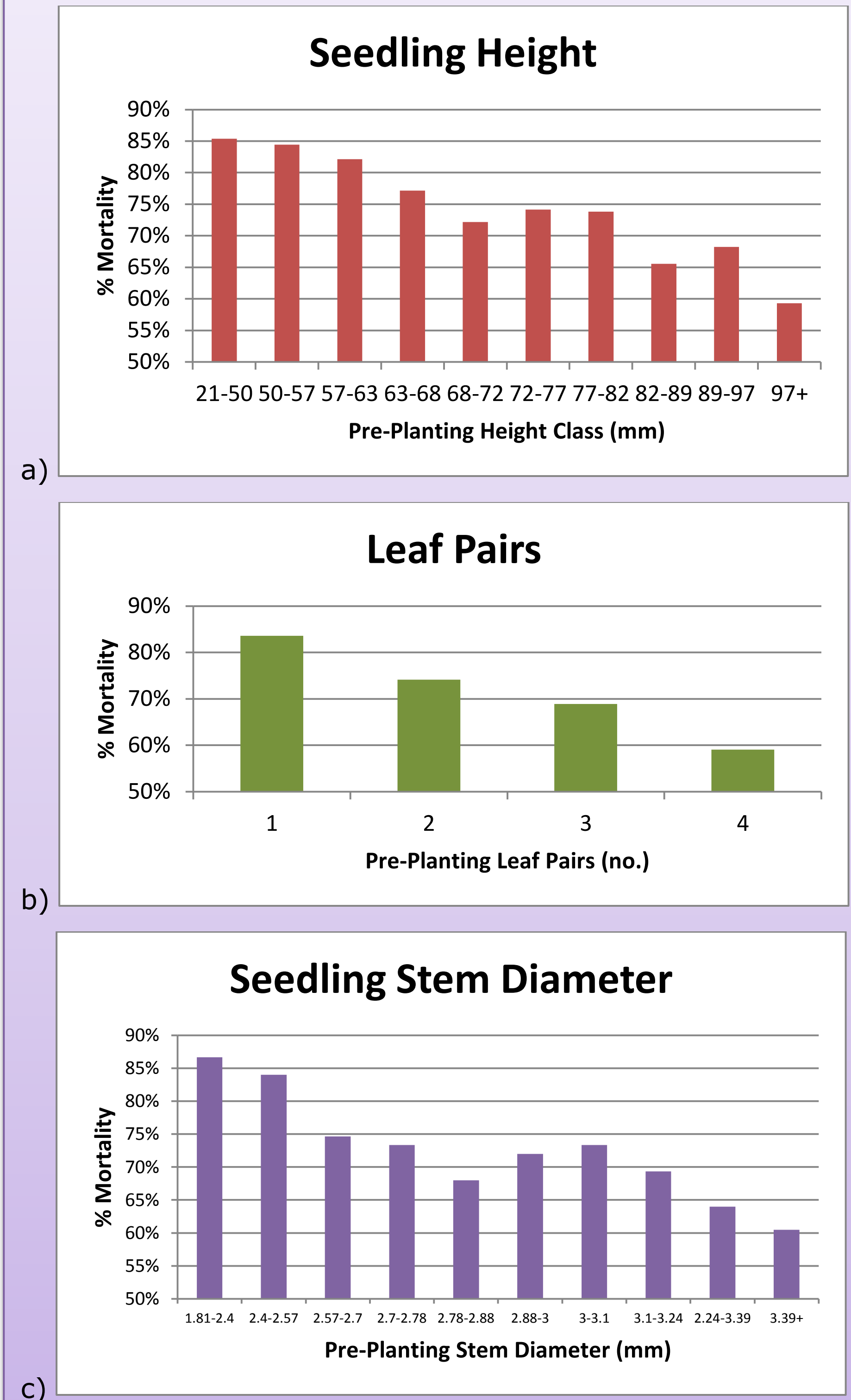


Figure 17: Seedling mortality 9 months after planting. a) Mortality by pre-planting height classes (n=302) b) Mortality by pre-planting leaf pair count (n=756). c) Mortality by pre-planting stem diameter classes (n=75).

Prior to planting, seedlings are watered with increasing salinities until it approximates full-strength seawater (35 PSU) over a period of about four weeks. This is known to be an important step to acclimatise the seedlings to marine conditions (Bhat & Suleiman, 2004).

4. Planting Mangroves

The Western Port Seagrass Partnership's criteria for determining when seedlings are ready for planting are as follows;

1. Seedlings had spent more than 4 months in the nursery,
2. The root system was well-formed, i.e. the root system was visible when carton was opened at the bottom
3. Seedlings were approximately 10-20cm tall, and
4. Seedlings had more than 2 pairs of leaves (Ealey, 2010).

WPSP plant in autumn/winter to avoid the necessity of storing them in the nursery over winter where they are thought to be more susceptible to frost damage (see Section 3). A similar planting regime was followed in this project, although there were concerns about the potential effect that cold winter weather and the incidence of frosts would have on seedling survival. Additionally, it is known that the growing season for *Avicennia marina* in Western Port Bay correlates to the months where the average maximum temperature is above 21^{o}C (Farrell & Ashton, 1974) and therefore seedlings that have been planted in autumn and winter are likely to have stopped or slowed growth. A slowing of growth was also observed in the nursery while they were being monitored over winter.

While adopting the autumn/winter planting regime developed by WPSP, this project also explored other options that would possibly allow better establishment of seedlings. In particular, the new covered storage system in the nursery allowed the storage of seedlings over the winter months and planting to occur in spring when the weather warmed and seedlings started to grow again. Additionally, direct seeding was trialled as a way to enable plants to establish during the warmer months and become better able to withstand the cold winter weather. This section discusses the planting techniques that were trialled.

4.1 Seedling Planting

Nursery grown seedlings were transported to the planting site and planted using the methods developed by the WPSP. This involves using a purpose built tool (Figure 18) that punches a hole in the mud about the same size as a milk carton. The carton slips straight into the tight-fitting hole and is held in place by the suction (see Section 3). Before inserting the seedling, the bottom flaps of the carton are folded up to allow downward root growth. The addition of a stake was seen as a way to improve stability of the plant, however observations have indicated that it may not be needed (i.e. suction in mud is sufficient) and may even damage the root system when inserted. Before planting, the tops of the milk cartons are stapled together (see figure 19) so that movement of the seedling by wave action is minimised.

Figure 18: Mangrove planting tool (Photo: Tim Ealey).

Figure 19: Planted mangrove seedling with top of milk carton stapled.

Given the aim of mangrove planting along the Lang Lang coast was to establish a protective barrier for the eroding coastline, the WPSP arranged their seedlings in a continuous belt along the shore consisting of two or three rows of seedlings planted around 1m apart (1 seedling/m^2) (see figure 20). This spacing was based on observation of older plantings done at the same spacing which now have a continuous canopy and do not appear to have competition problems (Ealey, 2010).

Figure 20: Mangrove seedlings planted in three rows at around 1m spacing at Grantville

The 1m spacing was used during this project but there is evidence that denser planting may be advantageous due to mangroves ability to take over the root systems and nutrients left by neighbouring plants that have died (N. Duke, 2013). Accordingly, some denser plantings were undertaken in 2012/13. The continuous three row technique was abandoned after the first year of planting due to low survival rates (discussed in Section 5). From 2011/12, plantings have been concentrated in the eroding coves which seem to provide more physical protection for the seedlings.

Mangroves require a certain wetting and drying regime for their survival and will therefore only grow within a specific tidal range. This is particularly important for the planning of a mangrove restoration project as seedlings that are planted outside of this range will be not survive (Lewis, 2005). This tidal range (which varies for different mangrove species) was determined in Western Port by surveying the topography of existing mangroves forests around the Grantville area (as part of the research project discussed in Box 2). The range was found to be between 0m to approximately 1m AHD. The mud flats along the Lang Lang coast were also surveyed to ensure that specific planting locations fell within this natural tidal range.

4.1.1 Seedlings planted along the Lang Lang coast

Seedlings were generally planted in the bench area of the coastline (see section 2.2) as this area provided the most stable substrate for planting. However, as discussed in section 2.2, the bench was not always available and attempts were made to plant some seedlings in the unconsolidated sediments, especially when a continuous belt of plants was the focus of the planting strategy. Figures 21 and 22 show the planting extent for each year of the project. In 2010/11, 9,000 seedlings were planted along about 3.5km of the eroding coastline. Planting started near the mouth of the Lang Lang River and plants were generally arranged in two or three rows, planted approximately 1m apart (see figure 23).

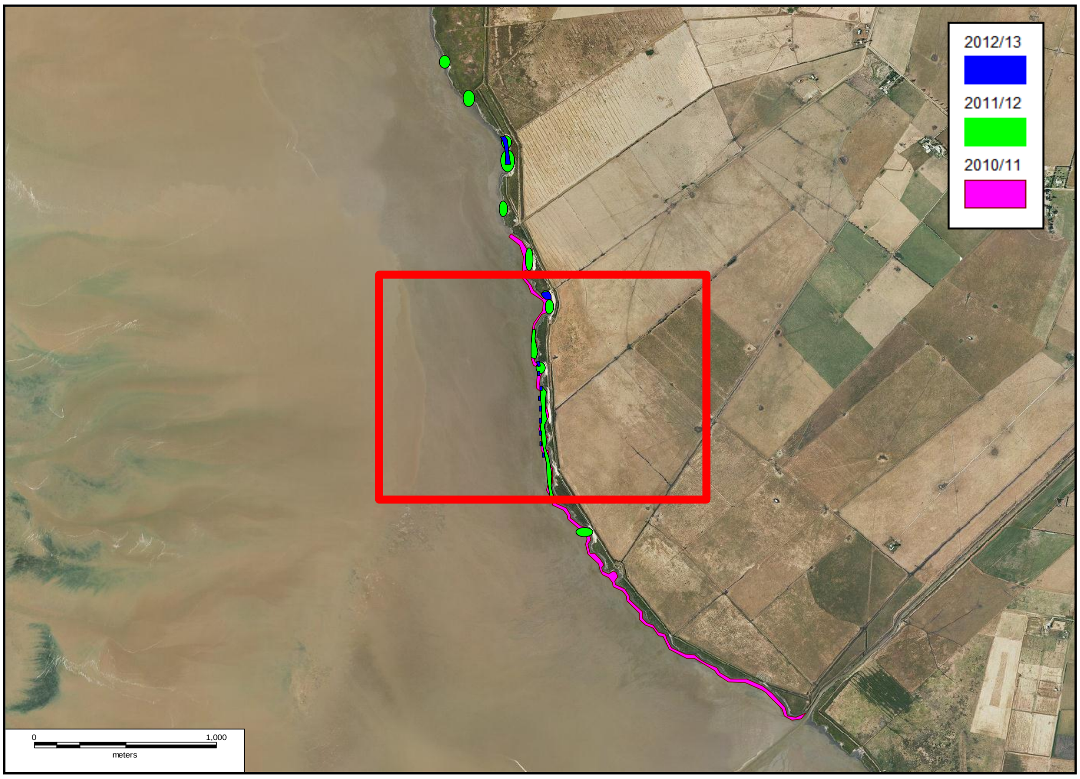


Figure 21: Mangrove planting areas by year (red box indicates area enlarged in Figure 22)

Figure 22: Mangrove planting areas by year (enlarged area indicated in Figure 21).

Figure 23: Mangrove planting in 2011. Two rows of seedlings spaced 1m apart.

Areas of higher survival from the previous year's planting were used to guide placement of new plantings (see section 5). In 2011/12, higher survival was generally observed in the protected coves of the coastline, therefore the 6,000 seedlings that were grown in the nursery were mostly planted in those areas (Figure 24). Some linear planting along the coast where 2010/11 survival was high also occurred (see Figure 22). The reduced number of seedlings planted in 2011/12 was less than the previous year due to a shortage of propagule production which occurs naturally in temperate mangrove forests (see Section 3).

Figure 24: Wider belt of planting in protective cove planted in 2012.

Figures 21 and 22 illustrate further modification of the planting strategy on 2012/13. Planting activities in this year were designed to test the effectiveness of various wave attenuation measures (discussed in section 6). In autumn/winter 2012, 3,000 plants were planted in nine experimental blocks and a further 3,000 plants were planted in areas that had consistently displayed high survival rates over the first two years of the project. Some of these plants were also planted at higher densities (1 plant/0.5m^2) to test the benefits of this approach. Additionally 4,000 plants were held in the nursery over winter and planted in spring 2013 (these plantings were yet to be completed at the time of writing this report and therefore do not appear in Figure 21 or 22).

Experience over the three years of the project has highlighted some logistical disadvantages of planting thousands of nursery-raised seedlings. For instance, each seedling in its soil-filled carton weighs around 1kg and they are therefore cumbersome to deliver to and transport around the site. Planting in autumn/winter can compound difficulties as the Lang Lang site is only accessed by traversing farm paddocks which become very wet in winter and, in at some cases, became inaccessible due to heavy rain.

4.2 Direct Seeding

Direct seeding involves taking the dehisced propagules and planting them directly into the mud in the field. This method was seen as a potential answer to the logistical problems that were associated with planting the nursery-raised seedlings. Direct seeding techniques have been reported to result in higher growth rates than nursery raised or transplanted mangrove seedlings (Ealey, 2008; Stewart & Fairfull, 2008). A small trial undertaken near Grantville during the summer 2010/11 also showed that growth rates were much higher than those that were being measured in other monitored seedlings (see Table 2).

Table 2: Direct seeding vs. nursery-reared seedlings. Monitoring results from May 2011. Propagules for direct seeding and nursery rearing were collected and planted at the same time (January 2011) so plants are essentially the same age.

	Direct Seeded Plants n=26	Nursery Grown Seedlings n=3024
Mean height (mm)	130.00	73.31
Mean Stem Diameter (mm)	4.87	2.91
Mean Leaf pair no.	3.11	2.07

The trial included pegging some bird wire mesh over the planted propagules to prevent them from being washed out by tidal movement (see figure 25). This mesh deteriorates quite rapidly and needs to be removed around 1-2 months after planting to avoid seedlings being damaged by flapping pieces of wire.

Removal of the mesh also prevents seedlings becoming deformed due to their attempt to grow through the mesh.

Figure 25: Direct seeding. Wire mesh covering newly planted propagules (left) and seedlings after 2 months (mesh removed).

The success of the trial led to the decision to introduce the direct seeding method to the Lang Lang site more broadly. In summer 2011/12, 2,000m^2 of direct seeding was planned, half of which occurred before Christmas 2011. On return to the site for the completion of the direct seeding in January 2012 almost zero seed survival was observed. It appeared that the propagules had been consumed by crabs as a number of propagule fragments were found with suspected chew markings (see Figure 26).

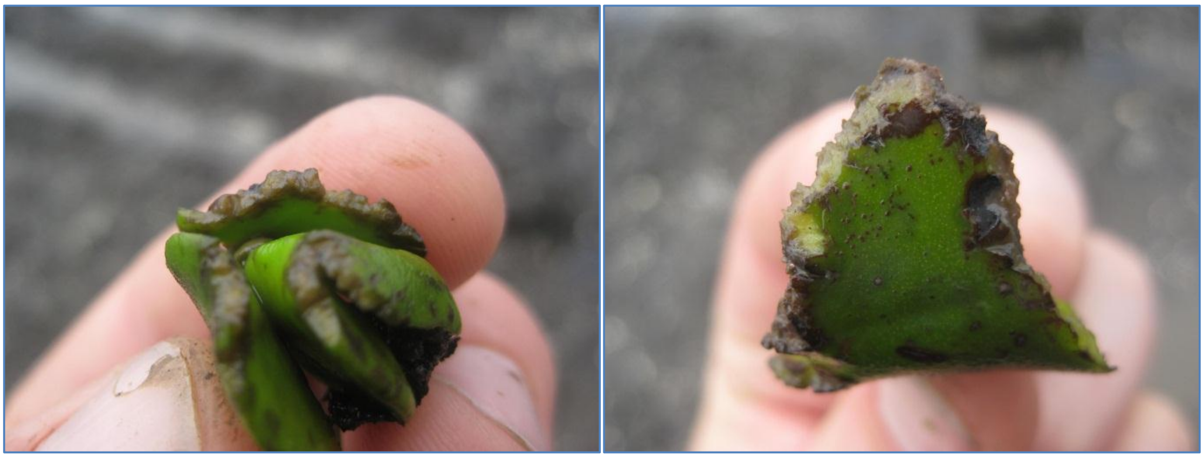


Figure 26: Damage to mangrove propagules suspected to be caused by crabs

Another possibility for the mass failure of seeding was under-ripe propagules, as further direct seeding during January had better success. The extra direct seeding in January was accompanied by some crab prevention measures (see Figure 27). This was briefly successful but the seedlings that had managed to establish did not survive over the winter and were probably washed out from the soil as a result of localised erosion on the mudflats.

Figure 27: Crab prevention measure. Mesh is kept above the surface of the mud to prevent crabs from chewing propagules from above the wire.

4.3 Seedling transplanting

Transplanting refers to moving established seedlings from a mangrove forest to a new location. This project did not attempt to undertake any revegetation by transplantation. However, this method has been used by the WPSP with mixed results. Literature on mangrove restoration suggests that the transplantation method is generally less successful, possibly due to damage of the root system when transplanting that leads to a period of less stability of the plant as it re-establishes in its new location (Kairo, Dahdouh-Guebas, Bosire, & Koedam, 2001; Stewart & Fairfull, 2008).

5. Monitoring and Adaptive Responses

As discussed in section 4.1.1, the planting strategy for the Lang Lang coastline was adjusted over the three years of the project. Survival counts were generally undertaken in the late spring/early summer after the seedlings were planted in the prior autumn. Most areas planted had been planted in previous years so a mix of seedling ages was present. On each monitoring occasion it was easy to tell which seedlings had been planted the previous autumn/winter, but difficult to differentiate between seedlings planted in years prior, as seedling growth was very slow and carton deterioration was too rapid to use as an indicator of planting year. Therefore, only single year survival counts were reliable. This section discusses the results of the monitoring activities that were undertaken and how they led to the adjustment of the planting strategy.

Figure 28: Planting Zones along Lang Lang Coast

Table 3: Survival of seedlings planted in 2011 and 2012

Zone	Survival 2011	Survival 2012
1	31%	32%
2	19%	1%
3	2%	N/A
4	37%	40%
5	15%	8%
6	39%	20%

Figure 28 shows a section of the Lang Lang coastline that has been divided into zones to illustrate how monitoring was segmented and then used to adjust the planting strategy. This section of the coast is represented because it is an area where planting was undertaken in all 3 years of the project and some of the highest survival rates were measured. Zones 1 to 5 correspond to eroded coves which are common along the entire length of the eroding coastline. Zone 6 is a more homogeneous section of the coast which also occurs in some other areas along the entire length. Table 3 displays the survival rates corresponding to each zone that resulted from the first two years of planting.

In 2011, as discussed in section 4.1.1, seedlings were planted in two or three rows approximately 20m from the base of the eroding bank so the rows followed the contours of the eroding coastline. Seedlings were generally planted in the firm sediments of the bench but had to be planted in the softer unconsolidated sediments where the bench did not exist. The planting started in mid-June and finished in early July 2011 and survival counts were undertaken at the end of November 2011. Overall survival of the 9,000 seedlings planted was 27% and varied between 2% and 39% in different zones (see table 3). Importantly, survival of seedlings was found to be higher where they had been planted in the coves which seemed to provide some protection from waves. Seedlings which did not survive were generally found to be defoliated, possibly due to tidal and wave movement providing constant stress on the leaves. Survival was very low where seedlings had been planted in unconsolidated sediments and many appeared to have washed out of the sediment.

Given the survival rates in 2011, planting in 2012 focussed on more intensively planting in protected coves (see Figure 24). Planting began in May and finished in June 2012 and survival counts were undertaken in late October 2012. Overall survival was only 19% and while this is a lower result than the first year of planting, there were still strong indications that survival rates were better in coves where there was protection from waves. Monitoring in 2012 also revealed that survival was especially high at the northern ends of zones 1 and 4 where the jutting shoreline seems to provide protection from wind and waves from the north-west. Additionally, survival was much higher where seedlings had been planted behind the remains of an old pipe outlet (see Figure 29). These observations were also supported by the experimental plantings that were established near Grantville and Corinella (see Box 2 below).

Figure 29: Healthy seedlings planted behind pipe outlet rubble

It's important to note that seedling survival rates were not high in every cove. For example, the coves represented by zone 2 and 3 in Figure 22 had low survival rates for both 2011 and 2012. Factors that may have reduced survival include the steepness of the shore at the rear of the cove causing higher turbulence as waves are reflected into in the planting zone, as well as the presence of a fairly pronounced shelf below the bench in the cove (see Figure 30) which may increase turbulence around the seedlings which are planted near the shelf. Evidence of higher wave energy in these coves is demonstrated by the presence of dynamic sand banks visible in Figure 30. Some seedlings were also killed when buried by these sand banks.

Figure 30: Low survival coves – zone 3 (left) and zone 2 (right)

Box 2: The effect of varying protection and inundation regimes on the survival and growth of planted mangrove seedlings.

In April 2011, 3,024 mangrove seedlings were planted experimentally at seven sites near the towns of Grantville and Corinella on the eastern shores of Western Port. At each site seedlings were planted at;

1. three heights on shore (0.1m AHD, 0.4m AHD and 0.7m AHD), and
2. three proximities to remnant patches of mangroves (Close, Mid and Far) (see Figure 31)

Individual plants were monitored at 3, 6, 9, 12, 18 and 24 months.

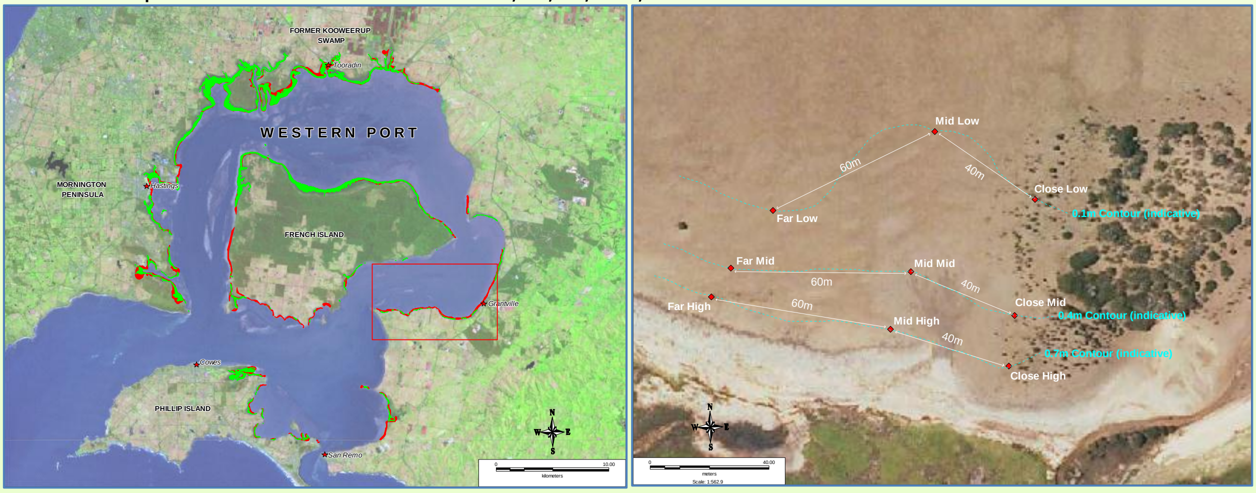
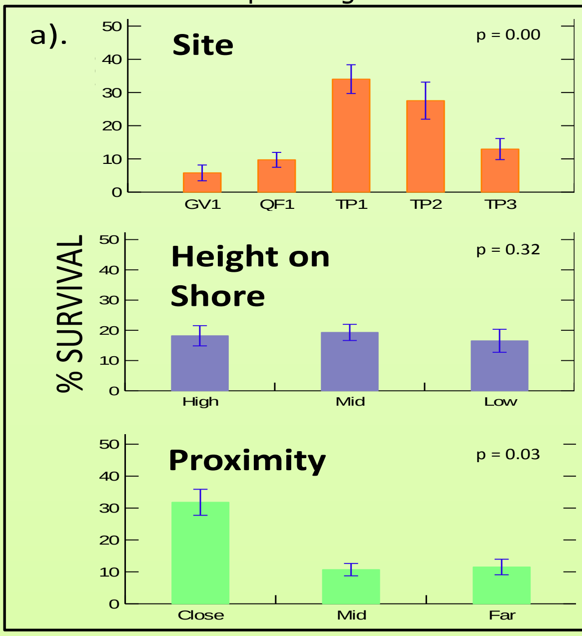


Figure 31: Experiment location (left) and experimental design (right).

After 24 months of monitoring, survival of seedlings planted close to remnant forests was three times as high as survival at the other proximities (Figure 32, a)). Additionally, survival varied across sites with the highest survivals found at north facing sites which are more protected from the prevailing westerly weather. High survival at the close proximity was not consistent across sites (c) with the more protected sites mainly responsible for the high survival shown in a). Growth rates were also higher at the north facing sites but height on shore played a greater role in growth than proximity at a site scale. Seedlings are still being monitored but initial analyses indicate that protection is important for the growth and survival of planted mangrove seedlings within and across planting sites.



b).

SOURCE	p-Value
PROXIMITY	0.03
HEIGHT ON SHORE	0.32
SITE	0.00
PROXIMITY X HEIGHT ON SHORE	0.21
PROXIMITY X SITE	0.00
HEIGHT ON SHORE X SITE	0.00
PROXIMITY X HEIGHT ON SHORE X SITE	0.12

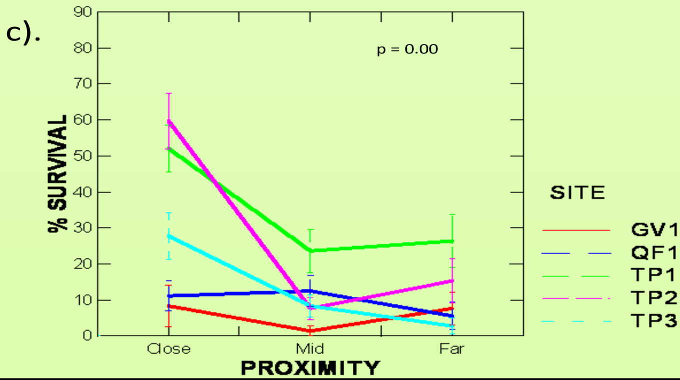


Figure 32: Survival after 24 months. a) Survival across site, height on shore and proximity treatments, b) Output p-values from 3-way ANOVA (significant results highlighted) and c) Proximity x site interaction plot.

Low survival rates for 2011 and 2012 may also have been the result of undersized seedlings being used for the planting that are less likely to survive after planting (see Section 3.2). The average height of seedlings that were planted in 2011 was approximately 75mm and they had an average of two pairs of leaves. In 2012, with the introduction of the tidal system, plant size had increased but due to propagule shortage and problems adjusting the new system, most of the plants were still very small (less than three pairs of leaves).

In 2013, the planting strategy focussed on three main areas;

1. Large seedling production: Given evidence that larger plants will result in higher survival rates, effort was put into utilising the tidal system by collecting propagules early in the season to give them more time for growth in the nursery before being planted. (Note that strategy was developed before data from propagule study (Box 1) was available).
2. Protection for seedlings: Given above evidence that seedlings will benefit from wave energy protection, a range of protective measures were trialled to evaluate their feasibility and effectiveness (discussed further in section 6).
3. Spring planting: 4,000 seedlings were kept in the nursery over winter to be planted in spring to determine if seedlings are able to establish better during their growing season.

As discussed in section 4.1, there seems to be some advantage in planting mangrove seedlings at a higher density than 1 plant/m^2 used by the WPSP. Therefore, some small areas of denser plantings (2 plants/m^2) were also undertaken.

6. Mangrove Seedling Protection

As discussed in the previous section, it appears that mangrove seedling survival can be enhanced by protecting them from hydrodynamic forces associated with tides and waves. This is especially important information for mangrove revegetation along the Lang Lang coast as it is subject to relatively high wave energy (see section 2). The planting strategy for 2013 included the use of wave attenuation measures with the intent of helping to protect seedlings and improving their survival rates. This approach is also being used by the Department of Environment and Primary Industries (DEPI) who have been investigating geotextile breakwaters for the protection of eroding coastlines. The use of the breakwaters provides immediate protection for the coastline but also provides a calmer water environment in their lee which is expected to be suitable for mangrove seedling establishment. This can then allow the establishment of a self-sustaining forest which will provide long-term protection for eroding coastlines.

6.1 Wave attenuation measure selection and description

In preparation for planting activities in 2013, a review of different mangrove seedling protection measures undertaken around the world was completed. The review recommended an integrated protection approach where protection was provided to the seedlings on a large (for a large group of seedlings) and small scale (for individual plants). Therefore an experiment was designed to test two large scale measures (pile fields and Enviro Rolls). These were implemented in combination with one small scale (PVC tree guards) protection measure.

The pile field wave attenuator is based upon a study which designed an optimal arrangement of vertically driven bamboo piles into the mudflats to reduce incoming wave energy (Halide, Brinkman, & Ridd, 2004). The study found that a pile field that was 30m wide consisting of 80mm piles spaced at

$4/m^2$ would be effective at attenuating 50% of incoming wave energy. The study also suggested that a minimum of 600mm of each pile should be embedded into the mud. This design was implemented at the Lang Lang coast where three 30m x 15m pile fields were constructed in winter 2013 using 2m lengths of 90mm PVC pipe pushed around one third of their length into the mud (see figure 33). PVC pipe was used as it was the cheapest and most readily available material for pile field construction. Bamboo poles of suitable length and diameter need to be shipped from overseas at a great expense and local natural materials (i.e. tea-tree poles) are not available in the correct dimensions.

Figure 33: PVC pipe pile field (with experimental plantings in foreground)

The second large-scale wave attenuation device, the Enviro-rolls, consist of a 10 x 3m piece of chain-link fencing wire which is used to create a roll that is 10m long by approximately 1m high (see Figure 34). The roll is fastened to the mud with 500mm steel pegs and supported by galvanised star pickets which are wired to the sides of the roll. The purpose of the rolls to provide a substrate onto which floating debris and algae can become caught and build up so that it becomes less ‘porous’ over time and more effective at attenuating hydrodynamic forces. Three 30m (3 x 10m lengths) Enviro-rolls were constructed in winter 2013 as part of the trial which is described below.

Figure 34: Enviro roll when constructed (left) and 4 months after construction (right) showing significant build-up of algae and other debris.

The final wave attenuation measure that was trialled was PVC pipe tree-guards. This technique is a modified version of the Riley-Encasement Method (REM) where a single mangrove seedling is raised in a length of PVC pipe which provides stem protection and promotes growth through phototropism (stimulation of growth towards light source) (Riley & Kent, 1999). The PVC pipe tree guard method aims to provide similar protective properties to REM but differs in that a 400mm piece of 100mm diameter pipe is fitted over an already planted seedling. The guard is pushed 100-200mm in the mud around the seedling and has been pre drilled to allow water to drain from the guard at low tide (see Figure 35).

Figure 35: PVC pipe tree guard (left) randomly placed in experimental plots (right)

The tree-guard aims to provide protection for the seedling in its early growth phases and may also help to reduce local erosion around the plants which has been undermining some seedlings at Lang Lang. It is not anticipated that trees will outgrow the guards for many years but they should be monitored to determine when the guards need to be removed. A biodegradable version of these guards made of rice husks has been developed and are being used for mangrove revegetation in Singapore and may be suitable for use in Western Port (Anon, 2013).

An experiment was designed to test the effectiveness of the three wave attenuation measures with nine 30x15m plots established along part of the Lang Lang coastline (Zone 6 in Figure 28). This part of the coastline was chosen as it is a relatively homogeneous section of coastline with mudflats that are wide enough to fit the plots. The area is also easily accessed, with the main access point used during the project existing at the north end of the site. 400 seedlings were planted in each plot and 200 were randomly assigned a PVC tree guard (see Figure 36). The pile fields and Enviro Rolls were each randomly assigned to three of the plots with the remaining three plots left as controls.

Figure 36: Experimental site viewed from north end. Enviro rolls in the foreground with two pile fields visible (one under construction) in the background. Planting plots with PVC pipe tree guards visible in lee of structures.

6.2 Monitoring results from October 2013.

Planting began in early May 2013 and was completed by the end of the month. The PVC tree guards and Enviro-rolls were installed during May as well but the pile fields took longer to install than anticipated. The first pile field was completed in June, the second in August and the third in early October. The results presented here must therefore be considered in the context of the delay in completion of the pile fields. Survival counts of the seedlings were undertaken in late October 2013. Importantly, the months preceding the monitoring included some extremely windy weather. The results of the monitoring are discussed below.

6.2.1 Planting density experiment

400 seedlings were planted at a 1 plant/0.5m^2 spacing in the middle of cove 1 (see Figure 28). This planting density is twice that of any previously undertaken plantings and the benefits of a higher planting density are discussed in section 4.1. Survival of the 400 seedlings was extremely low (<5%) even though this cove had had good survival rates in the past. Further seedlings that were planted around the rubble in this cove that had provided some protection in 2012 were also showing very low survival rates. A possible explanation for the low survival could be the windy weather that may have resulted in stronger waves. This explanation is strengthened by the fact that the seedlings that were killed appear to have been defoliated (see figure 37).

Figure 37: Defoliated seedling observed in October 2013.

It’s disappointing that survival of the higher density plantings was so low as the effectiveness of more closely spaced plants would probably not become apparent until they had grown a lot larger and their roots and/or canopies had a chance to interact.

6.2.2 Wave Attenuation Measure Experiment

Figure 38 displays the survival rates for the wave attenuation measures that are described in section 6.

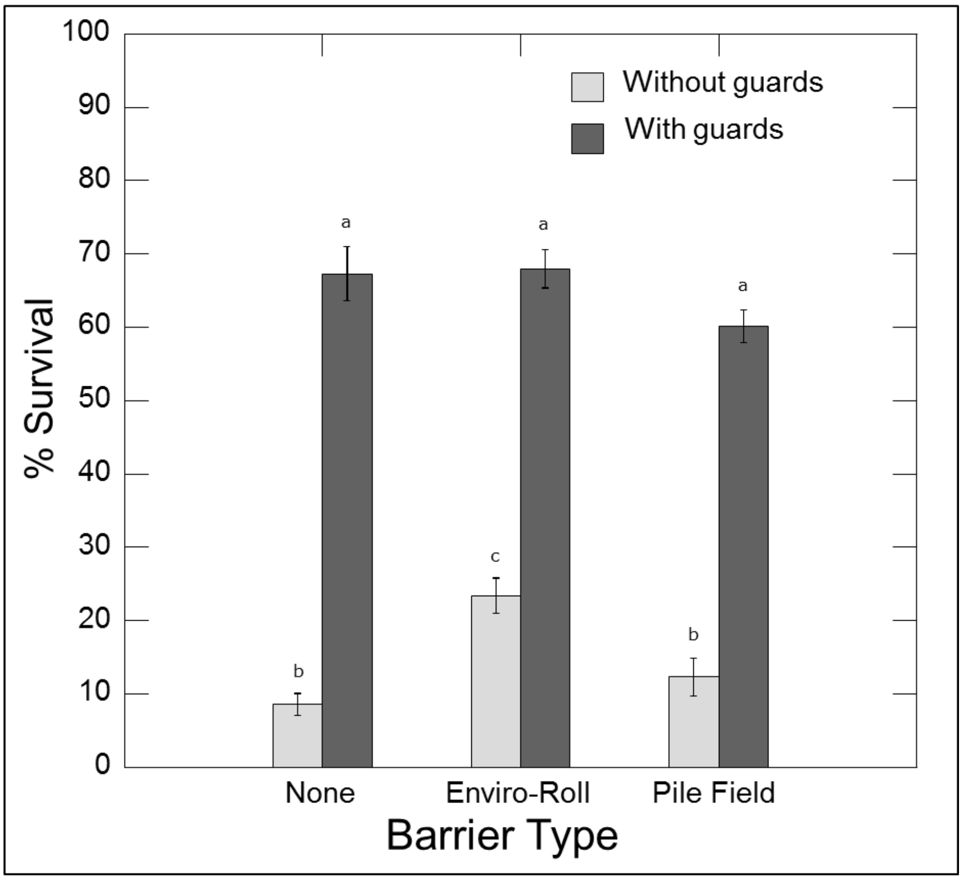


Figure 38: Seedling survival by barrier type and presence of PVC tree-guards. Error bars shown are ± 1 SE. Treatments with same letter are not significantly different.

Five months after planting, seedlings which had been protected with a PVC tree guard displayed an average 65% survival rate (no barrier 67%, Enviro-Roll 68%, Pile Field 60%) whereas an average of only 15% of seedlings that did not have a tree-guard were surviving (no barrier 8%, Enviro-Roll 23%, Pile Field 12%). Guarded seedling survival was not significantly different between barrier type, however it was slightly lower for the pile fields. This may have been caused by the disturbance to the planting plots that was a result of the construction of the fields as well as their delayed construction. Survival was significantly different between barrier types in unguarded plants with the Enviro-Rolls resulting in around twice the survival than displayed with the Pile Fields and control. Again, the lower survival results behind the pile fields may have been the result of disturbance and delay in completion of the structures (i.e. the first pile field completed showed a 23% survival rate in unguarded seedlings versus a 3% survival rate in the second completed and a 10% survival rate in the third).

These results indicate that unguarded seedlings can benefit from protection afforded to them by a wave attenuation structure with early results indicating that Enviro-rolls are the most effective. However when guarded, the seedlings show much higher survival rates and are seemingly unaffected by the presence of the wave attenuation structures. The very local protection from hydrodynamic energy that is gained from the PVC pipe tree-guard seems to be more important than larger scale reduction of energy that is being provided by the wave attenuation structures at this early stage in seedling development. It is possible that once the seedlings grow above the level of the guard and the higher parts of the plants become more exposed to wave movement, the benefit of the wave attenuation structures may become more apparent. Its therefore important that ongoing monitoring is undertaken to determine the longer term effects of the guards and wave attenuation structures.

It is particularly pleasing that such high survival rates are being show with the introduction of wave attenuation measures especially as there has been some very windy recent weather that has probably been responsible for widespread mortality of unprotected seedlings in other locations (see above).

6.2.3 Spring planting trial

In October 2013, three further plots of 400 seedlings were set up near the nine plots that were established in May. These plots were planted with seedlings that were kept in the nursery over winter to test whether survival rates improve when seedlings are actively growing. In each plot, PVC tree-guards were installed on around half of the planted seedlings.

7. Cost Analysis

As mentioned previously, some efforts have been made to review current projects and investigate alternatives for stabilising the Lang Lang coastline (GHD, 2006, 2010; Kirkman & Boon, 2012). These efforts also included some cost estimates of various alternatives. This section of the report provides details of the costs of mangrove revegetation and the wave attenuation structures from this project and how they compare to some of the alternatives that have been proposed by others. Cost estimates have been standardised to represent what the total cost of each option would be if implemented over 100m of the coastline.

7.1 Mangrove planting costs

Four people can feasibly plant approximately 1000 mangrove seedlings per day and this currently costs around $5,500 including supply and delivery of seedlings and labour to plant them. The total cost for revegetating 100m of coastline will obviously depend on the width and density of the plantings. A minimum planting arrangement of three rows of seedlings planted at 1/m^2 (300 seedlings) equates to $1,650. If the planting width was increase to 15m (to match the width of experimental plots from the wave attenuator trials) this would bring the cost to $8,250 for 100m (1500 seedlings). These costs are based on one seedling planted per square metre. If trials of denser plantings are successful and higher densities adopted, then the above costs would need to be adjusted.

7.2 Wave attenuation costs

The pile fields were the most costly of the wave attenuation structures. Materials cost around $26K for 100m and labour for their installation was higher than expected costing around $25K (a 30m length took 3-4 days to cut the pipe and insert all the piles manually). The Enviro rolls were far cheaper with $2K needed for purchase of materials and their simple design allowed them to be installed for around $1.7K. Monitoring of these structures has indicated that some are over performing and accumulating large quantities of algae and debris. Consequently some of the Enviro Rolls have started to sag and may need some extra support (i.e. more pickets, rolled concrete reinforcing mesh as a support frame etc.). This would add further, but probably not significant costs to these structures. The PVC pipe tree guards have been costed at about $1.60 per 40mm length and are estimated to cost around $2.50 per guard after cutting, drilling and installation.

7.3 Comparison of costs with alternative stabilisation techniques

GHD proposed a range of alternative stabilisation techniques and estimated the cost of each (GHD, 2010). Techniques included rock or geotextile sills which are low crested structures placed offshore parallel to the shoreline designed to reflect and dissipate incoming wave energy. These were costed by GHD at around $1700/m or $170K per 100m. DEPI's geotextile breakwaters are a version of these sills and were costed at around $96K for ~100m (Rennie et al., 2011). Other alternatives suggested by GHD included floating high density polyethylene (HDPE) breakwaters that are used to protect some marinas ($30K/100m) and traditional rock revetment works including seawalls ($210K/100m). GHD also pointed out that the difficult access to the site could add significant costs to any of these techniques.

Table 4 summarises the cost of each of the stabilisation techniques discussed in this section and allows comparison between them. It's clear that mangrove revegetation by itself is much cheaper than the conventional engineering techniques that have been suggested. When combined with wave attenuation structures, the cost of mangrove revegetation increases but is still generally less expensive than engineered solutions. Additionally, mangrove revegetation will need minimal maintenance in the long term and will not need to be replaced as engineered structures would need to be at the end of their lifespan.

Table 4: Comparison table of coastal stabilisation technique costs

Stabilisation Technique	Cost per 100m
Mangrove revegetation	
3m wide planting	$ 1,650.00
15m wide planting	$ 8,250.00
Wave Attenuators	
Pile field	$ 51,000.00
Pile field + 15m mangrove planting	$ 59,250.00
Enviro Roll	$ 3,700.00
Enviro Roll + 15m mangrove planting	$ 11,950.00
PVC pipe tree guards + 15m mangrove planting	$ 12,000.00
Engineering Solutions	
Rock or geotextile Sill	$ 170,000.00
Geotextile Breakwater (DEPI)	$ 96,000.00
Floating HDPE Breakwaters	$ 30,000.00
Revetment/Seawalls	$ 210,000.00

The engineering solutions, while very expensive, are likely to have an immediate impact on reducing the coastal erosion. Conversely, mangrove revegetation as a low-cost alternative will probably not significantly reduce the erosive force of tides and waves for many years. This certainly highlights the importance of producing a management strategy for this part of Western Port's coastline and is discussed further in the next section.

8. Recommendations

This section of the report provides some overall recommendations based on what we have learnt throughout the life of the project. There are some recommendations that relate to general mangrove revegetation techniques and could apply to other mangrove revegetation projects across Western Port or further abroad. There are also a few project specific recommendations which provide advice on how the Lang Lang coastal erosion issue could be addressed in the future.

1. **Propagule Collection:** Our study on propagule collection techniques (Box 1) indicates that the largest propagules collected from the ground should result in larger seedlings in the nursery. The study also showed us that collecting propagules early in the season is not necessarily advantageous and it is probably better to wait until the height of the fruiting season to collect. Although we found that propagules collected in January resulted in the largest plants, timing may vary from year to year based on climate so propagule size and abundance of propagules lying on the ground should also be used as indicators for when collection should occur.

2. **Seedling Containers:** While 600ml milk cartons have been used consistently during the project, there is concern that they may be too small and the seedlings could be becoming root-bound. This may become more likely if seedlings are kept for longer in the nursery and planted in spring. Therefore investigation of alternative containers is recommended.

3. **Nutrient Additions:** There is evidence that nutrient additions could be beneficial to mangrove seedlings raised in the nursery. Nitrogen additions in particular have been shown to promote growth of *A. marina* and this could be easily trialled in the nursery. It should be noted that there is little

evidence of nutrient limitation at the Lang Lang site as evidenced by our sediment sampling results discussed in section 2.2.

4. **Timing of planting:** Decisions about when to plant could be based upon the following although monitoring of 2013 plantings will give a better indication of how successful spring planting might be;
    a. **Seedling size:** Seedlings have generally been planted when they have grown 3 pairs of leaves. Number of leaf pairs has been used as it is a practical indicator that can easily be used by nursery staff who need to sort through large quantities of seedlings for delivery. As indicated in Figure 16, survival increases with number of leaf pairs grown. In 2013, around half of the seedlings growing in the nursery had reached this stage by late autumn.
    b. **Season:** Holding seedlings in the nursery over winter and planting in spring may be beneficial as seedlings may be able to better establish while they are actively growing. However, observations of seedlings being stored over winter 2013 indicate that seedlings appear to be losing condition (i.e. yellowing, losing some leaves, small number of deaths). As mentioned, monitoring of 2013 spring plantings will be essential to determine if this method is worth pursuing.

5. **Direct Seeding:** Based on the trials that were undertaken at Lang Lang, direct seeding would not be recommended at this location. Crab predation seemed to have been partially responsible for the failure, but more concerning is the longer-term undermining of seedlings that do successfully establish and are not protected by the milk carton or PVC pipe tree guards. However, the technique has been proven to be successful in other parts of the bay and the logistical advantages that are gained definitely make it worth considering in other mangrove revegetation projects.

6. **Planting location:** Monitoring of Lang Lang plantings and the research project near Grantville (see Box 2) suggest that mangrove seedlings will survive best when planted within the appropriate tidal range. Along the Lang Lang coast this generally corresponds to the bench areas as discussed in section 2.2. Seedlings that were planted below the bench in the

unconsolidated sediments were unstable and many were washed out. It is also recommended that planting should be concentrated in protected areas of the Lang Lang Coast i.e. coves. Where planting areas are less protected by the natural formations of the coastline, consider using wave attenuation measures. The monitoring that was undertaken in October 2013 indicates that the PVC tree-guards that were used were most effective in significantly increasing survival rates. There are some signals that the wave attenuation structures could also be effective but ongoing monitoring should be conducted as it seems that they may be more effective in later stages of mangrove growth. The Enviro-Rolls look the most promising as they are significantly cheaper and quicker to install and have thus far resulted in the highest survival of seedlings which are unprotected by the PVC tree-guards. The design of the Enviro-Rolls could be improved as they are prone to sagging with heavy accumulation of detritus and algae. The chain-mesh wire also tends to wear around the anchoring stakes.

7. **Ongoing Monitoring:** This project ends in October 2013 and there is no provision for future monitoring of the plantings. It is recommended that monitoring be continued, especially of the plantings that have been set up experimentally to test the effectiveness of the wave attenuation measures. Additionally, monitoring results from the spring plantings will provide valuable information for future planting efforts in Western Port. Longer term monitoring will also be necessary for maintenance of wave attenuation structures.

8. **Erosion considerations:**
    a. CSIRO's observations that erosion is occurring on the flat parts of the bench where mangroves are being planted is concerning and is resulting in the death of seedlings that are being undermined by the erosion. It is unknown whether this bench erosion is also occurring in more protected parts of the coastline or whether the wave attenuators will be effective at immediately reducing this erosion as well as promoting seedling survival. The PVC pipe tree guards may be effective at reducing undermining as well as protecting the seedlings from wave energy.

b. Preliminary findings indicate that the highest erosion rates are found on the headlands and are therefore the part of the Lang Lang coast which is contributing most sediment to the bay. These are the areas that need most protection from the erosive forces of waves but are also the areas that have had the lowest mangrove survival rates. The absence of the bench area below these headlands as well as in some other parts of the coast is probably a major reason for low survival as the unconsolidated sediments do not seem appropriate for planting. An approach which combines mangrove revegetation in the coves and other benched areas with some shorter-term engineering solutions on the headlands and benchless areas may be appropriate. The engineering solutions would help to immediately reduce sediment input to the bay while the mangroves have time to establish on the benches and in the coves with the view of them spreading across the entire coastline from well-vegetated nodes in the future. Seagrass meadows that may regenerate (or be revegetated) as the result of reduce sediment loads would be expected to further help to attenuate wave energy that attacks the Lang Lang coast.

9. **Coastal management strategy**: The erosion study that CSIRO are currently undertaking along the Lang Lang coast will provide a good picture of the coastal erosion issue and its relative importance as a contributor of sediment to the bay. Their study in combination with what has been learnt through this project and WPSP's experiences should provide a good basis upon which to create a management strategy for the Lang Lang coast. Responsibility for the issue has been unclear and the strategy would be useful in mapping out what would likely be a multi-agency (DEPI, Parks Victoria, Melbourne Water, EPA, Municipal Councils) collaboration.

10. **Climate Change considerations**: The expected effects of climate change are particularly relevant and complex for coastal environments. For example, a rising sea-level will shift the natural tidal range in which mangroves survive landward, while more frequent and intense storm events may increase the rate of coastal erosion and further reduce mangrove seedling survival rates. However, a warming climate may be beneficial for a

species which is limited in size and growth by cold weather. Potential climatic changes will certainly need to be considered when planning management action for eroding coastlines.

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