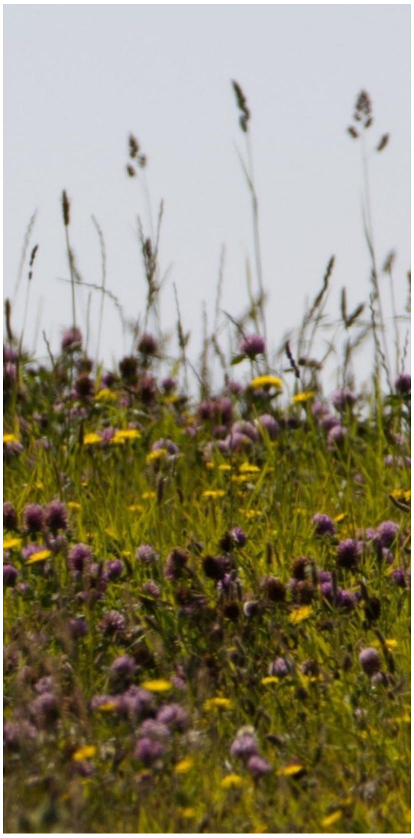
Oioi (jointed wire rush) planting experiments in Te Hakapupu

Monitoring survival, growth and spread.



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Author affiliations:

[1] Tūmai Beach Restoration Trust.
[2] Ecosystems Consultants, 30 Warden St., Dunedin, 9010.
[3] Kāti Huirapa ki Puketeraki Rūnaka Nursery, Karitāne.

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Executive Summary

Two experiments are in progress to test the constraints and opportunities for re-establishing oioi (Jointed wire rush, *Apodasmia [Leptocarpus] similis*) in a degraded arm of Te Hakapupu (Pleasant River) estuary. The first and main experiment tests spacing and site constraints on survival and spread of oioi; the second experiment tests whether nursery-grown oioi can be seasoned to better withstand salt shock before being planted into high-saline soils at Te Hakapupu.

The goals of this preliminary analysis are to evaluate (i) whether the monitoring method is fit for purpose, (ii) whether the experimental protocols need to be adjusted, and (iii) provide a very preliminary assessment of the prospects for establishing oioi in Te Hakapupu.

Experiment #1 compares survival, growth and spread of 1,664 oioi (i) planted in different elevations across the ecotone between estuarine and brackish habitats and adjoining abandoned pasture; and (ii) when planted 0.25 m, 0.5 m and 1 m apart. The experiment was established in November 2022. Monitoring methods and results from surveys in August 2023 and May 2024 are described here. A final survey is scheduled for May 2025.

Salient results include:

- Differences between quadrats with different spacing of plants are slight or non-existent so far, but strong differences are emerging between ‘Upper’ quadrats (those just above the high tide mark as indicated by glasswort cover) compared to ‘Lower’ quadrats within the glasswort salt meadow where they are periodically flooded during high tides.
- 84-92% of the original plants were still standing in the different experimental treatments by May 2024, 18 months after planting. These metrics overestimate survival of the plants because some of the plants still standing may have been dead or dying.
- 45% of the foliage looked a healthy bright green colour by the second survey.
- Percentage of foliage scored as bright green increased more between the surveys in the ‘Upper’ compared to ‘Lower’ quadrats.
- There is very little sign of life in plants in ‘Wet’ quadrats, so it is unlikely that they could ever survive there.
- Many oioi leaves are dark in colour, and some have obviously died. It is unclear whether this indicates that the plants are struggling to establish, especially in the Lower’ quadrats, and will eventually die.
- New shoots were detected emerging from the outside edge of the base of the majority of oioi in all ‘Level’ treatments.
- Oioi plants have begun to merge in two of the 0.25m spacing quadrats and spread outwards, presumably by lateral extension of rhizomes, in at least three other quadrats.
- 30-38% of the plants have been browsed at ‘Upper’ and ‘Lower’ quadrats, mainly following accidental incursions by sheep.
- Grass and thistles have grown very long and thick in many of the ‘Upper’ quadrats, so much so that it was often hard to find the oioi plants in the sward.

Competition between oioi and grass for space, light, water, and nutrients is the main threat to widespread establishment of oioi from this adaptive management project. Application of a graminicide, especially haloxyfop, is potentially the most practical solution to suppress the grass, provided that it does not harm the oioi and ecosystem. We will now conduct a literature review and consult agrichemical and biosecurity managers to assess the likely risks of applying a graminicide. This risk assessment will then be shared with the kaitiaki in Whakakaupapa Taiao from Kāti Huirapa Rūnaka ki Puketeraki, and with the directors of the Toitū Te Hakapupu project.

If they decide to proceed with graminicide application, we will conduct an immediate pilot trial by spraying 10 'Upper' quadrats that are being smothered by rank grass. Ten equivalent quadrats will also be hand-weeded to test the practicality and efficacy of avoiding use of the graminicide. Monitoring over the following 4-6 weeks will check for harm to oioi. If no (or very limited) damage is observed, and if hand-weeding proves impractical, the graminicide will be applied to half of all the remaining 'Upper' quadrats to test whether we can trigger improved oioi survival, growth and spread in the remaining year of the experiment.

Protection from farm stock has been reinstated and fortified, and some individual plant protectors will now be erected in one zone where fencing is impractical.

A second experiment tests whether seasoning of 80 nursery-grown oioi with different concentrations of seawater could enhance their ability to withstand sudden salt shock when first transplanted into hyper-saline soils. This experiment has not yet been underway for long enough to make any inferences about the effects seawater treatments under field conditions. However, strong effects of pretreatments on leaf length, colour and root development were detected when the oioi were grown in water bathes with different proportions of seawater. These findings confirm expectations that seawater inundation has a strong influence on the probability of establishing oioi for ecosystem restoration.

A report and recommendations for an adaptive management approach to re-establishing oioi in *Te Hakapupu* and other degraded estuaries will be published in mid-2025.

Summary: It is too early to conclude whether oioi can be successfully re-established through large stretches along the margin of South Arm of Te Hakapupu. There are encouraging examples of flourishing oioi in some quadrats, new shoot formation, and some limited (and very local) lateral spread. However, the fate of the oioi in 'Lower' levels of the glasswort salt meadow is more uncertain. Undoubtedly some are growing, but many may be persisting and growing new shoots by depleting the energy and nutrient reserves in the growing medium from the nursery before being planted out. Successful control of grasses in the 'Upper' quadrats by applying a graminicide or hand-weeding is the remaining main opportunity for improving the speed and extent of oioi restoration.

Contents

1. Monitoring oioi establishment and growth at Te Hakapupu

Two experiments are in progress to test the constraints and opportunities for re-establishing oioi (Jointed wire rush, *Apodasmia [Leptocarpus] similis*) in a degraded arm of Te Hakapupu (Pleasant River) estuary. The first and main experiment tests spacing and site constraints on survival and spread of oioi; the second experiment tests whether nursery-grown oioi can be seasoned to better withstand salt shock before being planted into high-saline soils at Te Hakapupu.

Challenges and benefits of re-establishing oioi, and the rationale for the design of these experiments, are detailed in two previous reports[1]. Here we record the monitoring methods to measure oioi survival, growth and spread since they were planted in November 2022 for experiment #1, and in August 2023 for experiment #2.

A preliminary analysis of results from two field surveys is presented along with recommendations for adjusting the adaptive management experiments and monitoring protocols for the remainder of the experiments. A fuller and more formal statistical analysis of the results will be reported in about a year from now to support *Toitū Te Hakapupu*, a five-year collaboration between local communities, Kāti Huirapa ki Puketeraki Rūnaka and Otago Regional Council to restore the entire Te Hakapupu catchment.

The goals of this preliminary analysis are to evaluate (i) whether the monitoring method is fit for purpose, (ii) whether the experimental protocols need to be adjusted, and (iii) provide a very preliminary assessment of the prospects for establishing oioi in Te Hakapupu.

2. Experiment #1: habitat and plant spacing selections

2.1 Aims

Determine optimum habitat and plant spacing to maximise survival, growth, and spread of oioi at South Arm, Te Hakapupu.

2.2 Experimental design

Following a review of research and best practice by restoration managers from around Aotearoa New Zealand[2], 1,664 oioi were planted in rectangles of 8 plants to form 208 'quadrats' spread across six zones (Fig. 1).

Most quadrats were divided between 'Upper' and 'Lower' levels around the edge of the estuary and a stream. 'Upper' quadrats were positioned on the inland edge of the estuary salt meadow, often on slightly elevated ground where introduced grasses grew. They are never flooded by tides and the ground is mainly covered by grasses and thistles. 'Lower' quadrats were placed 2m seawards of the estuary edge as defined by the upper edge of glasswort beds. They are periodically flooded at high tide and are nearly completely covered by glasswort (*Sarcocornea quinqueflora*).

[1] Moller *et al.* (2023), Young *et al.* (2023).
[2] Young *et al.* (2023).

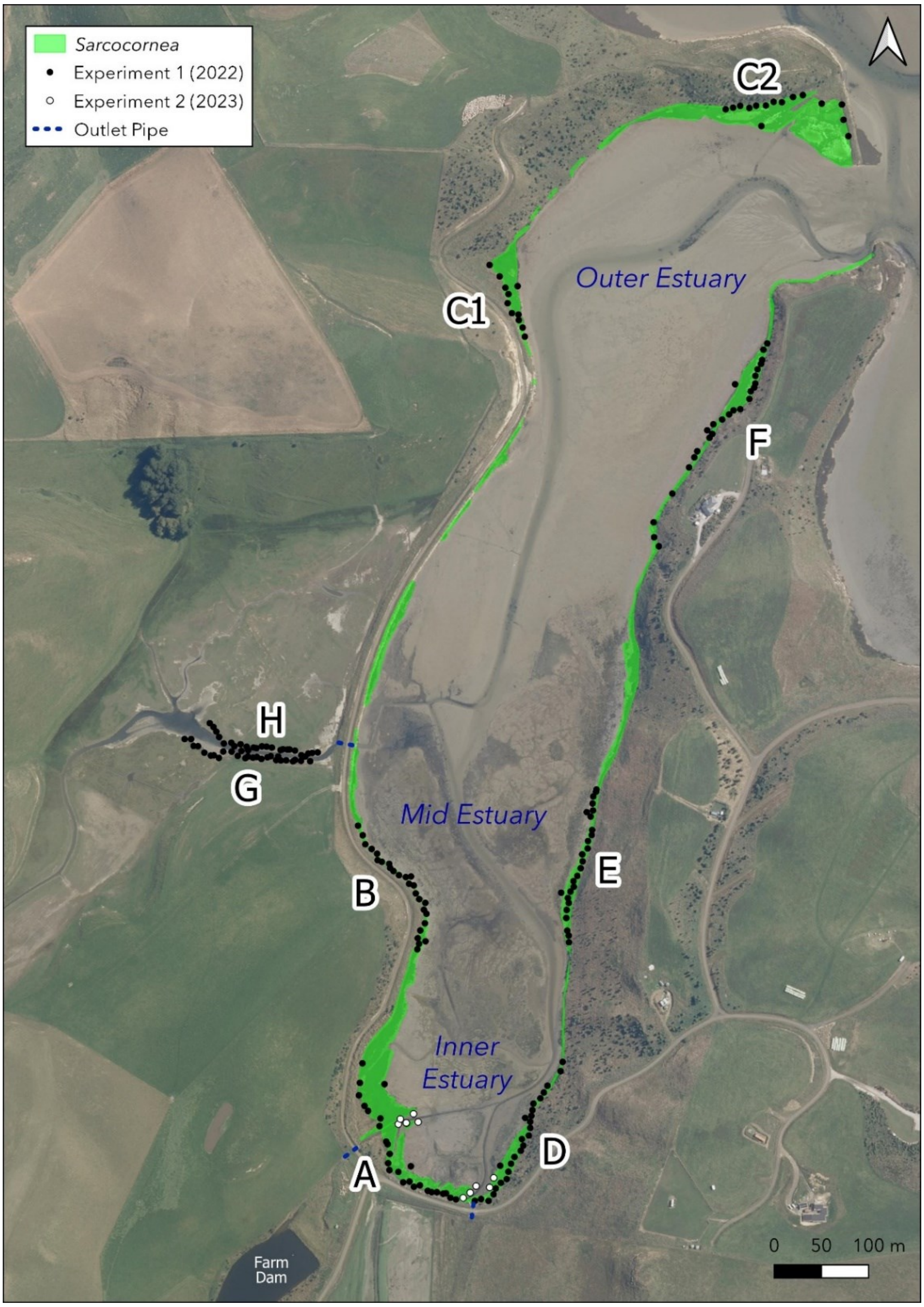

Figure 1: Arrangement of experimental oioi planting quadrats around South Arm, Te Hakapupu. Each quadrat received eight oioi plants, spread equally across eight zones (A-H) for Experiment #1. Two zones were placed along the margins of McWilliam Stream, and two zones in each of three strata ('Inner', 'Mid' and 'Outer' Estuary) to stretch the experiment across maximum tidal inundation frequencies. Matching zones were placed on opposite sides of the estuary and stream. Zone C was divided in two because a stretch of steep and rocky shoreline prevented establishment of glasswort and oioi there. Ten quadrats were established in the Inner Estuary zone and adjacent to two freshwater inflow channels for Experiment #2.

Zones G and H flanked a brackish stream that was only marginally affected by tidal inflow. Its water level was mainly determined by rainfall and runoff from the surrounding farmland. 'Lower' quadrats were positioned right in the lip of the streambed that defined the water level in most conditions, but the surrounding areas were periodically flooded after heavy rain. The 'Upper' quadrats were placed two meters away from the streambed lip, mostly on higher ground, so they are only occasionally flooded with mainly freshwater.

Each zone also had two 'Wet' quadrats placed out in the open estuary and streambed sediment and therefore are flooded by tidal flows (estuary) or continuously (McWilliams stream).

All 'wet' quadrats had 8 oioi planted 0.5 m apart in a rectangle. Quadrats in the remaining levels were divided equally between three spacing treatments i.e. planted 0.25m, 0.5m or 1.0m.

2.3 Monitoring methods

Quadrats were established between 24th and 27th November 2022[3]. 'Survey #1' was conducted on 4th and 5th August 2023, and 'Survey#2' on 13th and 14th May 2024. A final survey is scheduled for May 2025.

The following indicators of Oioi establishment were recorded for each quadrat:

1. 'Survival' was measured from the number of oioi plants still standing in the quadrat. This was facilitated by the arrangement of 8 plants in a rectangle. Even if a few leaves remained or it appeared to be dead or dying, the plant was counted as present, so this is not a true measure of survival *per se*.
2. 'Height' (mm) of a single middle-sized plant selected by eye from the remaining plants. The plant was gently stretched along a metal tape measure to measure the longest leaf in the plant.
3. The 'Colour' of the leaves was estimated by eye as a percentage divided between (i) 'Green', (ii) 'Dark', and (iii) 'Dead'. A single % colour estimate was recorded for the average over all oioi plants in the quadrat. 'Green' leaves had a bright green of obvious new growth. 'Dark' included leaves of a deeper green and sometimes almost grey colour. A surface contamination by silt made this determination extremely difficult, so we suspect that some of the leaves scored as dark were a brighter green. 'Dead' leaves were straw coloured – white and dried, sometimes with an orange tinge.
4. The number of the plants with 'New Shoots' emerging from their base.
5. The number of plants that showed any sign of 'Browse'. This usually showed as clipped off leaves, sometimes in a cluster of leaves or gnawed close to the ground (probably mainly browsed by sheep). Occasionally as single isolated leaf was observed (probably browse by rabbits, hares or insects).
6. 'Weed cover' was scored as a % of ground covered throughout the area between the 8 plants within each quadrat. The weeds were most often introduced grasses and thistles, but a small

[3] Data files, photographs, GPS co-ordinates and maps are lodged with both the Kāti Huirapa Ki Puketeraki Rūnaka team and Tūmai Beach Restoration Trust for safe storage for reference for later surveys.

low growing succulent was also present in the 'Lower' quadrats of the estuary. Glasswort itself was not scored as it was considered part of the experimental treatment and nearly always covered the entire area withing the 'Lower' quadrats.

7. 'Comments' were recorded less systematically for several quadrats, including whether there was sign of lateral spread (new shoots emerging from the substrate well away from the original plants), the presence of algal mats of other flotsam on or around the oioi plants, sign of rabbit or sheep faeces in the immediate vicinity of the quadrat, and the height of the grasses invading the quadrats.

2.4 Results and discussion

Preliminary analysis of data showed negligible differences in outcomes from quadrats at different spacing of oioi, but obvious differences between levels. Therefore, this interim report only explores differences between aggregated data for all spacing treatments. Also, most analyses here aggregate data from all zones. A formal search for more subtle interaction effects between levels, spacing treatments and zones will be completed when the next and final survey is completed in mid-2025.

Nearly all (98-99%) of the oioi were still standing in the quadrats during the first survey, 8 months after planting (Fig. 2). Nine months later (Survey#2), we could find only 90-92% of the original plants in the upper and lower levels, and only 84% of the ones planted in the exposed 'Wet' quadrats. These metrics overestimate survival of the plants because some of the plants still standing may have been dead or dying.

Colour of the leaves provides a more nuanced indication of plant vigour, especially the percent of leaves that are a bright verdant green. Only 13% of the leaves had this thriving colour in Survey#1, but encouragingly, 45% of the foliage looked healthy by the second survey (Fig. 3). Percentage of foliage scored as 'Green' increased more in the 'Upper' than 'Lower' quadrats (Fig.4). Very few of the leaves in 'Wet' quadrats were this bright green colour and there was no evidence that this thriving foliage increased between the first and second surveys in there (Fig.4). Scoring the colour was subjective, so the results are best used only as a relative measure for assessing differences between experimental treatments. The scores should not be interpreted as absolute measures of the percent of leaves that are healthy and photosynthesising or growing.

'New shoots' were detected emerging from the outside edge of the base of the majority of oioi in all 'Level' treatments (Fig. 5). These new shoots may have been generated from energy and nutrients stored in the roots and leaves while the oioi were being grown in the nursery prior to establishing the field experiment. Alternatively, emergence of new shoots may be a sign that the plants are establishing and beginning to grow in their new environment.

Oioi plants had begun to merge in two of the 0.25m spacing quadrats by Survey#2, indicating that some plants were growing or bulking up. Subterranean spread, presumably by lateral extension of rhizomes, was detected in three other quadrats i.e. new shoots were emerging from the substrate 100-150 mm from the edge of the original plant.

Oioi in a small number of the 'Lower' quadrats were covered in dried and dead algal mats, occasionally to the extent that they had been flattened to the ground. A few others, especially in zone G2 in the 'Outer' zone of the estuary (see Fig. 1), were partly covered by fragments of wood that had been washed up on the high tide. In one case, oioi were flattened by a small log.

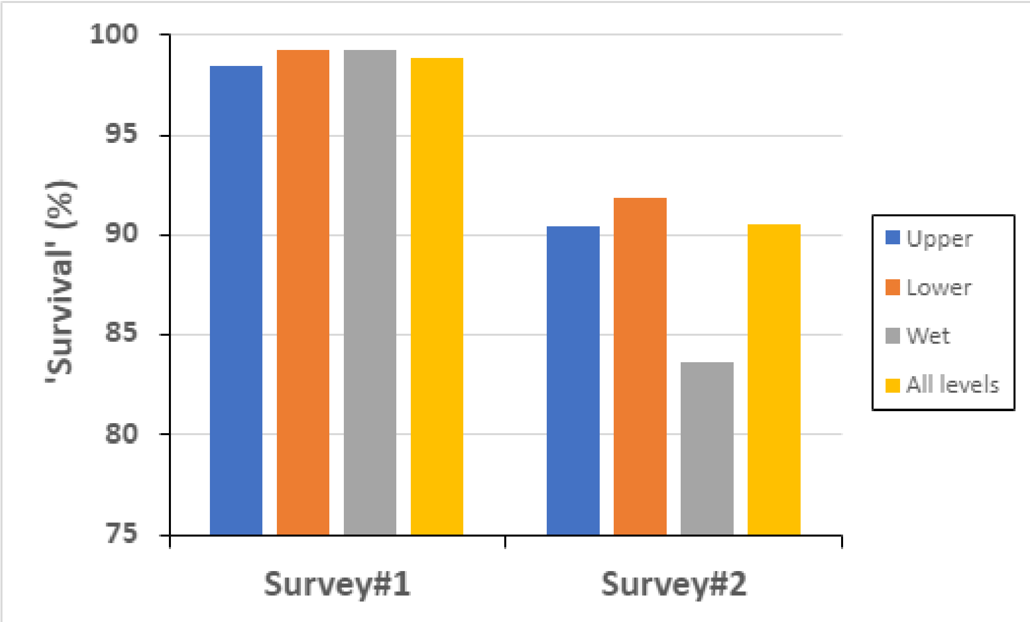

Figure 2: Percent of oioi plants 'Surviving' in quadrats at different level treatments. Data from all zones and spacing treatments are combined.

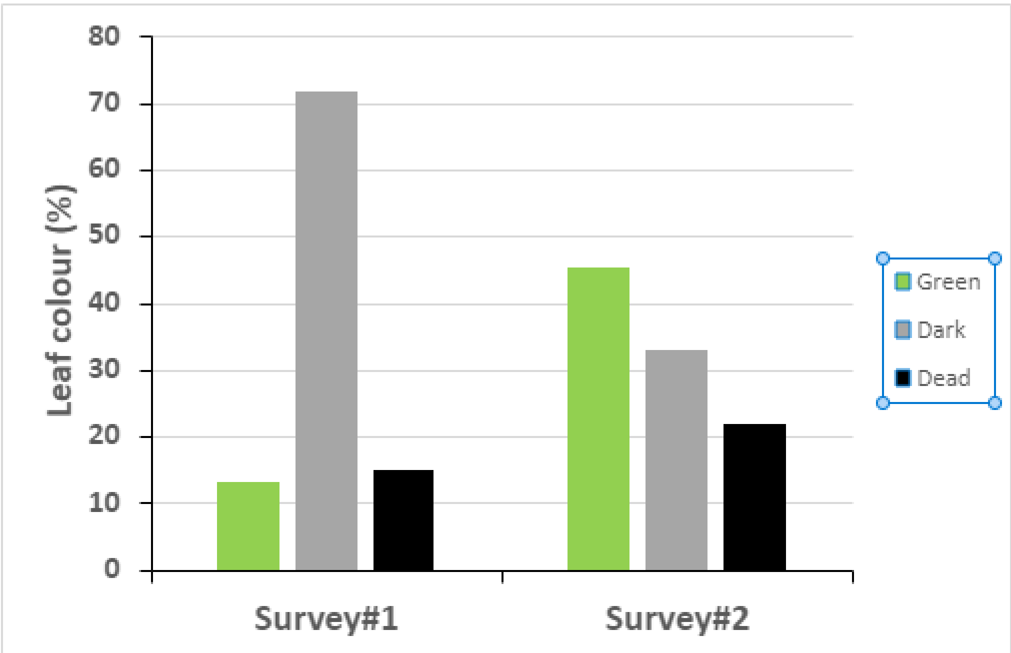

Figure 3: Colour of oioi leaves in each survey. Data from all zones and spacing treatments are combined.

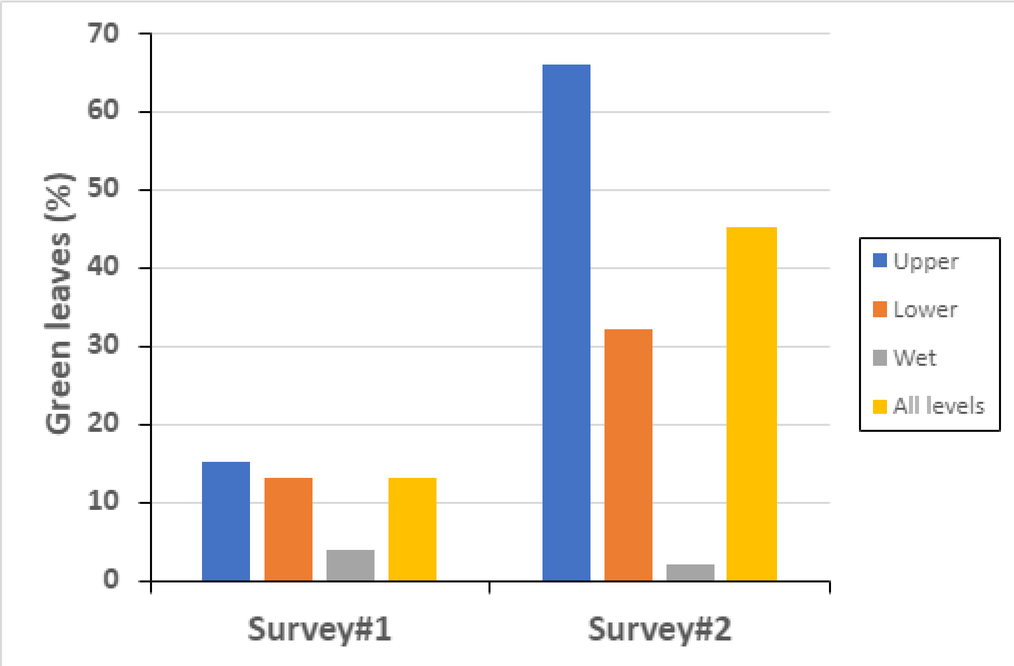

Figure 4: Percent of oioi leaves that were 'Green' in quadrats at different level treatments. Data from all zones and spacing treatments are combined.

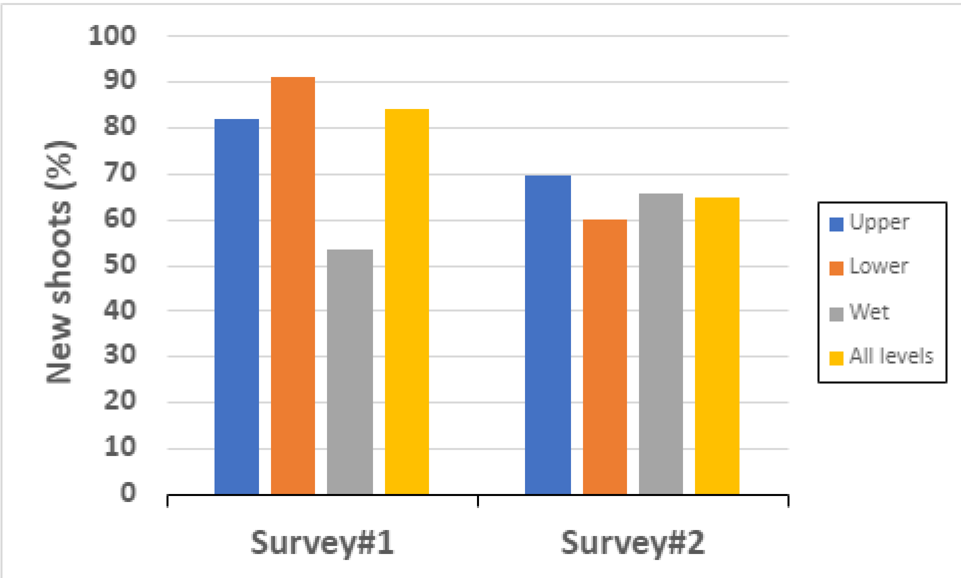

Figure 5: Percent of oioi with new shoots in quadrats at different level treatments. Data from all zones and spacing treatments are combined.

There was very little sign of browse on oioi planted in the 'Wet' quadrats, but approximately 14-15% and 30-38% of the plants had some sign of browse at 'Upper' and 'Lower' levels in the first and second surveys respectively (Fig. 6). Some leaves become brittle as they die and dry out, so it is possible that some of the 'browse' scored in this way was natural breakdown of the leaves. However, in many cases substantial shearing of adjacent leaves provided clear evidence of browsing by sheep and/or rabbits and hares. Rabbits and hares are occasionally flushed from the margins of the estuary and browsing of the nearby saltmarsh ribbonwood (*Plagianthus divaricatus*) seedlings is severe in patches.

Sheep were initially excluded from all zones except C2 by fencing, but the electric fence protecting the quadrats in zones G and H failed. Incursion by sheep also affected zones D, E and F in the summer holiday period in late December 2023 and January 2024[4]. Sign of browse was therefore most prevalent in zones C2, G, and H in the second survey (Fig. 7). Damage from these accidental incursions by farm stock provide corroboration of our assumption that oioi is likely to have been eliminated by sheep and cattle from South Arm when tidal flows were blocked by a causeway between mid-1950 and 2009 to 'reclaim' the land for farming[5].

The quadrat area was 'screafed' with a spade to shear off any grass and thistles growing where we planted the oioi. Regrowth by grasses and thistles covered 66% and 79% of the area between the oioi plants in 'Upper' quadrats by the time of Survey#1 and Survey#2 respectively (Fig. 8). The grass and thistles had grown very long and thick in the 'Upper' quadrats on the margin of the estuary, so much so that it was often hard to find the oioi plants in the sward. Grass was much less vigorous and shorter in the two freshwater stream zones (G and H), presumably because the soils were salted from early tidal flows[6]. There were less weeds in 'Lower' quadrats, and none in the 'Wet' quadrats.

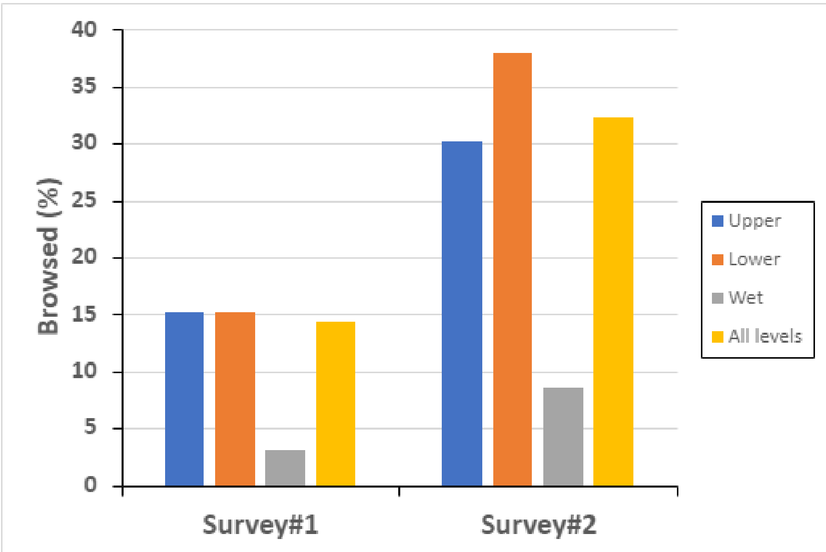

Figure 6: Percent of oioi plants that had been browsed in quadrats at different level treatments. Data from all zones and spacing treatments are combined.

[4] The neighbouring farmer was absent, so the sheep were present for a week or two before being removed.
[5] Tūmai Beach Environmental Enhancement Group (2024).
[6] Andrew McWilliam farms those paddocks and notes that pasture production is always much lower there. Despite this, the sheep and cattle favour that pasture, presumably because of the salt or nutrients in the grass.

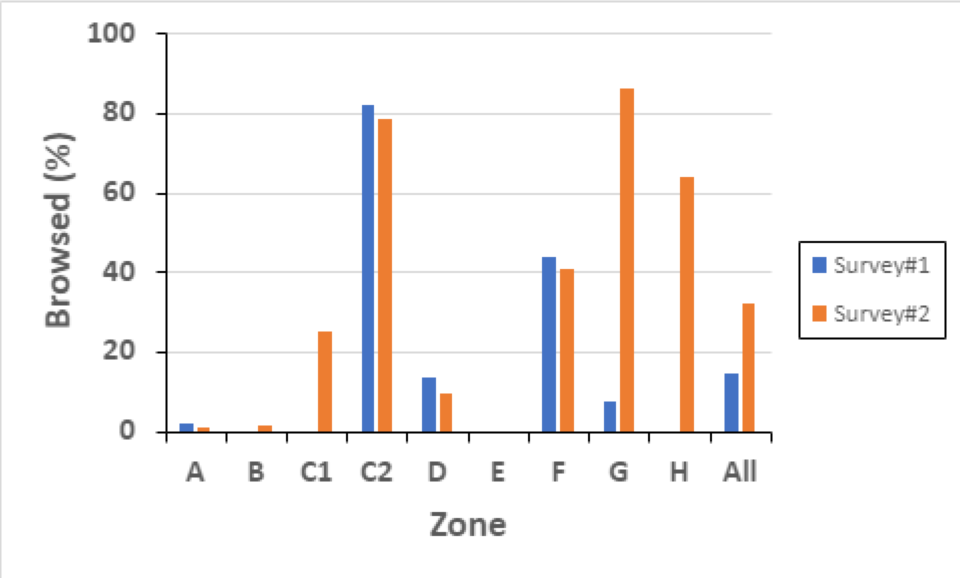

Figure 7: Percent of oioi plants that had been browsed within each zone in the two surveys. Zones are mapped in Figure 1. Data from all levels and spacing treatments are combined.

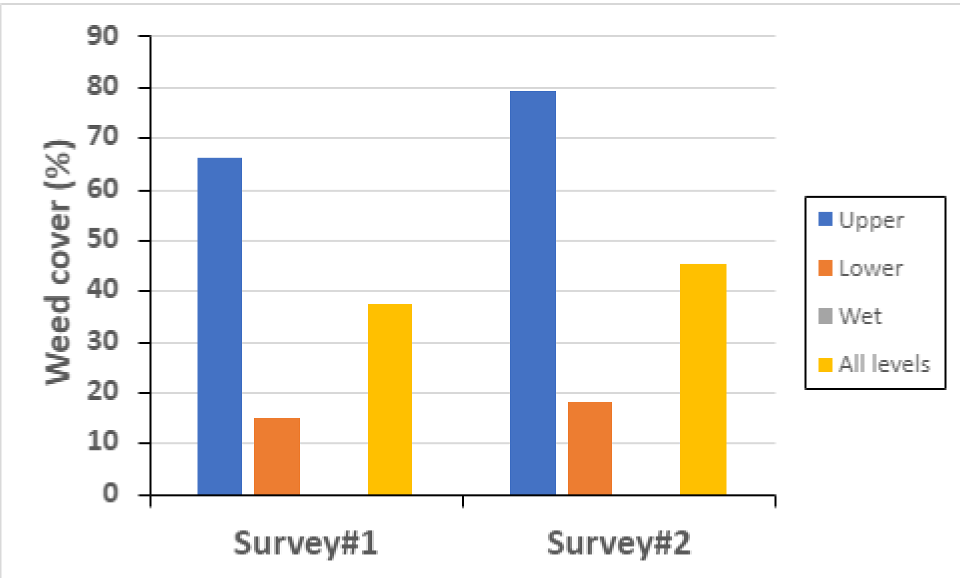

Figure 8: Percent of ground covered by 'weeds' in quadrats at different level treatments. Data from all zones and spacing treatments are combined.

3. Experiment #2: seasoning plants for salt shock protection

3.1 Aim

Test whether prior irrigation of oioi with seawater enhances their survival, growth and lateral spread when planted into estuary sediments.

3.2 Design and methods

We wondered if the impact of initial salt shock could be overcome by seasoning the plants with diluted seawater before they are transplanted into these more exposed areas of South Arm.

We retained a random selection of 80 oioi from the same stock as used for Experiment #1 to test the salt shock hypothesis.

Five groups, each of 16 plants within their original PB3 planter bags, were sat in five separate plastic trays inside three wooden crates at Tūmai Beach farm park[7]. Trays were irrigated in five treatments:

- Undiluted seawater
- 75% seawater, 25% rainwater
- 50% seawater, 50% rainwater
- 25% seawater, 75% rainwater
- 100% rainwater.

The plastic planter bags have holes cut in their sides to allow water into the roots, and trays were kept topped up to a level just below the top of each bag. The experimental plants were therefore sitting in a water bath and constantly saturated. The wooden crate was needed to exclude browsing by rabbits and to prevent wind from blowing over the plants within their water bath.

The pretreatments were established on 18th December 2022, and water replaced at every 4 to 6 weeks until planting within South Arm Estuary on 4th August 2023 (33 weeks later). They were planted in 10 quadrats to match the layout of the 'Wet' quadrats in Experiment #1. i.e. there were two replicates for each seawater treatment, each containing 8 oioi plants spaced 0.5 m apart and arranged in a rectangle. All were placed in the muddy sediment areas without glasswort cover because this was judged to be the most challenging habitat for oioi survival and growth. However, we clustered the quadrats in two patches close to freshwater inflow channels which are potentially more benign substrates for oioi growth (Fig. 9)[8].

3.2 Results & discussion

Changes in oioi survival, leaf colour, and root protrusion through the holes in the planter bags was scored at regular intervals[9]. Unfortunately, a computer disk failure destroyed the data from this regular monitoring. Paper versions of the final scores were saved, so measures of the health of the oioi at the time of field planting out are analysed here.

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[7] A more detailed description of the rationale and methods up until planting in the field is provided by Moller *et al.* (2023).

[8] A review of the literature and testimony from estuary managers predicted that growth and survival was better in brackish water than hyper saline conditions (Young *et al.* 2023).

[9]

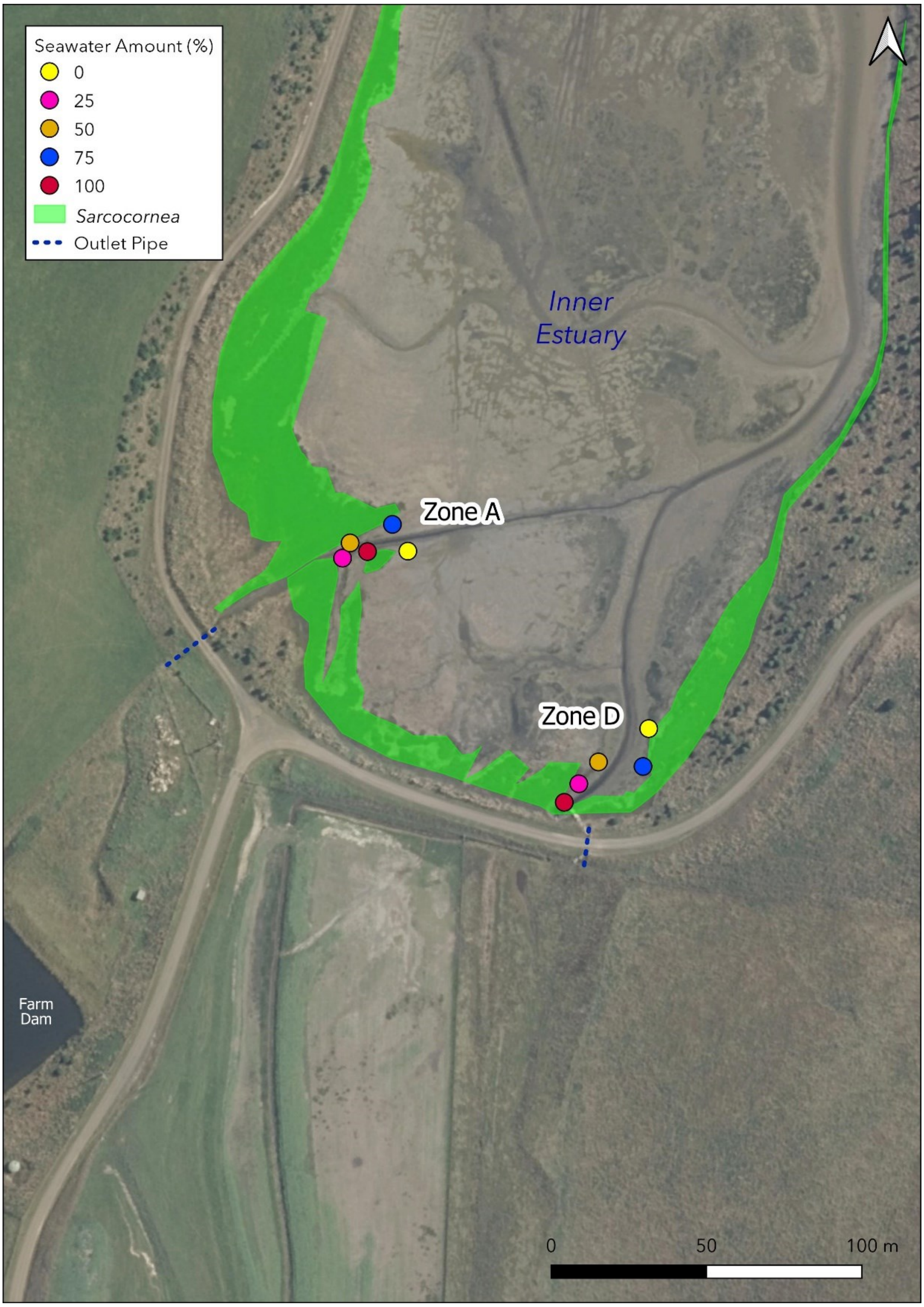

Figure 9. Location of ten oioi quadrats for Experiment #2 established in August 2023.

Oioi bathed in rainwater grew 12-33% longer than in treatments where seawater was added (Fig. 10).

A much higher proportion of the leaves were bright green in the pure rainwater treatment (Fig. 11).

The number and size of roots protruding through the holes in planter bags was scored for each treatment[10].

Pure rainwater treatments had more and larger roots just prior to planting into the estuary (Fig. 12).

The large roots became entangled in a mat, so they could not be counted separately once ten or more roots protruded, so the differences in number and size of roots between treatments were much larger than these data indicate.

Quadrats were monitored on 14 May 2024 using the same protocol as for Experiment#1. All plants were still standing. Average height was 862 mm and 35% of the leaves were bright green.

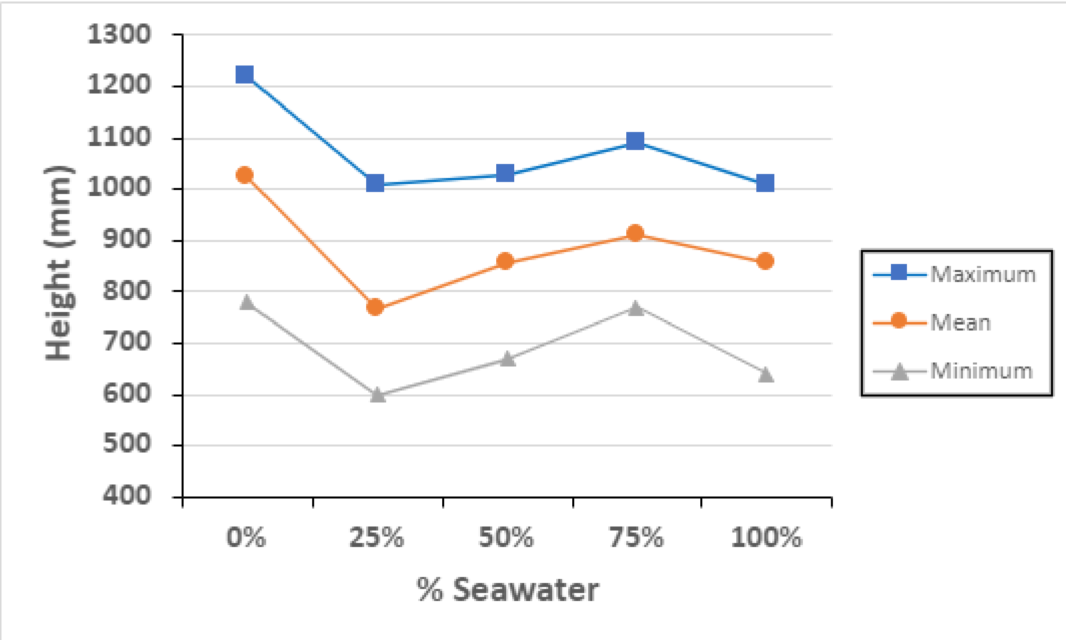

Figure 10: Height of oioi plants after being bathed in different seawater concentrations. These measurements were taken two weeks before establishing the field plots.

[10] See Fig. 8 of Moller *et al.* (2024).

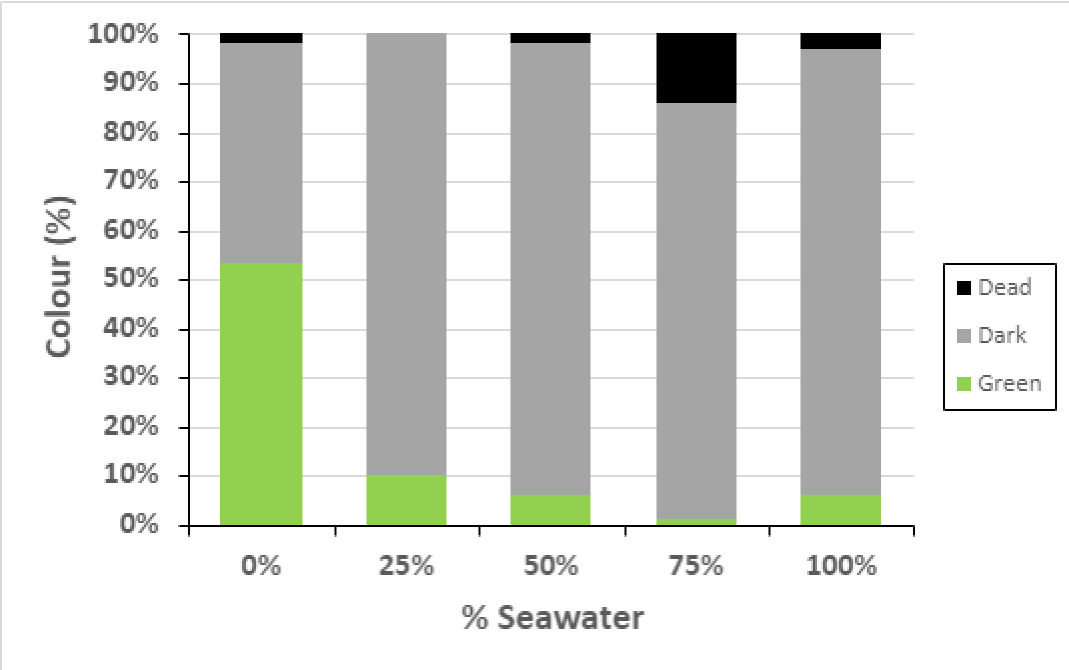

Figure 11: Colour of oioi plants after being bathed in different seawater concentrations. These measurements were taken two weeks before establishing the field plots.

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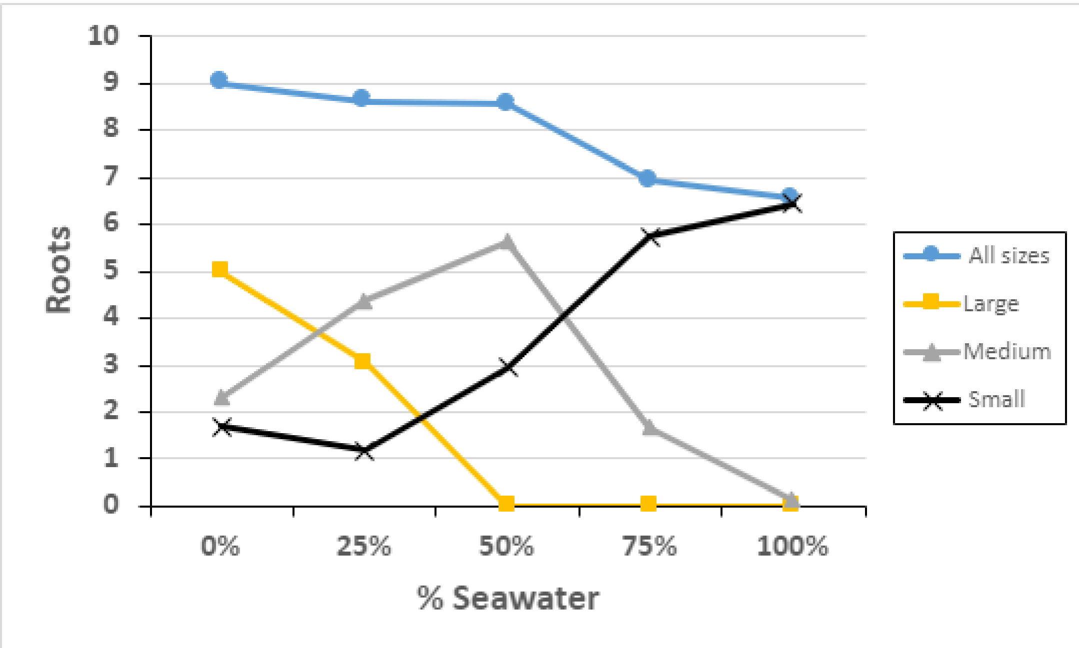

Figure 12: Number and size of roots protruding from oioi planter bags after being bathed in different seawater concentrations. These measurements were taken two weeks before establishing the field plots.

4. General discussion & recommendations

Experiment #2 quadrats have not been in place long enough to make any inferences about the effects seawater treatments under field conditions. However, strong effects of pretreatments on leaf length, colour and root development were detected when the oioi were grown in water bathes with different proportions of seawater. These findings confirm expectations that seawater inundation has a strong influence on the probability of establishing oioi for ecosystem restoration.

It is too early to conclude whether or not oioi can be successfully re-established through large stretches along the margin of South Arm of Te Hakapupu. There are encouraging examples of flourishing oioi in some quadrats, new shoot formation, and some limited (and very local) lateral spread of oioi by the time of Survey#2 (18 months after planting). However, a large number of the oioi leaves were dark in colour, and some have obviously died. There is little sign of life in plants in 'Wet' quadrats, so it is unlikely that they could ever survive there. More uncertain is the fate of the oioi in 'Lower' levels of the glasswort salt meadow. Undoubtedly some are growing, but many may be persisting and growing new shoots by depleting the energy and nutrient reserves in the growing medium from the nursery before being planted out. A lag in growth is commonly observed when plants are adapting to the wild and before roots are fully formed, especially in slower-growing species. They take longer to show signs that they are healthy (or not) after the initial shock and possible loss of vigour (and potentially even some loss of foliage).

Our review of formal scientific studies and planters' experience emphasised how patchy and uncertain oioi establishment can be[11], so the huge variation between quadrats within each experimental treatment is not surprising. Only more time can tell whether the lack of growth and lateral extension of many of the plants reflects a lag as they take root and respond to satisfactory field conditions, or whether they are faring just well enough to persist or fade away slowly because the habitat is not quite suitable.

Accidental incursions by sheep added to a low level of background browsing, probably mainly by rabbits and hares. Protection of our quadrats from sheep grazing was reinstated immediately after the damage was detected during Survey#2 but fencing of Zone C2 is impractical. We will now erect plant protectors[12] around individual quadrats in C2 and do regular checks of the electric fencing protecting zones G and H for the remainder of the experiment to test whether oioi regrowth occurs after browsing.

Competition for space, light, water and nutrients between grass and oioi presents a potentially serious threat to the long-term survival and spread of oioi planted in our trials, especially in the 'Upper' quadrats along the estuary. Inundation by weeds has been noted by some other managers attempting to restore oioi around New Zealand[13]. Several of the oioi that were crowded by grass still looked very healthy, and it may be that oioi plants can still spread outward from these planting sites. Alternatively, long term survival and spread may eventually be compromised by the grasses already present.

[11] Young *et al.* (2023)
[12] KBC TriGuard (450x200mm) combinations, as used to protect native woody plants on Tūmai Beach farm park.
[13] Young *et al.* (2023).

Removing this threat is the only potential way of increasing the probability and scope of oioi restoration resulting from this adaptive management project.

Hand weeding amongst the oioi is impractical for meaningful scales of ecological restoration. A motorised 'weed eater' can trim grasses around the quadrats but cannot remove the grasses and thistles that become closely entangled around the oioi leaves. A graminicide chemical spray, especially haloxyfop, is potentially the most practical solution to suppress the grass, provided it does not harm the oioi itself or cause significant ecosystem contamination.

A small and brief 'pot trial' showed good control of target grass weeds in wetlands without damaging many native species (Champion 1998). However, the study did not test the vulnerability of oioi itself[14] and laboratory conditions may give very different results than field trials. Therefore, we propose to:

1. Conduct a literature review and consult agrichemical and biosecurity managers to assess the likely risks of applying a graminicide.
2. Share this risk assessment with the kaitiaki in Whakakaupapa Taiao from Kāti Huirapa Rūnaka ki Puketeraki, and with the directors of the Toitū Te Hakapupu project.
3. Conduct an immediate pilot trial by spraying 10 'Upper' quadrats that are being smothered by rank grass in the 'Upper' levels, if, and only if, the kaitiaki and Toitū Te Hakapupu teams decide to proceed with graminicide application.
4. Hand-weed 10 equivalent 'Upper' quadrats to test the practicality and efficacy of hand-weeding to avoid use of the graminicide.
5. Trim grass and thistles up to the margin of quadrats before these treatments using a weed-eater, partly to minimise herbicide application, partly to facilitate hand-weeding and monitoring, and partly to encourage lateral spread of the oioi.
6. Monitor the pilot trial over the following 4-6 weeks to check for harm to oioi.
7. Spray half of the remaining 'Upper' quadrats with graminicide if, and only if, no (or minimal) damage to oioi is observed.
8. Hand weed as many 'Upper' quadrats as resources allow if graminicide application is to be avoided.
9. By mid-2025, compare oioi health and spread in quadrats which have been (a) sprayed with graminicide, (b) hand-weeded, and (c) not treated to evaluate whether competition with grasses is important threat.
10. Advise on whether graminicide spraying should be incorporated into oioi establishment protocols in future, and if so, for how long grass suppression needs to be applied.

Even with these safeguards, any applications of graminicide to release the oioi from weed competition will be risky, but this is as expected in any adaptive management approach. Careful 'before' vs 'after' comparison of oioi health, coupled with 'bet hedging' (only half the quadrats will be treated) means that lessons will be learned even if some damage to full oioi establishment occurs if oioi are damaged by the herbicide. The high probability of loss of oioi to weed competition in 'Upper' levels is the likely cost of doing nothing. The mediocre performance of oioi at 'Lower' suggests that the 'bridgehead' zones for landscape level reinvasion of Te Hakapupu will be mainly on the narrow strip along the upper

[14] A native rush, *Juncus holoschoenus*, was included and was not damaged by the graminicides.

levels of South Arm. Eventual spread of oioi down the elevations and out into the hyper-saline salt meadows might eventually succeed if we can first establish flourishing stands of oioi on the estuary margin.

A more definitive conclusion about prospects for long-term success may be possible in a year from now, two and a half years after initial planting, when a final monitoring survey has re-assessed oioi health and spread.

Many of the monitoring indicators deployed in this experiment are compromised in interpretation because of lack of knowledge: we do not know how long leaves of oioi are expected to grow; colour of the leaves is obscured by coatings of sediment; new shoots may not result from *in situ* growth and nourishment; and we do not know how long an oioi plant can persist when transplanted into a semi-hostile environment. One dimension of growth and survival is not being measured so far – it is clear that some plants are 'thinning out' due to a loss of leaves. We will add a measure of leaf bulk to the sampling for last Survey next year. Also, the importance of potential competition from grasses, and to a lesser extent thistles, is now evident. Quantitative measures of grass height and biomass should be added to the sampling protocol, especially if graminicide applications proceed. Root formation is presumably crucial for long-term growth and survival of the oioi, and lateral spread is mainly by subterranean rhizomes. Therefore, we propose to dig up a sample of apparently thriving and dying oioi to compare root and rhizome formation – this will give a more direct measure of whether the oioi in the lower levels are slowly dying or might eventually begin to grow beyond the scheduled period of experiments.

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