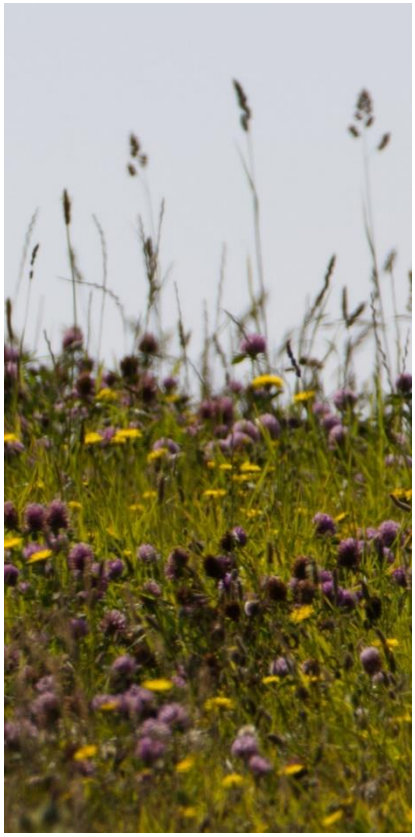
Oioi (jointed wire rush) restoration in Aotearoa - New Zealand

A review of literature and practitioners' experience



Tūmai Beach Community
Report Number 2023/01

July 2023

Suggested citation for this report:

Young, A.[1], Simcock, R.[2], Rance, B. [3], Fielding, C. [4], King, D.[5], Simpkins, E.[6], Stirling, F.F.[7], Koch, H.[8], Moller, H.[9], Bythell, J.[10], Lenting, J.[11], Stevens, L. [12], de Monchy, P.[13], Kitson, R.[14] (2023). Oioi (jointed wire rush) restoration in Aotearoa - New Zealand. *Tūmai Beach Report* No. 2023/01. 54 + v pages.

Author affiliations:

[1] Puketeraki Nursery, Kāti Huirapa Runaka ki Puketeraki, 121 Grimness St., Karitane, Waikouaiti 9471.
[2] Manaaki Whenua Landcare Research, Private Bag 92170 Auckland Mail Centre, Auckland 1142.
[3] Department of Conservation, 33, Don St., Invercargill 9810.
[4] Kopu Bridge Wetlands Care Group, Thames.
[5] For The Love of Trees, 10 Kennard Crescent, Rd 1, Waikouaiti, 9471.
[6] Auckland Council, 135 Albert Street, Auckland, New Zealand, 1010.
[7] Tūmai Beach Restoration Trust, c/o 376 Thorburn Rd., Waikouaiti.
[8] 8 Hoopers Inlet Rd., RD2, Otago Peninsula, Dunedin, 9077.
[9] Ecosystems Consultants, 30 Warden St., Dunedin, 9010.
[10] Southland Representative, QEII National Trust, PO Box 3341, Wellington, 6011.
[11] South Wairarapa Biodiversity Group, 41B Weld St., Martinborough, 5711.
[12] Salt Ecology, 21 Mount Vernon Place, Nelson, 7010.
[13] Bay of Plenty Regional Council, PO Box 364, Whakatāne, 3158.
[14] Waiheke Native Plants, 33 Pacific Parade, Waiheke Island, 1081.

Cover photo credits: Henrik Moller – www.ecosystemsphotography.com

Executive Summary

A review of literature and consultation with 20 environmental restoration managers and researchers underscored important roles of oioi (jointed wire rush, *Apodasmia [Leptocarpus] similis*) in saltmarsh, wetland, sand dune and urban habitats. Oioi provides environmental and cultural 'ecosystem services' by maintaining biodiversity, mitigating climate change effects, filtering sediments, and reducing runoff to waterways. Although restoration of oioi and companion species can initially be expensive and slow using nursery-raised seedlings, the environmental remediation provided by oioi is relatively inexpensive in the longer run compared alternative ways of solving these problems because their sustained actions become locked into our 'natural capital'.

Restoring oioi is relatively tricky compared to other more well-known and tested restoration programmes like indigenous forest establishment. Oioi can be slow to propagate, requires dense planting to avoid later weed infestation, spreads relatively slowly (apparently mainly by vegetative reproduction), and occupies a relatively narrow zone towards the top of the estuarine-terrestrial ecotone. Spread deep into intertidal zone is limited primarily by inability to deal with hyper-saline soils and prolonged inundation with tidal flows, though it survives and grows better where freshwater flows dilute the saltwater. It inhabits a wide range of freshwater and brackish ecotones and flourishes in gardens, but it cannot compete effectively in some of these more fertile terrestrial and semi-aquatic sites in the establishment phases without active weed and pest management. Oioi therefore remains a challenging and quite specialised plant for use in restoration projects.

There are still many unknowns when contemplating where and how best to plant it for fastest and most cost-effective results. Our most important recommendations include:

- Accelerate wetland and saltmarsh restoration, including by planting oioi in suitable habitat zones along estuarine/wetland/terrestrial ecotones.
- Instigate more Māori-led saltmarsh and wetland restoration initiatives.
- Plan and monitor for weed control, especially in oioi establishment phases, with best results probably from pre-planting weed control, and using weed-supressing mulches that allow oioi penetration.
- Exclude cattle and sheep and control rabbit and hares to limit browsing damage.
- Encourage more formal research of saltmarsh and wetland habitats in general.
- Advocate and educate to encourage more planting and city planning for bioretention in urban environments, including private gardens.
- Invest and manage to cope with uncertainty – expect surprise, some failures and considerable success as determined by local ecological conditions.
- Incorporate structured adaptive management ('learning by doing') to test and hone wetland management options.
- Institute more formal monitoring and report successes and failures.
- Extend monitoring from just measuring plant survival and growth to test broader ecosystem health improvement outcomes.
- Maintain monitoring for long periods to detect landscape and catchment level changes that are occurring naturally or are triggered by restoration interventions.

Contents

1. Need for oioi restoration and this research

Saltmarshes of Aotearoa New Zealand have significant value in providing important habitat for indigenous invertebrates, fish, and birdlife[1]. Over 74 species are found in New Zealand saltmarshes, of which 7 are endemic[2]. They also provide important ecosystem services of sediment stabilisation, water purification and carbon sequestration. Wetlands in general are of especial importance to Māori and traditionally a source of mahinga kai[3]. Many have been drained, burned or removed altogether ('reclaimed') for coastal development and farming. As salt marsh occupies flat fertile areas which are easily reclaimed for productive agricultural land use, including farming and urban settlements, salt marsh has greatly declined in spatial extent since Europeans arrived in New Zealand. For example[4], in Whangarei Harbour (Northland), saltmarsh extent declined from 5.56 to 4.05 km^2 between 1942 and 1966, and further reduced to 1.89 km^2 extent by 1985, representing an overall decline of 66%[5]. This does not include likely high losses prior to 1942. Similarly, in Whangaroa Harbour (Northland), its extent declined from 2.4 to 0.45 km^2 between 1909 and 1981, a decline of 78%[6]. The ecosystem health of saltmarshes that remain, and estuaries more generally, is often degraded by pollution, runoff, increased sedimentation, encroachment by mangroves, and invasion by introduced plants and animals[7]. Some are now threatened by climate change[8].

Oioi (Jointed wire rush, *Apodasmia similis*)[9] is a prominent endemic Restiad[10] in many New Zealand estuaries, wetlands, ponds and lake margins. It is a blueish-green, golden or grey rush-like plant with dark bands segmenting its leaves, often with a zigzag appearance (Figure 1). Its creeping rhizomes help it form dense rushlands up to 1.5 m tall. A meaning of 'oioi' is to sway gently, which is how oioi stems move in the wind[11]. The species is sometimes referred to as *Leptocarpus similis*[12].

This research began with a specific goal to restore oioi in 'South Arm' of Te Hakapupu (Pleasant River estuary), 5km northeast of Waikouaiti and 45 km north of Dunedin, South Island. A causeway was built over the entrance to South Arm in the 1950s to create paddocks for cattle and sheep farming. A Resource Management Act consent to create a farm park subdivision in 2008 required reinstatement of tidal flows on South Arm[13]. The ensuing Tūmai Environmental Enhancement Plan identified reintroduction of oioi to South Arm as an important step to create a self-sustaining coastal subdivision and ecological landscape[14]. Restoration of the estuary and hill slopes around the Tūmai farm park fits nicely within *Toitū Te Hakapupu*, a 5-year community partnership to restore the wider Pleasant River catchment. It began in 2022 and is funding this research and oioi planting trial[15].

Although a growing number of community groups and local government agencies are actively engaged in restoring saltmarsh and estuarine habitats, there has been relatively little formal research, monitoring, or recording of the success of their efforts. Planning restoration of oioi at Te Hakapupu quickly identified the value of gathering together testimony and advice from estuarine managers and researchers from throughout Aotearoa. This report summarises their experience and knowledge and formulates general recommendations for restoring ecological communities by planting Oioi[16].

Figure 1[17]. Oioi (*Apodasmia similis*) stands in Aotearoa New Zealand: (a - Top left) Merton, Waikouaiti Estuary; (b – Top middle) Stormwater swale, Christchurch Avon River walkway; (c – Top right) Sustainable Stormwater Trail, Auckland Botanic Garden (~ 2 years after planting, establ. Sept 2009); (d - Middle left) Orchard Stream, Nelson; (e - Middle right and f – bottom left) Honest Lawyer restoration planting by school parties, 2019, Nelson; (g – bottom right) Planting trials amongst glasswort, Te Hakapupu, North Otago 2022.

2. Review Methods

We first searched the 'Web of Science' and 'Google Scholar' online science databases and the New Zealand Plant Conservation Network's bibliography for formal scientific reports using search terms '*Apodasmia similis', 'Leptocarpus similis'*, 'oioi' or 'Jointed wire rush'. A majority of over 200 literature references found described species location records or broad-brush survey results, often recorded during botanical society field trips or for study area descriptions for research that do not inform our study goals. Others reported phylogenetic or historical analyses of microfauna deposits found in marshland deposits to analyse past sea level and climate change[18]. These distributional and deep historical reports have not been analysed in detail here[19]. Instead, we concentrated on summarising more generic written commentary about oioi habitat requirements, ecosystem services, threats, and restoration efforts.

Unpublished testimony was solicited through responses to a questionnaire (Appendix 2), email correspondence, and/or by interviewing experts with experience in planting oioi and similar saltmarsh species. We approached experts already known to us and invited them to suggest other contacts with relevant knowledge (the "snowballing" method used in qualitative research[20]). Informants were asked to send us any reports, planting and monitoring protocols that describe their own or other oioi managers' work. Calls for information were broadcast on social networks (Coastal Restoration Trust, National Wetlands Trust, NZ Plant Conservation Network).

Seven participants chose to be interviewed, five filled in the questionnaire, and five others provided shorter commentaries via email. The senior authors of the study provided their own knowledge of propagation and planting of oioi in the North Otago region. Interviews lasted 24 to 69 (average 43) minutes and were recorded and then transcribed for analysis. The questionnaire was used as a loose guide for the interview discussions, but the testimony is best characterised as semi-directed and gave lots of scope for interviewees to emphasise particular or new issues.

In total 20 informants provided their knowledge of oioi from their experiences with sites spread from Auckland to Southland. They included ecological restoration managers from community or environmental NGO groups and trusts, officers from local government agencies, plant propagators and ecological research scientists. All participants agreed to have their testimony attributed, so the identifiers 'A' to 'R' in Appendix 3 are used to reference specific information and quotes provided. Direct quotes are italicised.

Later interviews and questionnaires brought up few new issues or contradictions of earlier testimony, so we are confident that the information reported here is a relatively complete summary of existing knowledge and questions for future research and management.

The written record is presented alongside the interview and questionnaire testimony in the following 'Results' sections. A general discussion and list of recommendations for restoration practice concludes this report.

3 Restoration goals when planting oioi

3.1 Habitat and ecological communities

Our review of the literature underscored potentially important ecological and cultural roles of oioi in a wide range of habitats, including tidal estuaries, sand dune slacks[21], river margins[22], pond and lake edges[23], ephemeral wetlands[24] and built environments[25].

Oioi are known to be host plants for at least five endemic invertebrates – two moths, a beetle and two bugs[26]. In salt marshes where oioi usually occurs together with a common coastal rush (*Juncus* sp.) within the high tide zone, large numbers of adults and nymphs of the waka leafhopper were collected only on oioi[27]. On the very high tides the leafhoppers crawl up the rush stems and rest on the seed heads which emerge from the high water. This suggests a strong ecological dependence of the leafhoppers on the presence of oioi in particular. Larvae of an adventive moth from Australia is commonly found on oioi in wetlands in northern New Zealand[28]. However, the invertebrate communities associated with oioi wetlands on West Coast of South Island have been characterised as relatively species poor[29]. Detailed study would probably reveal many more species that rely heavily on oioi, but research to pinpoint the importance of oioi for persistence of other invertebrate species has not been reported. For instance, oioi occurs in the Northland habitats used by *Placostylus ambagiosus*[30], but it is unclear if its presence is important for the survival and resilience of this large endemic and nationally threatened herbivorous snail.

Micro-organisms associated with oioi have hardly been studied. Diatoms living on the surface of New Zealand lake margins show preferences for different edge species, including for oioi[31]. A new species of smut fungus occurs on oioi in the Chatham Islands[32].

Oioi in tidal areas provide good spawning ground for īnanga (whitebait)[33], a gradually declining and culturally important species. A newly introduced goby occupies oioi marshland in Northland[34]. Intertidal habitats like estuaries and marshlands are characterised as 'biogenic' because they potentially support marine fisheries by elevation of biodiversity, bentho-pelagic coupling, sediment baffling, protection from erosion, nutrient recycling, the provision of shelter and food for a wide range of other organisms[35].

Oioi and other rush species provide roosting, feeding and nesting environments for threatened and declining wading bird species like matuku (bittern)[36], banded rail[37] and marsh crakes[38], as well as unthreatened bird species like pūkeko. National booming and breeding records suggest oioi is an important breeding habitat for matuku, particularly in coastal regions[39]. Oioi occurs in banded rail habitat, but provides little cover and hinders movement, so dominance of the saltmarshes in southern South Island by oioi could explain the absence of banded rails there[40].

Strong plant species associations and potential co-dependence of species in oioi marshland are highlighted by many authors[41]. A newly described threatened sedge grows in association with oioi in northern New Zealand[42]. Species richness declines from north to south within Aotearoa, partly because of the prevalence of mangroves in northern New Zealand[43]. Oioi dominated communities in sand-dune ecosystems harbour a diverse range of native plant species[44]. *Juncus kraussii* may provide a sediment trap allowing invasion by oioi and *Baumea juncea* in northern saltmarshes, and then

eventual colonisation by woody species[45] – this illustrates the importance of longer-term successional changes where the earlier communities in the sere facilitate the establishment of later stages.

3.2 Ecosystem Services

Oioi and their ecological communities provide a wide range of 'ecosystem services' that maintain natural, social and economic capital in both natural and highly disturbed ecosystems.

Oioi provides important regulating services by stripping pollutants, holding sediment and baffling estuary, river and pond margins from physical disturbance. Oioi is planted to filter runoff to remove sediment[46], for bioremediation[47], pollution control[48] and management of stormwater in urban environments[49], especially for stormwater filtering, peak flow reduction, and flood protection as part of 'Bioretention'[50] and 'Low Impact Urban Designs' approaches[51]. These strategies will become all the more important with increased heavy rainfall and sea level rise because of climate change[52].

Oioi is considered one of the main species providing these services in manufactured 'rain gardens' and swales in Auckland and Christchurch (Figure 2)[53]. This is because oioi leaves filter flow (rather than concentrating or blocking flow as flax does) and becomes tall and dense enough to exclude weeds (and gross rubbish). Oioi leaves and roots also physically protect the soil surface making it highly resistant to erosion. Oioi roots are strong and fibrous, yet covered in dense soft hairs which grow upwards to create thick sponges that are capable of absorbing rainwater to 15 times their dry weight.

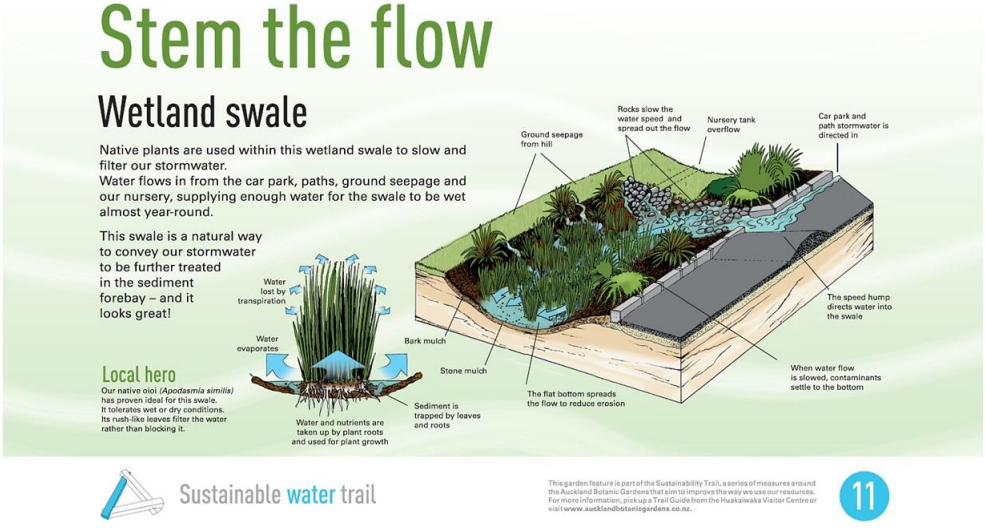


Figure 2. Oioi is a key plant for managing stormwater flows in swales within urban environments. [Source: Auckland Botanic Gardens; Design by Jan Ramp, Snapper Graphics]

Oioi are often used in private gardens, partly for ornamental reasons and partly for filtering stormwater or septic tank outflows[54].

Water retention gives oioi the ability to create raised bogs that do not dry out in summer and, over centuries, the decaying matter forms peat to depths of several metres[55]. Viewed long-term, oioi can be characterised as an 'Ecosystem engineer' in natural habitats i.e. a species that creates physical conditions for many other species. Oioi are therefore a 'keystone species' that promotes biodiversity resilience at a ecosystems and catchment scale.

Landward spread of *Spartina angelica*, an introduced (now considered pest) sedge, appears to be limited by the presence of oioi[56].

Planting of oioi in natural environments provides protection and resilience to climate change[57]. Wetlands and bogs are important carbon sinks[58]. A study of 'blue carbon' sequestration in five New Zealand estuaries has preliminarily predicted a net carbon sequestration of 2 tons per hectare per year [J]. When scaled against an estimated 5-12 tons of carbon lost per hectare per year on peat soil used for dairy farming, the value of reconversion of farmland to saltmarsh for carbon sequestration and combating climate change is all the more evident.

Oioi is a beautiful plant that is appreciated by many, so it provides 'cultural services' beyond the 'intrinsic' or 'existence value' afforded to endemic New Zealand biota. One of the planting teams participating in this research put it this way: "*We'd like to say that during summer the variety of colours of stems and inflorescences, are beautiful, especially in low light and when they gracefully sway in the wind*[E]". Although they primarily plant oioi to replace the saltmarsh that had been removed by farming, they also plant along cycle and walkways and include educational plaques to assist learning and appreciation of their restoration efforts.

Oioi is being planted in gardens[59] and along waterways, ponds and swales partly for aesthetic appreciation and recreational enhancement (Figure 1)[60]. It is often used to physically separate vehicle traffic from cycling and pedestrians with a frangible, attractive 'green' zone. They have much lower maintenance requirements compared to mown grass. Being low, oioi does not impede sight lines, thereby protecting views and meeting Crime Prevention Through Environmental Design (CiPTED) requirements within cities[61]. It may have more future use as parts of elevated urban gardens[62] which are potentially important for wellbeing of urban dwellers.

Oioi was traditionally used by Māori for thatching the walls of whare (houses). It was the best of all the rushes and sedges for walls because of its durability[63].

3.3 Threats

Saltmarshes appear to be very vulnerable to invasion by introduced species. A survey of saltmarshes throughout Aotearoa reported that 49% of the species present were introduced[64]. This has degraded the 'ecological integrity'[65] of the communities and in some situations the introduced plants have established as solitary stands covering large areas. Two introduced species of cord grass bind sediment at a much faster rate than native species. They change the morphology of the intertidal zones and displace whole saltmarsh communities, and so are considered to be the greatest ongoing threat to saltmarsh communities[66]. Willow planted for sediment stabilisation displaces oioi in some

places[67]. Clearing of surrounding land and resulting sedimentation triggers succession to more woody habitats[68] and weed invasion[69].

In dune slack ecosystems, establishment and dominance by oioi itself may become a conservation threat to rare plants that require open spaces. Weeds contributed to this loss of habitat for a range of species and their local extinction. However, the increase in oioi is indicative of natural plant succession with time in these sandy landscapes. In times when dune sand and river meanders occurred without human interference, new dune slacks would have been forming for the specialised inhabitants to occupy as their old sites gave way to taller species that create a total ground cover[70]. Ecologists recognise this as an example of the 'Intermediate Disturbance Hypothesis' which posits that some degree of disturbance is needed to maintain maximum biodiversity at larger spatial scales, commonly at an overall catchment level. Reduced disturbance and habitat space can sometimes threaten ecosystems as much as increased disturbance from human development impacts.

Climate change and associated sea-level rise is a serious long-term threat to saltmarsh habitats[71], particularly through increased water flow, storm surges and salt exposure[72]. It is logical to expect that such impacts will be most severe in the high littoral zone where oioi predominates – oioi inhabits a narrow zone towards the top of the marine-terrestrial ecotone and so is in the crucial impact zone from rising seawater.

Mangrove encroachment into saltmarsh is seen in Australia and the Americas, and it may be acerbated by climate change[73]. No research is reported to check whether this is happening in northern New Zealand but it has been observed in Bay of Plenty[J].

Threats to oioi itself include browsing by introduced pests (especially cattle[74] and rabbits[75]) and farm stock. Grazing by cattle eliminated oioi from the margins of Northland dune lakes[76]. Rabbits eat mature old oioi leaves, but favour the younger more tender shoots[F]. Pūkeko sometimes pull out oioi plants.

Grass can invade if the oioi shoots are sheared off to ground level, but sometimes they shoot back again. The most common threats to oioi in bioretention systems are kikuyu and lotus (which smother by growing over the top from adjacent areas), but most deaths come from poor maintenance practices (topping too close to the ground and herbicide).

Destruction of the vegetation and natural sediment profiles by off-road vehicles driving over saltmarsh and intertidal zones is a localised problem in some places[77].

An oioi bed was destroyed in the Bay of Plenty by people erecting a whitebait stand[J].

Smothering by loose mats of sea lettuce causes severe but localised damage to oioi planting beds:

> *"Sometimes get blooms of sea lettuce that can be quite problematic if a whole heap of it washes through your plantings on a king tide. It sort of wraps itself around new plants and they don't like it at all. There is often not a lot you can do about it because here in the BoP we could have a bad year and then go 4 or 5 years without seeing it again in a bad way"[J].*

Despite providing considerable 'cultural services', care for marshland has historically been hampered by low public appreciation for wetland habitats in general, in part because they are relatively unfamiliar to many New Zealand, difficult to navigate and therefore unseen and misunderstood. Some harbour nuisance insects like mosquitoes[78] and introduced wasps. For example, the ecological

communities dominated by oioi are probably impacted by dense infestations of Asian paper wasps[79]. A new family of non-biting midge was discovered in a Northland pond which is inhabited by oioi[80].

3.4 Restoration actions to protect and restore oioi habitats

In view of the importance of ecosystem services provided by oioi, it was encouraging to identify scores of case studies of oioi planting (Table 1), and especially that 20 managers and researchers shared their knowledge and experiences for this review (Appendix 3). There were few formal reports of planting goals, methods or success[81], so much of our analysis relies on informal testimony via questionnaires, interviews or email correspondence.

In most cases the primary goal of the programmes underway in more natural environments was simply sated as reinstatement of oioi, sometimes together with a suite of saltmarsh or wetland species, in areas where they previously existed (Table 1). This general goal of restoration or enhancement of the ecological integrity of the receiving environments is shaped by a general intrinsic value ethic rather than for reinstatement of specific ecosystem services which might then be monitored. Their rationale is simply that because the plants were there previously, they should now be put back. More targeted restoration efforts related to restoring a shoreline in Picton following its reshaping as part of offset mitigation for adjacent flood control works[82]. Initiatives to address coastal erosion were considered to be the next priority, after shellfish population restoration, in the marine ecosystems at the top of South Island[83]. This includes restoring salt marshes and seagrass, and softening coastal and estuarine edges (e.g., using terraces, living margins/buffer areas) in locations where coastal squeeze from sea-level rise allows.

The extensive re-creation of saltmarshes in pasture-estuary margins of Bay of Plenty stated broader goals of protecting and enhancing broader ecosystem services by reflooding rough pasture:

> "*If it has been rough pasture for example that has been separated from the tide by a flood gate or a bund, we reconnect the tide. The process usually starts off with the pasture dying off and the top soil remobilizing, and then gradually it becomes saltier. … More recently the driver for this saltmarsh restoration work rather than the dune work is to achieve a whole combination of benefits. It lined up very well with our biodiversity goals, fresh water and receiving environment goals and it meets the aspirations of Tāngata Whenua as expressed in the co-governance and iwi management plans in the region. Also it turns out quite good for 'blue carbon'[84] storage*"[J].

Community teams planting in coastal habitats of Waiheke use oioi to clean the water before it reaches the ocean, especially to filter runoff from areas with septic tanks:

> "*On the island there are a lot of septic systems at the moment so trying to get that water clean. Also the roots are kind of spongey and can soak up a lot of moisture as well. They can trap clay molecules to quite a good extent so reducing erosion as well. So trying to get the water clean before it reaches the ocean is pretty much the main goal*"[I].

Table 1. Goals and management actions of teams that have planted oioi in Aotearoa New Zealand.

Source	Project & place	Primary goals	Number planted	Intertidal zone	Freshwater, rain influences	Sand dune ecosystems
A - Questionnaire	Kaipatiki Project, Tāmaki/Eskdale.	Amenity planting in coastal margins and pathway edges.	200 in each of several small projects.	Planted in open areas above high tide level.	Planted above high-water line of ponds.	
B - Questionnaire and report (Johnson 1991)	Kaikourai Estuary, Dunedin.	Recreation of wetland rushes zone alongside waste and refuse landfill area; create a nutrient buffer zone, wildlife habitat and semi-natural margin where the landfill meets lagoon.	393		Margin of freshwater lagoon.	
C - Questionnaire	Estuary margin, Invercargill, Southland.	Repair of damage to vegetation from construction of Invercargill – Bluff cycle track.	500	Replanted into areas previously occupied "near the top of the tide".		
D - Questionnaire and reports (Stevens 2021, Stevens & Roberts 2021).	Saltmarsh restoration of Waikawa Estuary, Marlborough; and of Orchard Stream, Nelson.	Reinstatement of saltmarsh lost due to historical reclamation of the estuary.	560	Planted in spring tide inundation zone (1-2 days inundation per month) or in terrestrial areas.	Planted near the head of the estuary near freshwater inputs.	
E - Questionnaire and report (Fielding 2022).	Kopu Bridge Wetlands Care Group, oversight by Waikato Regional Council	Replacing oioi eliminated by farming; Aesthetic appreciation and educational outreach actions and goals are included.	100 - 300 each year since 2013.	No or only occasional gentle tidal inflow, at the top of a king tide.	Saltwater mixed with fresh water from the Waihou.	
F - Interview	Walton Park lagoon, Dunedin; Hawkesbury Lagoon; Waikouaiti River and a lagoon site; several gardens.		80 at Walton Park; 20 at Waikouaiti River.	Planted just on the dry side of the high-water mark.	River and lagoon margins tried.	Limited success establishing them.

Source	Project & place	Primary goals	Number planted	Intertidal zone	Freshwater, rain influences	Sand dune ecosystems
G - Interview and email	Hoopers Inlet, Kaikorai Estuary and several other projects near Dunedin; Plant propagator and habitat regenerator.	Reinstating the natural buffer on estuarine perimeters; countering introduced grasses; aesthetic value.	150	Planted where there is a slope above the tide line and where the soil is saline. There it out-competes everything else. If you take it up too far the rank grass gets the better of it. If you take it too far down, it drowns.	Plants on edges of brackish water ways, not where water is permanently standing.	
H - Interview	Private land, Southland.	Pond margin restoration.	12		Freshwater pond with fluctuating level.	
I - Interview and email	Waiheke Island, gardens and coastal restoration projects	Cleaning runoff before it reaches the ocean.	10,000	Planting where only occasionally inundated with tidal flows.	Does better in areas with freshwater streams or seeps.	
J - Interview	Coastal restoration projects, Bay of Plenty	Restoring dune slack ecosystems; later reforming saltmarsh in areas that had been converted to paddocks for farming. Fresh water quality and receiving environment goals, blue carbon sequestration, aligns with the aspirations of Tāngata Whenua; Blue carbon storage	10,000+ ongoing in 70 hectares of pasture but mostly sea rush.	Planted into retired farmland 0.7 to 0.95m above mean tide level.		Earlier planting in dune slacks to recreate previous vegetation composition.
K - Interview	Auckland Botanic Gardens and built environments.	Bioretention in swales and rain gardens for storm water management, cleaning water, recreation management.	1000s unplanted more widely; 45 in growth-form trials.		Used in wet habitats, often for managing stormwater flow and cleaning the water.	

Source	Project & place	Primary goals	Number planted	Intertidal zone	Freshwater, rain influences	Sand dune ecosystems
L - Interview	South Wairarapa Diversity Group,	Reinstatement of species that were previously there.	100-150		Killed by prolonged emersion when lagoon outflow becomes blocked.	Targeting patches of less sandy soil, in hollows, and periodically flooded.
M - Email	Smiths Creek, Otago Peninsula; DoC Reserve at Hoopers inlet, Otago Peninsula.		10 at Smith's Creek; maintenance at Hoopers Inlet			
N - Email	Waikawa & Niagara, Southland		5 clumps, each 15 cm across			
O - Email	Various bioretention projects in built environments, Auckland, Hamilton, Wellington, Christchurch.	Stormwater management, pollution control, amenity planting, weed suppression with oioi being low enough to maintain clear zones and sight lines (delivering CiPTED – Crime Prevention through Environmental Design)	Tens of thousands		Often intermittently wet and dry areas (water does not pond in most stormwater devices for more than 12 hours). Oioi ideal because it slows but does not block flow.	
P - Email	Coastal areas of Coromandel			Sheltered estuarine margins landward of sea rush and intermingled with saltmarsh ribbonwood.		

Several propagators and landscape gardeners are planting oioi for amenity and aesthetic reasons. One commented that it is a "*low and tough plant that is appropriate to saline edge*s" [A].

Planting for bioretention and amenity values in built environments had clearly defined goals relating to provision of ecosystem services (Table 1). The soils in swales are sometimes very shallow and oioi is an ideal stormwater filter as it avoids concentrating flow and has a high roughness coefficient[O]. LIUDD and Bioretention mitigate impacts of stormwater several ways - nearly all slow runoff and thereby reduce peak flows and erosion of streams, most reduce runoff volumes, and most improve water quality.

Oioi is out of favour when planted into highly fertile media (some raingarden media) adjacent to a path or road because the spears fall over and lodge, and so require trimming. Auckland Botanic Gardens has collected oioi with a range of growth forms from around Auckland and has tested them over the last 10 years. They are seeking smaller-statured upright forms to reduce maintenance[85]. Splitting favoured forms is one option for propagation, but the propagation teams hope to germinate their own seed lines and currently are exploring impacts of cross-pollination on form[K]. Small 'divisions' with as many stems has can be squeezed together in one hand were cut from wild growing stands for the growth form trials and transported to planting beds at the Botanic Gardens. The most promising cultivar of 15 being trailed was collected from alongside a motorway and not in conditions considered ideal for oioi, but after three years its form is holding true in ideal growing medium within garden propagating beds. This suggests the desired growth form traits are at least in partly genetically fixed[K]. However, plants collected from saline margins are sometimes stunted and quickly grow to normal height when transplanted to ideal nursery conditions, so at least some characteristics are locally driven by environmental factors.

4. Ecological niche: where to plant oioi

4.1 Estuarine environments

Species zonation within salt marsh and the broader marine to terrestrial ecotones is generally governed largely by tide levels and wave action, elevation, and salinity (Figure 3)[86]. Mean high tide is an important point separating the middle and upper marsh zones and is characterised by a sudden increase in the number of species and cover[87].

Oioi enters the sequence close to 'Mean High Water Springs' and is only occasionally immersed in saltwater (Figure 4)[88]. Above mean high tide level, oioi favours hollows seldom inundated by tides and where fine particles of clay and silt, organic content, and water content of soils are higher[89]. Correlations of field measurements and field distribution, glasshouse response studies and reciprocal field transplant experiments with oioi in Otago conclude that this pattern is primarily driven by changes in soil salinity and differences in the salt tolerance of the species [90]. Soil salinity is itself dictated by the frequency and duration of inundation by seawater. Secondary vegetation patterns reflect differences in soil moisture and texture[91]. Competition with more salt-tolerant species limits spread to lower elevations, whereas competition with faster growing species of less salt-tolerance limits spread to higher elevations[92].

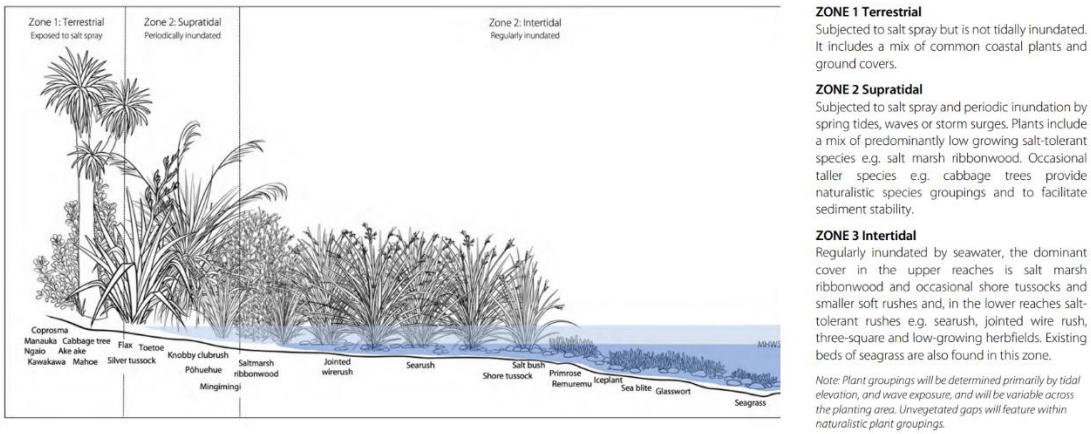


Figure 3. Species zonation examples from Nelson [Source: Stevens & Roberts 2021].

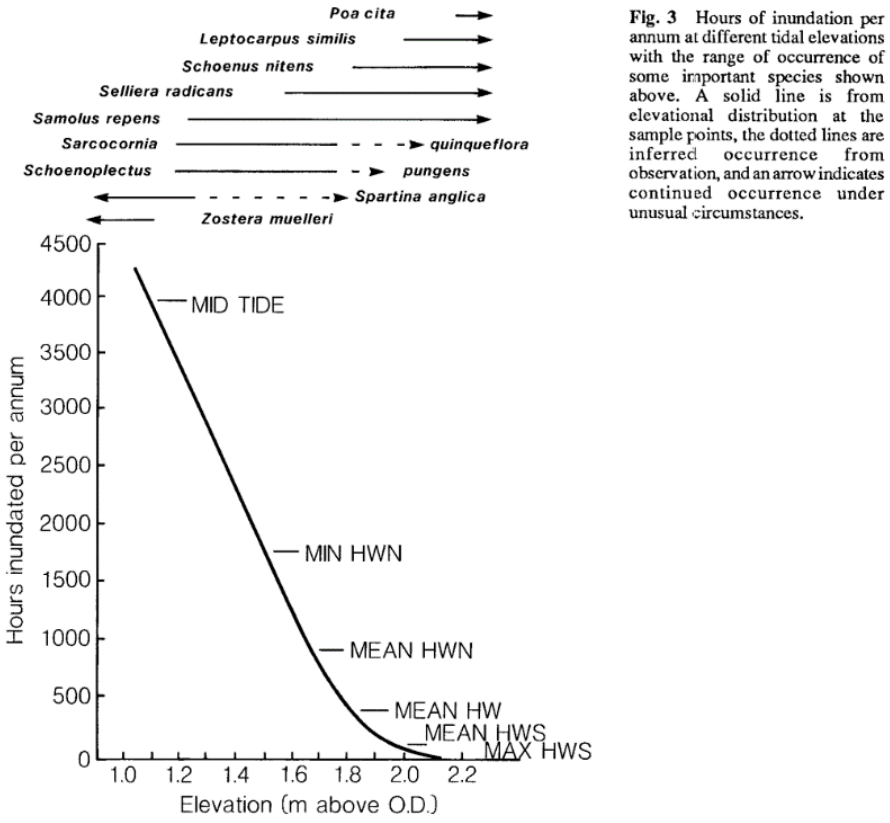


Fig. 3 Hours of inundation per annum at different tidal elevations with the range of occurrence of some important species shown above. A solid line is from elevational distribution at the sample points, the dotted lines are inferred occurrence from observation, and an arrow indicates continued occurrence under unusual circumstances.

Figure 4. Saltmarsh species distributions in Otago in relation to elevation and inundation by seawater. Oioi is designated as *Leptocarpus similis* in this graphic. [Source: Fig. 3 of Partridge & Wilson 1989].

These detailed studies of Otago saltmarshes show that salt tolerance and competition therefore determines the mix of species growing and around oioi. Distributional studies throughout New Zealand fit the same general thesis for drivers of plant communities throughout Aotearoa and place oioi as a 'high saltmarsh species' in the elevation and saltwater inundation sequences[93]. Above mean high tide oioi grows in hollows seldom inundated by tides[94]. Sea rush *Juncus maritimus* (= *J. kraussii*) and glasswort commonly occurs below oioi in the sequence and saltmarsh ribbonwood above it, especially near freshwater seeps (Figure 2)[95]. However, oioi occurs above the sea rush[96], or mixed stands of sea rush and Oioi are present[97]. Other upper marsh species like *Cotula dioica*, *Apium prostratum*, *Festuca arundinacea*, *Poa cita*, *Agrostis stolonifera* join oioi in these elevated non-saline sites[98].

A nationwide categorisation of saltmarsh plant communities identified four salt marsh vegetation complexes in the North Island, and three in the South Island[99]. An idealised depiction of one of the communities is provided in Figure 5.

Sea rush is favoured for restoration over oioi in some projects and appears to establish better than oioi in lower intertidal areas[D,J]. For example:

> *"I think sea rush is much more reliable as a restoration starting point. I don't know why but something about the Juncus kraussii [maritimus] that enables it to handle being stuck in exposed places a little bit better than oioi. Or maybe we are just better at propagating and planting sea rush than we are with oioi. We still use oioi, but we don't use as much of it as we do sea rush"[J].*

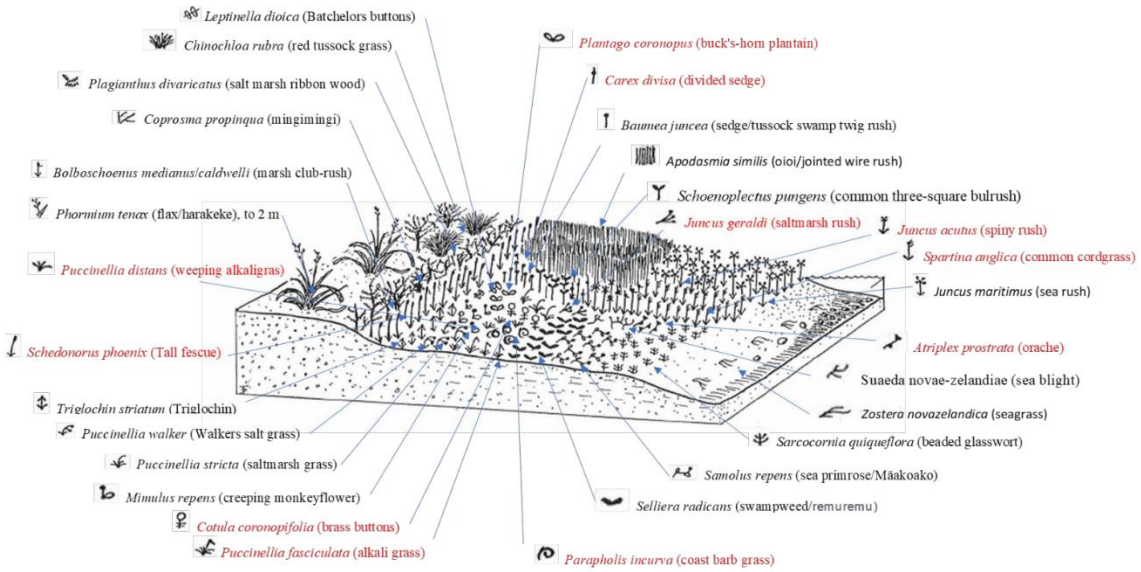


Figure 5. An idealised saltmarsh plant species profile. [Source, original diagram by Haacks & Thannheiser (2003), adapted by Morrison 2021].

Oioi grows in close proximity to glasswort in many areas with tidal flows. Our participants have not observed any competition or displacement between these two important species – instead their niche and habitat range borders on one another[100]. While glasswort can handle daily inundation of salt water, oioi tends to flourish back in the brackish water areas closer to the "sweet water"[I]. Similarly, saltmarsh ribbonwood borders oioi and is sometimes planted in conjunction with oioi, but there is no evidence of competitive displacement between the two[I].

Some observers note variable success in establishment and growth of oioi – if the conditions are right, it flourishes, but in other places it struggles and requires considerable work to get it established. For example:

> *"I have found it relatively easy to re-establish in the right place using seedlings – e.g. sheltered estuarine margins landward of sea rush and intermingled with saltmarsh ribbonwood. Have even seen it planted quite successfully in more elevated areas in such environments, though there it tends to be subject to lots more competition from other species in such areas (shrubs, exotic perennial grasses, etc). I have also seen it occasionally used on dunes – though I would not use it there unless a very low-lying site (such as a dune slack or close to an estuary margin). Strangely, I have even seen it used "successfully" (i.e. growing happily) in landscaping uses that seem inappropriate"*[P].

Oioi was characterised as "*quite sun-loving and needing lots of light and low surrounding vegetation*"[G]. Competition for root space with other plants in garden settings is suspected. "*On saline/brackish estuarine margins it is very easy to establish if you get the hydro-period/ground elevations right*" [P].

The Bay of Plenty Regional Council team have completed detailed water level surveys to formally identify areas for reinstating saltmarsh on land previously converted to farmland:

> *"We have identified that mangrove will grow from just above mean sea level to about 0.7 m above that; sea rush will grow from about 0.6 RL to about 0.95; and that oioi from about 0.7 to 0.95. Plagianthus- the saltmarsh ribbonwood, taupata, flax and raupo merge at the higher elevations. We use these elevation guidelines to put oioi in the places where the elevation best fits the oioi niche in the natural remnants of their previous habitat"J.*

Other restoration managers use less formal rules of thumb to identify target planting areas i.e. they reported their strategy was to plant areas immediately alongside, or "*just on the dry side*"[F] of saltwater (e.g. estuary margins) and freshwater (e.g. pond margins) inundations zones[G,H,101].

One propagator working with community restoration groups summarised their target areas in the following way:

> *"We are planting them either in freshwater areas just back from the beach, or brackish water areas where the tide sometimes, like say on a King tide, might get inundated with salt water. We are not planting them in a tidal area which would probably get daily inundation with salt water – it is more just a little bit back from that. But they seem to do very well in those areas. Also they can do quite well in coastal areas where there is a rocky area with a fresh water seepage. They can grow on banks and things quite well if they have a little bit of moisture coming from a spring or a stream. So they are very salt spray tolerant and brackish water tolerant, but up here at least you don't really find them growing in those fully tidal areas – more like just behind that"*[I].

They consider that too much inundation will hinder establishment, but once a robust source stand has been established it may naturally spread into the wetter and temporarily flooded zones. In the longer term the newly established stands can find their own natural limits of exposure to salt, current and saturated substrates.

> *"I suspect for some of these species it is the establishment that is critical, so in tidal situations where it is more commonly found, it is not inundated the whole time so it can probably establish. In freshwater situations it is more likely to establish in that upper part of the zone - above permanent water level – and as it grows it spreads down [into the flooded zone] using energy from the bulk of the plant. Planting it directly into standing water could be stressful and its success could be reduced"* [H].

When restoring highly degraded landscapes, oioi is seen as an opportunity to get "*biggest gains*" and create conditions for planting other species later[H]. It is particularly useful species to create a "buffer layer" and "natural sequence" between the mudflat and saltmarsh and the terrestrial zone just above the spring high tide lines. Saltmarsh ribbonwood, flax and occasional toetoe can then be added later. Tufted hairgrass, a threatened native species, could also be planted after establishment of the oioi buffer zone[H]. However, weed infestation often prevents natural spread higher in the ecotone[G].

Although the teams had clear understanding of where new patches of oioi could be created, some also emphasised longer term natural changes in its distribution in their vicinity. For example, oioi has been observed to respond to hydrology changes in Southland lagoons i.e. to gradually spread and adapt to the new saltwater inundation levels[H]; and oioi stands have generally spread in Papanui Inlet on Otago Peninsula in the past 20 years[G].

4.2 Sand dune ecosystem restoration

The niche requirements of oioi in sand dune systems are less well described. Its presence there is seen as an intermediate stage of a succession from ephemeral wetland harbouring specialised open space herbs to more permanent woody vegetation[102]. Oioi enters the sequence when and where organic matter has been trapped. It can outcompete other plants in these nutrient-poor soils[103] and then presumably accelerates soil formation over decades to allow woody plants to take over.

Oioi appears to struggle to establish in other parts of sand dunes. Planting of oioi and several other species in a sand dune flat at Ohinewaipera on the Waikouaiti spit had "very dismal success" despite being relatively wet[F]. It was previously pine forested, so this may have been a factor in its failure. Once established, oioi can grow very well in sandy soils[G]. A team restoring sandy ecosystems around a coastal Wairarapa lagoon has an added challenge of managing severely fluctuating saline and freshwater conditions. They target spots around the lagoon judged to periodically flood in order to avoiding the profound drying observed closer to the seashore and in more sandy soils. But water levels and salinity vary enormously according to whether the lagoon is cut off from the sea, and when the mouth of the lagoon is artificially reopened by diggers. Oioi does not withstand prolonged flooding by freshwater, nor prolonged drying out, so overall survival has been low (ca. 10%).

Oioi appears to grow relatively well where saltmarsh ribbonwood also prospers in sandy environments, presumably because they have similar niche requirements[L].

4.3 Freshwater ecosystem restoration

Oioi is very tolerant of inundation by freshwater, as seen in its use in swales in urban contexts and survival around freshwater ponds and ephemeral wetlands. Freshwater flows presumably dilute salinity of the soils, so oioi grows at lower elevations in the intertidal sere in the more inland reaches of estuaries and tidal lagoons[104,105]. Oioi will even extend into swamps which are brackish[106]. The

extensive swathes of oioi in the Catlins probably originate from large amounts of freshwater that regularly flush into these systems from large inland catchment areas[Q]. One study participant has restricted planting to one side of a small freshwater pond to prevent complete spread of oioi and consequent elimination of other biodiversity[107].

Despite tolerance and even encouragement by freshwater inputs, oioi does not necessarily flourish in all predominantly freshwater habitats.

> *"We have had real difficulty with oioi in some environments. In particular, around small exposed coastal wetlands on the coast where the stream waters are not saline or brackish (i.e. largely freshwater) – even when such environments are located right on the coastal edge and subject to salt spray and salt-laden winds. While we have had some survive in such small stream entrance "lagoon" areas, the survival rates have been low (<20% as opposed to> 90%+ in more appropriate areas). And the few plants that survive are quite badly stunted and "shorn" even 2-3 years later"[P].*

Prolonged or continuous saturation with freshwater hinders growth of oioi – it copes less well than raupō in these situations[G]. Establishing oioi around the margins of flax and toetoe is easier[G].

Planting into a loose slop sometimes succeeds in freshwater systems, but they rarely survive or at least recover very slowly after an initial shock when planted in sloppy estuary sediments[F,R]. A small experimental planting on the margin of Waikouaiti River was washed away or buried by a large flood two weeks after planting[F].

4.4 Restoration and bioretention in built environments

Oioi are a practical choice for amenity plantings in cities and within swales and rain gardens for bioretention because supply of plants from nurseries is assured and because they have relatively low maintenance requirements after establishment[K] except where adjacent areas have plants that can invade oioi, such as kikuyu, lotus, or pohuehue[108]. Oioi is often planted in riparian plantings in semi-urban and brackish water contexts. Detailed urban planting guides have been provided by the Auckland Transport[109].

Care is needed to not overwater oioi in gardens.

Oioi is a favoured plant on the edges of natural environments that border built up areas i.e. wealthy bach owners do not like it when the Regional Council plants tall trees like ngaio, karo, akeake or pōhutakawa because they spoil their view, but they find oioi in an attractive option for low stature revegetation[J].

5. Source of plants & propagation challenges

Most restoration projects obtain oioi from plant nurseries, but earlier trials tested success of transplanting individual plants or squares of oioi turf cut from wild populations (Table 2). Propagators generate most of their plants by collecting seed from the wild, geminating, growing them on, and then splitting well-growing plants before growing the split plants on sufficiently for transplanting by customers. Propagators occasionally gather or are given wild plants and grow them on in the nursery before planting out for restoration goals[110].

Many teams collect oioi seed from wild growing plants to grow oioi in nurseries (Table 2), sometimes as part of more organised seed banking initiatives[111]. Seed set is apparently regular and predictable in wild plants, but the quality of the seed varies[112].

Some of our contributors[I,K,N,Q] have found seed germination difficult, or at least slow[113,114].

> *"Oioi have separate male and female plants, so sometimes getting seed is a little bit tricky if you don't have both of them growing together. In some of our selections we were seeing we had more males than females".*[K]

Seed collection is tricky for the unwary. The species is dioecious (separate male and female plants) and this has caught a few folk out by collecting spent male flowers and not the rounded seed heads on female plants.

The Porirua Council Nursery team have been growing oioi from seed for the past decade and provided the following guidance:

> *"The collected seed is first dried out for storage in a fridge. The best time to sow seed is in the spring after pre-soaking in a mild seaweed solution. The seeds are then strained from solution and mixed with fine propagation sand which is then spread over the surface of a seed raising mix. A clear cover over the tray keeps in humidity but can cause a fungus to grow over the medium surface, but seaweed may curtail that causing any damage to the seed. Germination usually takes up to three weeks. We often sow just after the full moon for even germination. The plants are usually able to grow in the tray for up to nine weeks as the true leaves develop before pricking out. These are usually transplanted into a T 5cm. The plants will continue to grow for up to six months but they become much harder to separate. Pricked out seedlings are then placed in a greenhouse for four or five weeks to develop a root system. Some mild seaweed foliar feed can be applied to enhance the natural hardiness of the species. These plants can then be moved out of the greenhouse on a cloudy day. Bright sunny days can burn the plants recently moved from shelter"*[S].

Some propagators split well-grown stock that they first establish from seed:

> *"Because it is so slow we begin to split them once we get a good few hundred in that PB3 size in stock. Rather than dividing into small clumps, we split a PB3s into 2 or 3 because it comes away much faster. The larger we split them the quicker that time is – the split portions are ready for sale in about 2 months. That is a much more viable way once you have a stock of producing enough for sale for a project. We always hold back about 50 -100 just for splitting for the next year, however we still collect seed and try to grow it from seed annually as well"*[I].

Splitting is a difficult and skilled job to do well[115]. Splitting Oioi needs to be done in moderation – if split into small segments they do not survive and grow well[I,Q,116].

Some contributors to this study warn that problems and delays in seed germination and lags in plant growth combine to make oioi generally slow to propagate compared to many other plants[L,Q].

> *"I have found them painfully slow to get going. Like once they get to a certain size they seem to take off. But propagating them for the first year and half they just seem to do nothing. I don't know if all their growth is going on underground with the roots"*[F].

It requires at least two years to get a good quality plant from seed to sale, perhaps longer depending on which size you are selling at[117]. A lack of understanding about plant propagation realities and nursery constraints amongst ecologists and others designing planting plans often creates problems and can result in a gap between expectation and delivery of the desired outcome. Slow propagation adds considerable cost.

Table 2. Restoration methods used by teams planting oioi in Aotearoa.

Source	**Project & place**	**Stock planted**	**Spacing**	**Plant survival**	**Spread**	**Monitoring**	**Problems, Unintended consequences?**
A - Questionnaire	Kaipatiki Project, Tāmaki/Eskdale.	Grown in nursery from own seed before planting out when 500-700 at 1.5 to 2 years old.	500-1000	"Oioi survived best of all plantings".	"Took a year to settle in and then expanded".		"Can dominate an area".
B - Questionnaire and report (Johnson 1991)	Kaikourai Estuary, Dunedin.	Wild growing oioi transplanted.	Replicates at 500, 1000, 2000.	Preliminary survival 2-3 months after planting = 61%		Survival assessed after 3 months.	
C - Questionnaire	Estuary margin, Invercargill, Southland.	Split and replanted material removed by digger from a natural site.	300	Appears good.		None.	Stake to prevent water current displacing new plantings.
D - Questionnaire and reports (Stevens 2021, Stevens & Roberts 2021).	Saltmarsh restoration of Waikawa Estuary, Marlborough; and of Orchard Stream, Nelson.	Nursery propagated. Planted when about 300 mm tall and 4-5 months old.	Planted 200 to 500 apart; denser planting in higher energy areas to mitigate against erosion and provide a more rapid infilling of dense cover.	High. Some losses due to mowing of plants by adjacent landowner.	Spread is slow. Some infilling observed but only in the order of a few cm after two years. Root runners expand from planted oioi.	Repeat surveys during subsequent weeding and maintenance work.	Mark plants to avoid inadvertent losses from mowing & help relocate plants if they become covered in weeds. Use plant guards in terrestrial areas.
E - Questionnaire and report (Fielding 2022).	Kopu Bridge Wetlands Care Group, oversight by Waikato Regional Council	Spray sites with herbicide in advance of planting; Nursery propagation; Planted in clusters with other species between.	750	100%		Visual inspection	

Source	Project & place	Stock planted	Spacing	Plant survival	Spread	Monitoring	Problems, Unintended consequences?
F - Interview	Walton Park lagoon, Dunedin; Hawkesbury Lagoon; Waikouaiti River and a lagoon site; several gardens.	Nursery reared plants transplanted to wild, at least PB3 size and 200-300mm high.	"As close as you can afford"	>75% at Walton Park	Can be slow at first; spreads fast after initial lag in estuarine situations, but right away in garden and freshwater settings.		Washed away in flood just after planting at one site.
G - Interview and email	Hoopers Inlet, Kaikorai Estuary, and several other projects near Dunedin; Plant propagator and habitat regenerator.	Earlier transplanting wild plants unsuccessful; Transfer of clumps from the wild into gardens works well; propagation in garden, splitting them and then planting out when around 500 mm into natural habitats is the most used method.		Variable. Ideal target 80%.	Much less than 1 m a year - a lot less than raupo.		
H - Interview	Private land, Southland.	Germinated from seed and grown on in home nursery.	Planted 1m apart within clusters of 3 plants; clusters ca 5 m apart.	> 90%			
I - Interview and email	Waiheke Island, gardens and coastal restoration projects	Planting out nursery-grown stock propagated from local seed sources; 2 to 4 year old plants, 700-1000mm tall.	Usually 1 plant per m^2 (1.13 m spacing).	Close to 100% if planted well and in the right place.	1 m^2 coverage from a single plant in a year in ideal conditions.	Increased birdlife and cleaner water; survival, growth and colour of oioi plant health.	

Source	Project & place	Stock planted	Spacing	Plant survival	Spread	Monitoring	Problems, Unintended consequences?
J - Interview	Coastal restoration projects, Bay of Plenty	Mostly grown in nurseries; usually root trainer grade rather then PB2s or PB3s. Often snipped to ca. 300mm. If an area is being destroyed, wild plants harvested, split and replanted elsewhere.	Clusters of 35-45 plants in an area 3x3 m (equivalent to 250-290 mm apart); clusters 15-20m apart.	Target 80% on average, but varies from 0% to 100% with local site conditions.	ca 2 m lateral spread a year in good habitats.	Visual assessment of whether the saltmarsh is 'intact' 2-3 years after planting.	Volunteers can not always plant to high enough quality. Inundations of sea lettuce washed onto the beds can destroy young plantings.
K - Interview	Auckland Botanic Gardens and built environments.	Much planting out from nursery stocks; 700-1000mm high when plant out growth trials populated with 'squares' harvested from wild stands.	500-700 mm.	>95% if planted in Autumn or Winter; ca 50% if planted after September.	Plants spread laterally to become a closed sward after 2-3 years; Occasional planting at 1m spacing takes 5 years to close.		Split plants die if allowed to dry out or lie too long, even if covered by planting substrate, before planting.
L - Interview	South Wairarapa Diversity Group,	Nursery grown plants when around 600mm high.	1000mm.	ca 10%	Clumps are "self-seeding"; Filled in 0.5-1m over 4 years in garden conditions.		
M - Email	Smiths Creek, Otago Peninsula; DoC Reserve at Hoopers inlet, Otago Peninsula.	Nursery grown		10%			Require extensive weeding; only experienced volunteers can distinguish them from introduced grasses or other native grass and sedge, even if seeding.

Source	Project & place	Stock planted	Spacing	Plant survival	Spread	Monitoring	Problems, Unintended consequences?
N - Email	Waikawa & Niagara, Southland	Clumps of wild grown oioi rescued from washout; Seed collection and germination trials					Germination either very slow or non-existent - trials still underway.
O - Email	Various bioretention projects in built environments, Auckland, Hamilton, Wellington, Christchurch.	Nursery grown plants. Typically planted at 3-5/m2 at HTT/large root-trainer/1 litre size and mulched with an organic mulch (Auckland) or pebble mulch (Christchurch).	300-500 mm	Very high unless smothered by weeds or planted out of season	Complete cover within about 2 years.		In recent years much oioi in swales has been killed by a maintenance technique used on sedges of topping at 100-200 mm height.
P - Email	Coastal areas of Coromandel			Variable; <10% in some freshwater areas (even with some brackish water and salt spray), >90% where conditions are suitable.			Sometimes extreme difficulty in establishing around small exposed coastal wetlands on the coast where the stream waters are not saline or brackish (i.e. largely freshwater) – even when such environments are located right on the coastal edge and subject to salt spray and salt-laden winds.

In most cases oioi seed is sprouted and grown in pots in nurseries before being planted out. However three projects dug oioi from existing natural stands, split them and then replanted[B,C,K]. One eco-nursery is often provided with oioi dug out of people's gardens when they are relandscaping – they then split the rescued stock and grow them on in pots[I].

One project only harvested wild growing oioi if their area was about to be despoiled – in which case they rescued the plants, split them and planted them in other areas being reclaimed as estuary from farmland[J]. Their decision to avoid harvesting wild plants was based on concern for impact on the harvested sites and partly because a satisfactory alternative of using nursery-reared plants was easier:

> *"We have mapped all of the remaining indigenous ecosystems in the BoP region and most of the oioi is classed as being in an indigenous biodiversity area with an A classification, or an SNA, or both; or it is otherwise protected. There are enough places where it is declining due to threats or other issues that we should leave it alone as much as possible to do its own thing and maintain its density. And we can buy in new plants propagated from seed"[J].*

Oioi can transplant well as mats. Turf-like mats were transplanted in a flood plain near the Coromandel[O]. Protecting the edges of the turfs from erosion in the short term (maybe using material like open coir netting or even matting) might be useful. Using coir or wool or jute to stabilise and protect soil into which nursery-grown oioi is planted into (in slits) is common in Auckland riparian plantings where loose mulches cannot be used because flood waters would wash it away[O]. The weight and thickness and type of cloth governs its longevity but also what is able to also grow through or under it.

Some landscapers treat the rush like a sedge and severely cut the shoots before planting out, presumably in the expectation that it reduces transpiration and enhances survival. For oioi it does exactly the reverse and topping is not recommended by some of our informants[O,Q]. In two cases plants were cut to shortened them by a third to reduce transpiration loss, but other advisors are adamant that rushes should not be cut back in that way. If the plants are very tall they sometimes flop over, but that material dies off and resprouts naturally[I].

6. Planting: microsite selection, spacing and planting techniques

Microsite selection criteria relate to avoiding dislodgement by water flows, weed infestation, and bet hedging where uncertainty exists about survival and growth. Several techniques from terrestrial plant restoration programmes appear to have been transferred to assisting oioi restoration.

6.1 Avoiding displacement

Moderate water currents and tidal fluxes can displace newly planted oioi. Some planters anchor the clumps with stakes (Table 2)[C]. One team prioritises planting in the upper ends of harbours and lagoons to avoid disruption by wave action[J].

Teams usually plant "*where there is no or only occasional gentle tidal inflow, at the top of a king tide*"[E] and "*where water is brackish or at least refreshed by rains or seeps*"[E].

> *After we had done it for a few years we tend to put the oioi behind the sea rush because it likes to be protected. It did seem like it was a bit more touchy, so get the sea rush to take the*

energy from the water flow and then put the oioi in behind it. It is one of the reasons why we have ended up with more sea rush because it tends to survive that first year process better than the oioi."[J].

Low impact 'Chenier sills' can be constructed to dampen wave action to protect plantings, encourage the build-up of sediment and reduce shoreline erosion (Figure 6).

Figure 6. A 'Chenier sill' close to the mouth of the Orchard Stream in Stoke, near Nelson. Small boulders increase the height of the estuary bed over time and change the shape of the shoreline to make it more suitable for saltmarsh vegetation to grow. [Photograph supplied by Nelson City Council].

6.2 Companion planting

The importance of using sea rush to protect oioi from tidal flows has led the Bay of Plenty Regional Council to sequencing the plantings:

"It is better to get the salt marsh going with sea rush and then maybe bring in your oioi plantings in year 2 or 3, once you have got an effective buffer going because we tend to have really good uptake there and then really good success with the palustrine or terrestrial margins behind"[J].

A team restoring sandy ecosystems around a lagoon in south Wairarapa has set out to first establish saltmarsh plants in key areas to create seed sources and establish centres from which plants will naturally spread[L]. Successive years of planting add to the side of the earlier successfully established patches. They prioritise areas that are less sandy and hold more silt or loam. They don't plant where plantain is growing because it indicates that the soil will be compacted. Instead target patches where introduced pasture grasses are growing usually in hollows. These look weedy but they signal the presence of more fertile soils.

"We plant in patches, with our three species of rushes planted separately. Between these we plant Coprosma propinqua, ngaio, flax, and mākaka"[E].

6.3 Weed management

Microsites are prepared by spraying, usually with Roundup or similar, to clear vegetation in many cases[L].

> *"Grass is really annoying for it – it is really bad. It is really hard to release it and it hates spray. You cannot use weed matting on it"[F].*

However, vulnerability to glyphosate spray is not apparent in some roadsides managed by others – perhaps vulnerability depends on the penetrants and surfactants[O]. Some use a spade to cut away the root mass of grass and weeds in a 200mm radius around the planting spot[H].

Others use weed mats to suppress competition[118], especially on the land side of the high tide line where the goal is to establish an oioi stand that will then naturally spread down the elevation into the more saline substrates[G]. Large rocks, plastic, or very dense weed matting cannot be used because it prevents penetration by the leaves. More open weed matting such as coir or hemp allows oioi penetration but provides less weed suppression - it helps mainly by protecting bare soil from water erosion[O].

Others planted in open sediment, but along with a mix of other saltmarsh plants[D] where salt has usually eliminated many potential weeds:

> *"If it is saline enough to consider oioi there aren't usually a whole lot of exotics there, which is one of the beauties of salt marsh restoration – you don't have to go and get rid of the pampas and things – because generally the salt has taken care of that already"[J].*

Choosing the elevation of oioi planting is seen as a trade-off between matching the niche requirements of the rush (avoiding prolonged emersion and hyper-saline soils) and using the natural control of weeds by saline conditions. For example:

> *"The difficulty is they need saturated soil but take lots of releasing until established. Oioi do well in open sites and good soil but do risk getting outcompeted by roots of nearby plants. Their ideal site is at the edge of saline estuaries and initially planted a little above the high water mark"[G].*

The strategy has often been to establish a "bridgehead" stand of oioi as close to the saline estuary margin so it can grow down slope and find its own tolerance limits to local conditions as rapidly as possible:

> *"[We plant] where there is a slope above the tide line and where the soil is saline. There it out-competes everything else. If you take it up too far the rank grass gets the better of it. If you take it too far down it drowns – surprisingly"[G].*

Planting microsites are therefore chosen very precisely by some planters:

> *"Say you had it in PB 5 bag – you make sure only half of it is in the salt layer and make sure the rest of it is above it. Otherwise it just does not put up its breather roots. I do not know from a plant botantist's point of view how it actually breathes. But it must breathe just like mangroves and raupo."[G]*

Weed control by occasional flushing with saltwater could be considered as a non-chemical option.[D]

The quality of the planting is particularly important for a somewhat tricky plant as oioi.

> *"Everyone wants to get volunteers involved and it is the thing the volunteers most want to be involved with. But it is also the time when you run the biggest risk of putting the plant in a position where it is not going to survive. That is always the challenge because our council is really big on community participation, so we like to try and create as many of those opportunities as possible. But try not to throw money down the drain by having school kids planting in a situation where they are not really going to do a good enough job. Make sure your supervision ratios are ok. Maybe use the hardy species or lay them out for them first"[J].*

Immediate follow-up checks and some replanting is needed in many community and school planting projects[O].

Planting risks are reduced in bioretention projects because the soils are usually manufactured so therefore 'loose'[O]. It is therefore easy to plant oioi quickly and have high root contact without need to 'push' the brittle leaves and snap them). Also mass planting is more easily done in bioretention beds because there is little variation (no saline influence or 'sweet spot') to find.

6.4 Plant spacing

One restorer was doubtful that the plants need to be planted close together to offer each other stability and hold the substrates except in very new sites with soils that might be vulnerable to disruption by seawater surges[G]. In his and many other managers'[119] view, optimum spacing is dictated by the ability to maintain weed control in the establishment phase and by a wish to close the canopy as quickly as possible in order to prevent weed infestation. This strategy takes into consideration the size of the plants at maturity and so they will then just touch each other:

> *"The basic idea is to cover to minimize weed growth as quickly as possible and then when it all fills out you are not getting any weeds because you get natural competition. So the goal is to create habitat as natural as possible where seeds just drop down and grow where they grow. Sometimes they are too close together and one plant will succeed and another will not. It is all about crowding out the weeds first"*[I].

This same strategy leads one experience planter to advocate that people should:

> *"… plant them as close as you can afford to because grass, or whatever else invades the spaces, can be hard to release. When you pull weeds out from in between the oioi it damages the plant. In many situations it is far better to plant smaller dense areas rather than trying to cover a large area. That is just my approach to all planting - you are better off to get dense patches that are going to hold their own rather than widespread if you can afford to do it like that. You are just creating an environment where they are going to out compete any possible invasive weed and when you have a good established block that will spread faster than one plant on its own. It grows faster spreads faster"*[F].

Oioi are planted especially close in bioretention devices, in part for weed control but also to hasten closure of the stand to quickly stabilise soil against stormwater[O].

Some projects determined their spacing distance by spreading all the available plants evenly across the area to be restored[C]. Others sought to maximise the coverage area while leaving space for natural infilling. Planting closely in clumps that are then widely spaced is an intermediate strategy.

Planting in clumps is recommended by some restorers, in part to spread risk of failure over a wider area, in part to learn where exactly oioi will fit naturally in a local area, and ultimately to maximise the rate of colonisation of a wider landscape area. One team did field trials of different plant spacings at a series of elevations across the tidal zone to learn how to best proceed:

> *"We didn't have a clue, so we got those elevations surveyed, we ran some transects from mean sea level up to 1.4 m RL, well above the mean high water spring tide and then back down the other side on a estuarine margin. We just tried planting everything all the way up that transect to determine what would survive. Clumps were planted at 330mm, 500 mm spacing, 1m, and 1.5 m spacing. We just looked at what died and what didn't die. Then we planted in the places where it looked like the same hydro period and elevation. We have ended up with about 4 – 5 stems per metre when we establish this stuff, so really quite dense. We put 25, 35, 45 in each clump and then moved on - it was a little bit variable"*[J].

Spacing clumps out to sample a broader span of habitat:

> *"It has varied between the sites that we have done but a common pattern would be you have a 3x3m patch, and then you might have 15 – 20 m gap, and then another 3x3 patch and 15-20 m gap. This allowed us to see which of the species did best, and then come back the next year with additional plants to try and boost the numbers of the species that looked like it was handling the habitat best"*[J].

One observer suggested that gaining establishment is the first crucial step. Bulking up and infilling by direct transfer/transplanting within the site can happen later[H].

Plant spacing is often closer in garden projects than in restoration of natural areas:

> *"In landscaping projects where they want it to look nice really quickly, planters might put 3 per square meter because they just want it to hurry up and grow. But out in a restoration project I don't think you really need to do that. It would be a little bit of an overkill really"*[I].

In most urban settings plants are placed 500- 700 mm apart, which is a reasonably consistent practice when planting most grasses for horticultural needs[K]. When planting into a garden setting the goal is to cover the ground without natural recruitment, but also to avoid 'overplanting' which could encourage pests and diseases and will waste money[K]. Very close spacing (200 mm) is used in garden settings where a hedge effect is wanted[C].

6.5 Planting techniques

Oioi plants from nurseries are commonly planted out when relatively well grown with a strong root mass, in bags of at least PB3 size[F]. If planted in small containers they often needed cutting out and loosening of the rhizomes. They are usually 25 to 50 cm tall (Table 2).

None of those planting oioi into natural ecosystems irrigate to help plant establishment.

> *"There is plenty of rain water for 6-7 months of the year, but summer and autumn months can be very dry; we don't irrigate anything so we plant only when the autumn to winter rain has broken any drought"*[E].

Seven oioi were planted in loose sediment where they were regularly covered by tidal flows of Te Hakapupu's South Arm in autumn 2022[R]. This was intended as a preliminary trial to see if planting beyond the glasswort beds flanking the estuary might succeed. The oioi turned brown and grey, and shoots became brittle within the first year. However small green shoots were visible by November and the plants remain intact[R]. We do not yet know if they will survive and eventually prosper[120], but the initial signals led to a hypothesis that an initial salt shock challenges the plant's physiology and curiosity about whether some preconditioning of plants in benign nursery conditions might enhance growth and survival when they are first planted out into challenging estuary conditions. Accordingly our Questionnaire and interviews (Appendix 2) explored whether such preconditioning might be helpful.

None of our featured projects report seasoning of plants with salt irrigation or similar though sometimes they noted a two to three year lag while the new plants 'settled in' when planted in estuaries, before growing strongly. The plants' top dies and goes brown, but the roots keep going and eventually send new shoots up. This same slow start immediately after planting does not happen in freshwater or garden planting situations[F].

Some participants thought that trials to test for salt shock and ways to prepare the plants would be very valuable. Irrigation with salt water was one suggested option; blending beach sand with the

potting mix another[F,G]. One expert was sceptical that immersing in brine would be a good idea and suggested using a seaweed fertiliser or bath with nutrients instead of brine:

> *"I would not really recommend watering them with salt to harden them up. I would think more along the lines of using a seaweed fertilizer that has a mineral content they might be coming into contact with – you know in their natural areas they have seagrass and seaweed there all the time, so you might want to consider doing a seaweed or even a fish fertilizer or a mixture of the two. And you might precondition them and then obviously they are getting a nutrient as well as just a bit of salt. We do use fertilizers such as seaweed and fish fertilizer regularly in the nursery and never seen any of that yellowing displayed when we have planted them out"[I].*

Fertiliser tablets are placed under the root mass at planting by some teams[L], but others consider this a waste of money and effort in saltmarsh conditions[F].

> *"We dig to a spade's depth, put slow-release fertiliser into each planting hole and plant at that depth. We need the gluggy mud to hold them in place when the tide does come over their bases" [E].*

Mulching new plantings with seaweed at estuary margins was suggested by one contributor[F] though we did not hear of anyone trying it.

Oioi were planted "in summer conditions" around a pond in Southland to "reduce stress"[H].

Plant protectors are used to prevent browsing by rabbits and hares[L] and help with weed management, partly by protecting them from sprays and partly by encouraging an upright growth form.

> *"We find that the plants have to be caged with a stake marking their location. The cage assists by forcing the leaves and seedheads to grow upwards rather than being buried under the exotic grasses. The stake marks the location even when long grass has grown completely up the side of the cage" [M].*

7. Plant survival and spread

Restoration teams experience variable survival rates of oioi (Table 2):

> *"I reckon anything over about 80% survival is pretty good. But I think restoration ecology especially in places like that can be pretty hit and miss, even if you try and get the elevations and stuff like that right. You do have to be ready for the 0% survival scenario sometimes, and sometimes you get really lucky and everything survives"[J].*

> *"There is an excellent survival rate. On visual inspection, no losses, i.e. we don't need to replant or patch-plant. In their first year some oioi are nibbled by rabbits and hares (we've seen both), but there is no long term ill effect"[E].*

Plant growth, reproduction and spread are useful indicators of plant health and prospects for successful restoration.

> *"Each plant spreads itself by rhizome and the earlier ones are now forming a total canopy at about 1.2m in height and 1.5 metres wide. We haven't noticed any seedling oioi, but we have amazing production of flowers on both male and female plants, and seeds on the females"[E].*

However some planters emphasis that growth and spread can be quite slow for 2-3 years before the transplants appear to settle and start spreading, so initial disappointment may be misleading[L].

The relative role of sexual and asexual reproduction by oioi in natural habitats is unknown.

> *"There is probably a mixture of both, but definitely the vegetative is a lot faster at a local patch. The seeds take quite some time to find their way down to the ground and then you may not even notice the new ones sprouting up because it is all just growing in one giant*

> *patch. So it is a little bit hard to gauge, but just judging on how slow the seeds can take to sprout in a seed tray, I would say vegetative would usually over take the seed dispersal"*[I].

Detecting establishment of whole new patches at considerable distance from its nearest neighbour would be the main sign of sexual reproduction and seed dispersal, but this requires monitoring over decades. There has been no sign of spread to the other side of a small pond in Southland where the sparsity of planting is ideally suited to detect spread via seeds, but there has been some lateral spread of rhizomes that send up new shoots in the vicinity of planted clumps[H]. However rapid and extensive spread of oioi within Hoopers Inlet (near Dunedin) has occurred over the past decade, probably faster than could be explained simply by lateral spread of rhizomes[G]. Some new clumps are appearing more than a meter from the nearest established oioi clumps.

None of the restoration teams designed strategies to plant oioi in strategic positions to encourage spread via seed dispersal on water currents – rather, they targeted microhabitats suitable for establishment and lateral spread by vegetative means.

Within Auckland urban applications, spacing initial planting between 500 and 700mm normally results in sward closure by lateral vegetative spread of oioi within 2-3 years[K]. Occasional wider spacing of 1000mm is deployed which takes over 5 years to close. The plants send out lateral rhizomes that then come up within about 100mm from the edge of the parent plant[K]. Rates of spread are much slower in estuarine and wild settings – way less than 1m per year is common[G], but up to 2m is observed in favourable sites of Bay of Plenty[J] (Table 2). On Waiheke Island each oioi spreads to fill out about a square metre in two years[I].

One environmental manager refers to oioi as "*easy, fail-proof plant*" when planted in urban settings[K]. They are mainly planted in Autumn and Winter – establishment success declines after September. Except where some human error has occurred[121], survival is >95%.

8. Monitoring success and failure

Apart from one example of water quality measurements, we did not hear of any formal monitoring programmes to quantify the ecosystem health gains from the oioi restoration projects. Success or failure is therefore mainly based on qualitative and rapid assessments:

> *"I don't monitor. But it is just fantastic to go back 2 or 3 years after you have done something and see the "intactness". If you look over it from more than 20 m away and you don't see mud or ground between the plants, then there is a good chance that your restored area will persist"*[J].

One team considers that increased bird life and water quality are the principal indicators of success:

> *"One thing I do pay close attention to is birdlife – I am a member of Forest and Bird and enjoy keeping a look out for things. If you are doing a restoration of a wetland area or estuary if you get increase in bird numbers and nesting birds, then you have been successful. And obviously water quality - you would be testing the water quality and if the water quality goes up significantly in a short period of time - a couple of years - then I would say that is working. One of our projects –community project - recently did some water testing after just 2 years of us planting an upper valley wetland area with Carex grass and also lower down with the oioi. They found that the water was just so much cleaner"*[I].

In the Bay of Plenty, bittern and banded rail have already been sighted in recently recreated oioi habitat[J].

It is expected that saltmarsh recreation will enhance mahinga kai values for Māori. However there are no recorded cases of using cultural health indices to direct restoration of saltmarshes with oioi, nor follow-up cultural monitoring to see if it delivers expected benefits.

The success of the programmes is more simply assessed from the survival, growth and spread of the oioi plants themselves. Of these, plant survival is the most important and fundamental indicator. One expert considers oioi to be very hardy:

> *"It is pretty hard to kill, so if it died, you are definitely doing something wrong"*[I].

We found some informal reports of monitoring establishment rate soon after planting[122], but no long-term formal quantitative monitoring of plant survival and ecosystem responses to oioi restoration.

Targets for eventual survival and spread varied widely. One manager's targeted optimum survival is 80% or more[G], whereas others expect over 90% e.g.

> *"I do expect survival to be almost 100%. If you lost a few it might be from pūkeko pulling them out or something like that. If you plant them in the right area, basically they should all survive. I would be aiming for 100% success and if you got 90% -then you are getting there"*[I].

Expected rate of spread also varied from infilling plants spaced between 0.5 and 1 m apart in anything from 1 to 5 years (Table 2). e.g.

> *"At times they are quite slow growers, but if you can get an individual plant to fill out a square metre in a year then they should be happy"*[I].

Discolouration is another indicator of plant health. Oioi turn yellow and brown when they dry out[I].

> *"Browning can be seasonal as well. They replace themselves a little bit like most plants, but if they are going very very brown and they are losing their green foliage – then something is wrong -usually it is too dry, but they can usually survive that"*[I].

9. Maintenance challenges

Herbaceous weed suppression is considered the most important maintenance challenge by many of the planting teams, especial in terrestrial sites to control grass and other weeds[D,E]. This is considered crucial in the Auckland area where kikuya grass will quickly smother them[A]. Bark mulch cannot be applied as a weed suppressant due to risk of tides washing it away. Kikuyu is naturally excluded in saline conditions[O].

> *"Our difficulty has been with all wetland sedges and grasses, that they need regular releasing if they are to survive. Only very competent experienced volunteers manage to distinguish them from the invading exotic grasses or other native grasses and sedge, and that is generally only when they are seeding. And of course you want to release them more often than only when they are seeding"* [M].

> *"We spray the annual planting area for the year several times to kill tall fescue, twitch and orache [before we plant the oioi]. We are therefore planting into bare ground. Sea meadow plants and new seedlings of the weeds then grow. Weeding becomes our work for most of the year. In one season, one orache plant can spread like an octopus, enveloping a metre-high oioi. Most years there's not enough frosted mornings to kill them off"*[E].

Oioi is susceptible to herbicides, including the most commonly used glyphosate and Triclopyr Triethylamine[123].

Once established, oioi can become dominant and naturally suppress weeds, so it is planted in built environments and around ponds because of this 'biocontrol' service. "*Once it is established it holds its own really well*"[F]. Its erect growth form may give it a competitive advantage in some situations:

> *"The pond margin was pretty weedy and oioi, being taller, is something that I thought could tolerate that and outgrow some of those grasses."*[H]

Woody species are also a problem in special circumstances where they compete for space and light with oioi. For example:

> *"Oioi is sometimes mass-planted for landscaping along roadsides into often compacted earthworked soils that are very wet in winter and concrete-hard in summer. In these plantings it is vulnerable to invasion and eventual shading displacement by large seeded native species (e.g. Coprosma robusta seems a common one)"*[O].

Natural succession of oioi in ephemeral wetlands within sand dune stacks (Section 4.2) presents a management choice – either new ephemeral wetlands may be created to support it's rare plants, or woody plants and perhaps oioi should be removed to maintain the remaining wetlands at its early stage of succession. No active interventions to trigger or block these natural succession processes have been recorded.

Maintenance of bioretention devices in urban areas require prescribed, regular maintenance to maintain their ecosystem functions [124], including: weed control and removing accumulated sediment to ensure inflows and overflows are clear; pruning surrounding trees when necessary to ensure adequate light levels to support groundcovers; mulching bare ground; and minimising herbicide use (Figure 7). Trimming of the oioi must be done carefully, never reducing the leaves below ~30 to 50% of full height. Such work is preferably done before the end of the spring growth phase to reduce risk of them drying out and avoid creating bare ground that could then be colonised by weeds[O]. Although some added costs are associated with establishing and maintaining bioretention devices, these are probably far outweighed by savings from avoiding financial and human wellbeing costs if we do not implement sustainable 'water sensitive urban design'[125].

Figure 7. Opportunities and challenges when growing oioi in urban stormwater and garden environments. *Top left & middle*: Oioi has been cut almost vertically and mainly along the edge, so that leaves do not flop onto the pavement but very little bare ground is exposed (reducing weed invasion) and survival is not impaired. The plants are sometimes topped high create a 'hedged' aesthetic and keep sight lines open[126]. *Top, right*: The landscaped edge to riparian planting at Orewa (North Auckland) does not need trimming; the side abutting the grass verge is maintained by mowing of grass and some spraying along the edge. *Bottom, left*: Severe cutting of this berm risks killing the oioi. *Bottom, right:* Heavily strimmed oioi in this Panmure (Auckland) raingarden eventually died.

10. General discussion

10.1 The value of restoring oioi

Our review underscores the value of oioi across a wide range of environmental and cultural 'ecosystem services' by mitigating climate change effects and filtering sediments and reducing runoff to waterways. Although not quantified or remarked upon in the literature, it is inescapable that this remarkable plant also provides economically important services. Demonstration of environmental best practice in New Zealand food and fibre production helps maintain market access and premium prices for New Zealand's exports[127]. Also the environmental remediation provided by oioi is relatively inexpensive in the longer run compared alternative ways of solving these problems because their sustained actions become locked into our 'natural capital'.

Restoring oioi and co-dependent species in some habitats is at first expensive and relatively tricky compared to other more well-known and tested restoration programmes like indigenous forest establishment. Oioi is slow to propagate, requires dense planting to avoid later weed infestation, spreads relatively slowly (apparently mainly by vegetative reproduction), and occupies a relatively narrow zone towards the top of the estuarine-terrestrial ecotone. It inhabits a wide range of freshwater and brackish ecotones and flourishes in gardens, but it can not compete effectively in some of these more fertile terrestrial and semi-aquatic sites in the establishment phases without active weed and pest management. There is a natural wish to accelerate restoration and reduce costs by hastening success and spreading actions as widely as possible in a given area, but too much haste can be counterproductive in some situations[128]. Oioi therefore remains a challenging and quite specialised plant for use in restoration projects.

There are still many unknowns when contemplating where and how best to plant it for fastest and most cost-effective results.

10.2 Knowledge gaps: a need for more research, monitoring & reporting

Wetlands, especially swamps and marshlands, are less well researched than terrestrial environments. Many contributors to this research expressed delight that a formal review and analysis of both the scientific literature and practical management experience was being prepared. One contributor pointed to a lack of descriptions of management options as one reason why restoration of estuaries, and wetland habitat more generally, lags that seen in forest ecosystems:

> *"Most of our restoration is forest – we have done it for a long time and we have got the techniques well honed and understood. Forests occur on private land and people want to restore them. Estuaries are often crown land, so individuals perhaps have not taken initiative. Over the last decade or so, lots of community groups have established to do restoration work that is nice for the wider community rather than being limited to working on their own properties. So I suppose the doors now open to be able to work on estuaries on crown or council land. I suppose the progress in conservation thinking means more work will be invested in estuaries and wetland restoration. This research helps develop a proven method and recipe to make it easier and maybe people go to the tried and true because they know they will get results then".*[H,129]

Excellent and practical descriptions of bioretention plantings in built environments are published (Table 1). However, with some notable exceptions[130], we found few formal, detailed and excellent written reports of oioi restoration planting into natural environments. Other short and more informal reports and the interviews and questionnaires testimony signal general intent and scale of restoration

work, but declaration of primary goals, monitoring protocols, measures of success, or even associated wider management plans are often not available[131]. The few monitoring reports are short term, often just after the initial intervention.

Lack of clear goal setting and monitoring occurs despite tools and strong environmental management strategies being available as models[132]. This mainly reflects the primary focus of many community-led restoration efforts which prefer to invest in practical action in their local patch rather than diverting energy to planning and reporting for others to learn from. For them a general understanding of importance of saltmarsh, wetlands and sand dunes[133] is enough incentive for their hard work. The dilemma is that without precise and measurable objectives and monitoring along the way, it is difficult to measure success and, if necessary, adjust restoration actions and investments. Commitment to monitoring and reporting must be long-term because the important changes and trends in ecosystem health may take decades to emerge.

Monitoring of ecosystem outcomes are particularly lacking – simple reporting of the number of oioi successfully established or of the area restored are simply measures of inputs, not the crucial outcomes that we hope will result. This makes it much harder to scale the relative investments needed in restoring saltmarshes and wetlands compared to other ecosystems.

10.3 Managing with uncertainty

Care is needed to not displace naturally occurring saltmarsh communities. We could find no examples of competitive displacement of other species by oioi except in sand dune systems where natural succession potentially threatens displacement of rare plants. However, one contributor warned:

> *"I think there is the risk that if you plant into an established saltmarsh community oioi will take over"[H].*

He urges consideration of trying to recreate a natural sequence and ecotone between the marine and terrestrial ends of the sere.

Low and small herbaceous species are occasional eliminated by the dense planting of oioi in urban gardens and swales[K].

Unless unexpected and unwanted outcomes, failures, and successes are quantified and reported, the restoration community risks wasting resources and delay in environmental remediation. Nevertheless, there was strong alignment between managers' experience, loosely quantified observations, local knowledge reported in questionnaires, interviews and email correspondence with limited formal research conclusions available in the written record.

The adaptive management ("learning by doing")[134] approaches demonstrated by many of the oioi restoration teams, helps ensure a match of species selections to local conditions and helps fill the gap left by lack of research. Many of our contributors identified the unknowns and encountering surprise outcomes, so there is a need to 'manage with uncertainty' and adapt by trial and error. For example one manager stated:

> *"We usually don't fully mass plant oioi. Instead we usually do dense clumps of oioi and searush and a couple of other things, and then we go back the next year to see what has worked. If we need to, we will push a bit more in to try and establish it. Each site can be quite different and you may think this is the perfect site for oioi and then you come back and it is*

> *reverting to bachelors buttons - all by itself and it doesn't really want to move on from that! It throws you some curve balls"*[J].

Learning goes much quicker if some educated guesses and risks are embraced. One participant urges us to "*Be bold. Right from the beginning try oioi and other species at different sites*"[G].

Gradual escalation of planting in a new area, especially when coupled with deliberate management experiments, minimises risk of mistakes yet allows immediate action while learning.

10.4 Accelerating restoration of oioi: prospects for the future?

The bioretention devices in Auckland and Christchurch have demonstrated the value of oioi in managing stormwater and pollution within built environments. Oioi also promote personal safety by separating vehicle traffic from cycling and pedestrians with a frangible, attractive 'green' zone. They have much lower maintenance requirements compared to mown grass, do not impede sight lines, and meet CiPTED requirements within urban design. Oioi also contributes significantly to people's enjoyment and understanding of urban nature. Recognition of these benefits in public spaces and by urban authorities could now be leveraged to encourage more planting of oioi on private land. There is scope to encourage a next generation of bioretention devices to be deployed in suitable parts of the gardens within the sunnier areas of small private sections that are now becoming more prevalent. Selection of rain chains, planter boxes with oioi, and oioi within tree pits can 'disconnect' downpipes to slow and filter stormwater flow. Smart arrangements of permeable and hard paving in urban areas help cool surface, and reduce risk of flooding that will become more frequent and severe with climate change.

More research could potentially accelerate wider uptake of oioi planting for ecosystem and human health improvements. A potential role of reducing air pollution from roads has not been formally investigated but is a likely prospect judging from its other filtering functions. We could find no information on oioi evapotranspiration rates. We expect low transpiration due to density, even height, (i.e. creating a deep boundary layer) and the leaves' waxy cuticle. Investigation of safe herbicide applications to facilitate weed management would be of considerable practical benefit. Improved design and tests of low-impact Chenier sills could help establishment of oioi in more disturbed intertidal zones. More investigation of transfer of mats of well-grown oioi, rather than planting individual seedlings, could reveal a faster establishment and spread strategy, especially in marginal habitats.

Maintaining the supply of nursery-reared oioi is one potential barrier to accelerating restoration because some eco-nurseries are struggling financially and have recently closed down:

> "*I have been working here since I was a teenager and I am 41 now and I feel like in the last 20 years a lot of specially eco nurseries have closed down because they could not pass them on or couldn't pay their bills – maybe a few new initiatives are starting up which are great to replace them but a lot of them in the last 15 years have had to close down. People are getting older and not finding others to take business over and costs have gone up exponentially – labour, fertilizer, potting mix, rent access to water all cost more*"[I].

There is need for increased advocacy for retaining and restoring natural wetlands in general. Relatively few members of the public are aware of the important roles wetlands like ponds, saltmarshes and

estuaries play in regulating our natural environments[F,G]. However, there is an increasing number of teams talking and asking about options to restore saltmarsh in New Zealand, in part following excellent examples from South Australia[J]. Strong NGO wetland and coastal advocacy groups are building awareness and networking efficiently to share their concerns and resources for restoration work.

We hope that this review of current knowledge for just one of the important endemic saltmarsh and wetland species helps spur collective effort to reinstate the natural processes that create and protect habitat, cleanse water, and regulate ecosystems and cycles in both built and natural environments.

11. Recommendations

Our review and testimony from environmental restoration practitioners identified the following key recommendations:

1. Accelerate wetland and saltmarsh restoration – they remain severely depleted and degraded habitats that provide a broad suite of ecosystem services which have become increasingly important in view of ongoing industrialisation, intensive farming and forestry, pollution, urbanisation and climate change.
2. Instigate more Māori-led saltmarsh and wetland restoration initiatives, including mātauranga and cultural health assessments to target investments, choose restoration methods, and monitor success.
3. Consider planting oioi, along with companion species, in estuarine and wetland fringes that are protected from strong currents and not flooded for prolonged periods.
4. Choose hollows or sites with freshwater flows or seepages if present – survival of oioi is more assured there.
5. In saline habitats, plant oioi just above the elevations that are regularly inundated by tide and therefore develop hyper-saline soils. These higher-level 'bridgehead' colonies can then spread down the ecotone to find their natural limit of penetration into local saline conditions.
6. Plan and monitor for weed control, especially in oioi establishment phases.
7. Exclude cattle and sheep and control rabbit and hares to limit browsing damage.
8. Encourage more formal research of saltmarsh and wetland habitats in general.
9. Advocate and educate to encourage more planting and city planning for bioretention in urban environments, including private gardens. Support by quantifying water retention, surface roughness, and air quality mitigation parameters
10. Incorporate structured adaptive management ('learning by doing') to test and hone wetland management options. Maximise learning by bet hedging strategies which test extreme options as well as following educated guesses of the most successful restoration strategies.
11. Institute more formal monitoring and report successes and failures.
12. Extend monitoring from just measuring plant survival and growth to test broader ecosystem health improvement outcomes.
13. Maintain monitoring for long periods to detect landscape and catchment level changes that are occurring naturally or are triggered by restoration interventions.

Acknowledgements

This report was draft by Angelina Young, Henrik Moller and Fiona Stirling on behalf of the Kāti Huirapa Runaka ki Puketeraki and the Tūmai Beach Restoration Trust. Fiona Stirling transcribed the interviews. The other co-authors provided valuable information in interviews and/or questionnaire returns, and peer reviewed a draft of the report.

Additional information and resources were provided by: James Holloway (Pukerau Nursery); National Wetlands Trust; Tim Park & Lyneke Onderwater (Coastal Restoration Trust); Monica Peters (People+Science); Gretchen Brownstein, Bev Clarkson, Paula Godfrey, Peter Johnson (Manaaki Whenua Landcare Research); Micheline Newton and Barbara Wheeler (Auckland Botanic Gardens); Sam Thomas (Otago Regional Council); and Robert Guyton (Riverton Estuary Care Society); and Andrew Jinks (Porirua Council Nursery).

We thank Salt Ecology, The Royal Society of New Zealand, *Phytocoenologia*, NIWA, Ministry for Primary Industries, Auckland Botanical Gardens, and Nelson City Council for permission to reprint Figures 2-6. Photographs in Figure 1 were by Henrik Moller, and in Figure 7 by Robyn Simcock.

This research was mainly funded by the Ministry for Environment through the Toitū Te Hakapupu Project which is directed by the Otago Regional Council and Kāti Huirapa Runaka ki Puketeraki. That project is managed by Melanie White (Otago Regional Council).

References

Andrew, R., Vesely, E.T. (2008). Life-cycle energy and CO2 analysis of stormwater treatment devices. *Water Science and Technology* 58(5): 985-993.

Anon. (n.d.) Thatching in Australia, New Zealand & the Islands of the Pacific. The craft in Australasia, Melanesia, Micronesia & Polynesia; until c1930. Accessed 2023, from https://thatchinginfo.com/thatching-australia-new-zealand-oceania/.

Anon (2021). OIOI **Jointed Wire Rush *Apodasmia similis*. Taranaki Educational Resource Research, Analysis and Information. Accessed by Carol Fielding, 2021.

Auckland Botanic Gardens (2023). Searching for an upright oioi. Oioi for water sensitive design. 2023, from https://www.aucklandbotanicgardens.co.nz/whats-on/news/searching-for-an-upright-oioi/.

Auckland Transport (2021). *Bioretention planting guide. Right plant. Right place. Right maintenance.* Auckland Transport: 36 pp.

Beauchamp, A. (2015). Banded rail (*Gallirallus philippensis*) occupancy and detection in saltmarsh mangrove systems at Onerahi, Whangarei Harbour. *Notornis* 62: 14-20.

Bergin, D. O. (1994). Performance of transplanted indigenous salt marsh species, Maketu estuary. *Conservation Advisory Science Notes*: 16p.

Bishop, C., Landers, T. J. (2019). *Climate change risk assessment for terrestrial species and ecosystems in the Auckland region*, Auckland Council.

Blakely, J. (2020). *Access and impact: The spatial effects of off-road vehicles on a saltmarsh wetland in Canterbury, New Zealand*: Master of Landscape Architecture Thesis, Lincoln University.

Bodley, E. (2017). Auckland Botanic Gardens: A hub for plant conservation. *Australasian Plant Conservation: Journal of the Australian Network for Plant Conservation* 26(2): 3-5.

Bodley, E., Simcock, R., Stanley ,R. (2022). Plant evaluations for living roofs in Auckland, New Zealand. *Sibbaldia: the International Journal of Botanic Garden Horticulture*(21): 57-74.

Briggs, B. G. (2001). The restiads invade the north: the diaspora of the Restionaceae. *Faunal and floral migrations and evolution in SE Asia–Australasia. Balkema, Lisse, The Netherlands*: 237-241.

Briggs, B. G., Marchant, A.D., Perkins, A.J., Seberg, O., Petersen, G. (2010). Phylogeny and features in Restionaceae, Centrolepidaceae and Anarthriaceae (the restiid clade of Poales). *Diversity, phylogeny, and evolution in the monocotyledons:* 357-388.

Burrows, C. J. (2008). Genus *Pimelea* (Thymelaeaceae) in New Zealand 1. The taxonomic treatment of

seven endemic, glabrous-leaved species. *New Zealand Journal of Botany* 46(2): 127-176.

Burrows, C. J. (2009). Genus *Pimelea* (Thymelaeaceae) in New Zealand 3. The taxonomic treatment of six endemic hairy-leaved species. *New Zealand Journal of Botany* 47(3): 325-354.

Cartman, J. (2012). Christchurch City Council Nursery Seed Collection and Processing. *Proceedings of the International Plant Propagators Society-2012 1014:* 31-32.

Champion, P. D. Reeves, P. (2008). Factors causing dune ephemeral wetlands to be vulnerable to weed invasion. *DOC Research & Development Series* 310. 9 pp.

Chapman, V. J. (1974). *Salt marshes and salt deserts of the world.* Germany, Cramer.

Chapman, V. J., Ronaldson, J. W. (1958). The mangrove and saltmarsh flats of Auckland Isthmus. *New Zealand Department of Science and Industrial Research Bulletin*. Wellington. 125: 80 p.

CitSciHub. (2023). *Apodasmia similis* (Jointed Wire Rush) Native. Retrieved 2023, from https://www.citscihub.nz/Phil_Bendle_Collection:Apodasmia_similis_(Jointed_Wire_Rush)_Native#:~:text=Binomial%20name%3A%20Apodasmia%20similis%20Synonym%3A%20Leptocarpus%20similis%20Common,the%20leaves%20and%20is%20endemic%20to%20New%20Zealand

Clarke, L. D.; Hannon, N. J. (1967). The mangrove and salt marsh communities of the Sydney district, I. Vegetation, soils and climate. *Journal of Ecology* 55: 753-771.

Clarke, L. D.; Hannon, N. J. (1971). The mangrove and saltmarsh communities of the Sydney district, IV. The significance of species interaction. *Journal of Ecology* 59: 535-553.

Clarkson, B., Peters, M. (2010). *Wetland Restoration: A Handbook for NZ Freshwater Systems*., Manaaki Whenua Press.

Clarkson, B. R., Schipper, L. A., Clarkson, B. D. (2004). Vegetation and peat characteristics of restiad bogs on Chatham Island (Rekohu), New Zealand. *New Zealand Journal of Botany* 42(2): 293-312.

Clarkson, B. R., Sorrell, B. K., Reeves, P. N. Champion, P. D., Partridge, T. R., Clarkson, B. D. (2003). Handbook for monitoring wetland condition. *Coordinated monitoring of New Zealand wetlands.* A Ministry for the Environment SMF funded project. Ministry for the Environment, Wellington.

Cromarty, P.; Scott, D.A. (eds). (1995). *A directory of wetlands in New Zealand*. Department of Conservation, Wellington, New Zealand

Davie-Martin, R. (2015). Wastewater for resilient 21st century cities. Thesis, Master in Landscape Architecture, Unitec Institute of Technology.

Davis, A.; Bellingham, M. (1984). *Hokianga Harbour Wildlife survey*. Wellington: Unpublished report of the New Zealand Wildlife Service, Department of Internal Affairs. 127 pp and appendices.

Denyer, K., Robertson, H. (2016). *National guidelines for the assessment of potential Ramsar wetlands in New Zealand*. Department of Conservation, Wellington. 58 p.

de Lange, W. P., de Lange P. J., Moon, V.G. (2006). Boulder transport by waterspouts: an example from Aorangi Island, New Zealand. *Marine Geology* 230(1-2): 115-125.

Deng, Y., Ogden, J., Horrocks, M., Anderson, S. (2006). Application of palynology to describe vegetation succession in estuarine wetlands on Great Barrier Island, northern New Zealand. *Journal of Vegetation Science* 17(6): 765-782.

Denyer, K., Peters, M. (2012). WETMAK: *Wetland Monitoring and Assessment Kit*, NZ Landcare Trust.

Doody, J. P. (2012). *Sand dune conservation, management and restoration*, Springer Science & Business Media.

Dunedin City Council (2008). [*Tūmai resource consent decision*] SUB-2007-252 & LUC 2007-708 / 5044599 / 222134, 222135 & 252885.

Edgar, E. (1968). The New Zealand species of *Leptocarpus* (Restionaceae). *New Zealand Journal of Botany* 6(4): 467-469.

Elliott, G. (1987). Habitat use by the Banded Rail. *New Zealand Journal of Ecology* 10: 109-115.

Esler, A. (1991). Changes of native plant cover of urban Auckland. *New Zealand Journal of Botany* 29: 177-196.

Fielding, C. (2022). *Planting for Biodiversity at Kopu Bridge near Thames*. Kopu Bridge Wetlands Care Group: 3 pp.

Frances, H. (2014). At the confluence: heritage, landscape and the construction of belonging. Thesis, Master in Landscape Architecture, Unitec Institute of Technology.

Freeman, C. (2023). *Banking with Banks Peninsula: a seed bank strategy for the wider Christchurch area*. MSC Thesis, University of Canterbury. 153 pp.

Gear, H., T. R. Glare and M. Callaghan (2014). Maintaining environmental integrity in invasion areas. *Mosquito Eradication: The Story of Killing campto*. B. Kay and R. Russell (Eds.). Collingwood, Victoria, CSIRO Publishing: 197.

Goodrich, J. P., Campbell, D. I., Schipper, L.A. (2017). Southern Hemisphere bog persists as a strong carbon sink during droughts. *Biogeosciences* 14(20): 4563-4576.

Griffiths, J. W., McAlpine, K.G. (2017). Aerial glyphosate application reduces grey willow (*Salix cinerea*) canopy cover, increases light availability, and stimulates kahikatea (*Dacrycarpus dacrydioides*) growth.

New Zealand Journal of Ecology 41(2): 234-239.

Haacks, M., Thannheiser, D. (2003). The salt-marsh vegetation of New Zealand. *Phytocoenologia* 33(2/3): 267-288.

Hackett, K., Winterbourn, M., Cook, T., Ball, O. (2020). First record of larvae of *Dasyhelea* (Diptera: Ceratopogonidae) in New Zealand. *The Wētā* 54: 47-55.

Handford, P., Denyer, K., Peters, M. (2018). *Auckland Community Ecological Monitoring Guide: A Framework for selecting monitoring methods*, Groundtruth Ltd.

Handley, S. (2022). Technical options for marine coastal habitat restoration in Te Tauihu. *NIWA Client Report*. Nelson, NIWA. No: 2022170NE: 127.

Harmsworth, G. (n.d.) 1. Māori values-concepts and perspectives. Available Online at: https://oldwww.landcareresearch.co.nz/__data/assets/pdf_file/0004/135085/Poster-1-maori-values.pdf

Heenan, P., de Lange, P. (2005). *Cyperus insularis* (Cyperaceae), a new species of sedge from northern New Zealand. *New Zealand Journal of Botany* 43(1): 351-359.

Heenan, P., Mitchell, A., de Lange, P., Keeling, J., Paterson, A. (2010). Late-Cenozoic origin and diversification of Chatham Islands endemic plant species revealed by analyses of DNA sequence data. *New Zealand Journal of Botany* 48(2): 83-136.

Heritage New Zealand (2019). *Writing Archaeological Assessments* Archaeological Guidelines Series No. 2. I SBN 978-1-877563-36-2 (online). 14 pp.

Hoare, R. J., Hudson, N. (2018). Adventive moths (Lepidoptera) established in mainland New Zealand: additions and new identifications since 2001. *The Australian Entomologist* 45(3): 273-324.

Hobbs, J., Stanley, R. (2014). Garden Profile: Auckland Botanic Gardens. *Sibbaldia: the International Journal of Botanic Garden Horticulture* (12): 11-24.

Hope, L. (2012). Collection and Cleaning of Seed in the Gisborne District, New Zealand. *Proceedings of the International Plant Propagators Society*-2012 1014: 71-72.

Hubbard, J. C. E., Partridge, T.R. (1981). Tidal immersion and the growth of Spartina anglica marshes in the Waihopai River Estuary, New Zealand. *New Zealand Journal of Botany* 19(1): 115-121.

Ignatieva, M., Meurk, C., Stewart, G.H. (2008a). Low Impact Urban Design and Development (LIUDD): matching urban design and urban ecology. *Landscape Review* 12: 61-73.

Ignatieva, M., Meurk, C., Van Roon, M., Simcock, R., Stewart, G.H. (2008b). How to put nature into our neighbourhoods: application of Low Impact Urban Design and Development (LIUDD) principles, with a biodiversity focus, for New Zealand developers and homeowners. *Landcare Research Science*

series no. 35). Manaaki Whenua Press, 2008. ISBN: 978-0-478-09397-1

Ira, S., Simcock, R. (2019). *Understanding Costs and Maintenance of WSUD in New Zealand. Activating WSUD for Healthy Resilient Communities*: 69.

Johnson, P. N. (1991). Kaikorai Estuary Revegetation Trial: Progress Report. *DSIR Land Resources Scientific Report* 5.

Johnson P.N. (1992). The sand dune and beach vegetation inventory of New Zealand II. South Island and Stewart Island. *DSIR Land Resources Scientific Report* Number 16. DSIR Land Resources, Christchurch.

Johnson, P., Rogers, G. (2003). Ephemeral wetlands and their turfs in New Zealand. *Science for Conservation* 230: 1-109.

Küchly, H., Hartley, S. (2006). *Monitoring Coastal Sand Dune Vegetation Communities for Conservation.* Victoria University of Wellington. 86 pp. Online at: https://ref.coastalrestorationtrust.org.nz/documents/monitoring-coastal-sand-dune-vegetation-communities-for-conservation/

Lewis, M., Simcock, R., Davidson, G., Bull, L. (2010). Landscape and Ecology Values within Stormwater Management. Prepared by Boffa Miskell for Auckland Regional Council. *Auckland Regional Council Technical Report* TR2009/083

McGlone, M. S., McNutt, K., Richardson, S. J., Bellingham, P. J., Wright, E.F. (2020). Biodiversity monitoring, ecological integrity, and the design of the New Zealand Biodiversity Assessment Framework. *New Zealand Journal of Ecology* 44(2).

Ministry of Justice (2005). *National Guidelines for Crime Prevention through Environmental Design in New Zealand. Part 1: Seven Qualities of Safer Places*: 40.

Moller, H., Stirling, F., Young, A., Garden, C., McWilliam, A., McWilliam, S., Kinaston, R., Johnson, G. (2023). Oioi (jointed wire rush) planting experiments at Te Hakapupu. Experimental rationales and designs. *Tūmai Beach Community Report* No. 2023/02. 22 + iv pages.

Morrison, M. (2021). Hauraki Gulf Marine Park habitat restoration potential, Ministry for Primary Industries. *New Zealand Aquatic Environment and Biodiversity Report* No. 265. Fisheries New Zealand, Wellington. 132pp. ISSN 1179-6480 (online).

Morrison, M., Jones, E. G. , Consalvey, M., Berkenbusch, K. (2014). *Linking marine fisheries species to biogenic habitats in New Zealand: a review and synthesis of knowledge*, Ministry for Primary Industries Wellington.

Murphy, A. L., Singers, N.J., Rapson G.L. (2019). Created dune slack wetlands effectively host rare early successional turf communities in a dynamic dunefield, New Zealand. *Journal of Coastal Conservation*

23: 203-225.

O'Donnell, C. F. J. (2011). Breeding of the Australasian bittern (*Botaurus poiciloptilus*) in New Zealand. *Emu* 111: 197-201.

Ogden, J. (2010). Wetland processes and data storage, with particular reference to Great Barrier Island. *Auckland Botanical Society Journal* 65: 85-92.

Ogle, C. C. (2008). Vegetation and threatened and adventive plants of the Wanganui sand country. *Proceedings of the Dune Restoration Trust of New Zealand Annual Conference*, Wanganui Sailing Club 5-7 March 2008.

Orchard, S., Hickford, M.J. (2018). Census survey approach to quantifying īnanga spawning habitat for conservation and management. *New Zealand Journal of Marine and Freshwater Research* 52(2): 284-294.

Orchard, S., Schiel, D.R. (2020). Nature-based solutions for climate change on a peri-urban sandspit. *Resilient Shorelines*: 61.

Orchard, S., Schiel, D.R. (2021). Enabling nature-based solutions for climate change on a peri-urban sandspit in Christchurch, New Zealand. *Regional Environmental Change* 21(3): 66.

Otago Regional Council (1992). *Waikouaiti River Catchment. Resource Inventory*. Unpublished report, Otago Regional Council.

Otago Regional Council (2005). *Environmental Considerations for Clean Streams, A guide to managing waterways in Otago*, Otago Regional Council, Dunedin, New Zealand.

Parrish, G.R. (1985). Whangarei Harbour wildlife survey. *New Zealand Wildlife Service Technical Report* No. 8. 68 p.

Parrish, G. R., I. A. Stringer and G. H. Sherley (2014). The biology of *Placostylus ambagiosus* (Pulmonata: Bulimulidae) in New Zealand: Part 1. Behaviour, habitat use, abundance, site fidelity, homing and the dimensions of eggs and snails. *Molluscan Research* 34(3): 139-154.

Partridge, T. R. Wilson, J.B. (1988a). The use of field transplants in determining environmental tolerance in salt marshes of Otago, New Zealand. *New Zealand Journal of Botany* 26(2): 183-192.

Partridge, T. R., Wilson, J.B. (1988b). Vegetation patterns in salt marshes of Otago, New Zealand. *New Zealand Journal of Botany* 26(4): 497-510.

Partridge, T. R., Wilson, J.B. (1989). Methods for investigating vegetation environment relations - a test using the salt-marsh vegetation of Otago, New Zealand. *New Zealand Journal of Botany* 27(1): 35-47.

Pegman, M., Rapson, G. (2005). Plant succession and dune dynamics on actively prograding dunes,

Whatipu Beach, northern New Zealand. *New Zealand Journal of Botany* 43(1): 223-244.

Prebble, M., Anderson, A.J., Augustinus, P., Emmitt, J., Fallon, S.J., Furey, L.L., Holdaway, S.J., Jorgensen, A., Ladefoged, T.N., Matthews, P.J. (2020). Reply to Barber: Marginal evidence for taro production in northern New Zealand between 1200 and 1500 CE. *Proceedings of the National Academy of Sciences* 117(3): 1259-1260.

Priestley, S. (2017). A large multi-functional bioretention device. *Water New Zealand's 2017 Stormwater Conference*: 7.

Rapson, G., Smith, A.R., Murphy, A.L. (2016). Sand-dune vegetation of the Foxtangi region, Manawatu coast, New Zealand. Unpublished report to Department of Conservation, New Zealand 43 pp.

Reason, A. (2023). Invasive paper wasp (*Polistes chinensis*) ecology and invertebrate conservation on Onetahua (Farewell Spit), MSc Thesis. Te Herenga Waka-Victoria University of Wellington.

Richardson, J., Taylor M.J. (2004). A guide to restoring inanga habitat. *NIWA Science and Technology Series* 50 Wellington, NIWA: 31.

Roberts, C. D., Stewart, A.L. (2022). The first record of Australian flatback mangrove goby *Mugilogobius platynotus* (Günther 1861) (Gobiidae; Tridentigerinae) from New Zealand. *New Zealand Journal of Marine and Freshwater Research* 1-15.

Roxburgh, S. H., Wilson, J.B., Gitay, H., King, W.M. (1994). Dune slack vegetation in southern New Zealand. *New Zealand Journal of Ecology* 18(1): 51-64.

Saintilan, N., Rogers, K., McKee, K.L. (2019). The shifting saltmarsh-mangrove ecotone in Australasia and the Americas. *Coastal wetlands*, Elsevier: 915-945.

Short, J. E. (2022). The changing water quality of New Zealand's lakes in response to anthropogenic activities. PhD Thesis, University of Adelaide.

Stevens, L. M. (2021). A summary of salt marsh restoration, Waikawa Estuary, Marlborough. *Salt Ecology Report* 081: 14pp. Salt Ecology, Nelson.

Stevens, L. M., Roberts, K.L. (2021). Waimeha/Waimea Inlet Estuary Restoration, Orchard Stream Mouth: Restoration Options, Plant Schedule, Restoration Guidance. *Salt Ecology Report* 078: 19 pp. Salt Ecology, Nelson.

Suren, A. M., Lambert, P., Image, K., Sorrell, B.K. (2008). Variation in wetland invertebrate communities in lowland acidic fens and swamps. *Freshwater Biology* 53(4): 727-744.

Tait, P., Saunders, C., Guenther, M., Rutherford, P. (2016). Emerging versus developed economy consumer willingness to pay for environmentally sustainable food production: A choice experiment approach comparing Indian, Chinese and United Kingdom lamb consumers. *Journal of Cleaner*

Production 124, 65–72 [online].

Tanner, C. C. (1992). A review of cattle grazing effects on lake margin vegetation with observations from Dune Lakes in Northland, New Zealand. *New Zealand Natural Sciences* 19(0): 1-14.

Thomsen, D., Marsden, I.D., Sparrow, A.D. (2005). A field experiment to assess the transplant success of salt marsh plants into tidal wetlands. *Wetlands Ecology and Management* 13(5): 489-497.

Thomsen, M. S., Adam, P., Silliman, B.R. (2009). Anthropogenic threats to Australasian coastal salt marshes. *Human Impacts on Salt Marshes: A Global Perspective*, edited by: Silliman, B. R., Grosholz, E.D., and Bertness, M.D. University of California Press, Berkley, CA, USA: 361-390.

Tolich, M., Davidson, C. (2011). *Getting started An Introduction to Research Methods*. Pearson, Australia. 222 + x pp. ISBN 978-1-4425-4736-0.

Townsend, M., Thrush, S. (2010). Ecosystem functioning, goods and services in the coastal environment. *Auckland Regional Council Technical Report*, Prepared by the National Institute of Water and Atmospheric Research for Auckland Regional Council. 2010/033.

Trowsdale, S. A., Simcock, R. (2011). Urban stormwater treatment using bioretention. *Journal of Hydrology* 397(3-4): 167-174.

Trowsdale, S., Simcock, R., Gabe, J., Vale, R. (2007). Integrated urban water balance of an eco-building. *Novatech 2007-6ème Conférence sur les techniques et stratégies durables pour la gestion des eaux urbaines par temps de pluie/Sixth International Conference on Sustainable Techniques and Strategies in Urban Water Management*, GRAIE, Lyon, France.

Tūmai Beach Environmental Enhancement Group (2021). Environmental Enhancement at Tūmai Beach. A restoration plan prepared by the Tūmai residents. *Tūmai Beach Community Report* No. 2021/01. 25 + v pages.

Urlich, S. C., Hodder-Swain, J.L. (2022). Untangling the Gordian knot: estuary survival under sea-level rise and catchment pollution requires a new policy and governance approach. *New Zealand Journal of Marine and Freshwater Research* 56(3): 312-332.

Vanky, K., McKenzie, E.H.C. (2002). Two new species of Ustilaginomycetes from New Zealand. *New Zealand Journal of Botany* 40(1): 117-121.

Waitaki District Council (2004) *Waitaki District Plan.* Oamaru. New Zealand.

Walker, A. K., Lariviere, M.C. (2014). Confirmation of host plant relationships between the two species of waka leafhoppers, Paracephaleus (Hemiptera: Cicadellidae: Ulopinae) and rushes in New Zealand. *The Wētā* 47: 12-16.

Walters, C. J., Holling, C.S. (1990). Large-Scale Management Experiments and Learning by Doing.

Ecology 71: 2060-2068.

Wardle, P. (1991). *Vegetation of New Zealand*. Cambridge University Press, 1991.

Whitehead J., Manhire J., Moller H., Barber A., Reid J., Benge J., MacLeod C., Collins K., Neumann M. (2018). *The New Zealand Sustainability Dashboard Synthesis Report*. (2019). Published by ARGOS. https://www.sustainablewellbeing.nz/nzsd.

Williams, E. M. (2018). Wairarapa Moana Bittern/Matuku Management Strategy DRAFT 29/06/18. Unpublished Report to Department of Conservation, Matuku Ecology Wildlife Monitoring Solutions, Christchurch.
https://ref.coastalrestorationtrust.org.nz/site/assets/files/8673/wairarapa_moana_bittern_management_plan_draft_-_doc-5529159.pdf

Wilson, J. B., Stubbs, W.J. (2012). Evidence for assembly rules: limiting similarity within a saltmarsh. *Journal of Ecology* 100(1): 210-221.

Appendix 1: Common names for plants and animals

Māori name(s)	English name(s)	Taxonomic name
Akeake		*Dodonaea viscosa*
Karo	Stiffleaf Cheesewood	*Pittosporum crassifolium*
Īnanga	Whitebait	*Galaxias maculatus*
Koitareke	Marsh crake	*Porzana pusilla affinis*
Mākaka	Saltmarsh ribbonwood	*Plagianthus divaricatus*
Manawa	NZ Mangrove	*Avicennia marina australasica*
Matuku	Bittern	*Botaurus poiciloptilus*
Moho pererū	Banded rail	*Gallirallus philippensis*
Ngaio	Mousehole Tree	*Myoporum laetum*
Oioi	Jointed wire rush	*Apodasmia similis, Leptocarpus similis*
Pōhutakawa	NZ Christmas Tree	*Metrosideros excelsa*
Pohuehue	Mattress vine	*Meuhlenbeckia complexa*
Pūkeko	Australasian swamp hen	*Porphyrio melanotus*
Toetoe		*Cortaderia richardii*
Raupō	Bulrush	*Typha orientalis*
	Asian paper wasp	*Polistes chinensis*
	Glasswort, Saltwort	*Salicorniaquinquefolia, Sarcocornia quinquefolia*
	kikuyu	*Cenchrus clandestinus*
	Lotus	
	Tufted hairgrass	*Deschampsia cespitosa*
	Sea rush	*Juncus maritimus, Juncus kraussii*
	Silver tussock	*Poa cita*
	Waka leafhoppers	*Paracephaleus curtus, Paracephaleus hudsoni*

Appendix 2: Questionnaire and interview guide

Tēnā koe

We would much appreciate your guidance on how to maximize survival and spread of oioi (jointed wire rush,) which we are about to plant in Te Hakapupu (Pleasant River Estuary) next month.

15 minutes of your time?

If you can spare us 20 minutes, could we please talk by telephone Zoom? If so, please email one of us to fix a time for a korero:

- Angelina: 021 0706466, "Angelina Young" <nursery@puketeraki.nz>
- Henrik: 027 2268688, henrik.moller@otago.ac.nz

If you prefer, you could insert notes against each of the following questions and email the file to us at henrik.moller@otago.ac.nz.

About you:

1. Your name?
2. Your affiliation and job?
3. Your email?
4. Your phone number?

Your work with oioi:

5. What experience have you had with planting oioi and monitoring their performance? e.g. Where? When?
6. What were your main reasons for planting oioi?
7. How many did you plant/transplant?

Preparation:

8. Did you plant or grow stems propagated in the nursery or did you transplant wild growing plants?
9. If you grew the oioi yourself, did you irrigate them with salt water before transplanting to help them cope with salt shock? If you did not season them beforehand, did they appear to suffer once you had planted them?
10. Roughly how tall and old were the oioi you planted/transplanted?

Layout guidelines:

11. We would like to hear about your general approach to where you planted oioi e.g. Depth and time immersed by the tide? Strength of tidal flow? Mix of fresh and salt water? Near the mouth or at the top of the estuary?
12. Did you plant in open sediment areas, or amongst other plants (e.g. Sarcocornea?
13. How widely spaced did you plant and what determined this?
14. If you were to plant oioi in future, what spacing would you advise as optimal?
15. Any other rules or guidelines?

Planting success:

16. How did you monitor success or otherwise of your mahi?
17. How was survival overall?
18. Have they spread out from where you planted/transplanted them? If so, how fast and far have they spread?
19. What was the vegetative method and pattern of spread?
20. Did the newly planted oioi displace other species in the estuary sediment?

Anything we missed?

21. Did any other issues or outcomes arise that surprised you, or that can't help the success of our own attempts to restore oioi at Te Hakapupu.
22. Would you attempt planting of oioi again, and if so, what would you do differently next time?

Follow up:

23. Are there any reports that we might read about your planting to learn from? We could only find one report on oioi planting success – if you know of reports prepared by other teams, please send us a reference or best of all, a copy.
24. Do you know of other people all projects in your area who have experience of planting oioi that we could talk to? If so, please provide an email or phone number so that we can contact them.
25. We would like to acknowledge your help in our report if you are comfortable to be named. But we can keep your input anonymous if you prefer. Are you happy to be named alongside the information you have provided here?
26. We are also happy to add you as coauthors on the report if you wish. If so, we will send you a draft version of the report for you to peer review. Do you want to be included as an author?
27. Would you like to receive a copy of our report next year?

Many thanks for sharing your knowledge and giving your time. We are very grateful.

Mauri ora!

Angelina young and Henrik Moller

20th October 2022.

Appendix 3: Study participants

Superscript	Participant	Affilation/Role/Location	Testimony
A	Derek Craig	Kaipatiki Project, Tāmaki/Eskdale	Questionnaire
B	Peter Johnson	Retired ecologist, Dunedin	Questionnaire
C	James & Maree Holloway	Pukerau Nursery (Propagators), Southland	Questionnaire
D	Leigh Stevens	Salt, Ecological Consultant, Nelson	Questionnaire
E	Carol Fielding	Kopu Bridge Wetlands Care Group	Questionnaire
F	Dylan King	For the Love of Trees, Landscaping company, Otago	Interview
G	Hendrik Koch	Restoration manager, Otago	Interview
H	Brian Rance	DoC Southland, Conservation Manager, Southland	Interview
I	Rahn Kitson	Waiheke Native Plants, Propagators, Waiheke Island	Interview
J	Pim de Monchy	Bay of Plenty Regional Council, Tauranga	Interview
K	Emma Simpkins	Auckland City Council, Auckland	Interview
L	Jane Lenting	Ōkorewa Lagoon, Wairarapa	Interview
M	Lala Fraser	Save The Otago Peninsula, Otago	Email
N	Jesse Bythell	QEII Representative, Southland	Email
O	Robyn Simcock	Manaaki Whenua, Landcare Research	Email
P	Jim Dahm	Eco Nomos Ltd., Ecological consultant	Email
Q	Angelina Young	Puketeraki Native Plant Nursery, Nursery Co-ordinator, Otago	In litt.
R	Fiona Stirling & Henrik Moller	Tūmai Beach Restoration Trust, Otago	In litt.
S	Andrew Jinks	Porirua Council Nursery	In litt.

Endnotes

[1] Otago Regional Council (1992, 2005); Clarkson et al. (2003); McGlone (2009); Morrison et al. (2014); Denyer and Robertson (2016).
[2] Haacks and Thannheiser (2003).
[3] Harmsworth (No date).
[4] Morrison et al. (2014).
[5] Parrish (1985); Cromarty and Scott (1995).
[6] Unpublished "Whangaroa Harbour Study (1985)", cited in Morrison et al. (2014).
[7] Haacks and Thannheiser (2003); Thomsen et al. (2009).
[8] Urlich and Hodder-Swain (2022).
[9] Māori, common and taxonomic names for plants and animals referenced in this report are listed in Appendix 1.
[10] Southern Hemisphere monocotyledons that include several similar families, such as the sedges, rushes, and grasses.
[11] CitSciHub (2023).
[12] Nomenclature following Edgar (1968).
[13] Dunedin City Council (2008).
[14] Tūmai Beach Environmental Enhancement Group (2021).
[15] Toitū Te Hakapupu is jointly led by Kāti Huirapa Runaka ki Puketeraki and Otago Regional Council (described here). It is funded by the Ministry for Environment.
[16] A companion report describes how the findings were used to establish a planting trial in South Arm of Te Hakapupu which will now be monitored over the next three years (Moller et al. 2023).
[17] Photo credits: a & g Henrik Moller; b, c Robyn Simcock; d, e, f Leigh Stevens.
[18] Briggs (2001); Briggs et al. (2010) highlight closely related species in Australia and Chile, but confirm the endemic status of *Apodasmia similis* to New Zealand. Heenan et al. (2010) note that a larger and potentially separate species of *Apodasmia* occurs on the Chatham Islands.
[19] Nevertheless, all the references have been collated into a bibliography which is available on request from henrik.moller@otago.ac.nz.
[20] Tolich and Davidson (2011).
[21] Roxburgh et al. (1994).
[22] Pegman and Rapson (2005).
[23] Pegman and Rapson (2005).
[24] Townsend and Thrush (2010); Johnson 1992; Johnson and Rogers (2003).
[25] Auckland Transport (2021).
[26] *Apodasmia similis* triggers the following known host plant associations in Manaaki Whenua Landcare Research's *PlantSy* database (https://plant-synz.landcareresearch.co.nz/). i.e. *Dysnocryptus inflatus* (Sharp, 1876) (Coleoptera: Anthribidae); *Megacraspedus sp. 2* (Patrick 1994) (Lepidoptera: Gelechiidae); *Microdes epicryptis* (Meyrick, 1887) (*Lepidoptera: Geometridae*); *Paracephaleus hudsoni* (Myers, 1923) (*Hemiptera: Cicadellidae*) - Sucking bug leaf hopper; *Poliaspoides leptocarpi* (Brittin, 1916) (*Hemiptera: Diaspididae*) - scale insect.
[27] Walker and Lariviere (2014).
[28] Hoare and Hudson (2018).
[29] Suren et al. (2008).
[30] Parrish et al. (2014).
[31] Short (2022).
[32] Vanky and McKenzie (2002).
[33] Richardson and Taylor (2004); Orchard and Hickford (2018).
[34] Roberts and Stewart (2022).
[35] Morrison et al. (2014).
[36] O'Donnell 2011; Williams (2018).
[37] Although oioi occurs in banded rail habitat, it provides little cover and hinders movement. Elliott (1987) hypothesised that banded rail are absent from southern South Island because oioi becomes more dominant in the saltmarshes in the south.
[38] Davis and Bellingham, M. 1984; Beauchamp (2015); Williams (2018); Anon (2021).
[39] O'Donnell (2011).
[40] Elliott (1987).
[41] Burrows (2008, 2009).
[42] Heenan and de Lange (2005).
[43] Haacks and Thannheiser (2003).

[44] Rapson et al. (2016). *Apodasmia similis* and *Schoenus nitens* dominate this wetland type, underlain by extensive *Myriophyllum votschii*. This community has the highest total cover, and total number and cover of native species (Table 3). It is the common wetland type at Tawhirihoe Scientific Reserve and has a range of native shrub species including *Pimelea villosa ssp. arenaria, Coprosma spp.,* and *Leptospermum scoparium*, though *Schedonurus phoenix* and *Arrhenatherum elatius* are very common.
[45] Deng et al. (2004).
[46] Trowsdale et al. (2007).
[47] Trowsdale and Simcock (2011).
[48] Davie-Martin (2015).
[49] Priestley (2017).
[50] Auckland Transport (2021).
[51] Ignatieva et al. (2008 a & b).
[52] Orchard and Schiel (2020, 2021).
[53] Andrew and Vesely (2008).
[54] "*They are certainly favoured in areas around septic systems. Some say there could be an issue with the fine roots invading drip fields, but in my experience it doesn't really happen that much. A lot of the time people use them in landscaping in dry bank areas on driplines for a septic system and they survive that pretty well if someone is living in the house*"[I].
[55] Clarkson et al. (2004); Clarkson 2005).
[56]Hubbard and Partridge (1981).
[57] Orchard and Schiel (2020, 2021).
[58] Goodrich et al. (2017). But note that this study focuses on bogs dominated by *Empodisma robustum,* another endemic restiad and refers to it as 'jointed wire rush'. *E. robustum* is usually referred to as 'wire rush' and *Apodasmia similis* as 'jointed wire rush'. The same general conclusion of important carbon sequestration for bogs dominated by *E. robustum* probably also applies to *A. similis*.
[59] Hobbs and Stanley (2014).
[60] Lewis et al. (2010); Frances (2014).
[61] Ministry of Justice (2005).
[62] Bodley et al. (2022).
[63] Anon. (n.d.) "Thatching in Australia, New Zealand & the Islands of the Pacific. The craft in Australasia, Melanesia, Micronesia & Polynesia; until c1930."Accessed 2023, from https://thatchinginfo.com/thatching-australia-new-zealand-oceania/.
[64] Haacks and Thannheiser (2003).
[65] McGlone et al. (2020).
[66] Esler (1991).
[67] Griffiths and McAlpine (2017).
[68] Deng et al. (2006); Ogden (2010).
[69] Champion and Reeves (2008).
[70] Ogle (2008).
[71] Bishop and Landers (2019); Saintilan et al. (2019).
[72] de Lange et al. (2006).
[73] Saintilan et al. (2019).
[74] Pegman and Rapson (2005).
[75] Murphy et al. (2019); Thomsen et al. (2005).
[76] Tanner (1992).
[77] Blakely (2020), Interviewee J.
[78] Gear et al. (2013); Hackett et al. (2020).
[79] Reason (2023).
[80] The adults feed on nectar and pollen (Hackett et al. 2020).
[81] Fine exceptions were Johnson (1991), Stevens (2021), Stevens and Roberts (2021).
[82] Stevens (2021).
[83] Handley (2022).
[84] 'Blue Carbon'refers to carbon captured in oceans and estuaries.
[85] Bodley (2017); Auckland Botanical Gardens (n.d.); Interview K.
[86] Clarke and Hannon (1967, 1971).
[87] Chapman (1974).
[88] Partridge and Wilson (1988a,b, 1989); Ogden (2010), citing Deng (2006); Wilson and Stubbs (2012).
[89] Partridge and Wilson (1989).
[90] Partridge and Wilson (1988a,b; 1989).
[91] Partridge and Wilson (1989).
[92] Partridge and Wilson (1988a).
[93] Roberts and Stewart (2022).

[94] Partridge and Wilson (1989).
[95] Stevens and Roberts (2021).
[96] Chapman (1974).
[97] Chapman and Ronaldson (1958).
[98] Partridge and Wilson (1989).
[99] Morrison (2021).
[100] Oio and glasswort have been observed to grow together at Whakanewha Regional Park[I] and Southland[H].
[101] "*Target the top quarter of tide extreme maybe – so that in terms of establishment that they are not flooded for extensive periods during the day*"[H].
[102] Ogle (2008); Rapson (2016).
[103] Prebble et al. (2020), including citing Wardle (1991).
[104] Partridge and Wilson (1988a & b).
[105] "*We have planted the oioi along that stream edge in the fresh water in small streams that come out at a small bay, so when you get a very high tide the salt water comes up into it. There we also plant native flaxes along that bank area. In a big open area we would just plant oioi on its own, and put the flax around the patch*"[I].
[106] Partridge and Wilson (1988b).
[107] "*We have only planted it on one side of the pond to maintain some diversity of habitat. Once well established, oioi can form quite dense sways of vegetation and out compete other things*"[H].
[108] Pohuehue pushed oioi out to margins in parts of the Auckland Botanic Gardens swale over 10 years[O].
[109] Auckland Transport (2021).
[110] One propagator[N] successfully planted divisions from a few plants eroded out of a mud flat at Waikawa Harbour in January 2022. Five clumps approximately 15 cm across were planted in peaty soils at Niagara where they are subject to some competition from exotic grasses and frosts, but no salt influence. The site is very wet and plants appear to be coping, some new shoots observed Oct 2022. Some of the rescued clumps were potted up (about 15 cm in diameter) and brought inland to my home in western Southland. Potting mix is 50% peat, 50% sand, and plants are kept in full sun and well-watered. The site prone to some harsh frosts, at 160 m asl. Some new growth apparent at Oct 2022.
[111] Cartman (2012); Hope (2012); Freeman (2023).
[112] "*On the areas that we collect there is pretty much seed every year. If it is fully formed or not is hard to tell, because it is small seed*"[I].
[113] "*Sometimes the seed comes up quickly, sometimes it comes up after about 6 or 8 months. So it can be a 2 -3 year process to get some germination from the seed into a 3PB or 1.5 L pot ready for planting. It is actually quite slow. Obviously pollination is an issue but it seems to be able to store itself for a while. Maybe it's the following year that it pops up or it needs certain temperature conditions for it to come right. When you sow it, it can often take 3-5 months to start coming up – actually that is not too unusual for native plants – some like Carex are really fast, others like native irises always take about 5 months*"[I].
[114] One collected ripe nuts in January 2021, taking care to collect new season ripe seed (reddy brown) and not old season's seed (dried, less red)[N]. This seed was then dried and stored in a cool dry place before sowed in February 2021 in a deep tray with 75% peat and 25% sand. A layer of pea gravel was added to the top of the sand on half of tray, and seed lightly sown on top of this and then watered into the crevices. The other half of the tray had a light dusting of potting mix on top of the just to help keep the seeds in place. The tray has been kept in full sun and watered regularly but there has been no germination by November 2022.
[115] "*It is quite hard to do. The roots are very very dense so you need a very sharp spade or some very sharp tools to cut them into pieces. Ideally you want pieces that are a minimum of about 10cm x 10cm - chunks with a decent amount of root on them. If you try to divide a clump into to very small divisions you often lose about 50% of them. Bigger clumps usually take off, but you definitely need to keep them moist for a period of about 6 months before they happily kind of take off, or 3- 6 months if it is the middle of winter which is the best time*"[I].
[116] Similar vulnerability is seen in *Chionochloa rubra* and *C. juncea*[O].
[117] "*We germinated from seed and then grew the oioi on at a home nursery on our property. We first planted in small pots. The plants that we planted out were in PB3s, about 3 years old, and quite well established with dense root mass. They were not big robust plants, but they were half a meter tall*"[H].
[118] "*The planting area has to be completely clear of the roots of any exotic grass (or in fact any other native sedge or grass that is not the desired species). Using a biodegradable weedmat such as a coffee sack, assists to a certain extent in keeping the area around the desired plant clear of invaders and as long as it degrades rapidly does not seem to affect the natural growth outwards*"[M].
[119] "*We plant at 750mm centres to allow for eventual growth. This means that for about five years we have diminishing weeding to do*"[E].
[120] Obviously it pays to leave dead looking oioi in situ for a long time because they quite often shoot back[F].

[121] One error was discovered during the Auckland growth form trials. They were lifted and divided and left to 'heel over' before being transplanted to trial sites i.e. left in the compost and with the root masses covered and so they are not actively growing. On one occasion plants left for 3-4 months died because their root mass dried out. Normally this preparation technique is used for just a few weeks and no damage is done.
[122] Johnson (1991).
[123] Champion et. al. (2008).
[124] Pages 29-34 of Auckland City (2021); Ira and Simcock (2019).
[125] Ira and Simcock (2019).
[126] *Top left*, A 10+ year old swale at Auckland Botanic gardens swale that was planted ~ 1 m back from the edge and has grown to cover the soil in the subsequent decade; *Top right*, old Waitakere City Council civic building where the Council demonstrated a range of water sensitive design practices that were just starting in New Zealand – here oioi was used in raingardens and swales (they also established a large greenroof, and roof-water reuse).
[127] Tait et al. (2016); Whitehead et.al. (2018).
[128] For example, in stormwater management, fastest is not necessarily better because 'fast' growing oioi tend to also be 'tall' and floppy and later require maintenance to trim plants when they fall onto footpaths or roads. Bioretention media are usually weed-free and mulched, so slower growth rates can lead to better outcomes.
[129] "In general there is a lot of scientific information missing when it comes to native plants and native restoration. Most of what you can access is observational and anecdotal and it is very area specific. The more scientific research that goes on the better really. It has been suggested that the roots collect clay molecules for example so some science to back that up would be very helpful I think. All you could do is put it out there and everyone else can say, hey look, this works here"[l].
[130] Bergin (1994); Stevens (2021); Stevens and Roberts (2021).
[131] One participant emphasised that this is part of a much wider limitation of plant management in New Zealand – "*a lot of NZ plant research is not actually backed up scientifically by the literature*"[k].
[132] For examples: Clarkson et al. (2003); Küchly and Hartley (2006); Clarkson and Peters (2010); Denyer and Peters (2012); Handford et al. (2018).
[133] Doody (2012); Denyer and Robertson (2016).
[134] Walters and Holling (1990).