FOREST RESEARCH INSTITUTE

EXPERIMENTAL RESTORATION OF INDIGENOUS SALT MARSH MAKETU ESTUARY

INVESTIGATION NO : S621
KEY OUTPUT NO: 4.19

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D.O. Bergin

Northern Wildlands Section
Forest & Wildland Ecosystems Division
Forest Research Institute
Private Bag 3020, Rotorua

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CONTENTS

EXECUTIVE SUMMARY (FINAL):

KEY OUTPUT NO: 4.19
INVESTIGATION NO: S621

INVESTIGATION TITLE:	Experimental restoration of indigenous salt marsh Maketu Estuary
STUDY VENUE:	Bay of Plenty
INVESTIGATION LEADER:	D.O. Bergin
INVESTIGATION STATUS:	Completed
CLIENT:	DOC, Science and Research Division

INVESTIGATION OVERVIEW:

An estimated 95% of the indigenous salt marsh at Maketu Estuary has been lost over the last 50 years. In 1990-91 the Northern Wildlands section, Forest Research Institute, Rotorua, initiated monitoring of some factors that could affect the status of the only remaining piece of salt marsh, and investigated techniques for re-establishing salt-marsh vegetation on mudflats for the Department of Conservation.

OBJECTIVES:

- To review previous consultants' reports and early aerial photographs, of the decline of salt-marsh, and review suggestions for its restoration.
- To describe the status of remnant salt-marsh vegetation.
- To begin investigations into the factors affecting the status of major indigenous salt-marsh species.
- To test whether selected salt-marsh species can be successfully transplanted onto mudflat.
- To investigate whether eradication of the introduced species, spartina, with herbicides is feasible.
- To interpret preliminary results, with emphasis on determining site requirements for establishment of indigenous salt-marsh species.

METHODS:

- The vegetation pattern, composition, and health of the salt marsh was described from aerial photographs and field inspections. The margin of the salt-marsh was inspected to determine the extent of plant dieback.
- Water samples taken from the surface and from two levels in the substrate were analysed for chloride content, and salinity gradients were mapped. Permanent datum pegs were established for future monitoring margin retreat and changes in substrate levels.
- Over 2500 transplants of *Juncus maritimus* and *Leptocarpus similis* were planted on one sheltered and one exposed site adjacent to the salt marsh. Treatment factors tested were

clump-size, spacing, and application of fertiliser at planting. Several plots of mangroves were also established. Perfomance was assessed 5 months after planting.

- Two rates of Roundup and Gallant herbicide were applied to plots of spartina in spring and autumn by knapsack sprayer.

RESULTS:

The dominant *J. maritimus* forms an extensive stand on the seaward (north and western) side of the salt marsh. At the southern end are *J. maritimus* and scattered clumps of *L. similis*, with *Plagianthus divaricatus* on higher parts.

Approximately two-thirds of the salt-marsh margin is retreating, with an estimated 40% severely eroding. Along much of the retreating margin, the vegetation is growing on a surface up to 150 mm higher than the surrounding mudflats. Root systems of undermined plants are reduced to blackened, hollowed-out root bases.

Salinity levels form a gradient from low salinities on the inland side of the estuary to salinities close to that of sea water on the seaward side. Freshwater ponds on the inland sheltered site during high tides. There was little difference in salinity between the upper peat layer and the sand layer.

Five months after planting, the medium and large clumps of *J. maritimus* survived significantly better than small clumps on the sheltered site. On the exposed site, only the large clumps have reasonable survival. The large clumps of *L. similis* have survived significantly better than smaller clumps on the sheltered site. Only small mangrove propagules had survived 5 months after transplanting, and only on the sheltered site.

Neither Roundup nor Gallant had a significant effect on spartina applied in spring. It is too early to assess the effect of autumn spraying.

CONCLUSIONS:

Without a very large commitment of resources, it is impossible to identify which factors are chiefly responsible for the decline of salt-marsh vegetation at Maketu Estuary. The pattern of vegetation at Maketu is similar to that of other salt-marsh communities. Salinity gradients indicate that species are within their tolerance limits.

Salt-marsh vegetation is on a higher level than surrounding mudflats, suggesting that the level of the estuary is decreasing. Physical abrasion by wave action is a significant factor in undermining marginal plants, particularly on the exposed site. A contributing factor may be changes in soil chemistry that lead to root death and pre-dispose margins to rapid erosion.

Early results indicate the dominant rush species can be transplanted successfully to sheltered mudflats.

2. INTRODUCTION

An estimated 95% of the indigenous salt-marsh at Maketu Estuary has been lost over the last 50 years. Since the diversion of the Kaituna River in 1957 the remaining salt-marsh has continued to decline. Only one major piece of salt-marsh of about 5-ha now remains on the inland side of the estuary (Fig. 1). Parts of the estuary are also under threat from invasion by the introduced species, spartina (*Spartina alterniflora*).

Restoration of Maketu Estuary, even in part, is considered ecologically and socially desirable (Richmond 1989). The Bay of Plenty Conservancy of the Department of Conservation has therefore formulated a restoration strategy for the estuary. The rehabilitation of salt-marsh is one component of this restoration plan.

The Northern Wildlands section, Forest Research Institute, Rotorua, initiated monitoring of some of the factors that could affect the status of the only remaining piece of salt-marsh, and investigated techniques for re-establishing salt-marsh vegetation on mudflats. The work was done for the Department of Conservation during 1990-91.

3. OBJECTIVES

- To review previous consultants' reports and early aerial photographs, of the decline of salt-marsh, and review suggestions for its restoration.
- To describe the status of remnant salt-marsh vegetation.
- To begin investigations into the factors affecting the status of major indigenous salt-marsh species.
- To test whether selected salt-marsh species can be successfully transplanted onto mudflat.
- To investigate whether eradication of the introduced species, spartina, with herbicides is feasible.
- To interpret preliminary results, with emphasis on determining site requirements for establishment of indigenous salt-marsh species.

4. METHODS

4.1 Review of previous work

Consultants' reports covering various aspects of the decline of salt-marsh and changes to the estuary at Maketu were reviewed. Some of the recommendations made were used to determine methods for monitoring environmental factors and establishing transplanting trials.

4.2 Status of vegetation

Aerial photographs were used to map distribution of major species within and around the main salt-marsh remnant adjacent to Maketu Road. The general vegetation pattern, composition, and health of stands were described for the salt-marsh community. The margin of the remnant was also inspected to determine the extent of plant dieback. Unthrifty plants or plants that were undermined and breaking away from root systems were classed as unhealthy. The rooting depth of major species was estimated for typical healthy plants by excavating. Root systems of both healthy and unhealthy plants were described and photographed.

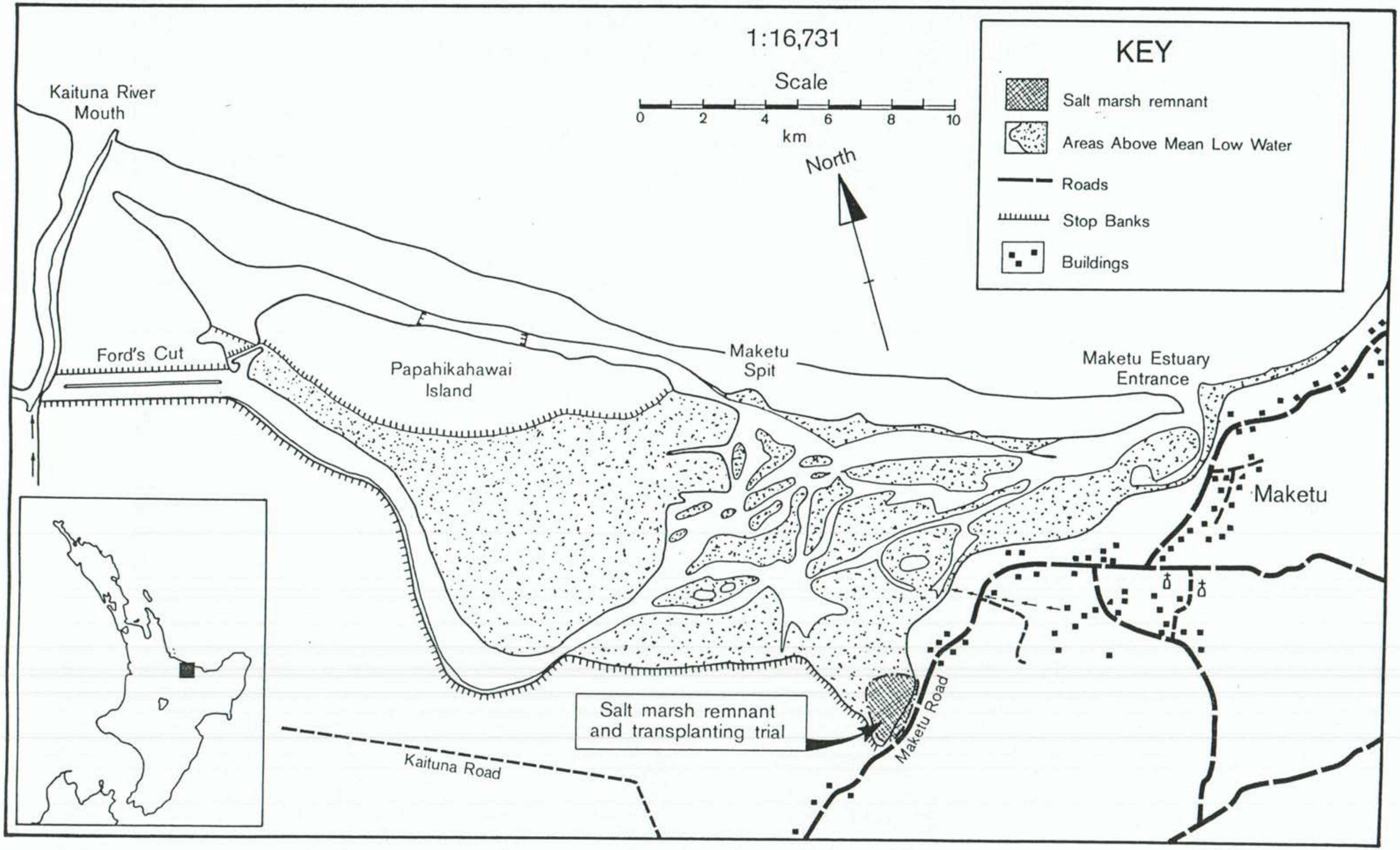


Figure 1: Location of trial area and main features of Maketu Estuary (Modified from Murray 1978).

4.3 Factors affecting salt-marsh

4.3.1 Monitoring of salinity levels and tidal inundation

Surface water flows in relation to tidal elevation were observed within and around the salt-marsh remnant. To determine whether salinity levels were suitable for salt-marsh plants, two transects of sampling points were established in the salt-marsh trial area so that salinity gradients could be plotted. One transect was placed parallel to the road, with sample points 90 m apart, and the second was placed at right angles to the road, with sample points 50 m apart. The vegetation and soil profile were described at each sample point.

Water samples were taken in April and May from two levels in the substrate at each sample point for analysis of chloride and conductivity. Suction-cup lysimeters were placed 300-500 mm within the upper layer of peat and piezometers were placed up to 1 m below ground level within a layer of sand. Further sampling points were established at three locations either side of the road as well as along the exposed margin of the salt-marsh remnant. In July 1990 a further set of water samples, including samples of surface water, was taken 1 hour before high tide and 1 hour after high tide.

Water samples were chemically analysed for concentration of chloride by the FRI Soils group using techniques described by Nicholson (1984). Salinity is defined as the total mass in grams of all dissolved substances per kilogram of sea water (Stowe 1983). In most sea water there is approximately 19 parts per thousand of chloride. As chloride is 55.04% of the total weight of principal salts and ions in sea water, multiplying chloride content for each sample by 1.817 gave salinity in parts per thousand for each sample. Salinity for most sea water is about 35 parts per thousand.

Salinity gradients were mapped for both surface and subterranean water throughout the study site at Maketu. Where possible these gradients were used to infer water flow patterns, particularly for surface water during high tide.

4.3.2 Pathological factors

Samples of plant material from healthy and degraded plants were collected for analysis by FRI Forest Health Group to determine whether any fungal diseases may be contributing to the decline of salt-marsh species.

4.3.3 Datum points

The long-term rate at which the salt-marsh vegetation is retreating will be monitored by 15 treated pegs (2 m long) placed in permanent positions around the existing margin. Distances were measured along a compass bearing to the nearest live plant on the edge of the remnant as reference points for any future retreat of salt-marsh vegetation. The datum pegs were also used to establish a reference mark so that any increase or decrease in substrate level can be identified.

4.4 Transplanting trial

4.4.1 Species and layout

The two main species tested in the trial were *Juncus maritimus* and *Leptocarpus similis*. Over 2500 transplants were planted in 20 seedling groups in November 1990. The planting pattern was designed to blend in with the natural vegetation as much as possible.

The trial was located at two sites, one on the exposed side of the main salt-marsh remnant where wave action could uproot plants during stormy conditions, and one on the inland side of the estuary between the vegetation remnant and Maketu Road. Placement of transplanted seedlings was influenced by four site factors: salinity levels of surface water that covered planting sites during high tides, proximity to existing vegetation, type of substrate covering planting sites, and degree of exposure to wave action and wind.

4.4.2 Treatment factors

The treatment factors tested at each trial site for *J. maritimus* were clump-size (small, medium, large), fertiliser (present, absent), and spacing of clumps within plots (wide - one plant/m, medium - two plants/m, narrow - four plants/m).

The effect of removing transplants from healthy plants along the edge of the main remnant was minimal. Large sections of healthy plant were separated with a spade, with at least a spade depth of mud containing the roots. Sections of plant material were then dragged over to each planting site and clumps of the appropriate size cut by spade.

The large clumps were 100 x 100 x 150 mm depth, medium-size clumps 50 x 50 x 150 mm depth, and small clumps were bare-root transplants with a few leaves and attached roots. The large and medium clumps had intact root systems with substrate still attached. Time to prepare transplants and plant each plot took a minimum of 15 minutes for small clumps and 25 minutes for larger clumps.

Spacing was determined by marking 5 m, 3.6 m, or 2.5 m diameter circles for the wide, medium, and narrow spacings, respectively. Seedlings were then planted at a relatively even spacing within and up to the edge of marked circles to give the same number/spacing.

Fertilised plants were treated by placing 25 g of a slow-release NPK fertiliser (Magamp coarse granules) in the planting hole before the transplant was inserted to reduce the chance of it being washed away by tidal water.

4.4.3 Trial design

At each site, three replicate blocks were planted. For *J. maritimus*, all treatment combinations were tested at each site. For *L. similis*, only the sheltered site was used, and only the clump-size treatment factor tested at medium spacing, without fertiliser. Seedlings were planted in plots of 20 transplants with a single treatment combination assigned randomly to each plot.

4.4.4 Monitoring

The transplanting trial was assessed for survival 5 months after planting. Transplant groups were rated for health, based on the proportion of live shoots (good - greater than 50% live leaves, intermediate - 25-50% live leaves, poor - less than 25% live leaves). The number of plants within each group considered unthrifty was also recorded. Analysis of variance methods were used to test the significance of treatment and site effects on survival and health of transplants.

4.4.5 Transplanting of mangroves

A mangrove (*Avicennia resinifera*) pilot trial was established in mid-1990, with 10-50 cm high mangroves plants transplanted from Tauranga Harbour. Additional plots of freshly collected small propagules of mangrove were established in January 1991, two plots at both the exposed and the sheltered site. Propagules with roots less than 3 cm long and those with roots longer than 3 cm were planted in separate plots, and their performance was monitored.

4.5 Eradication of spartina

Eradication of spartina was attempted with the intention of eventually establishing indigenous salt-marsh species in areas previously occupied by spartina. A small pilot trial tested two different rates of Roundup (10 ml and 20 ml/litre) and Gallant (5 ml and 12.5 ml/litre). The spray treatments were applied by knapsack to sections within a large semi-circular dense colony of spartina adjacent to Maketu Road. Spraying was carried out - in spring (September) and autumn (April).

5. RESULTS

5.1 Review of previous work

The retreat of salt-marsh at Maketu has been well documented by KRTA (1986 unpublished report), using a series of aerial photographs dating back to 1939. Most of the maritime salt-marsh has been virtually eliminated from the estuary as a result of farmland development, largely since diversion of the river. The 1959 aerial photographs, taken about 3 years after the diversion, show what appears to be healthy salt-marsh over much of the estuary. The 1963-64 photographs taken before stopbanking on the seaward side of the estuary, show some degeneration of the salt-marsh vegetation. By 1977, photographs taken after completion of stopbanking show extensive destruction of salt-marsh and its conversion into tidal mudflat. The damage to salt-marsh was thought to be caused by increased penetration of saline water into the marsh as a result of the river diversion and dredging associated with the stopbanking, together with more frequent tidal inundation as a result of subsidence of the area (KRTA 1986). Murray (1978) also indicated that there was insufficient sediment flow (since the diversion) to counteract the probable subsidence and erosion of the land.

In 1988 a Cawthron Institute report commissioned by the Department of Conservation recommended that restoration of the salt marsh was feasible to a "limited extent", and suggested an inland area of the estuary adjacent to Maketu Road as a potential site for replanting the dominant salt-marsh species, *J. maritimus* (Gillespie 1988). This area still receives some fresh water and has the last major stand of salt marsh in the estuary. It was suggested that a range of treatments be tested in a transplanting trial including clump-size, spacing and response to slow release fertilisers before any large-scale planting programmes are planned for the estuary.

Few examples of rehabilitation of salt-marshes in New Zealand using indigenous species have been recorded. A trial-planting of about 300 transplants of *J. maritimus* and of *L. similis* was established by predecessors of the Wellington Regional Council in 1983 on the banks of the Hutt River to prevent erosion (G.R. Dick, Wellington Regional Council, pers. comm.). The transplants were a similar size to the large clump-size used in the Maketu trial and were planted at 1-m spacing. Initial survival was high, especially on sites protected by brush batters. Survival 7 years after planting was estimated at 30% for *J. maritimus*. Most losses were attributed to burial, localised erosion, and vandalism.

5.2 Status of vegetation remnant

The dominant plant species is *J. maritimus*, which forms a pure dense stand over a major part of the northern end of the salt-marsh remnant (Fig. 2). Here *J. maritimus* is 50-70 cm tall, and although plants appear healthy, they carry a lot of dead leaf material. In contrast, *J. maritimus* on the more sheltered southern side of the remnant is up to 1.2 m tall, with less dead leaf material associated with plants. Scattered clumps of *L. similis* are present in dense *J. maritimus* stands on the south side of remnant and along the eastern sheltered edges near the road. *Plagianthus divaricatus* grows with the dense *J. maritimus* on the higher parts of the southern half of the remnant. Occasional mangrove plants, mostly seedlings less than 30 cm high, are established on the mudflats, particularly along the exposed north-western side of the salt-marsh.

Three clumps of spartina occur within the study area other than the large continuous stand on the western side of the stream. However, numerous sections of spartina that had broken away and floated to new sites were scattered around the salt-marsh margins. Some of these appear to be taking root. A row of pampas (*Cortaderia selloana*) occurs along the roadside, and occasional well-established plants occur on drier mounds amongst salt-marsh vegetation further out in the estuary.

Cores showed that the soil profile consists of an organic-rich, dark-brown peaty horizon 300 mm - 800 mm thick, overlying coarse grey sand of volcanic origin. Rooting depth of salt-marsh vegetation exceeds 800 mm.

Two-thirds of the salt-marsh margin is retreating, with an estimated 40% showing severe erosion (Fig. 2). The unhealthy margin forms an almost continuous ribbon along the western and southern edges of the salt-marsh. The worst affected margins are on western edges most exposed to the prevailing wind, and along the stream and an associated channel on the south side of the remnant.

Along much of the retreating margin, the salt-marsh vegetation is growing on a surface raised up to 150 mm higher than the surrounding mudflats. Around the edges of this raised surface, *J. maritimus* is often undermined, and its roots are reduced to blackened, hollowed-out root bases. In more exposed areas on the seaward side, wave action is eroding some of the plants, which still have roots but have lost all substrate. However, a high proportion of undermined plants have eroded root systems that are not characteristic of wave action alone.

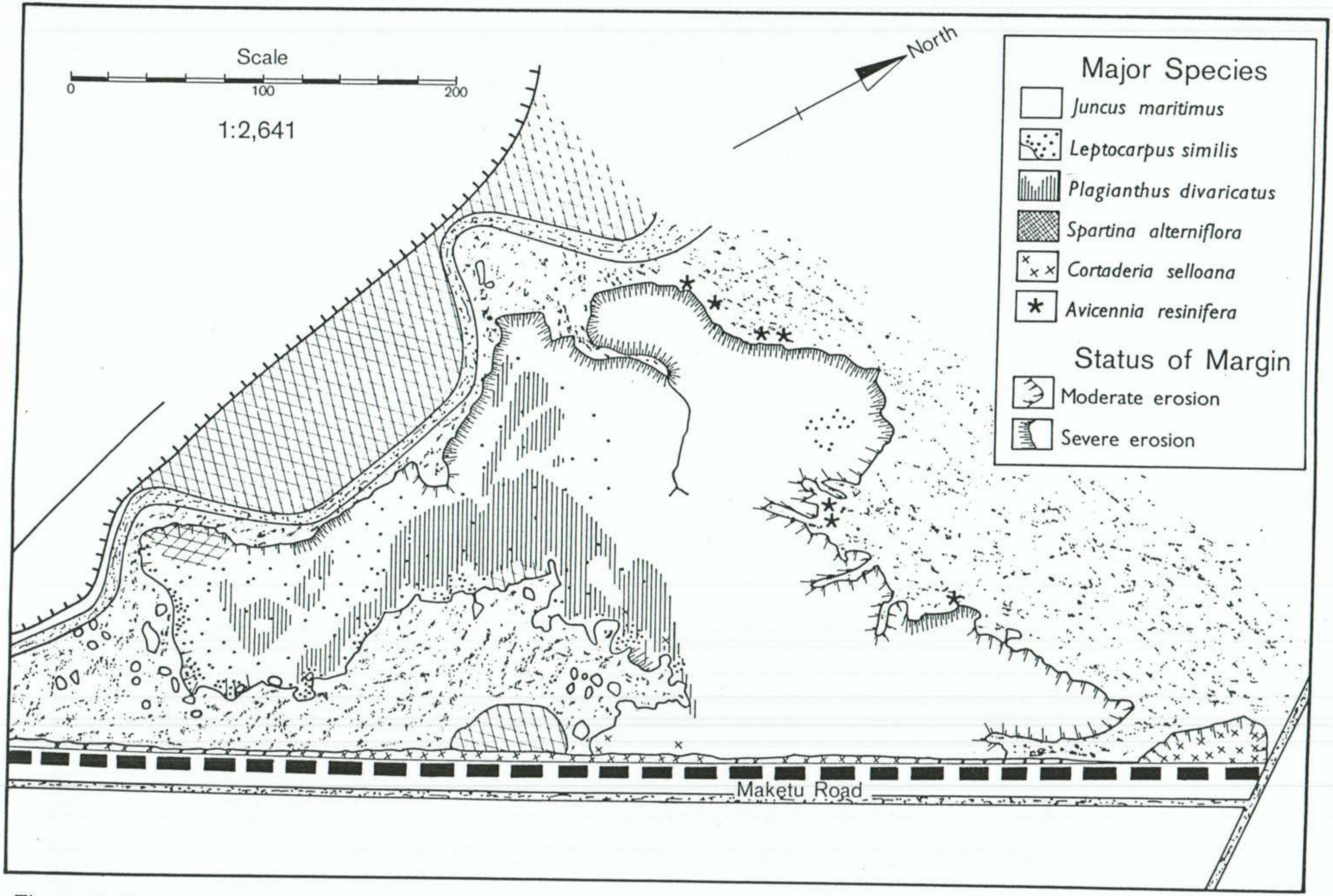


Figure 2: Vegetation pattern and status of margins, salt marsh remnant, Maketu Estuary.

Evidence of the retreat of salt-marsh in the form of eroded peat beds and woody stumps (probably mangrove or *P. divaricatus*) is seen in numerous areas at considerable distances from the margin of the present remnant.

5.3 Factors affecting salt-marsh

5.3.1 Monitoring of salinity levels

Salinity gradients of surface water around the salt-marsh change before and after high tide (Fig. 3). As expected, salinities are very low for samples taken before high tide in the stream on the south-west side of the salt-marsh (samples 31, 32) and the sheltered site between the road and the marsh (samples 33-37). In contrast, salinities along the northern edge of the marsh, which is the first area to become flooded by tidal water, indicate that samples 41 and 42 are largely sea water.

One hour after high tide, sea water had begun to back up along the stream on the south-west margin of the marsh, with a major increase in salinity where the channel widens out into the estuary (sample 43). As sea water backs up along the stream, mainly fresh water is ponded in the sheltered area (samples 33-37). Generally, salinity levels were lower on the inland side of the transects than on the seaward side of the estuary (Fig. 4). There was little difference in salinity between the upper peat layer and the sand layer. Salinity gradients in ground-water samples taken in July showed similar trends to those taken in April and May.

5.3.2 Pathological factors

No pathological cause for the decline was discovered during an examination of healthy and unhealthy *J. maritimus* plants (M. Dick, FRI, pers. comm.). Although, this possibility could not be ruled out completely, vertification would involve substantial work. A mealy bug (*Trionymus diminutus*) found in the sheath at the base of all plants examined, but in greater concentrations in plants from eroding sites, could be contributing to the decline, but it is unlikely to be a major factor.

5.3.3 Datum points

Although datum pegs have been established for 1 year only (Fig. 5), the margin of salt-marsh at one peg located on the seaward side has retreated toward the east by approximately 400 mm. In places nearby, the retreat has probably been greater as recent undermining extends up to 1 m from the previous margin.

Remeasurement of vertical heights between reference points on datum pegs and the level of surrounding substrate has shown small increases and decreases in substrate levels over a 6-month period. At this early stage there are no particular trends in these changes.

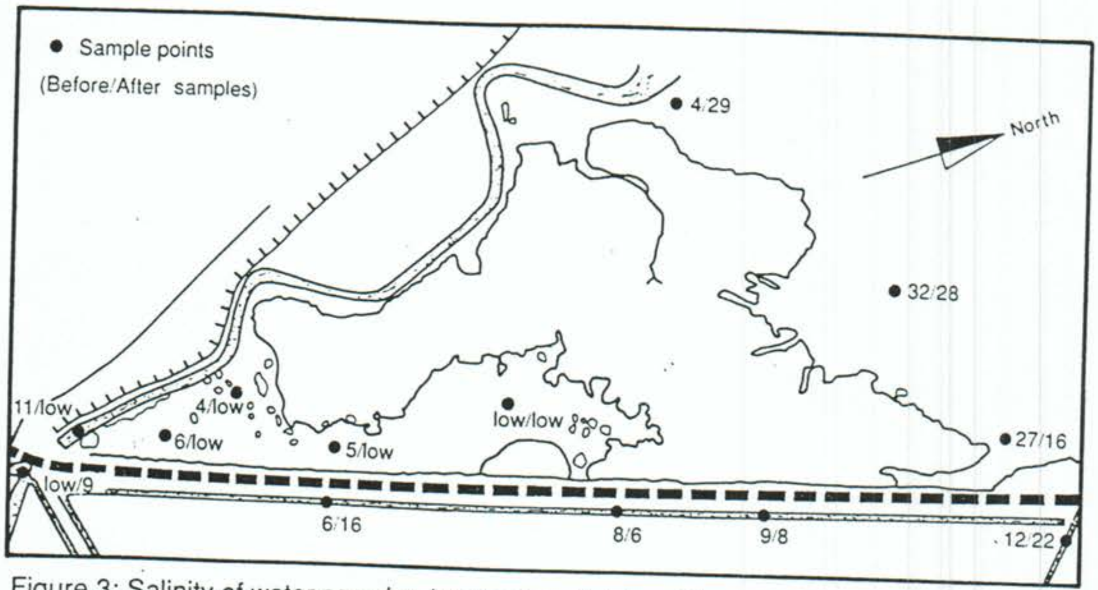


Figure 3: Salinity of water samples (pp thousand) taken 1 hour before/after high tide, Maketu salt marsh. Seawater salinity is 35 pp thousand.

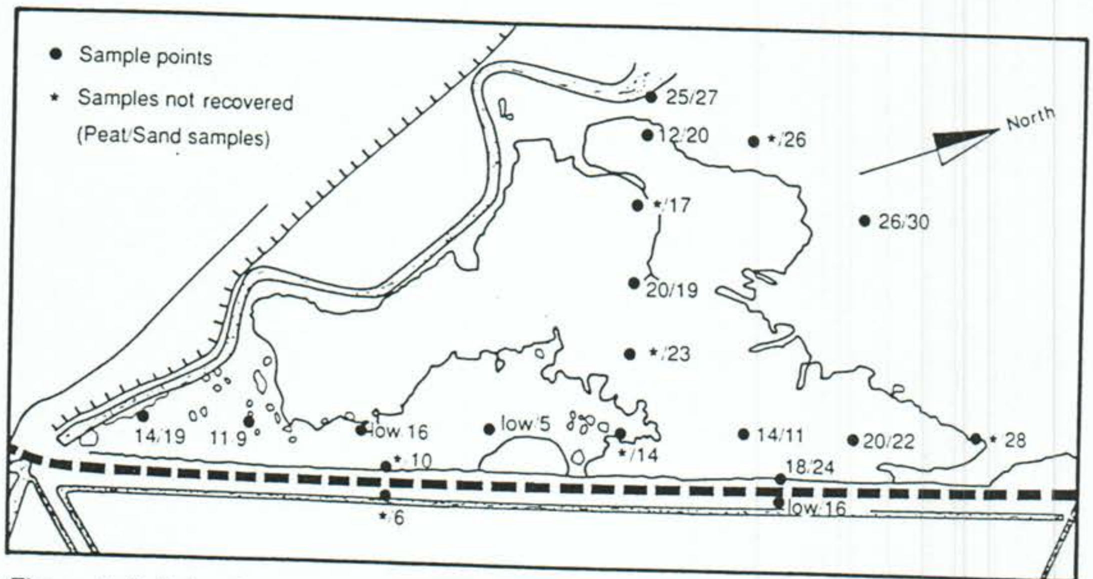


Figure 4: Salinity of ground water samples taken in July 1990 from upper peat layer/lower sand layer, Maketu salt marsh. Seawater salinity is 35 pp thousand.

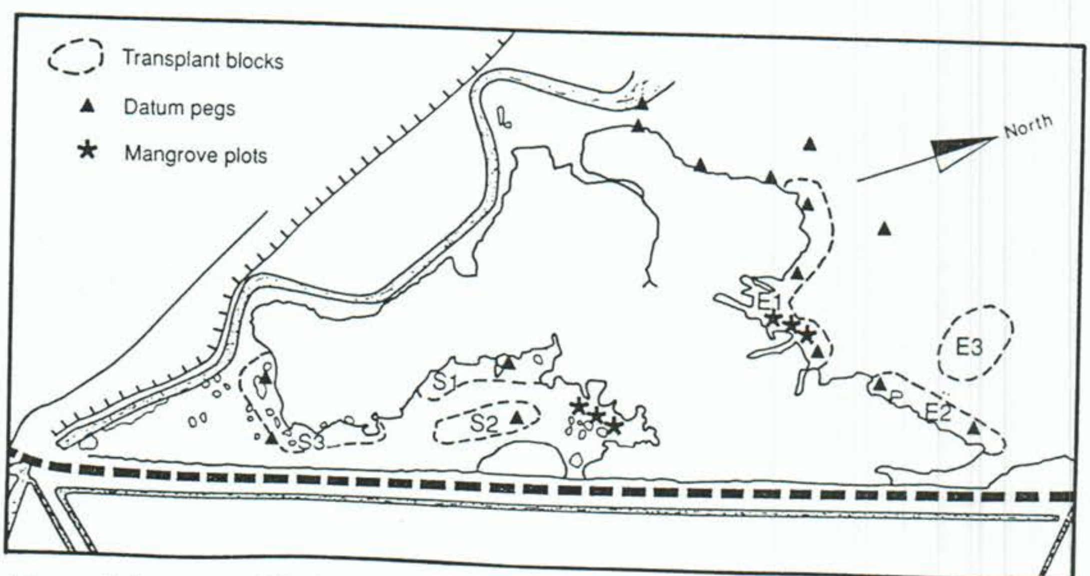


Figure 5: Location of blocks of transplanted *Juncus maritimus* and *Leptocarpus similis*, mangrove plots, datum pegs and spartina herbicide trial.

5.4 Transplanting trial

After only 5 months, there are clear trends in the performance of transplanted seedlings in both sites (Fig. 5). In general, significantly more *J. maritimus* plants have survived on the sheltered site than on the exposed site (Fig. 6). On the sheltered site, significantly fewer small clump-size plants (79%) have survived than plants in the larger clump-sizes (both over 95%). The proportion of unthrifty transplants and seedling health also showed significant differences (Appendix 10.1). The large clump-size in particular had a low percentage of unthrifty plants, and most plants were classed as having good health. On the sheltered site, performance of *J. maritimus* did not differ significantly in the different blocks.

On the exposed site, approximately one-third of medium clump-size and two-thirds of small clump-size transplants of *J. maritimus* have died (Fig. 6). Although 84% of the large clumps have survived the first 5 months, all transplants on the exposed site have been rated unthrifty, with poor health (Appendix 10.1). Performance of *J. maritimus* in Block E3, located on a previously vegetated area, was significantly better than survival in the sheltered blocks.

Significantly more (90%) large *L. similis* clumps have survived on the sheltered site (the only site planted with this species) than the smaller clumps, less than two-thirds of which survived (Fig. 7). This trend was reflected in the number of unthrifty transplants and seedling health (Appendix 10.1). *L. similis* has performed significantly better in Block S2, the centre of the sheltered mudflat area, than in blocks located near the edge of the existing salt-marsh.

Different spacings and fertiliser treatments had no significant effect in initial performance of transplants. No transplanted clumps were washed out of planting holes, even on the exposed site.

5.5 Transplanting mangroves

Pilot trials indicated that transplanting large seedlings of mangrove was time consuming and largely unsuccessful as most seedlings died within a few weeks of planting. However, on the sheltered site 80% of small seedlings (5-10 cm-high propagules with roots less than 3 cm long) had survived 5 months after transplanting. Only 25% of larger seedlings (roots greater than 3 cm) survived over the same time period. Surviving seedlings had not grown, and foliage and buds frequently showed signs of insect damage. Survival of even small seedlings on the exposed site was low.

5.6 Control of spartina

Neither Roundup nor Gallant at either application rate gave significant control of spartina in spring. It is too early to assess the effect of spraying in autumn.

Figure 6: Effect of site & clump-size on % survival of *Juncus maritimus*

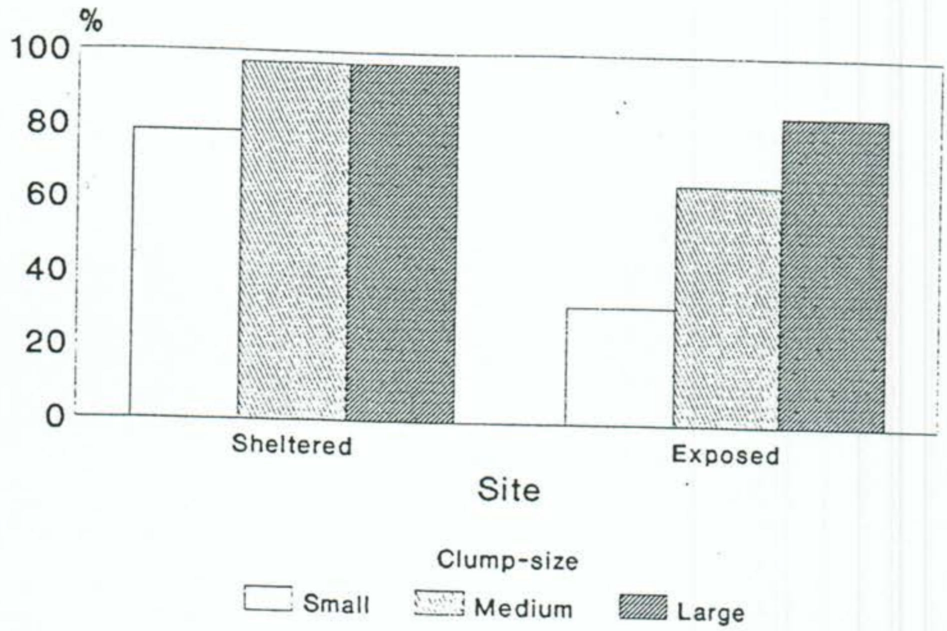
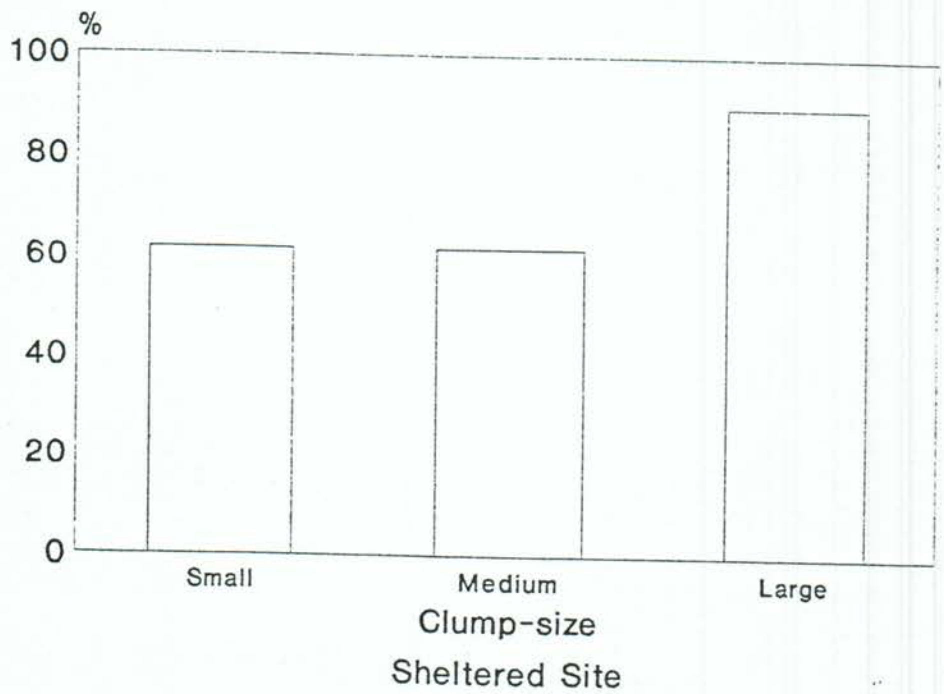


Figure 7: Effect of clump-size on % survival of *Leptocarpus similis*



6. CONCLUSIONS

6.1 Factors affecting salt-marsh

Salinity and tidal inundation are major factors in maintenance of salt-marsh vegetation (Gillespie 1988, Partridge & Wilson 1988a). Stopbanking, drainage works, and possibly the diversion of the river from the estuary, may be causing changes in salinity levels (Gillespie 1988, C. Richmond (DOC) pers. comm.).

J. maritimus is tolerant of a wide range of salinities, maximum growth occurs in salinities ranging from 5 to 30 parts per thousand (Partridge & Wilson 1987), and it forms dense stands at lower elevations where salinities are high. *L. similis* and *P. divaricatus*, however, are normally found at higher elevations where salinities are lower (Partridge & Wilson 1988a).

For example, in the Pauatahanui Inlet, near Wellington, Healy (1980) found that *J. maritimus* inhabits the low- to mid-tidal region but at higher elevations begins to thin out as *L. similis* becomes more common. *Juncus/Leptocarpus* salt-marsh occurs in several Bay of Plenty estuaries. A similar gradient occurs at Ohiwa Harbour (Daniel 1984).

The salinity gradients of surface water and ground water at the Maketu Estuary (Figs. 3, 4) show that plant species are sited within their tolerance limits for salinity. This suggests that decline of the salt-marsh at Maketu is probably not due to major changes in salinities in the area. Without a large commitment of resources, it would be impossible to identify which factors are chiefly responsible.

6.2 Retreat of salt-marsh vegetation

The salt-marsh at Maketu is still degrading. The retreat of vegetation from one datum peg of 400 mm in just 6 months indicates that some margins are actively eroding at an alarming rate. A significant feature of these margins is the abrupt difference in levels between the salt-marsh and the lower adjacent mudflat. This suggests that the level of the estuary in the vicinity of the salt-marsh remnant, particularly on the exposed north-western side, is decreasing. Both KRTA (1986 unpublished report) and Murray (1978) suggested that decline of salt-marsh is a result of the reducing elevation of the area. The diversion of the river has caused substantial changes to the water flows and conflicting evidence of changes to sedimentation within the estuary (Rutherford *et al.* 1989). Bed-level surveys suggest that sedimentation in the lower estuary may have reached an equilibrium. However, estuary levels may still be changing at higher elevations, such as around the trial site. Constant abrasion by waves of the root zone on the exposed seaward side of the estuary undermines the margins of the salt-marsh, wearing away root systems and redistributing plant and sediment material to other parts of the estuary.

In addition to or in association with physical abrasion, another possible cause of the root decay may be changes in pH levels in the root zone (R. Jackson (FRI) pers. comm.). If the level of the estuary has changed in recent years as a result of draining and stopbanking, and the soil in the root zone becomes aerated, sulphides that have accumulated under the previously anaerobic conditions may oxidise to form sulphuric acid. The resultant drop in the pH in the root zone may be enough to kill or weaken roots, pre-disposing marginal plants to rapid erosion by waves.

6.3 Transplanting trial

Trial results indicate that on a sheltered site medium-sized clumps of *J. maritimus* and larger clumps of *L. similis* can be successfully transplanted. However large clumps involve more planting effort than smaller clumps and cause greater disturbance to collection sites. For large-scale transplanting, the most economic techniques would include using clumps as small as possible. However, this needs to be balanced with the performance of the different sized clumps. Partridge and Wilson (1988b) for instance, found that transplanting of small clumps of *J. maritimus* measuring 25 mm radius and 100 mm depth resulted in complete failure.

It is too early to assess the effect of different spacing on transplant performance and the time required for clumps to coalesce into a continuous cover of vegetation. Gillespie (1988) suggested that at wide spacing (1 m between plants), it may take up to 3 years for clumps to coalesce into a uniform marsh. Where resources are limited, planting large clumps of salt-marsh species at a wider spacing (>1 m) is likely to be more successful than planting large numbers of small transplants at a greater density (<1 m).

It is likely that losses of *J. maritimus* transplants on the exposed site will continue because wave action constantly buffets transplants at high tides when it is windy. If transplanting is to be considered on such sites, temporary artificial barriers should be erected to reduce wave action.

6.4 Mangroves

There has been no significant increase in recruitment of mangroves over the last decade at Maketu. Only eight small plants were found in the vicinity of the salt-marsh remnant in 1977 (Murray 1978). The low numbers of natural mangroves and the failure to get mangroves established on the exposed side of the salt-marsh remnant may be the result of too much wave action and the possible decreasing substrate level within parts of the estuary as mangroves need minimal wave action and accumulating silt and mud (Murray 1978, Daniel 1984).

6.5 Control of spartina

The Cawthron Institute recommended autumn spraying of spartina using a formulation containing dalapon and amitrole (Gillespie 1988). However, conflicting results indicate a kill rate from 30 to 90%, and this formulation is toxic to mangroves and possibly to other salt-marsh vegetation (N. Davenhill (FRI) pers. comm.). Gallant (haloxyfop) or high application rates of Roundup (glyphosate) were recommended for the Maketu trials (N. Davenhill (FRI) pers. comm.). Gallant is rainfast after 2 hours and may not be affected by rising tides. The Department of Conservation have recently established a trial on extensive stands of spartina at Ohiwa Harbour to test a range of herbicides, including various application rates of Zero, Fusilade, and Roundup (W.B. Shaw (DOC) pers. comm.). Results of this trial should have a bearing on further spraying at Maketu.

Once spartina is killed, root material stays largely intact and decomposes slowly (Gillespie 1988), which could be of some advantage for re-establishing indigenous salt-marsh species as it would provide a stable substrate.

7. RECOMMENDATIONS

It is too early to base recommendations for large-scale rehabilitation of salt-marsh vegetation on this trial. Only preliminary recommendations are offered, mainly for further research directions.

- Periodic measurement of the retreat of the vegetation along active margins should continue including measurement of substrate levels around the salt-marsh remnant.
- Temporary barriers should be established around a portion of severely eroding margin to reduce wave action to assess the significance of physical abrasion on the decline of the salt-marsh. The practicality of erecting barriers on a large scale for protecting transplanted areas needs investigation.
- Soil chemistry should be assessed to determine whether low pH levels or other factors are affecting the health of salt-marsh vegetation.
- Continued monitoring is needed to determine whether transplants will respond to fertilisers and whether they will survive on exposed sites. The most desirable spacing and clump-size combination to achieve a continuous cover of vegetation as quickly and economically as possible still needs to be determined.
- Other suitable areas within the mid- to upper tidal zones in Maketu Estuary should be evaluated for transplanting salt-marsh species.
- Further research is required to determine whether transplanting of mangroves is feasible.
- Further work is required on monitoring spartina sprayed with various herbicide treatments and the practicality of replacing spartina with indigenous salt-marsh species.

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10. APPENDICES

Appendix 10.1 - Survival, unthrifty seedlings, and group health score of transplanted salt-marsh species 5 months after planting, Maketu Estuary. Vertical lines indicate treatments are significantly different

Species	Site	Treatment	Survival (%)	Unthrifty seedlings (%)	Group Health score (1-3)[a]
Juncus maritimus	Exposed	**Clump-Size**	**		
		large	84	100	3.0
		medium	65	100	3.0
		small	30	100	3.0
		Block	**		
		E1	59	100	3.0
		E2	50	100	3.0
		E3	70	100	3.0
		Spacing			
		wide	63	100	3.0
		medium	56	100	3.0
		narrow	61	100	3.0
		Fertiliser			
		absent	62	100	3.0
		pres.	58	100	3.0
	Sheltered	**Clump-Size**	**	**	**
		large	97	5	1.1
		medium	96	12	1.4
		small	79	23	1.9
		Block			
		S1	89	16	1.6
		S2	87	14	1.2
		S3	96	10	1.5
		Spacing			
		wide	89	16	1.4
		medium	91	12	1.4
		narrow	93	12	1.5
		Fertiliser			
		absent	92	13	1.4
		present	89	14	1.4
Leptocarpus similis	Sheltered	**Clump-Size**	**	**	**
		large	90	16	1.3
		medium	62	67	2.7
		small	62	63	3.0
		Block	**	**	**
		S1	57	72	2.3
		S2	87	5	2.0
		S3	70	69	2.7

** Significantly different ($p < 0.01$)

a Group health assessed as 1 - good. 2 - intermediate. 3 - poor