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Front cover: The semi-shade tolerant arum lily, *Zantedeschia aethiopica* 'Green Goddess', which is found in damp gullies and seeps on Banks Peninsula, can dominate the understorey of native woodland. It exemplifies the problem of introduced plant species escaping from cultivation to invade regenerating or established, predominantly indigenous, communities.

Preface

This issue of the *Canterbury Botanical Society Journal* has a biosecurity theme with contributions that span better border biosecurity, the role of plant-fungal mutualisms in plant invasion biology, entraining members of the public to track and report invasions, educating the public about the importance of biosecurity for primary production and native ecosystems, and detailed studies of particularly troublesome pest plants.

I would like to thank the people who have found the time in their busy lives to write for the *Journal* on this important topic, also to the Committee, Technical Editor Joy Talbot, and Journal Reviewer Bryony Macmillan who are inspirational and essential for production.

I hope that there will be something of interest and use for every reader, whether they be actively involved in the prevention of unwanted incursions or in the management of existing invasions, or simply keen to learn more about our environment and protecting our biodiversity.

John Clemens
1 November 2019

Contents

Information about the Canterbury Botanical Society Inc.

Aims of the Society

To promote interest in the study of botany, especially that of New Zealand, and in the preservation of plants and habitats, and to disseminate current scientific information specific to New Zealand botany.

Membership

Membership is open to all those interested in plants, especially our local Canterbury indigenous plants and their habitats.

The Canterbury Botanical Society is a group for those interested in learning more about New Zealand plants and their stories. Speakers and field trips help us increase our knowledge of current botanical and ecological research and this in turn helps us value, celebrate, and advocate for our indigenous plants and their habitats.

Members receive a monthly newsletter, a regular journal, and a regular programme of meetings, field trips and field camps. A meeting with a speaker is held at 7.30 pm on the first Monday of each month, except for January and June, with a field trip being held on the Saturday, the week following the monthly meeting.

Meetings are held at the Upper Riccarton library meeting room at 71 Main South Road, Sockburn. The Society AGM, held at 10 am on the second Saturday in June, continues to be held at St Ninian's Presbyterian Church rooms, Puriri Street.

How to join

A membership form can be picked up at a meeting or downloaded from the Society website.

Electronic newsletter subscription		Posted newsletter subscription*	
Individual or NGO	$30	Individual or NGO	$40
Family	$35	Family	$45
Student	$20	Student	$30

All subscriptions are reduced by $5 if paid before 31 July

* There is a $10 surcharge for posted newsletter subscriptions to cover part of the distribution cost.

Society Administration

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Membership Coordinator	Judy Bugo

Committee Alice Shanks, Miles Giller, Melissa Hutchison, Bryony Macmillan, Dean Pendrigh, Sarah Wright, Paul Maurice (to August 2018), Geoff Henderson (to Apr 2019).

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Gillian and Miles Giller, Life Membership recipients

Gillian and Miles Giller were awarded life memberships of the Canterbury Botanical Society at the 2019 Annual General Meeting. Both have a strong sense of community mindedness. They have given unswerving loyalty and participation to the Society for many years.

Miles and Gillian's association with the Society started in 1991 when Derek Cook visited their native plant nursery and suggested they join the Society, which they did that year.

In 1993 they joined the committee and were on the programme subcommittee as well. They continued to help with the organisation of field trips after they resigned from the committee in 1997. Miles is recorded as leading a field trip to Glentui River Gorge in 1999. In 1998 they were awarded the Senior Bledisloe Trophy "for energetic organisation of camps and arrangement and leadership of the field programme".

Gillian joined the committee again at the 2005 AGM and in 2008 became the membership coordinator. She held this position until 2014, developing organised spreadsheets, and for part of the time acted as secretary as well. Gillian competently managed the system changes required when the Society became a registered charity in 2008, no easy task. She resigned from the committee in 2014 but a year later both she and Miles re-joined the committee. Gillian was president from 2015-2018 and covered the position of treasurer for part of that time. At the 2018 AGM she was elected as treasurer. In this role, she has implemented practical changes to help ensure that the Society stays on a sound financial footing. Furthermore, she has a very good knowledge of the Society's rules and gets details correct.

Camps that Miles and Gillian have organised were based at Island Hills, Gunn's Bush, Conway Flat, Waingaro, Arapawa Island, Hinewai, Tautuku, Lake Ohau and Murchison.

Miles and Gillian place high value on the protection of remnant flora and fauna. These values have led them to prepare and present several submissions to their local council, in support of protecting these remnants.

Working as QEII representative in Canterbury since 2001 has enabled Miles to obtain access to some interesting areas on private land where camps and field trips have been held. In his spare time Miles did and still does a lot of work as a member of the Matawai Park Advisory Group, maintaining and developing Matawai Park in Rangiora.

As Alice Shanks commented at a committee meeting, "we set the bar high for awarding Life Memberships".

Fay Farrant

The role of mycorrhizal fungi in plant invasions

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New Zealand is a country dominated by invasive plants. Since the arrival of Māori (1280-1300), and particularly Europeans some 500 years later, more than 24,000 alien species of plants have become established (Duncan and Williams 2002). Of those 24,000 established alien plants, more than 2500 have become invasive. This is a remarkable number given that New Zealand has only around 2400 native plant species – there are now more invasive alien than native plant species (and 10× more alien species than native overall).

All plants are hosts to a wide range of co-evolved beneficial and harmful organisms, but the process of being introduced can result in non-native plants leaving behind many of these mutualists and antagonists (Diez et al. 2010; Dickie et al. 2017). This can give introduced plants an advantage over native plants: while native plants struggle with herbivores, pathogens, and parasites many introduced plants do not. This process, called "enemy release" by ecologists, is believed to play a role in allowing invasive plants to establish and spread. However, just as a loss of specialised enemies may benefit plants, a loss of specialised mutualists may be an important limitation (Nunez et al. 2009; Nunez and Dickie 2014). Plants rely on a wide range of mutualists for pollination, seed dispersal, nitrogen fixation, nutrient uptake, and herbivore defence. When introduced to a new range, these mutualists may be left behind, reducing the ability of a plant to establish, survive and grow. Better understanding of this process may help both manage existing plant invasions and prevent new ones.

The mycorrhizal side of invasions

Perhaps the most widespread plant-fungal mutualisms are "mycorrhizas" in which fungi colonise plant roots. The vast majority (94%) of plants rely on these beneficial fungi for their normal growth, with the plant supplying the fungus with an abundant source of carbon and the fungus, in turn, providing the plant with mineral nutrients and other benefits (pathogen protection, water uptake). Mycorrhizal nutrient uptake is the most common way plants acquire nutrients, and can be responsible for up to 100% of plant phosphorus uptake (Smith and Read 2008).

Around 76% of invasive plants in New Zealand rely on one type of mycorrhizas, known as "arbuscular mycorrhizas" (Fig. 1, p. 6). The fungi that form arbuscular

mycorrhizas are inconspicuous, reproducing through relatively small, soil-borne spores. There are relatively few known fungi that form arbuscular mycorrhizas, with 350 to 1000 defined species (Davison et al. 2015). With so few species, it is not surprising that many arbuscular mycorrhizal fungi have very large (cross-continental) scale natural distributions, and while different plant hosts do support different fungal communities, strict host-specificity is rare (Davison et al. 2015; Martinez-Garcia et al. 2015).

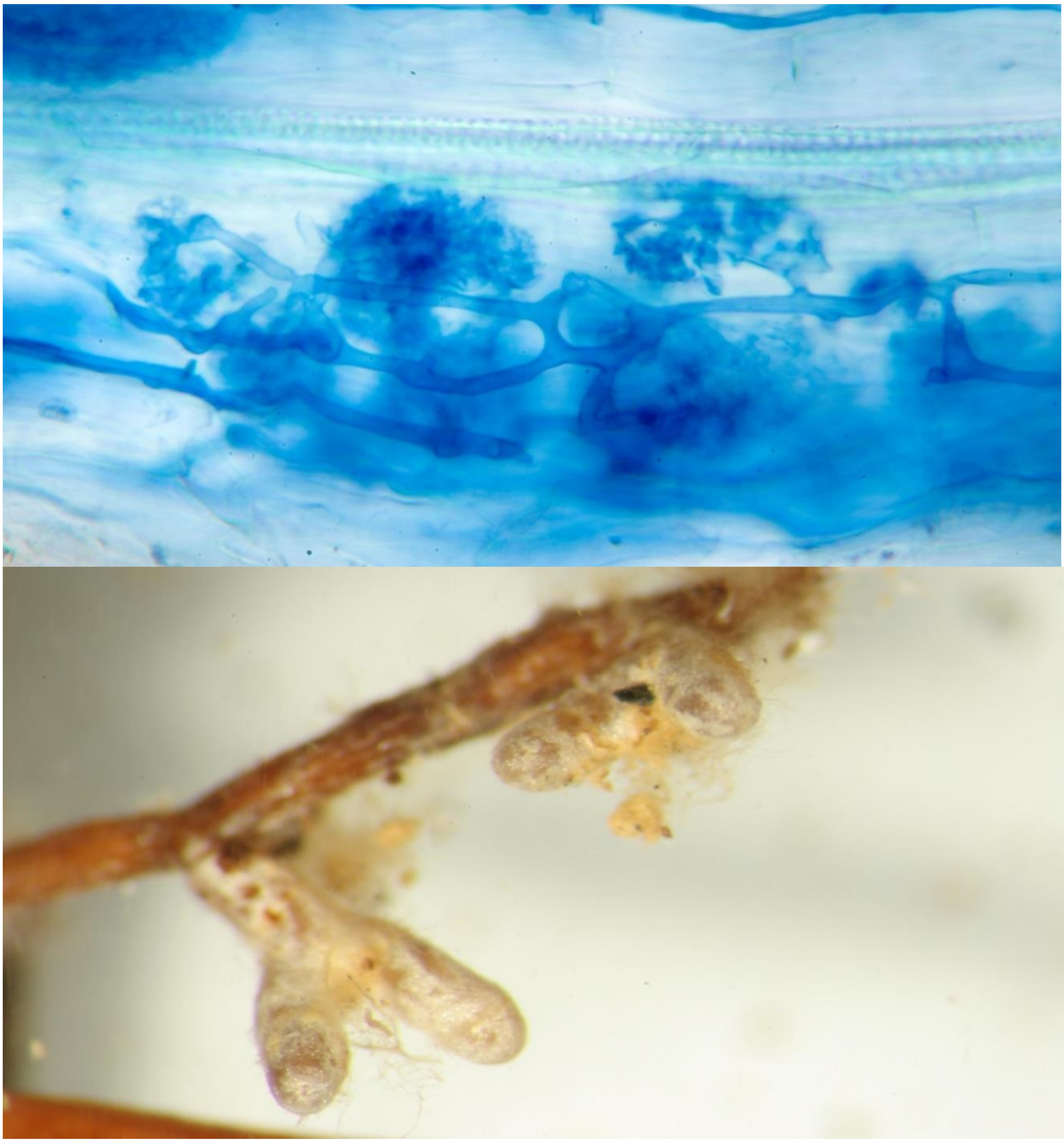

Figure 1. The two dominant types of mycorrhizal associations are arbuscular mycorrhizas (top) and ectomycorrhizas (bottom). The *Buddleja davidii* root in the top photograph has been cleared and stained to reveal the characteristic branching ("tree-like") structure known as an "arbuscule" where nutrient exchange between plant and fungus occurs, and the thicker fungal hyphae. In ectomycorrhizas, as shown in *Pinus contorta* (bottom), fungal hyphae wrap around the outside of roots and penetrate between, but not into, plant cells.

As host-specificity of arbuscular mycorrhizal fungi is low, invasive arbuscular mycorrhizal plants generally have few problems finding partners and forming the mycorrhizal associations they need, as shown for invasive grasses (Johansen et al. 2017). The main exceptions would be in ecosystems where there are no established arbuscular mycorrhizal plants, such as very low diversity mountain beech forest (*Fuscospora cliffortioides*). The southern beeches do not form arbuscular mycorrhizas, and hence the invasion of tussock hawkweed (*Hieracium lepidulum*) into such forests may be limited by a lack of available arbuscular mycorrhizas. By contrast, where arbuscular mycorrhizal plants have previously established, they can then provide a source of inoculum and hence facilitate hawkweed invasion (Spence et al. 2011).

Ectomycorrhizas and tree invasions

A much less common type of mycorrhizas are known as ectomycorrhizas (see Fig 1, p. 6), which are formed by only around 2% of land plants. While relatively small in number, the plants that form ectomycorrhizas include many dominant forest trees. Among invasive woody plants, ectomycorrhizas are formed by wilding pines (*Pinus*), Douglas-fir (*Pseudotsuga*), willow (*Salix*), and alder (*Alnus*), as well as many less-invasive alien trees such as oaks (*Quercus*), eucalypts (*Eucalyptus*), birch (*Betula*), and poplar (*Populus*). Among native species, only the beeches (*Fuscospora* and *Lophozonia*), manuka and kanuka, and *Pomaderris* form ectomycorrhizas (Warcup 1980; Orlovich and Cairney 2004)

The fungi involved in ectomycorrhizas are entirely distinct from the fungi involved in arbuscular mycorrhizas. Ectomycorrhizal fungi are incredibly diverse, including an estimated 20 000 to 25 000 species of fungi from 66 lineages spanning three phyla of fungi (predominantly Basidiomycota and Ascomycota, along with some Mucoromycota) (Tedersoo et al. 2010). Many ectomycorrhizal fungi produce large mushrooms in a brilliant array of colours and forms (Fig. 2, p. 8), while others produce less conspicuous fruiting bodies. Unlike arbuscular mycorrhizal fungi, ectomycorrhizal fungi show a high level of endemism in New Zealand. Ectomycorrhizal fungi can also show host specificity, with some fungi only associating with, for example, pine trees (including most *Suillus*), alders (the fungus *Alnicola*), or birch (birch bolete, *Leccinum scabrum*).

Host specificity of fungi presented a unique challenge to the establishment of pine trees in New Zealand and elsewhere in the southern hemisphere. When pine trees, Douglas-fir, alder, willows and other ectomycorrhizal species were first planted in the southern hemisphere, establishment and growth were frequently poor (Gilmour 1958). The failure of early plantings played a large role in scientific recognition of the importance of mycorrhizal fungi to plants. Once the importance of a lack of mycorrhizal fungi was recognised, active inoculation programs were developed, with government forestry researchers promoting the spread of ectomycorrhizal fungi in order to enhance alien tree establishment as late as the 1970s and 80s (Ledgard 1976).

Figure 2. Some examples of native (a - d) and alien (e - h) ectomycorrhizal fungi, including the native species (a) *Amanita pekeoides*, (b) *Porphyrellus formosus*, (c) *Cortinarius* sp., and (d) *Octaviania* sp.; and the alien species (e) *Boletus edulis*, a choice edible fungus growing on native beech, (f) *Tricholoma terreum*, (g) *Amanita muscaria*, and (h) *Suillus luteus*.

The arrival and spread of mutualists

The ectomycorrhizal fungi that are now widespread on pines, birches, willows and alders were probably primarily introduced by happenstance on living plant roots. Transport of living plants was remarkably common in the 1800s, and each plant likely brought along fungi on its roots and in the surrounding soil. For example, it is quite likely that the choice edible ectomycorrhizal fungus *Boletus edulis* (porcini, cepes), currently found primarily in and around Christchurch, was brought from the UK to New Zealand on the roots of large living oak trees that were planted in Hagley Park (Herriott 1919).

Pines may have taken a circuitous route to arriving in New Zealand. Radiata pine was introduced to New Zealand by at least 1859 as a seedling transplanted from Australia (https://teara.govt.nz/en/photograph/16831/radiata-pine-at-mt-peel-station), although there may have been earlier introductions (Sutton 2011). The source of the Australian populations may have been from seedlings transplanted from Britain (Fielding 1957), where radiata pine had been introduced in 1833 (Green 1954). The movement of seedlings with associated soils was likely a main source of fungal inoculum. One of the curious results of this circuitous introduction route is that invasive North American *Pinus contorta* in New Zealand seem to associate with a number of fungi from Europe, including *Suillus luteus*.

In some cases, deliberate efforts to spread ectomycorrhizal inoculum have taken place. In 1939, R J Lawrence, a Forest Ranger with knowledge of mycorrhizal activity, theorised that the poor health of Douglas-fir in the Nelson area was due to a lack of suitable symbiotes in most local nurseries (Lawrence 1945). Lawrence transported forest floor material from a successful Douglas-fir stand in Hanmer Springs and applied it to various Nelson Douglas-fir stands with the express intention of introducing suitable mycorrhiza, thereby improving the health and growth of the trees (Gilmour 1958). Lawrence was subsequently involved in several other trials in the Canterbury region that explored the impact of incorporating litter from well-performing local Douglas-fir stands into nursery seedbed soil. This research also indicated the positive impact of this putative mycorrhizal introduction on the later growth of the Douglas-fir seedlings generated from these trials (Lawrence 1945). This early work culminated in a significant trial set up to improve Douglas-fir establishment in Otago in the 1950s. Assessments of root morphology across healthy and poor performing trees indicated mycorrhizal presence was a key factor in good growth, and this factor was determined by the nursery that supplied the trees (Gilmour 1958). Forest floor material was then introduced to a nursery that was producing poorly performing stock; subsequent seedling crops from that nursery were observed to be colonised by suitable mycorrhiza, and performed well in the field. Other introductions have used fungal sporocarps, particularly of *Rhizopogon parksii* which was systematically introduced into Douglas-fir nurseries in the 1980s to enhance the establishment of Douglas-fir plantations (Davis 2008). Deliberate spread of fungal sporocarps and forest floor material as inoculum played a large role in establishing the New Zealand forest industry, but also contributed substantially to the success of both pine and Douglas-fir as invasive species.

Once mycorrhizal fungi were established into tree nurseries, the widespread planting of pine seedlings, often by researchers (Ledgard and Baker 1988), into high-country grasslands led to the initial introduction of non-native ectomycorrhizal fungi to these ecosystems. Ectomycorrhizal fungi produce abundant sporocarps (mushrooms), each one of which can contain millions to billions of fungal spores. Curiously, although the general expectation might be that wind would be the primary dispersal agent of these fungi, it actually appears that mammals, including Australian brush-tailed possums (*Trichosurus vulpecula*) and red deer (*Cervus elaphus*), are vital dispersal agents. These mammals seek out and consume fungal sporocarps of both native and alien fungi, but work by Wood and colleagues demonstrates that they are only effective dispersal agents for alien fungi (Wood et al. 2015). As a result of repeated introductions and subsequent spread, alien mycorrhizal fungi are now widespread in many areas. As a result, a lack of mycorrhizal inoculum no longer precludes tree invasion in many areas (Davis and Smaill 2009; Dickie et al. 2014b).

While most fungal introductions are inadvertent, there have been a few deliberate introductions (Schwartz et al. 2006). These include ectomycorrhizal truffle species and other edible species, as well as mycorrhizal inoculum products (including both arbuscular and ectomycorrhizal fungi).

Invasive plants and fungi transform ecosystems

The invasion of ectomycorrhizal trees such as wilding pines, alders, and willows in most cases represents a shift from arbuscular mycorrhizal dominance (native grasses and many native shrubs) to ectomycorrhizal dominance. It has long been recognised that arbuscular mycorrhizal and ectomycorrhizal vegetation drive fundamentally different ecosystem processes (Read 1991; Lambers et al. 2008; Dickie et al. 2015). In particular, ectomycorrhizal fungi have a much greater ability to directly access organic nutrients than arbuscular mycorrhizal fungi. Over long time periods, this direct nutrient uptake can lead to a short-circuiting of the nitrogen cycle, build-up of organic carbon, and reduced plant diversity (Orwin et al. 2011; Phillips et al. 2013; Dickie et al. 2014c). However, long-term outcomes of changes in mycorrhizal status may not be particularly relevant to invasions.

The short-term soil ecosystem effects of ectomycorrhizal plant invasions are profound, but often opposite to longer-term predictions. In the short-term, the invasion of pines is associated with a substantial loss, rather than gain, of soil carbon and an increasing availability of both nitrogen and phosphorus (Chen et al. 2000; Chapela et al. 2001; Dickie et al. 2014a; Dickie et al. 2014b). These changes may reflect the novel enzymatic capabilities of ectomycorrhizal fungi, potentially releasing nutrients from soil organic compounds that have accumulated over extended time periods. There are also very large shifts in the rate of nutrient cycling. Decomposer communities in native grasslands tend to be fungal dominated, resulting in relatively slow cycling of nutrients. Following the invasion of ectomycorrhizal wilding conifers, these systems shift into a bacterial dominated state (Dickie et al. 2011; Dickie et al. 2014b). Bacteria are much more susceptible to predation than

fungi, hence bacterial dominated soils tend towards much faster nutrient cycling (Wardle 2002), further contributing to a higher availability of nitrogen and phosphorus following tree invasion.

Changes in belowground ecosystems have profound implications for restoration. At present, most efforts to control plant invasions focus nearly entirely on killing invasive plants. This is a necessary first step, and sufficient to play an important role in preventing further spread. However, simply killing and removing invasive plants does little to reverse changes in soil functioning and hence does not restore the local ecosystem. Rather, areas where invasive ectomycorrhizal trees have been removed tend to be rapidly dominated by invasive alien grasses (Dickie et al. 2014b). While grass dominance may partially reflect high seed availability and an ability to rapidly colonise disturbances, soil bioassays demonstrate that soil legacies of invasive trees are playing a major role (Dickie et al. 2014b). Invasive ectomycorrhizal plants also build up fungal inoculum over time, which can be highly persistent (Bruns et al. 2009). This suggests that over time, removal of invasive trees will lead to invasion by non-native grasses, which are then re-invaded by invasive trees, resulting in a potentially endless cycle of tree invasion, control, and reinvasion.

Restoring ecosystems rather than killing trees

At present, millions of dollars are being spent annually on controlling tree invasions using herbicide and other treatments to attempt to eradicate the invasion and restore native grasslands. Whether long-term eradication can be achieved remains to be seen, but better management of ecosystem legacies of pines will be required if native grasslands are to be restored. Further, this strategy will require an ongoing investment of considerable resources to prevent any pines from reaching seeding age if long-term eradication is to be achieved.

Given the difficulty in restoring native ecosystems following invasion, is it worth continuing to try? There are certainly some who have argued that invasive plants are a positive change to our ecosystems, and advocate for simply accepting them as part of the new normal. Invasive plants do provide positive ecosystem services (Dickie et al. 2014a), including fixing a substantial amount of carbon (Dickie et al. 2011), and some would argue that invasive species add to the diversity of plants in New Zealand. Nonetheless, while invasive species may add to species numbers at a national scale, this comes at a high cost to species diversity at a local scale, and the loss of iconic New Zealand landscapes.

There may be a third possibility that doesn't require accepting pine dominance of landscapes, but also reduces future reinvasion. We might consider whether the time of the New Zealand tussock grasslands is simply past. Many of these grasslands were forest before Māori and particularly European settlement (Hobbs et al. 2006), and the suitability of climatic conditions in these grasslands for forest is clearly evident in the success of tree invasions. Management to restore these ecosystems to native forest might provide a much longer-term solution than trying to maintain grasslands. Doing so might require careful planting of native species either before or after removing

invasive trees, and incur substantially higher costs than simply spraying herbicide from a helicopter. Nonetheless, establishing a tall native woody cover is perhaps the only strategy that would limit the ability of pines to reinvade. This approach would not prevent Douglas-fir invasion, given its high shade tolerance, but could greatly reduce most of the other invasive pine species.

Biosecurity implications

Given what we now know about the role of mutualisms in plant invasion, there are some ways in which we may be able to reduce future invasions. Firstly, it is important to recognise that a plant species that is not currently invasive could become invasive if a particular fungus arrives. Risk assessments need to consider the possibility that plant phenotypes are a function not only of physiology, but also of ecological interactions. For example, *Eucalyptus* was present for a considerable time in Spain before becoming invasive, and some have suggested that late arriving co-invading Australian ectomycorrhizal fungi may be driving that invasion (Diez 2005; Dickie et al. 2016). Given the risk, it might be prudent to monitor the 220 species of introduced *Eucalyptus* in New Zealand to ensure that a late-arriving fungus doesn't drive a similar transition here.

Very few fungi were deliberately introduced to New Zealand, with most arriving on soils and roots of plants. Live plant imports are well recognised as a source of pathogen and insect invasions (Liebhold et al. 2012), but also represent a major pathway for mycorrhizal fungal invasions. Botanic gardens (Hulme 2011), urban plantings, and forestry trial sites may have particularly high levels of non-native fungi present. Managing soil movements from these sites may help delay future invasions. In some cases, such as the highly poisonous *Amanita phalloides*, eradication of currently limited populations should be considered (Dickie et al. 2016).

Lastly, ongoing efforts to import new species of mycorrhizal fungi should be viewed with extreme caution. There are a number of mycorrhizal inoculum products that are sold overseas and applications are periodically made for permission to import to New Zealand. In general, these products contain fungal species that have been selected for high spore production for ease of production (Schwartz et al. 2006; Vellinga et al. 2009). The value of mycorrhizal inoculum products is often unclear, and at least in the context of New Zealand restoration projects native fungi may provide stronger benefits (Williams et al. 2012). Conversely, the risks of introducing new fungi may be considerable, given the history of non-native fungi facilitating weed invasions.

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Branch River - the catchment of greatest vegetation change?

Nick Ledgard

Retired FRI (Scion) researcher

Back in the 1970s and 80s I used to spend a fair bit of time in the Branch catchment in South Marlborough. This river drains into the Wairau River alongside SH63, which runs from Blenheim up to St Arnaud. Being remote and rugged, with a demanding river crossing and 4WD track through original beech forest to reach the main hut (Grieg's), it was always an attractive destination for a young man keen on the backcountry and 'hunting, shooting and fishing'. It is also home to a fascinating tale of major vegetation change over a relatively short period of time. In his 1996 book *Steepland Forests*, Peter McKelvey describes the Branch catchment work as "easily the largest purely protective reforestation project in the NZ mountainlands". Much of the following is extracted from Peter's book, aided by the results of research trials in which I was involved.

Originally the Branch catchment was densely forested up to a timber line at about 1500 m. The dominant forest species were red and mountain beech, with areas of kanuka and shrubland (mainly Ca*rpodetus*, *Pittosporum*, *Cassinia* and *Senecio* species). Above 900 m there is increasing grassland dominated by *Rytidosperma setifolium* and *Festuca matthewsii* / *Poa colensoi*, with areas of *Chionochloa australis* (carpet grass) or *C. pallens* (snow grass). The most extensive vegetation clearances took place about the turn of the century, with the last major fires between 1917 and 1920. It is likely that forest destruction through burning had been underway for several centuries before that, but the prospect of grazing sheep accelerated it in the early 1900s. The end result was thousands of hectares of largely bare, erosion-prone slopes. I have slides taken in the early 1970s of huge areas of such steep land, with the most obvious above-ground feature being the widely scattered spars of large burnt beech trees. The only wildlife seen was rapidly retreating goats, hares and the occasional chamois. So open was the country that it was hard for even a fit, keen young man to get within assured rifle range.

Animal control in the catchment began in the 1950s, and by the mid-1960s this, combined with a restriction on burning had halted the major depletion of vegetation. Below 900 m the bare and eroding slopes had begun to heal, but above that, widespread erosion and soil loss continued. A Forest Research Institute survey in the summer of 1959-60 confirmed this, and resulted in experimental planting of a range of indigenous trees and shrubs – but this failed completely. Hence, Forest Service staff turned to exotic tree species to hold the upper slopes with the thought that these might serve as a nurse cover for later native species establishment. A revegetation programme began, tentatively and experimentally, with hand planting in 1963-64. Irregularly shaped groups of trees were planted at an average spacing of one group per 4 ha, with the intention of creating seed sources for subsequent in-filling by seedlings. By 1969 some 100s of hectares had been so covered in the most accessible areas up to 1400 m. In that year blanket planting of small areas began in sheet-eroded areas at higher altitude. As can be seen, this was very successful in arresting soil loss (Fig. 1).

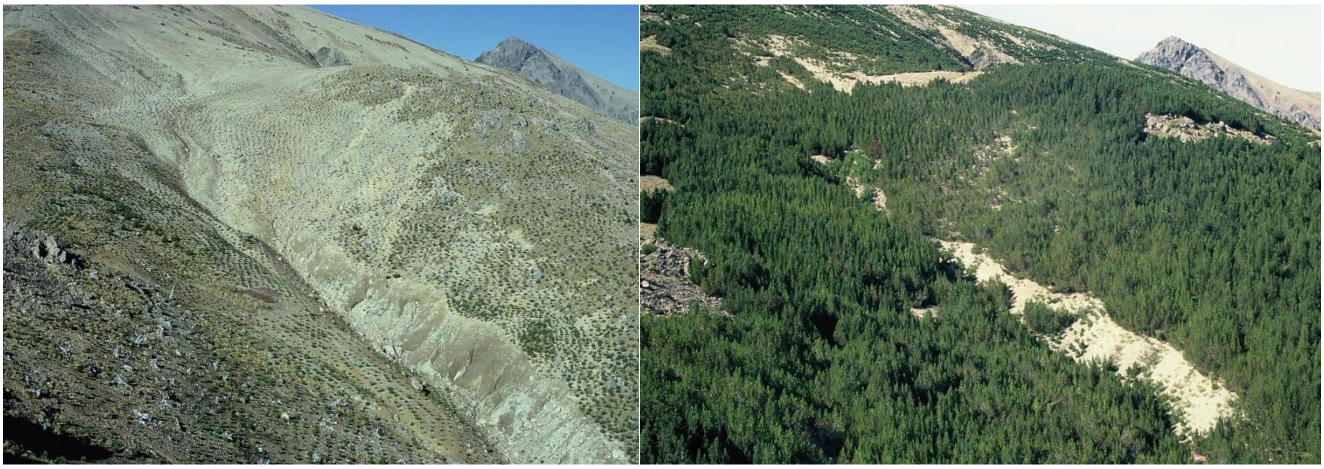

Figure 1. An eroding Branch headwater planted in the 1970s (left), re-photographed in 2007 (right).

By 1973, almost half a million trees had been planted. The main species were contorta/lodgepole pine (*Pinus contorta*), followed by Corsican, mountain and radiata pine (*P. nigra*, *P. mugo* and *P. radiata*) and Douglas-fir (*Pseudotsuga menziesii*). In addition, poplars and willows were established experimentally up to 1100 m, but this was so laborious that it was soon restricted to road stabilisation and amenity plantings.

Hand sowing of tree seed began in 1966, when 270 ha were covered using the same pattern as in group planting. However, this was soon superseded by cheaper aerial seeding, which showed similar results to the hand sowing. Initially, both fixed wing and helicopters were used, flying along the contour in flight lines 75-90 m apart. Images taken by myself in 1981 and 2007 clearly show the results (Fig. 2, p.18).

By 1969, the strip sowing looked so effective that it was replaced by aerial blanket sowing. Between 1965 and 1973, almost half a tonne of seed was sown, almost half of which was contorta pine. The main species were the same as those planted (listed above), with the addition of Scots and ponderosa pine (*P. sylvestris* and *P. ponderosa*), and European larch (*Larix decidua*).

Figure 2. Lines from sown conifer seed on eroding Branch slopes in 1981 (left), and re-photographed after further sowing and in-filling in 2007 (right).

The larger scale reforestation work was encouraged by the prospect of a Branch River Hydroelectric Power Scheme, which would take clean water out of the Branch River (plus its major tributary, the Leatham) to fill Lake Argyle (29 ha), from which the water would be directed down through a power station into the Wairau River. This Scheme was eventually commissioned in 1983. The eroding slopes in the upper catchment was sending huge amounts of shingle down the river, and directly threatening the viability of the power scheme. I remember an old lady who lived by the lower river, pointing out a spot a little further up where, when she was a child, her father had felled a tall beech tree so that they could cross the river with dry feet. My response was that one would need the equivalent of ten trees to make a dry foot crossing now.

At the time, the cost of aerial seeding ranged from $3.79/ha through to $7/ha, with seed being 75% of that cost and helicopter hire 20%. Initial mortality of germinated seedlings was excessive, especially at higher altitude, with over 50% dying in the first season – lifted out of the ground by frost, or as a result of desiccation and animal damage. Best results were in broken, rocky faces and on sites where tussock cover was incomplete. Poorest results were where tussock, shrub or forest cover was dense. After a few years the seedling mortality fell abruptly and growth rates approached those of planted trees. Contorta pine was the fastest, especially at higher altitudes, followed by Scots pine. At lower altitudes, radiata and ponderosa pine did well. Douglas-fir was slow at first, but once the mycorrhizal problem was overcome (in the 1980s) it has arguably become the most successful species (more later). Mycorrhizal fungi live in a symbiotic association with plant roots and can greatly increase water

and nutrient absorption, and hence overall growth. Douglas-fir seedlings struggle without the correct mycorrhizae working for them.

In all this sowing work, it proved impossible to establish tree seedlings directly onto bare, exposed subsoils. It was soon realised that it was essential to stabilise such sites first, to provide protection from frost-lift, desiccation, wind, and water erosion. Research elsewhere had shown that aerial oversowing with grasses and legumes plus fertiliser could provide the required protection in the early years. Trial and error in the Branch showed that this technique could succeed, and that if pine seed was incorporated in the mix, the woody species could be sufficiently well established to survive by the time declining soil fertility had led to the disappearance of the herbaceous species. After 1975, this vegetation establishment technique was widely used.

Right from the word ‘go’, an absolutely vital component for revegetation success was control of wild animals. Reducing numbers of the large animals – deer, goats, chamois, and pigs – was not too difficult, but the smaller animals – hares and possums – proved more troublesome. Initially, control of the latter was by shooting combined with hand poisoning using cyanide and compound 1080. However, more extensive coverage was needed, so aerial poisoning began in 1970, and it was accepted that continuous pressure on animal herbivory had to be maintained into the future.

By the mid-1970s, overall results were considered promising enough to be undertaken annually, and this continued through to 1986. Some workers were almost full-time in the Branch, controlling animals over summer, and establishing a new vegetation cover over winter. Over 1 million trees were planted and more than a tonne of seed sown. In the 30 years since that time, the cover of vegetation has thickened and spread enormously. Even on the steepest slopes, where the initial sowings failed in the actively eroding gullies, there is now increasing closure. This is because trees established and grew well alongside gullies, so that when undermined by the expanding sides, they fell alive into the gully with part of their root system still intact. This stopped further soil loss beneath the fallen tree, and created small check dams which arrested debris from proceeding further downslope. As more and more trees fell in the same way, seedlings were enabled to establish on the now stable gully surfaces, and a continuous tree cover is currently developing across the slope (Fig. 2). The riverbed has also stabilised, with vegetation (mostly wilding conifers) now dominant (Fig. 3, p. 20).

To my knowledge, no-one has attempted to quantify the within-catchment environmental gains that all the revegetation efforts have achieved in the Branch. However, my own observations are that the rate of erosion has declined significantly (no doubt about that) and that there are now soils (with A horizons) developing under the conifers, where just bare subsoils existed before. Consequently, the water flow in the river is now more steady, consistent and cleaner – approaching the state it would have been in before the forest destruction began in earnest. Within-river aquatic

insect life would also be returning to normal. Trout can now be seen in the river – and I can assure readers that there were none present in the 1970s and 80s. Bird life, both native and introduced, can now be seen in amongst the new woody cover, where none was present before. And where there are margins of indigenous plant species, new native seedlings can be found under the exotic cover. To my mind, that is the current major challenge – to promote increasing numbers of native plants to establish under the protective exotic woody cover, where their greater shade tolerance gives them an advantage over the more pioneering, light dependent exotic species. For that was the ultimate objective of the revegetation efforts – to facilitate a return to an indigenous plant cover.

Figure 3. Tramping by the Branch River in 2007. The formerly barren and mobile riverbed is now almost totally covered with wilding confers.

One should never end an article such as this with negatives, but unfortunately, it is the negative consequences of the Branch revegetation efforts that now capture the most outside attention. So successful has been the growth of introduced trees within the catchment, that the No 1 concern of present-day managers is the unwanted spread of wilding trees beyond the catchment boundaries. Huge areas are being invaded downwind to the east in the Waihopai catchment and the headwaters of the Saxton River on Molesworth Station. There is little doubt that if these invasions are not stopped, conifers will soon become the dominant cover outside closed canopy native

shrub and forest lands. Even within the Branch, the successional move towards more shade tolerant native species will be compromised by an almost-as-shade-tolerant introduced species – Douglas-fir. Since its mycorrhizal problems were overcome in the 1980s, this species has become rampant, now appearing in sites where it was once considered to be a non-starter.

As Peter McKelvey concluded in his book "Anyone viewing the Branch valley today, with knowledge of what it was once like, will be impressed by the more stable, productive environment". He went on to add "But the 'foreign' plant cover will be emphatically noticeable too". If he was still alive today, he would underline, bold and italicise that last statement. And what are my thoughts almost 50 years since I first strode those steep bare Branch catchment slopes? I knew the benefits of establishing a new vegetation cover on eroding country as I was trained in that discipline – but I did not envisage the magnitude of it. We were also not sufficiently knowledgeable about differing species performance ('the right species in the right place'). Hence I regret that contorta pine and Douglas-fir were included in the mix of species used (Fig. 4).

Figure 4. Looking south from ridge tops in the Branch catchment in the 1970s (left) and again in the early 2000s (right). Below 1600 m all this catchment was beech forest prior to sweeping fires in the early 1900s. A small remnant can be seen in the far distant left of the 1970s image. All the other subsequent vegetation in the right image is introduced conifers – mostly established from aerially sown seed. The result is a stabilising cover with soil forming benefits, plus biodiversity gains and improved sites for more shade-tolerant native plant successions. But the pioneer conifers are now moving on to where they are not needed.

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The New Zealand Wilding Conifer Group: working with communities to boost wilding conifer control and collaboration

Rowan Sprague

Coordinator of the New Zealand Wilding Conifer Group

It's a sunny and unusually warm September day when I visit the Craigieburn area to meet with Ray and Maree Goldring from the Waimakariri Ecological and Landscape Restoration Alliance, or WELRA (Fig. 1). I am talking with them about their recent Wilding Conifer Control Strategy as well as catching up about the work they have done over the last decade of wilding conifer control. Their ongoing dedication to wilding conifer control is an example among many of community members volunteering countless hours and effort to stop the spread of wilding conifers across New Zealand's iconic landscapes.

Figure 1. Maree and Ray Goldring tackle wilding seedlings on the flats near Flock Hill. Photo taken by Chris Macann

Wilding conifers: a major biosecurity challenge for New Zealand

We can think of biosecurity risk management as being split into areas based on different spatial and temporal scales. New species that are detected at the border are limited in impact and in the area they affect if the response is rapid and effective, although it may be ongoing if there are repeated incursions. On the other hand, once a pest has breached the border and established in the country, it can affect large areas (sometimes landscapes) where over time the response shifts from eradication to containment, to long-term management.

One such pest plant in a long-term management programme that has spread into most if not all regions of New Zealand is the wilding conifer. The term refers to a number of conifer species that have naturalised and self-established from intentionally-planted or self-seeded individuals (Ledgard 2004; Froude 2011). They are also called wildings, or wilding pines (some of which are not pines at all). In Canterbury, we are unfortunate to have several species of wilding conifers: *Pinus contorta* (lodgepole pine), *P. nigra* (Corsican pine), *P. sylvestris* (Scots pine), *P. ponderosa* (Ponderosa pine), *P. mugo* (mountain pine), *P. radiata* (radiata or Monterey pine), *Larix decidua* (European larch), and *Pseudotsuga menziesii* (Douglas fir). You can find wildings across Canterbury, although more typically in the high country (Fig. 2). They invade tussock grasslands, farmland, native shrubland, coastal banks, riverbeds, and even native beech forests. Across New Zealand, the approximate area wilding conifers affect was estimated to be about 2 million ha in 2014, more than the area of plantation forests.

Figure 2. *Pinus nigra* invading the flats below Mt Barker in Canterbury. Photo taken by author.

Both human-mediated factors, such as forestry use and amenity plantings, as well as biogeographic factors, such as climate match, have contributed to the wide distribution and success of these species (Hunter and Douglas 1984; McGregor et al. 2012). In part due to their ability to mature early, produce small seeds, and frequently having large seed crops (Richardson et al. 1994), wilding conifer species have invaded vast areas of vulnerable land in New Zealand. Where they invade at exponential rates, wildings threaten native biodiversity, cause economic losses on productive land, and reduce water yields in infested catchments (Mark and Dickinson 2008; Dickie et al. 2014; Rundel et al. 2014). They can also impact on social and cultural values.

However, all is not lost. Control of wilding conifers has been going on for decades, undertaken by the Department of Conservation, regional councils, and landholders. In 2014 the Government launched the NZ Wilding Conifer Management Strategy - 'The Right Tree in the Right Place' - to promote a national approach to the problem. As a result of the strategy, the National Wilding Conifer Control Programme started in 2016 to coordinate and manage wilding conifer control efforts and to provide co-funding from Central Government. Since 2016, over 2 million hectares of affected land in Canterbury has been searched and treated for wilding conifers under this programme (Environment Canterbury 2018), and more control is planned for 2019-2020.

The New Zealand Wilding Conifer Group

The NZ Wilding Conifer Group (NZWCG) (https://www.wildingconifers.org.nz/research/) formed in 2018 to address the need to have an independent stakeholder group to advise the National Wilding Conifer Control Programme as well as to connect agencies and community groups. It comprises representatives from community groups, farmers, foresters, iwi, Government agencies (MPI, DOC, LINZ, NZ Defence Force), local government and NGOs. It advocates for achieving the goals of the NZ Wilding Conifer Management Strategy and facilitates information transfer between scientific research and operational management. In 2018 the NZWCG was able to employ me as its National Coordinator on a 0.5 FTE (Full Time Equivalent) basis.

In this past year, the NZ Wilding Conifer Group has established itself as an independent legal entity, lobbied central government on behalf of the National Wilding Conifer Control Programme, and provided more support to community groups. We have talked with 20 such groups who carry out wilding conifer control and we are encouraging new groups to start up all over New Zealand where wilding conifers are a problem. While speaking with these groups, I have learned about how they operate, their aims, and challenges (Fig. 3, p. 25).

Community groups are seen as an integral part of wilding conifer management in New Zealand (Fig. 4, p. 26). They all want to care for their land and are passionate about finding solutions to wilding problems. Groups often apply for grants to undertake control and put together detailed strategies and plans for management and

post-removal restoration and revegetation. Community groups also advocate for wilding conifer control in an area, getting Government agencies and local regional councils on board and generally raising awareness in their areas. The NZ Wilding Conifer Group is working to support these existing community groups by providing advice on funding opportunities, connecting groups to the National Programme and ensuring they have a voice in management decisions, and to help new groups form.

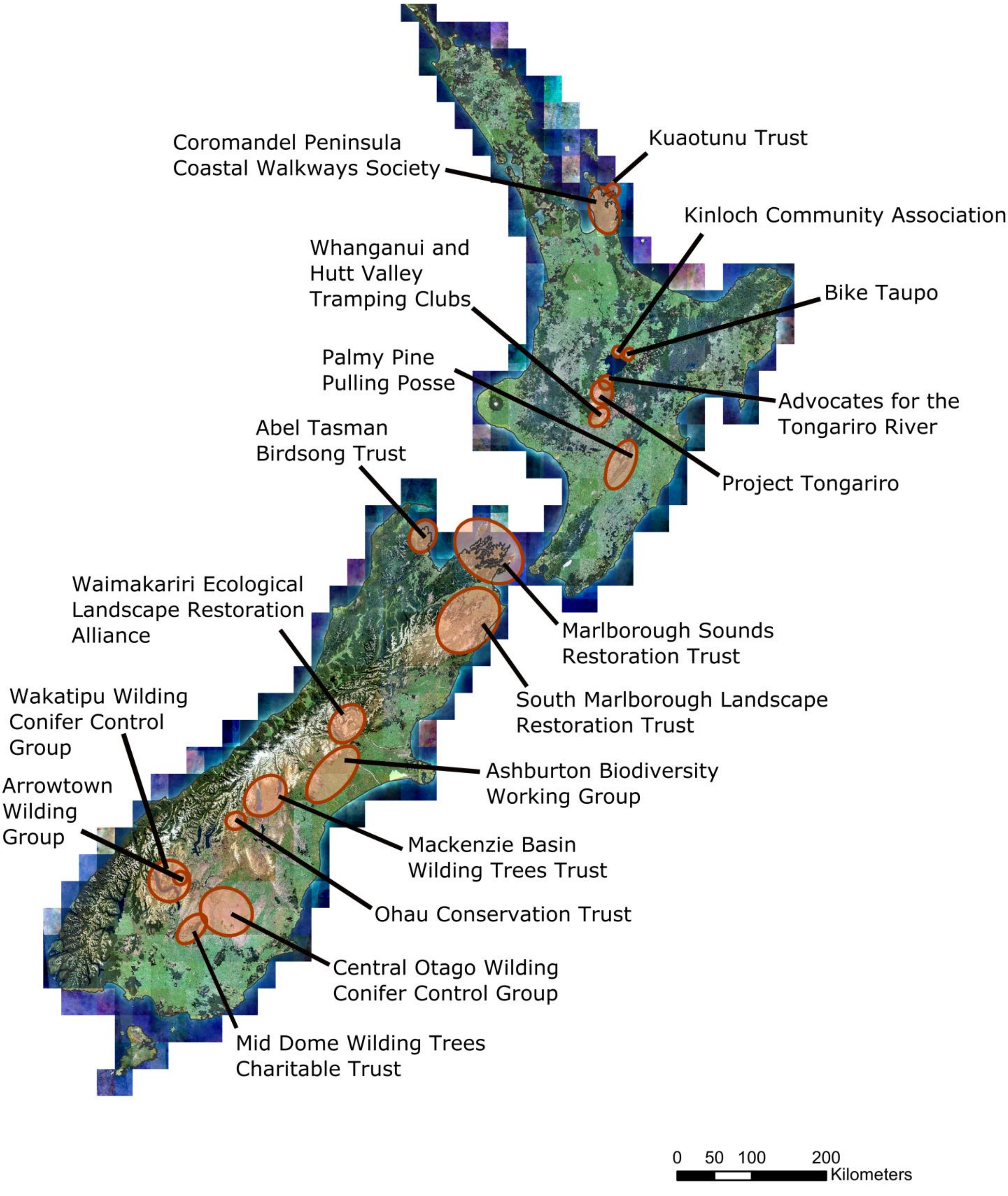

Figure 3. Locations of community groups involved in wilding conifer control and contacted by the NZWCG

Figure 4. The Whanganui and Hutt Valley Tramping Clubs pause for a group photo during their annual pine pulling weekend on the slopes of Mt Ruapehu. Photo taken by author.

Creating a bridge between science and management

Along with our work connecting with and mobilising communities, we also aim to link science and management. The Winning Against Wildings programme, funded by the Ministry of Business, Innovation, and Employment, is a research programme focused on wildings research aimed to assist management. I am working closely with researchers to update the wilding conifers website. I am also working to increase the visibility of current research and trying to strengthen the relationship and communication with operations managers.

The NZ Wilding Conifer Group is also seeking to act as a link between the National Wilding Conifer Control Programme and the Winning Against Wildings programme. The research projects can feed into different aspects of the National Programme, from increasing the efficacy of herbicides used and advising on where to survey for new wildings, to quantifying the impacts and legacies of wilding invasions and preventing future invasions. Additionally, as a community-based stakeholder group representing a wide range of organisations, the NZ Wilding Conifer Group is uniquely placed to advise these research projects and provide end-user feedback.

Wilding Free 2050?

We have no doubt heard about Predator Free 2050, but what about Wilding Free 2050? Is that goal even possible? There is a lot of work to do if we want to rid our

environment of wildings. While some success in wilding conifer control has been achieved to date, many areas are still affected. Additionally, the wilding conifer issue is complicated by the potential spread from plantation forests, with more forests predicted to be planted through the One Billion Trees Initiative and pressure from the plantation forests sector. Along with this, limited funding has hindered our ability to control wildings in all areas. The recent investment from the central government of $21 million over two years in this year's budget is not nearly enough to tackle this massive issue.

However, the commitment of community groups and the ability of many agencies to band together against the spread of wildings inspires me and gives me hope. Furthermore, the seed bank of exotic conifers is short-lived (approximately five years or less), and we know how effectively to kill these trees. The NZ Wilding Conifer Management Strategy proposes a reasonable stepping stone to Wilding Free 2050 by preventing the spread of wilding conifers and containing established conifer areas by 2030. Continuing on from there, if we all work together (and with more funding!), we can become Wilding Free by 2050 with appropriate measures in place to prevent any future spread from plantation forests.

Want to learn more or join a community group? Please get in touch with Rowan Sprague at rowan@nzwildingconifergroup.org.

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The growing role of botanic gardens to mitigate the impact of Invasive Alien Species

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Preamble

New Zealand faces immense, insidious and often irreversible economic, environmental and social impacts from Invasive Alien Species (IAS), including pests, diseases and weeds, to our valued productive and natural plant systems. Because of New Zealand's economic reliance on primary production, and our unique flora and fauna, this country is especially vulnerable to IAS. New Zealand's defence from IAS (i.e. border biosecurity) has been the top priority for our productive sector for the last nine years (KPMG 2019) and is a concern of many New Zealanders. Additionally, Biosecurity 2025 Strategic Direction 1 (1 of 5) "A Biosecurity Team of 4.7 Million" aims to make all New Zealanders aware of the importance of biosecurity and to get them involved in pest and disease management (MPI 2018). The goal of the Canterbury Botanical Society is "to promote interest in the study of botany, especially that of New Zealand, and in the preservation of plants and habitats, and to disseminate current scientific information specific to New Zealand botany". It is therefore within the stated concern, interest and capability of its members to become part of the solution to mitigate the impact of IAS to New Zealand's valued plants, species and systems. This article illustrates three areas where the New Zealand botanic community, and specifically botanical gardens, can make a difference to

mitigate the impact of IAS in the areas of biosecurity risk assessment, surveillance and awareness raising.

Introduction

New Zealand's relative isolation has provided it with a natural advantage to exclude the many pests, diseases and weeds that attack valued plant and animal systems overseas. However, the biosecurity challenges New Zealand faces are intensifying with changing trade, tourism and climate, and we need to respond accordingly. Despite a few well-publicised setbacks, there are positive signs that our biosecurity system is working. Analysis of invasion data indicates decreasing and static rates for the establishment of invasive insects and fungal pathogens, respectively. Overall the number of newly recorded insect species in New Zealand steadily increased from 1769 with pulses of establishment during 1920–25 and 1975–80, but since then the rate of non-native insect species establishing in NZ has been slowly decreasing (Edney-Browne et al. 2018). Similarly, the annual arrival rate of new fungal pathogens in New Zealand increased from 1880 to about 1980, but subsequently stabilised. Pathogen arrival rates for crop and pasture species declined in recent decades, but arrival rates increased for forestry and fruit tree species (Sikes et al. 2018). Notwithstanding the reasonable claim that New Zealand has one of the best biosecurity systems in the world, it cannot create perfect biosecurity. There will always be an ongoing need to do better.

Better Border Biosecurity (B3)

Better Border Biosecurity (B3) (http://b3nz.org/) acts as the pre-eminent research provider for science-based plant border biosecurity solutions in New Zealand and provides a single point access to the New Zealand science system for plant biosecurity research. B3's mission is to provide "science-based border biosecurity solutions underpinning the vitality of New Zealand's natural and productive plant landscapes (forestry, horticulture, arable, pastoral) and other plant-based industries, through a research-industry-government collaboration delivering world-leading science and technology development, enabling stakeholders to implement results for *better border biosecurity*". B3 especially targets cross-sectoral issues where plant pests, diseases and weeds do not respect the productive and natural system boundaries. Research Parties include: Plant & Food Research, AgResearch, Scion, Manaaki Whenua – Landcare Research and the Bio-Protection Research Centre hosted by Lincoln University. End-user Parties include: Ministry for Primary Industries (MPI), Department of Conservation, Forest Owners' Association, Horticulture NZ, The Environmental Protection Authority, and Beef and Lamb. Science provides the basis for an effective biosecurity system and B3 parties (science, government, and industry) co-innovate to ensure that research within the B3 suite of science projects is implemented into biosecurity outcomes. B3 researchers are increasingly involved with the translation of science to the broader community,

including hāpu/iwi, and are therefore playing an active role in growing New Zealand's "Biosecurity Team of 4.7 Million" as part of Biosecurity 2025 (MPI 2018).

Biosecurity 2025 re-emphasises our unquestionable need to reduce the cumulative impact of IAS on New Zealand's valued productive sector and natural ecosystems. The magnitude, complexity and sheer importance of the biosecurity challenge New Zealand faces dictate that everyone in New Zealand needs to be actively involved and the New Zealand botanical community, especially New Zealand botanic gardens, can have an ever increasing part to play in this.

There are many compelling reasons why **botanic gardens** can play an important role in plant border biosecurity. Botanic gardens have experienced staff with a wealth of knowledge of plant systems. They provide an incomparable source of curated plant specimens from a range of native and non-native species – often with known provenance; they often contain novel pest/plant host associations; they employ knowledgeable, experienced and enthusiastic people, sometimes with access to diagnostic capabilities; they have strong professional international connections; and they have access to informative international databases. Gardens can provide a source of easily accessible plants growing outside their native range. It is estimated that the more than 3000 botanic gardens worldwide have a wide geographical distribution and house an estimated 30–40% of known plants (K McDonnell/BGCI pers. comm.). The **International Plant Sentinel Network (IPSN)** (https://www.plantsentinel.org/) is a network of over 40 botanical gardens and arboreta from 17 countries including botanic gardens in Auckland, Wellington, Christchurch and Dunedin. It aims to provide an early warning system to recognise new and emerging pest risks and provide a network for exchanging information on plant health. IPSN sustains a network for both national and international partnerships between scientists and botanic gardens and arboreta around the world. B3 is a founding member of IPSN and maintains a role on the IPSN International Advisory Group.

This article provides some outstanding examples where botanic gardens can make a tangible difference to mitigate the impact of IAS through biosecurity risk assessment, surveillance and awareness raising.

Sentinel (expatriate) plants for biosecurity risk assessment

This concept is based on plant species being grown in overseas botanic gardens or arboreta where these plants may be exposed to pests and diseases they would not encounter, for example New Zealand plant specimens present in botanic gardens or arboreta overseas. B3 has developed a database for international gardens that contain significant planting of New Zealand native/indigenous plant species (http://b3.net.nz/expat/view.php) (Fig. 1). Information from these novel pest/plant interactions might then provide useful guidance on the potential damages caused if these pest and diseases were to invade New Zealand. The sentinel/expatriate approach can be particularly useful for native/indigenous plants that are predominantly grown in their native range and have limited international distribution and exposure to pests and pathogens. New Zealand native plants grown in botanic

gardens and arboreta overseas offer an elegant tool for biosecurity risk assessment for these plant species. The support from professionals located in international botanic gardens where New Zealand plants are present is critical to the success of this approach. B3 has been an international leader in the development of the sentinel/expatriate plants concept for plant border biosecurity (Fagan et al. 2008, Mansfield et al. 2019).

Figure 1. The New Zealand native/indigenous plant collection in the Royal Botanic Gardens Melbourne.

Perhaps the most useful example of this approach is a study by Groenteman et al. (2015) examining the status of the deadly plant pathogen *Xylella fastidiosa* and New Zealand indigenous plant species in California. Important information was gained on the host status of this plant pathogen on a range of New Zealand indigenous plant species. Another, but less successful example, is a project examining the status of myrtle rust on New Zealand Myrtaceae in international gardens (Marroni et al. 2018). Very little useful information for biosecurity risk assessors was obtained from this study. The sentinel plant concept works in the other direction as well, where New Zealand botanic gardens can inform other countries about the unique pest/plant associations found here. Such an approach was taken by B3 and Christchurch Botanic Gardens researchers to assess novel pine aphid/conifer tree interactions (Redlich et al. 2019). The study identified numerous novel insect-plant interactions that are likely

to materialise if these aphids colonise new host plants, confirming the utility of the plant sentinel approach.

Botanic gardens and arboreta provide a unique opportunity to assess the pests and diseases found inhabiting and damaging foreign plant species outside of their native distribution. However, the information gained from these assessments must be treated with some caution as foreign botanic gardens and arboreta will not necessarily reflect the conditions or factors represented in the disease triangle, an established plant pathology paradigm that is used to explain plant disease interactions. The host plant and plant pathogen factors are represented in foreign gardens but suitable or comparable environment conditions for disease expression may be absent.

Plant pest surveillance in botanic gardens

The combination of the wide range of plant species and experienced professionals within botanical gardens provides an opportunity to undertake strategic surveillance for pests, diseases and weeds.

In New Zealand, the Auckland Botanic Gardens carried out some of the first (and thereafter regular and ongoing) surveillance for myrtle rust starting in 2014 before this disease was found in New Zealand. Following detection in New Zealand, the main botanical gardens in Auckland, Wellington, Christchurch and Dunedin all contributed to the national surveillance programme for myrtle rust with additional data from a range of alternative sources (Campbell and Teulon 2018). There is no doubt that having more gardens involved in this programme would have been beneficial in understanding the distribution of myrtle rust as it spread throughout New Zealand (Fig. 2, p. 33). Auckland Botanic Gardens also hosts one of the many MPI High Risk Surveillance Sites where regular monitoring of plants occurs near likely points of pest entry, such as airports, seaports and container devanning sites (Stevens 2008).

New Zealand botanic gardens have also been involved in the development of a new surveillance initiative in Australia to establish a programme of plant pest surveillance within botanic gardens and arboreta facilitated by Plant Health Australia (http://www.planthealthaustralia.com.au/plant-pest-surveillance-in-botanic-gardens/). This is intended to become part of the Australia National Surveillance Framework. Australia has over 150 botanic gardens and arboreta that are spread around Australia holding a range of native flora, exotic species and relatives of crop species, and are visited by millions of people each year. This initiative recognises the unique resource of living plant collections in these gardens to provide vital information for plant health. A number of activities are underway to fully implement the programme, including: identification of priority target species based on the characteristics and location of each garden; the Australian National Priority Plant Pest list and the draft Environmental Priority Pest list; development of surveillance training methods and communication materials (i.e. for generic biosecurity/specific targets); agreement on the diagnostic resources needed for each garden; and access to appropriate data capture resources.

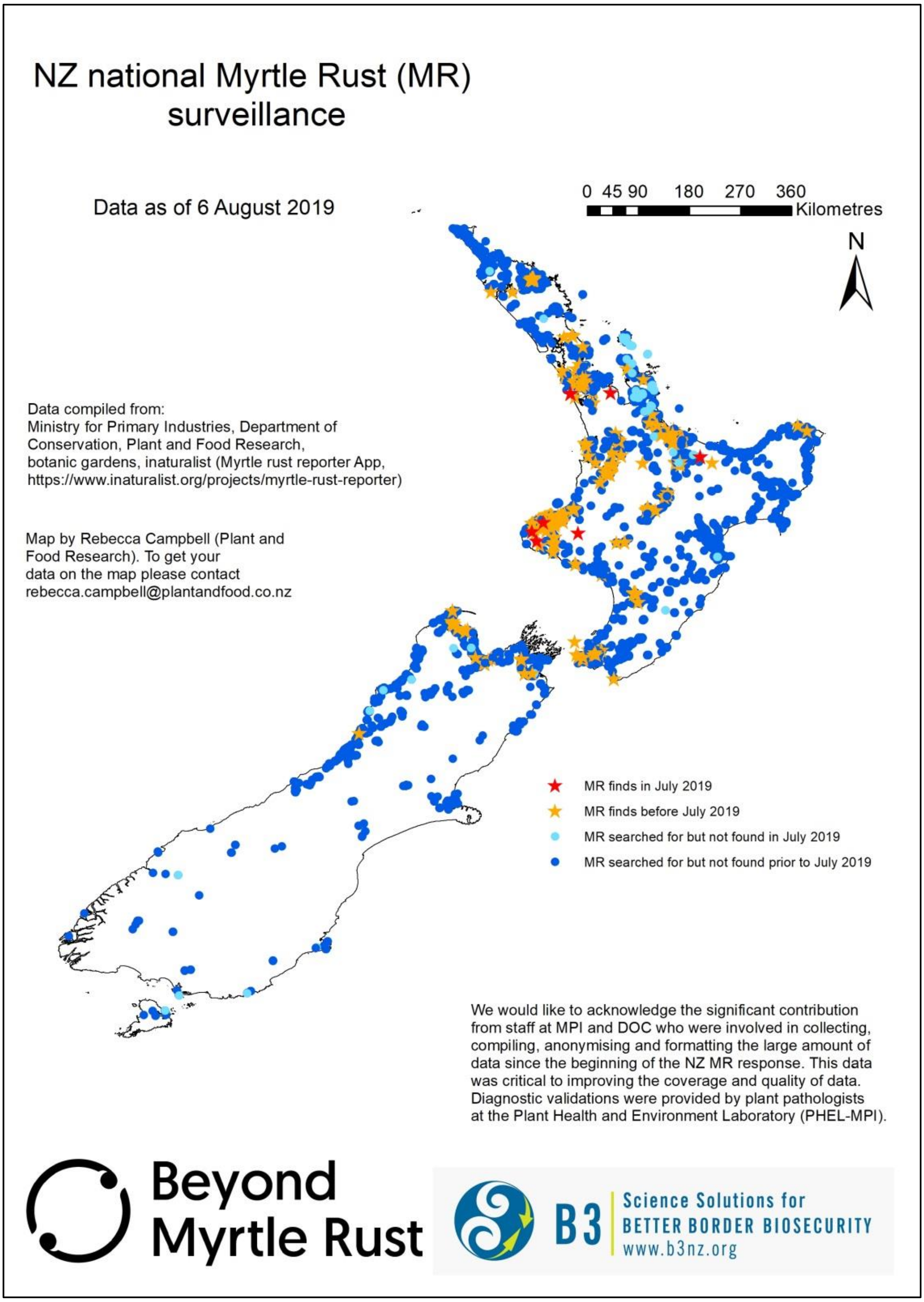

Figure 2. Myrtle rust distribution in July 2018. Four botanic gardens contributed surveillance data.

As noted above, *Xylella fastidiosa* is a devastating pathogen of many plant species, vectored by xylem-feeding insects. The pathogen is not found in New Zealand but it is of considerable biosecurity concern to both our introduced and indigenous plant species. One of the known vectors of *Xylella*, the exotic spittlebug *Philaenus spumarius* is found in New Zealand, as are several indigenous spittlebugs and

indigenous cicadas (Hamilton and Morales 1992) of unknown vector status. Botanic gardens in the United Kingdom (UK) took part in a crowd-sourced survey to improve understanding of host plants of spittlebugs in the UK (Fig. 3). Spittlebugs provide an ideal model for 'citizen' participation because of the very obvious spit ('cuckoo spit') they produce when feeding. The results from this survey expanded the list of potential hosts of spittlebugs for the UK, demonstrated the range of managed and unmanaged habitats that spittlebugs can been found in, emphasised the widespread distribution of spittlebugs in the UK, and provided information on the time of year when spittlebug larvae are active. Similar information could be useful in New Zealand and could be co-ordinated through the New Zealand botanic gardens network.

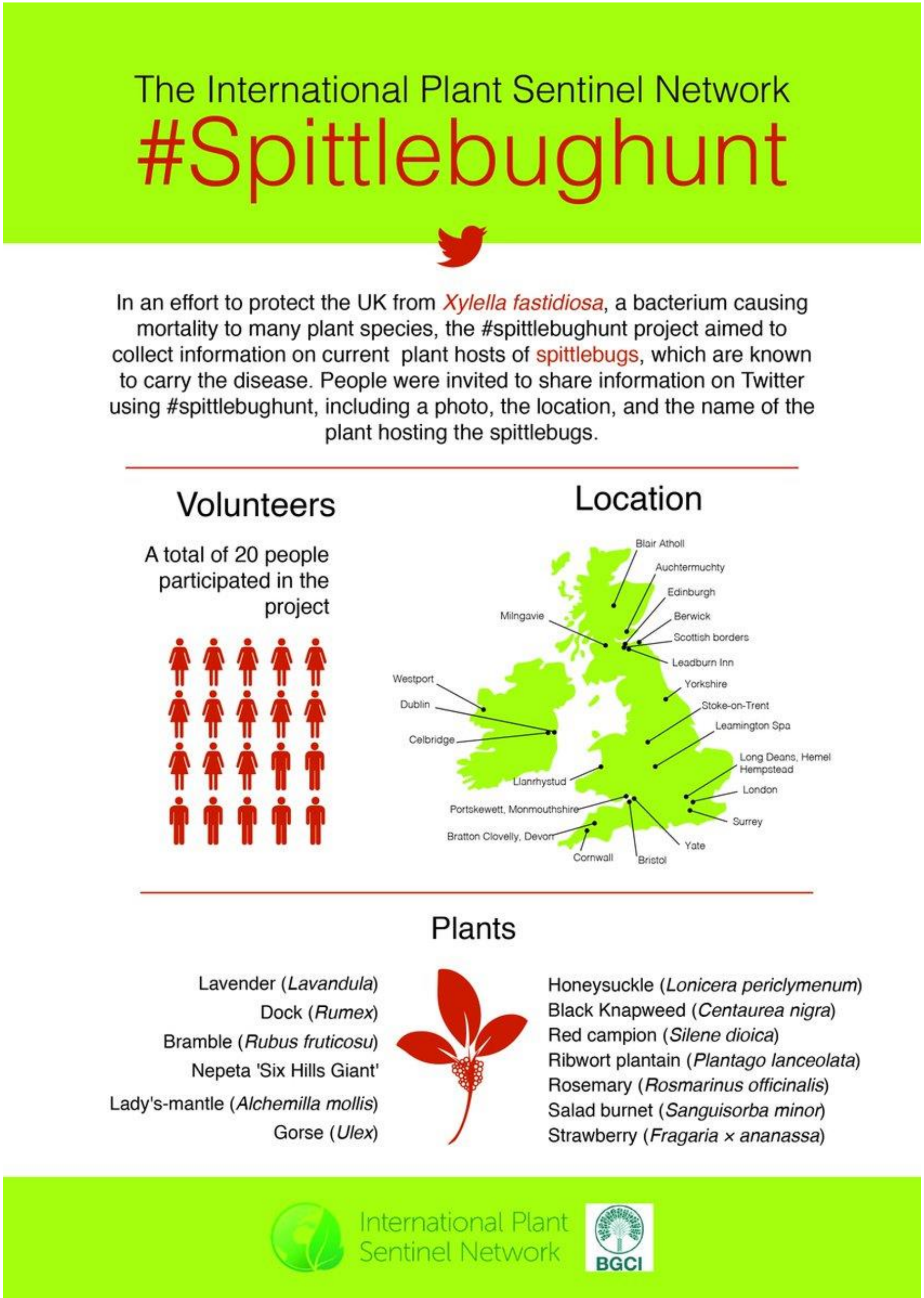

Figure 3. The International Plant Sentinel Network spittlebug hunt in the United Kingdom (IPSN no date).

Biosecurity trail

Botanic gardens receive millions of visitors each year with interests in the plants found within those gardens and presumably their continued health. This provides a great opportunity to get across the important issues relating to plant biosecurity. A new walking trail at the Auckland Botanic Gardens provides an opportunity for local and overseas visitors to learn about New Zealand's flora as well as their potential role in protecting it. The Biosecurity Trail is a collaboration between B3 and the Auckland Botanic Gardens. Visitors can embark on a 1.8-km walk around the garden and discover biosecurity facts at their own pace as they admire more than 10,000 native and exotic plants. *Ko Tātou This Is Us,* an initiative under Biosecurity 2025 (https://www.thisisus.nz), is also promoted within the trail. *Ko Tātou* recognises the role that every New Zealander needs to play in preventing pests and diseases from getting into New Zealand, or helping to stop their spread if they do get here. Brief information about pests and diseases that threaten New Zealand's flora and primary industries, including brown marmorated stink bug, myrtle rust and kauri dieback, is displayed at each of the 12 check points along the path (Table 1). Visitors can scan the QR code at each checkpoint to be directed to either a video or website for additional information on the pest or the disease and how to prevent its spread (Fig. 4, p. 36). While locals are encouraged to experience the trail, the project team wanted to raise biosecurity awareness amongst overseas visitors too.

Table 1. Pest and disease organisms profiled in the Auckland Botanic Gardens Biosecurity Trail

Site	Common name	Species	Organism	Primary system
1	Red imported fire ant	*Solenopsis invicta*	Insect	Natural
2	Myrtle rust	*Austropuccinia psidii*	Pathogen	Natural
3	Queensland fruit fly	*Bactrocera tryoni*	Insect	Horticulture
4	Brown marmorated stink bug	*Halyomorpha halys*	Insect	Horticulture
5	Pierce's disease of grape	*Xylella fastidiosa*	Pathogen	Horticulture
6	Nun moth	*Lymantria monacha*	Insect	Forest
7	Maize rough dwarf disease	*Fijivirus* spp.	Pathogen	Pasture
8	Pitch canker	*Fusarium circinatum*	Pathogen	Forest
9	Kauri dieback	*Phytophthora agathidicida*	Pathogen	Natural
10	Ceratocystis wilt	*Ceratocystis fimbriata*	Pathogen	Natural
11	Clover weevil	*Sitona hispidulus*	Insect	Pasture
12	Asian citrus psyllid	*Diaphorina citri*	Insect	Horticulture

Figure 4. Visitors to the Auckland Botanic Gardens Biosecurity Trail can scan the QR code at each check point to be directed to either a video or website for additional information on the pest or the disease and how to prevent its spread (photo credit Plant & Food Research).

Auckland Botanic Gardens has about 1.2 million visitors per year with about 15% of them coming from overseas, and the Gardens could be the first stop for many of them. The intention of the trail is that visitors can apply the new knowledge they gain to the rest of their stay in New Zealand to help to control existing diseases, e.g. by cleaning their shoes before and after heading into the forest to help stop the spread of kauri dieback. While the trail will help raise the profile of invasive pests and diseases with overseas visitors and the general public, aligned research on the trail will be used to improve New Zealand's biosecurity system. The insights that visitors gain on the Auckland Botanic Gardens Trail can be a significant way of engaging them with this important topic. The trail entered a 12-month trial period in April 2019, during which time it will continue to be improved on from the experience gained by feedback from visitors. Information sheets in other major languages, in addition to English, will become available at this time.

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What do we do with the weeds of Canterbury?

Emerging biosecurity risks for Canterbury's natural biota and timely responses

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Summary

Canterbury's biodiversity, natural heritage and landscape character of forest, woodland, shrubland, grassland, and wetland is dependent on maintaining a critical mass of un-cultivated habitat (>10% of total area – Meurk and Hall 2006), protecting viable populations of all indigenous species by removing degrading factors and processes (browsing and predatory mammals, and competitive exotic plants), and promoting the positive (habitat restoration and landscape/habitat patch connectivity). A culturally necessary complement to this is a strong visibility of native species, vegetation and wildlife that engender identity and protectiveness. The continual invasive and deliberate spread of visually dominating exotic species undermines this outcome. This paper draws on our latest understanding of weed threats on a national and Canterbury regional scale. It extracts the ranked threat level of ca. 200 exotic species from the iNaturalist NZ – Mātaki Taiao citizen science website. We comment on priority and nuanced management of exotic plants based on well-established,

legally sanctioned, consensus-determined (or ecologically predicted) weed species, emerging threats, and attrition of natural character through deliberate designing of exotic species into prominent locations based on fashion and marketing rather than historic or ecologic connection to this land. This appears to fly in the face of one of Landscape Architecture's key tenets: legibility. We need to address all 200 of the species listed, but if we were to pick some special concerns that deserve renewed attention (whether it's mechanical, chemical, biocontrol, or through managed competition) our not-so-short list for Canterbury, in no particular order, is: sycamore, blackberry, holly, ivy, Russell lupin, *Myricaria*, hanging sedge, grey willow, barberry, cotoneaster, boxthorn, arum, veldt grass, hawthorn, irises, conifers, banana passionfruits, male and female ferns, common polypody, Chilean flame creeper, cherry laurel, Spanish heath, heather, sweet briar, aralia, onion weed, mayten, pig's ear (and other succulents), rowan, beggars' ticks, yew, silver birch, alder, ash, tree of heaven, bay, river lily, and horse chestnut.

Introduction

New plant pests are continually entering or establishing in the Canterbury Region from a large pool of naturalised exotic species (Meurk 1996; Meurk 2008, p. 221 and Table 2). Whereas blanket spraying or mechanical removal may work to remove weeds in agricultural or industrial landscapes (notwithstanding growing concerns about human and ecological health impacts), many native plant communities are being threatened by a Trojan Horse effect. This is where an initial exotic plant entry into tussockland, grey shrubland or forest understorey is undetected or ignored and a seed bank becomes established. Broadcast chemical or mechanical control, or fire, from then on creates (disturbance) conditions that usually favours further retreat of the sensitive indigenous component and proliferation or spread of continentally adapted weeds. This is typically happening with broom among high country matagouri, veldt grass in lowland forest, and hanging sedge along riverbanks. Scattered roadside remnants of native shrubs are being mistaken for shrub weeds and sprayed out – often leaving the exotics to prosper. Loss of local ecological authenticity is also being perpetuated by well-meaning but unknowing professionals and home gardeners who are operating with limited palettes of (indigenous) species or ecological knowledge. They promote plant aesthetics and fashions that have unintended consequences, propagate weed species through neighbourly sharing, or dig up attractive and vigorous exotic or non-ecosourced native species from their gardens for community restoration projects, school fairs, garage sales and roadside stalls.

Here we will touch on these emerging biosecurity threats (species-specific, ecological, socio-cultural and economic) to biodiversity and natural landscape character, and strategic actions needed to combat these ecological and cultural, even existential, threats.

What is a weed?

When is a weed a weed? There are both popular/sociological and ecological definitions of this concept. Socio-culturally a weed is a plant growing in the wrong place, that is, simply an “unwanted plant” from a particular cultural perspective (putting aside various other metaphorical applications). Ecologically a weed is a plant species that typically pioneers open, bare or disturbed ground. Weeds have been called ruderals (Grime 1979) or r-selected species, which have the characteristics of prolific seed production and rapid growth or colonising ability. Often they are light-demanding annuals, biennials or short-lived perennials that can quickly occupy a site and stabilise it or provide a substrate for later successional species (tall perennial grasses, shrubs and trees) (see Burrows 1990). Typically, such species are legumes (clovers, lupins, brooms), grasses, daisies, docks and chickweeds that like fresh soils, rich in mineral nutrients but low in organic matter and nitrogen (e.g. riverbeds), and the absence of competition (bare soil). They produce abundant, often wind or water-dispersed, seed.

The English ecologist, Philip Grime (1979), developed a model for plant strategies: the Competitor - Stress Tolerator - Ruderal (CSR) triangle. Application to the real world is a little problematic as many plant species have a little bit of everything. Take, for example, our native mountain beech (and many of our forest species). They are both colonising species, requiring light to stimulate growth to adulthood, and tolerating relatively cold conditions and low soil fertility in order to avoid competition, yet they are quite long-lived and competitive in their montane environment (“climax” species in old Clementsian terminology).

Whether a plant is in the “wrong place” is a matter of attitude, knowledge and human desire to power over the environment. In post-earthquake Christchurch the “weedy” rubble of the inner city has been condemned by city leaders espousing traditional values of tidiness, control, even sanitisation. In fact, it is likely that such fastidiousness is a minority view but one that has a loud voice. And yet, almost paradoxically, (west) Berlin instigated a no-spray regime in the city more than 30 years ago, and this allowed for many ruderal ”weeds” to grow in footpath cracks and edges, rock walls, grass verges, and gutters – where rampant growth is contained mechanically. In a sense this mimics, in a semi-controlled way, the natural habitats of riverbeds, sand dunes, cliffs and crags. Such artificial alternatives have been termed “surrogate” habitats. Indeed, the whole discipline of urban ecology was largely instigated out of WWII rubble where these plant successions were given freedom to develop (mainly because of the enormity of control costs and therefore delays to reconstruction) and produce novel insights into plant ecology in general. To some extent it is being rediscovered in the international “urban wild” movement today. There are ways of accommodating the range of human aesthetics and sensitivities to landscape through what Joan Nassauer called “cues for care” in which “messy ecosystems” may be contained within “tidy frames” (Nassauer 1995).

Weeds are thus part of natural succession, but introduced species having evolved in continental, mammal-driven ecosystems are generally much more successful as

weeds than their indigenous counterparts. Nevertheless, we can, in cultural landscapes, engineer stressed (coarse or shallow) substrate and continually disturbed (grazed, mown, gardened) environments that reduce competition from exotic species and allow the indigenes to persist or co-exist. Landscape management to accommodate all these seral stages, and the greatest array of native species, needs therefore to operate across gradients of natural stress and disturbance (Meurk and Greenup 2003).

Introduced species may be categorised according to their relative benign-ness or invasiveness and their management profile; although with changing climates, adaptation, or new-found fertility, species may move from one (benign) category to another more aggressive one; or from a sterile to fertile state. All ecosystems in the world are now regarded as "recombinant" (Meurk 2011). We will never, nor would we want to, get rid of all alien species. As Meurk (2011) surmised, there are beneficial, benign, honorary native, invasive, and non-provenance introductions in any landscape. However, New Zealand has special value and high vulnerability in terms of its unique endemic biota due to its Gondwanic connections and long evolutionary isolation (Meurk 1995; 2007; see McGlone 2006 for contemporary thinking on the origins and formulation of our biota).

Management of these threats to productive or natural ecosystems in Canterbury comes from international or North Island experience of species, the latter being the entry point for many exotics. High priority is given to those where border control can prevent initial entry or establishment (**exclusion** species in national pest management terms), or **eradication** can be contemplated early in their establishment phase. Those that are widely established, but which are still spreading, come under a **sustained control** or **progressive containment** regime. **Site-led suppression** applies to places of high ecological value where local eradication is pursued.

However, there are many that are never going to be eliminated across a whole region with current technology and are relatively benign or even offer some values to, for example, native wildlife. The few that may fall into this category are either relatively low-growing, shade-intolerant, mammal-palatable, poorly dispersed, or non-exclusive competitors. These may be termed **co-existent** species. And then there are the **productive species** our economy depends upon and ideally are also dependent on our active management to maintain them. That is, they don't prosper in the wild. Among the worst combination of characteristics for alien forest species are those that are evergreen, shade-tolerant, unpalatable, and bird-dispersed. However, wind-dispersed pines invade non-forest areas and shade-tolerant Douglas fir can displace montane native forests (Meurk and Hall 2006).

A recent publication by Wotton and McAlpine (2013) collates current knowledge about the role of different exotic species as potential nurseries for native plant succession. The classic exemplar of this notion has been the management of the Hinewai Reserve on Banks Peninsula (Wilson 1994). They highlight the plant traits and environmental conditions associated with facultative versus disabling or suppressive, and therefore undesirable colonising species. In general exotic forbs are

least competitive. Some exotic trees/shrubs provide shelter for regeneration. However, shade-intolerance in nursery canopy species is vital to facilitate native forest succession. In addition, a nearby native seed source with frugivorous bush birds within a moist climate and low browsing regime, and permanent suppression of fire are prerequisites for this concept to work for conservation.

Of the more than 30,000 exotic vascular plant species in New Zealand (cf. to about 2,600 indigenous; http://www.nzpcn.org.nz/) most are regarded as non-naturalised so have only a passive expression in the (internal, protected garden) landscape. These include indoor pot plants, sterile species or hybrids, cultivars or crop plants that require continual human support to survive. The wild exotic plants in New Zealand now outnumber the native flora (https://www.mfe.govt.nz/environment-aotearoa-2019-summary). Of these, 43 are officially declared pests of Canterbury (Table 1 - from ECan), and an additional 58 are classed as "Species of Interest" (including unwanted plants, Table 2). These latter category names are somewhat euphemistic when they present a "serious problem" but are so embedded, ecologically and/or socio-culturally, that they pose an insurmountable challenge to control. This doesn't mean we should give up. The consequences of giving up are serious not just because of economic impacts, but because it would undermine the whole Aotearoa – NZ identity and further fuel the extinction of experience that our urban and rural culture already suffers. With likely smaller discretionary budgets in future, if we aren't proactive, we may never again have the resources to act. This will strip away one of the tenets of well-being: a sense of place and point of difference, perhaps also the basis for future low impact tourism.

The following lists (Tables 1 and 2) are based on national concerns, compiled by biosecurity experts, drawing on international or national knowledge of species invasiveness. Table 1 is largely (apart from gorse, broom, boneseed and banana passionfruit) species that have not yet established in Canterbury and are intended to be prevented from entering the region, or will be eradicated if already present in small numbers.

Table 1: Declared pests of Canterbury in alphabetical order by common name (Total = 43; source Environment Canterbury).

African feather grass (*Cenchrus macrourus*), African love grass (*Eragrostis curvula*), baccharis (*Baccharis halimifolia*), banana and other passionfruit (*Passiflora tripartita* var. *mollissima*, *P. tripartita* var. *azuayansis*, *P. tarminiana*, *P. pinnatistipula*, *Passiflora* x *rosea*, *P. caerulea*), bell heather (*Erica cinerea*), boneseed (*Chrysanthemoides monilifera*), broom (*Cytisus scoparius, C. multiflorus, Teline monspessulana*), bur daisy (*Calotis lappulacea*), cathedral bells (*Cobaea scandens*), Chilean needle grass (*Nassella neesiana*), coltsfoot (*Tussilago farfara*), Darwin's barberry (*Berberis darwinii*), egeria (*Egeria densai*), entire marshwort (*Nymphoides

geminata), gorse (*Ulex europaeus*), Japanese, giant and Indian/Himalayan knotweed (*Fallopia japonica*, *F. sachalinensis* and *Persicaria wallichii*), nassella tussock (*Nassella trichotoma*), moth plant (*Araujia sericifera*), old man's beard (*Clematis vitalba*), phragmites (*Phragmites australis*), puna grass (*Achnatherum caudatum*), purple loosestrife (*Lythrum salicaria*), saffron thistle (*Carthamus lanatus*), spartina (*Spartina anglica*), wilding conifers (*Pinus contorta*, *P. nigra*, *P. sylvestris*, *P. uncinata*, *P. mugo* and *Larix decidua*), wild Russell lupin (*Lupinus polyphyllus*), white-edged nightshade (*Solanum marginatum*), wild thyme (*Thymus vulgaris*), yellow bristle grass (*Setaria pumila*), yellow water lily (*Nuphar lutea*).

Table 2: Species of Interest in Canterbury (*Total = 58;* * = unwanted organisms; source Environment Canterbury). Plant species that are largely already established in Canterbury but are in a control and containment category because of their known propensity to spread.

Ash *(Fraxinus excelsior),* barberry *(Berberis glaucocarpa),* Bathurst bur *(Xanthium spinosum),* beggars' ticks *(Bidens frondosa),* Bermuda buttercup *(Oxalis pes-caprae),* blackberry agg. *(Rubus fruticosus agg.),* boxthorn *(Lycium ferocissimum),* buddleja *(Buddleja davidii,* excluding hybrids*),* burdock *(Arctium minus),* reed canary grass *(Phalaris arundinacea),* Cape honey flower *(Melianthus major),* Cape ivy *(Senecio angulatus),* hanging sedge *(Carex pendula*),* Chilean flamecreeper *(Tropaeolum speciosum*),* Chilean glory vine *(Eccremocarpus scaber*),* Chilean mayten *(Maytenus boaria*),* common polypody *(Polypodium vulgare),* false tamarisk *(Myricaria germanica),* German ivy *(Senecio mikanioides),* goat's rue *(Galega officinalis),* hawthorn *(Crataegus monogyna),* hemlock *(Conium maculatum),* hawkweed *(Hieracium spp.*),* Himalayan balsam *(Impatiens glandulifera),* Himalayan honeysuckle *(Leycesteria formosa),* holly *(Ilex aquifolium),* horsetail *(Equisetum hyemale),* horehound *(Marrubium vulgare),* mistflower *(Ageratina riparia),* nardoo *(Marsilea mutica),* parrot's feather *(Myriophyllum demersum),* perennial nettle *(Urtica dioica),* pig's ear *(Cotyledon orbiculata),* plectranthus *(Plectranthus grandis*),* plumeless thistle *(Carduus acanthoides),* Chinese privet *(Ligustrum sinense),* ragwort *(Senecio jacobaea),* red flowering currant *(Ribes sanguineum),* rowan *(Sorbus aucuparia),* rum cherry *(Prunus serotina),* sagittaria *(Sagittaria platyphylla),* Senegal tea *(Gymnocoronis spilanthoides),* sheep's bur *(Acaena agnipila),* birch *(Betula pendula),* Spanish heath *(Erica lusitanica),* spur

valerian *(Centranthus ruber),* spurge laurel *(Daphne laureola),* St John's wort *(Hypericum perforatum),* sweet briar *(Rosa rubiginosa),* sweet reed grass *(Glyceria maxima),* sycamore *(Acer pseudoplatanus),* tree lucerne *(Chamaecytisus palmensis / Cytisus proliferus),* tree lupin *(Lupinus arboreus),* variegated thistle *(Silybum marianum),* viper's bugloss *(Echium vulgare),* wild cotoneaster *(Cotoneaster glaucophyllus and C. franchetii*),* wild elaeagnus *(Elaeagnus x reflexa).*

Information from iNaturalist NZ – Mātaki Taiao

We have another source of information via the citizen science platform iNaturalist NZ – Mātaki Taiao (Sullivan et al. 2019). The Project – "Pest Plants (weeds) of NZ" (see https://inaturalist.nz/projects/pest-plants-weeds-of-nz) records community-reported occurrences of plants deemed by the observer to be "pesky" in some weedy way. That is, it is accumulated wisdom, or a kind of consensus, among 377 observers around the country who have judged a species to be invasive and therefore potentially transformative to ecosystems.

The 991 species from 10,220 New Zealand observations made by 377 people (as at 22 October 2019) have been arranged according to the number of times they occur in this national database (Table 3, p.45). When the data are filtered for species reported as weeds in Canterbury there are 2,967 observations of 417 species recorded by 125 people; see https://inaturalist.nz/observations?place_id=82108&project_id=pest-plants-weeds-of-nz&verifiable=any). The species order is much the same although some species move up or down in prominence, reflecting the regional rather than national situation. For instance, old man's beard is the most frequently recorded weed on the national list (Table 3), but in Canterbury it is ranked second behind the highest ranked grey willow, which is ninth on the national list. The names of the species reported as weeds in Canterbury are shown in bold, along with their rank order number for Canterbury (Table 3).

The species that are currently confined to other, typically more northern, districts could arrive in Canterbury through normal migration, possibly accelerated by climate change. For instance, kahili ginger does not rank at all in Canterbury but comes seventh in the national Pest Plants (weeds) of NZ list (Table 3). Sullivan et al. (2019) document examples of recent incursions reported on iNaturalist NZ.

Table 3. Weed species occurrences throughout New Zealand as recorded in the iNaturalist NZ – Mātaki Taiao database as at 22 October 2019 arranged according to the number of times they have been reported from 10,220 observations (most frequent first). The **bolded species names** and **numbers** indicate species reported as occurring problematically in Canterbury and the rank order of the respective species in the region (as distinct from the order based on national data).

≥17 records in New Zealand

Old man's beard 2 (*Clematis vitalba*), **ivy 5** (*Hedera helix*), **wandering willy 12** (*Tradescantia fluminensis*), **Japanese honeysuckle 37** (*Lonicera japonica*), **gorse 6** (*Ulex europaeus*), **blackberry 7** (*Rubus fruticosus* agg.), kahili ginger (*Hedychium gardnerianum*), **sycamore 3** (*Acer pseudoplatanus*), **grey willow 1** (*Salix cinerea*), **tree privet 217** (*Ligustrum lucidum*), Moreton Bay fig (*Ficus macrophylla*), **Scottish broom 4** (*Cytisus scoparius*), woolly nightshade (*Solanum mauritianum*), **climbing asparagus 60** (*Asparagus scandens*), **Darwin's barberry 70** (*Berberis darwinii*), **arum lily 33** (*Zantedeschia aethiopica*), **montbretia 38** (*Crocosmia* x *crocosmiiflora*), **brush wattle 87** (*Paraserianthes lophantha*), **boneseed 8** (*Osteospermum moniliferum*), **common pampas grass 163** (*Cortaderia selloana*), **agapanthus 102** (*Agapanthus praecox*), Krauss's spikemoss (*Selaginella kraussiana*), **ragwort 36** (*Jacobaea vulgaris*), **veldt grass 30** (*Ehrharta erecta*), **Himalayan honeysuckle 66** (*Leycestaria formosa*), **Chinese privet 230** (*Ligustrum sinense*), **European holly 22** (*Ilex aquifolium*), **hawthorn 15** (*Crataegus monogyna*), **stinking iris 11** (*Iris foetidissima*), **boxthorn 18** (*Lycium ferocissimum*), **moth plant 396** (*Araujia hortorum*), **Chilean rhubarb 26** (*Gunnera tinctoria*), tuber ladder fern (*Nephrolepis cordifolia*), **tree lupin 34** (*Lupinus arboreus*), **Mexican daisy 48** (*Erigeron karvinskianus*), **tutsan 62** (*Hypericum androsaemum*), **elderberry 10** (*Sambucus nigra*), blue corn lily (*Aristea ecklonii*), **European spindle tree 9** (*Euonymus europaeus*), **butterfly bush 58** (*Buddleja davidii*), **banana passionfruit 27** (*Passiflora tripartita*), kikuyu (*Pennisetum clandestinum*), **large bindweed 23** (*Calystegia sylvatica*), **periwinkle 21** (*Vinca major*), **German ivy 51** (*Delairea odorata*), **Monterey pine 106** (*Pinus radiata*), **male fern 16** (*Dryopteris filix-mas*), **hanging sedge 14** (*Carex pendula*), **Chilean flame creeper 32** (*Tropaeolum speciosum*), **common polypody 13** (*Polypodium vulgare*), **phoenix palm 71** (*Phoenix canariensis*), **wine raspberry 351** (*Rubus phoenicolasius*), coral tree (*Erythrina* x *sykesii*), **spear thistle 96** (*Cirsium vulgare*), **tall flat sedge 31** (*Cyperus eragrostis*), **cherry laurel 40** (*Prunus laurocerasus*), **Spanish heath 115** (*Erica lusitanica*), **blue morning glory 216** (*Ipomoea indica*), **aluminium plant 42** (*Lamium galeobdolon*), **sweet briar 19** (*Rosa rubiginosa*), **pink jasmine 381** (*Jasminum polyanthum*), **great barberry 77** (*Berberis glaucocarpa*), **fennel 61** (*Foeniculum vulgare*), **Japanese aralia 41** (*Fatsia japonica*), **giant hogweed 17** (*Heracleum mantegazzianum*), **Himalayan corokia 44** (*Corokia simonsii*), **crack**

willow 24 (*Salix fragilis*), **yellow flag iris 25** (*Iris pseudacorus*), bulbil bugle lily (*Watsonia meriana*), **onion weed 90** (*Allium triquetrum*), **red valerian 29** (*Centranthus ruber*), creeping buttercup (*Ranunculus repens*), **mayten 20** (*Maytenus boaria*), **cape honey flower 233** (*Melianthus major*), pink ragwort (*Senecio glastifolius*), **Douglas fir 145** (*Pseudotsuga menziesii*), **pig's ear 28** (*Cotyledon orbiculata*), **giant reed 323** (*Arundo donax*), prickly hakea (*Hakea sericea*), **flowering currant 64** (*Ribes sanguineum*), **monkey musk 45** (*Erythranthe guttata*), **rowan 46** (*Sorbus aucuparia*), **large-leaf cotoneaster 118** (*Cotoneaster glaucophyllus*), **elaeagnus 395** (*Elaeagnus* x *reflexa*), **Himalayan balsam 49** (*Impatiens glandulifera*), **cape ivy 240** (*Senecio angulatus*), **beggars' ticks 55** (*Bidens frondosa*), foxglove (*Digitalis purpureus*), **Russell lupin 43** (*Lupinus polyphyllus*), **purple loosestrife 35** (*Lythrum salicaria*), **Chusan palm 132** (*Trachycarpus fortunei*), **bear's breeches 99** (*Acanthus mollis*), **yew 54** (*Taxus baccata*), **hemlock 68** (*Conium maculatum*), **stonecrop 39** (*Sedum acre*), **Madeira vine 133** (*Anredera cordifolia*), bangelow palm (*Archontophoenix cunninghamii*), **inkweed 178** (*Phytolacca octandra*), **variegated thistle 78** (*Silybum marianum*), common honeysuckle (*Lonicera periclymenum)*, **Cape weed 57** (*Arctotheca calendula*), **bridal creeper 84** (*Asparagus asparagoides*), queen palm (*Syagrus romanzoffiana*), **velvety nightshade 52** (*Solanum chenopodioides*), Cretan brake (*Pteris cretica*), **greater birdsfoot trefoil 142** (*Lotus pedunculatus*), **mouse-ear hawkweed 50** (*Pilosella officinarum*), **lodgepole pine 67** (*Pinus contorta*), **African ice-plant 89** (*Carpobrotus edulis*), **purple pampas 80** (*Cortaderia jubata*), **silver birch 59** (*Betula pendula*), nasturtium (*Tropaeolum majus*), **thorn apple 108** (*Datura stramonium*), **marram grass 130** (*Ammophila arenaria*), Sydney golden wattle (*Acacia longifolia*), **loquat 337** (*Eriobotrya japonica*), **red-purple ragwort 101** (*Senecio elegans*), black nightshade (*Solanum nigrum*), monkey apple (*Syzygium smithii*), **Chilean glory creeper 53** (*Eccremocarpus scaber*), **pride of Madeira 46** (*Echium candicans*), **Franchet's cotoneaster 85** (*Cotoneaster franchetii*), **evergreen buckthorn 117** (*Rhamnus alaternus*), banana passionfruit (*Passiflora mollissima*), mile a minute (*Dipogon lignosus*). Total = 125 species.

≥10 records in New Zealand

Species shown only those relevant to Canterbury at present.

Alligator weed (*Alternanthera philoxeroides*), heather (*Calluna vulgaris*), **late cotoneaster 121** (*Cotoneaster coriaceus*), **Californian thistle 91** (*Cirsium arvense*), moth plant (*Araujia sericifera*), **California poppy 62** (*Eschscholzia californica*), **plums & cherries 92** (*Prunus* spp.), **coastal banksia 372** (*Banksia integrifolia*), **lantana 252** (*Lantana camara*), **French broom 105** (Genista monspessulana), **European alder 81** (*Alnus glutinosa*), **black locust 73** (*Robinia pseudoacacia*),

impatiens (*Impatiens walleriana*), **nodding thistle 86** (*Carduus nutans*), mist flower (*Ageratina riparia*), **gooseberry 82** (*Ribes uva-crispa*), **tree of heaven 74** (*Ailanthus altissima*), Mexican devil (*Ageratina adenophora*), **caper spurge 170** (*Euphorbia lathyris*), **green daphne laurel 176** (*Daphne laureola*), **bay laurel 107** (*Laurus nobilis*), parrot's feather (*Myriophyllum aquaticum*), **reed canary grass 69** (*Phalaris arundinacea*), **Australian sheep's burr 76** (*Acaena agnipila*), **myricaria 72** (*Myricaria germanica*), **lady fern 79** (*Athyrium filix-femina*), **wild parsnip 98** (*Pastinaca sativa*). Total = 27 species.

≥5 records in New Zealand

Species shown only those relevant to Canterbury at present.

Common rhododendron (*Rhododendron ponticum*), **giant vipers-bugloss 168** (*Echium pininana*), heath rush (*Juncus squarrosus*), **lesser burdock 112** (*Arctium minus*), **karo 136** (*Pittosporum crassifolium*), **lesser celandine 119** (*Ficaria verna*), **common cordgrass 88** (*Sporobolus anglicus*), **white poplar 122** (*Populus alba*), **field & rough horsetail 94** (*Equisetum arvense* & *E. hyemale*), **Chilean ice plant 127** (*Carpobrotus chilensis*), **blue sedge 179** (*Carex flacca*), **river lily 182** (*Hesperantha coccinea*), **slender winged thistle 194** (*Carduus pycnocephalus*), **ivy-leaved toadflax 200** (*Cymbalaria muralis*), **kiwifruit 285** (*Actinidium sinense*), **pellitory of the wall 304** (*Parietaria judaica*), **cutleaf blackberry 173** (*Rubus laciniatus*), **Canadian pondweed 169** (*Elodea canadensis*), **evening primrose 209** (*Oenothera glasioviana*, *O. stricta*), **crisp-leaved pondweed 116** (*Potamogeton crispus*), American pokeweed (*Phytolacca americana*), hornwort (*Ceratophyllum demersum*), **red fescue 113** (*Festuca rubra*), Asiatic knotweed (*Reynoutria japonica*). Total = 25 species.

<5 records in New Zealand

Species not often seen or recognised ("under the radar" species) or not judged a danger, but potentially so. Nassella is an exception; it has its own control programme.

Tall oat grass 165 (*Arrhenatherum elatius*), **grey sedge 166** (*Carex divulsa*), **common privet 174** (*Ligustrum vulgare*), **European larch 159** (*Larix decidua*), **horse chestnut 140** (*Aesculus hippocastanum*), **European ash 141** (*Fraxinus excelsior*), gravel groundsel (*Senecio skirrhodon*), **serrated tussock 236** (*Nassella trichotoma*), **giant Himalayan lily 241** (*Cardiocrinum giganteum*), **salt marsh lavender 184** (*Limonium campanyonis*), **rockspray cotoneaster 370** (*Cotoneaster microphyllus*), **Portuguese laurel 228** (*Prunus lusitanica*), Brazilian waterweed (*Egeria densa*), honey locust (*Gleditsia triacanthos*), Bathurst burr (*Xanthium spinosum*), **caterpillar grass 315** (*Paspalum dilatatum*). Total = 16 species.

The above list (Table 3) does not deal strongly with montane wildling conifers (iNaturalist NZ has other projects which identify these threats - https://inaturalist.nz/projects/wilding-conifers), nor with aquatic weeds. There are also many Mediterranean succulents and shrubs (not so diligently recorded or identified), which are increasingly occupying rocky ledges and cliffs and squeezing out often the last native species in the landscape – having previously escaped fire and grazing and only recently being invaded by exotic competitors – e.g. pig's ear, *Crassula alata*, stonecrop, red valerian, pink dew plant, Mexican daisy, the shrubs boneseed and boxthorn, and common polypody fern. These are a particular problem in eastern Canterbury (Port Hills), which have a somewhat Mediterranean climate that suits these species, and which are also home for several restricted and endemic rock ledge species.

Those not indicated in bold (Table 3) are either so far found only in the northern part of New Zealand, or are of little perceived consequence in the south. Partly they are co-existent recombinants (Meurk 2011).

Sadly, some exotic weeds pose a threat because native species are confused with them, e.g. nassella control sometimes unwittingly results in elimination of similar looking native short tussocks, such as *Carex comans*, *C. flagellifera*, silver tussock and fescue tussock. And roadside remnant native broom, matagouri and pohuehue have been frequently mistaken for Scottish broom or exotic thorny shrub weeds and have disappeared from the rural landscape quite recently.

Some particular species to look out for and deal with as soon as possible are *Berberis aquifolium*, arum lily (Fig. 1, p. 49), Cape gooseberry, *Brugmansia*, bay laurel, spindle-berry, wild cherries/plums, Chilean glory vine, the four passion vine species, holly (despite there being some sterile cultivars), and *Juncus squarrosus* and *Nardus stricta* (in bogs). *Carex pendula* and river lily pose major threats along waterways and water races across Canterbury – they are just too beautiful – and the ferns *Cystopteris fragilis* and lady fern are increasingly intrusive. It seems we have given up on *Myricaria* in river beds, which could add to the already serious transformation caused by Russell lupins, gorse and broom.

Finally, the role of exotic trees and shrubs as nurseries for natural regeneration has gained some attention in recent times (Wotton and McAlpine 2013). This has been promoted for old growth pine forests, willows, and gorse/broom ("Fools and Dreamers" – what a wonderful model Hugh Wilson has provided at Hinewai). Like all things, there are 'horses for courses' and we need to apply these wisdoms with some caveats. It is desirable to use nature to help us restore nature. Shade-intolerant willows are great and can eventually be succeeded by native seed dropped by kereru that feed on the young spring shoots. But we need to make sure they are male willows (or single sex populations) that won't themselves spread all over the landscape. There are four prerequisites for the gorse model (Wilson 1994): fire must be kept out of the regenerating forest, browsing mammals must be fully excluded or they will remove palatable native seedlings; there must be a nearby natural seed source (within 2-3 km); and it really only works well in moist/warmer climes (cf. Lee et al. 1986). And

certainly don't encourage gorse amongst species-rich and rare natural grey scrub thinking this will be a great nursery for the future! It will just be a Trojan Horse leading to disappearance of that precious ecosystem and the natural landscape character.

Figure 1. Plants that are semi-shade tolerant like the pictured arum lily, *Zantedeschia aethiopica* 'Green Goddess', which is found in damp gullies and seeps on Banks Peninsula, male fern, ivy and veldt grass, are dominating the understorey of native woodland. (Photo: Alice Shanks)

Discussion and Recommended Actions

There is a lot of information there and a lot of chewing, swallowing and digestion still to go. The following actions are some steps towards deactivating those ticking time bombs in the landscape (Meurk 1996). It's often hard to go past the old wise proverbs: "one year's seeding, seven year's weeding" and "a stitch in time saves nine".

Start with commitment to no further loss of primary habitat – all the compromises have been made in Canterbury! We can't afford to lose any more. Even degraded habitat on uncultivated soils are important seed, subterranean faunal, and microbial sources and starting points for recovery of ecosystem health, landscape integrity and natural character across the Region.

Use citizen science to report/map distributions of weeds on https://inaturalist.nz/projects/pest-plants-weeds-of-nz so new incursions can be spotted, and localities targeted and communicated to local authorities, landowners or community volunteers via URLs.

Avoid adding to the threat load by not "nipping known risks in the bud" – like letting gorse/broom become a Trojan Horse in high country grey scrub (Fig. 2), arum in the woods (Fig. 1, p.49), or pink dew and gazanias in beach gravel (Fig. 3, p. 51) where they haven't been before, and…

Avoid inappropriate landscape planting of exotic species for amenity and show, or for spurious climate resilience reasons – as has been recently promoted for *Lomandra*, bee blossom and Australian dianella in our rain gardens – even if they are promoted as sterile cultivars now, as fertility may be restored!

Provide more ecological education and literacy for the general public, schools, landscape architects, arborists, planners, farmers, etc. about the existential threat to the natural character and place-making within Aotearoa – New Zealand cultural landscapes: follow Leonard Cockayne's dictum on planting **local** native species in schools. Visibility and continual daily experience and connection to our flora is vital to its survival. There is literature to support richer, functional, and more historically legible landscapes (Meurk and Hall 2006; Ignatieva et al. 2008).

Figure 2. The Trojan Horse effect of broom or gorse and elderberry establishing in grey scrub in Castle Hill Basin. A few years ago there were only a few scattered yellow bushes here. Now there is a substantial seedbank which will require more than seven years weeding! The danger now is that it will take over and even be encouraged as a nursery. Alternatively, it might be burnt or blanket sprayed, which will only serve to further promote the yellow stuff. (Photo: Colin Meurk).

Figure 3. Colourful garden escapes, like the intruders pink dew plant (possibly *Lampranthus*) and *Gazania*, are displacing leafless pohuehue (*Muehlenbeckia ephedroides*) in an endangered habitat type at Birdlings Flat. (Photo: Alice Shanks).

Educate landscape maintenance operators about ring-barking, spray drift, and species differentiation (Fig. 4, p. 52). Do we need fines or loss of contract in cases of negligence and/or lack of training/supervision?

Some form of plant nursery registration and training is needed to stem the flow of non-ecosourced native plants and of species from the North Island, Chatham Islands, Marlborough or West Coast that hybridise with local gene pools; and non-native ferns need to be taken off the shelf. There are plenty of local New Zealand species to do the job. Aesthetics has to be a secondary criterion for plant promotion after due diligence on risk to biodiversity.

Promote a more relaxed attitude to "urban wild" that allows for co-existence of native and some exotic "weed" species in the rubble and waste places - surrogates of riverbeds, dunes and crags. Weed control in such places needs to be strategic, targeted, and surgical.

Consider the full range of gradient management for the widest array of (positive) outcomes for biodiversity – competitive exclusion (fencing option), grazing (controlled disturbance), biocontrol, and engineered (stressed) substrates (Meurk and Greenep 2003; Meurk 2004).

Embark on prioritised weed eradication based on the lists and evolving information presented here, continually updated through institutional and citizen science.

Figure 4. Poorly trained and poorly informed maintenance contractors are eliminating often the last visible individuals of a species on the Plains. Note the live scotch broom in the now dead *Carmichaelia* in this Canterbury Plains roadside picture. (Photo Jason Butt)

Establish rapid reaction teams that can be deployed to immediately deal with identified incursions.

Preserve water races – these are the cumulative repositories of much lowland wetland flora and fauna of Canterbury (almost the only remaining "natural" wetlands of the Plains) and indeed are historic (1880s) artefacts in their own right. Industrial strength, scorched earth "weed" control needs to be suspended until there is better knowledge of how to maintain and manage their biota and control serious but beautiful weeds such as river lily and Chilean rhubarb.

Provide support to landowners through subsidies and/or rates relief.

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Crowdsourcing the discovery of new plant naturalisations in Canterbury using iNaturalist NZ

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Introduction

> "The new flora and vegetation are in their making. The future of glorious New Zealand plants and the beautiful primitive vegetation lies not in the lap of the gods but in the good sense of us New Zealanders and in our love for beautiful New Zealand." Cockayne (1967, p. 201)

Weeds are on the march in New Zealand and their impacts on New Zealand's indigenous vegetation will be felt over centuries to come (e.g., Williams and Braithwaite 2003; Williams and Cameron 2006). New plant species continue to naturalise from New Zealanders' gardens and spread across the country (Gatehouse 2008). The much older human history in Europe indicates that this invasion will take millennia to complete; it can take more than a century before woody garden plants are first discovered in the wild (Kowarik 1995), and naturalised plants that have "only" been in Europe for a thousand years are on average less widespread than those that naturalised earlier (Pўsek and Jarŏsík 2005). The weed invasion of New Zealand has just begun, and our actions today have the potential to make a big difference to New Zealand's future vegetation.

Climate change may accelerate this process. It's likely to make southern regions like Canterbury suitable for weeds of more northern parts of NZ (Williams and

Braithwaite 2003). It’s also likely to put locally adapted native plant populations at a disadvantage in competition with some of the newcomers. If we’re not careful, human responses to the threat of climate change, like the One Billion Trees programme, may also provide opportunities for weeds to spread, depending on what species and genotypes are planted and how well these plantings are maintained. Regardless, with or without climate change, our diverse gardens ensure that the plant invasion of wild New Zealand will continue well beyond our lifetimes.

Rolling back widespread Canterbury weeds like gorse, Scotch broom, and wilding pines is expensive and suitable for site-led and landscape-scale weed management and biological control programmes. Many other weeds, like boneseed, hawthorn, rowan, and sycamore maple, are still on the move but are already entrenched enough in many places to be expensive to push back. All of Canterbury’s institutional weed control budgets could be spent on these established weeds. That would be a mistake, as there are many more new weeds waiting in gardens to naturalise or that have recently jumped the garden fence (e.g., Hulme 2014).

Getting ahead of the invasion curve by stopping newcomers in their tracks is much less costly than dealing with established weeds, when combined with dedication and persistence. The essential ingredients are early detection and swift, sustained action. Modern technologies like smart phones, combined with apps and websites for reporting weeds, and online weed identification tools, all make it easier than ever for the wider public to play a prominent role in weed surveillance and the early detection of new naturalisations.

One such tool for the early detection of new weeds is iNaturalist NZ – Mātaki Taiao (previously NatureWatch NZ). iNaturalist NZ combines a social network of nature watchers, an online database of observations and photos, and a species identification engine. By encouraging people to report new and unusual species, the iNaturalist NZ community can help discover new plant naturalisations. Those discoveries can be new naturalisations to New Zealand, new to Canterbury, or new to their local district. All such early reports of incipient weed populations are useful when combined with prompt control.

In this article, we introduce iNaturalist NZ – Mātaki Taiao and explore some of the important naturalised plant discoveries in Canterbury that have been made so far by the iNaturalist NZ community.

iNaturalist NZ: a brief history

iNaturalist NZ – Mātaki Taiao (https://inaturalist.nz) is the New Zealand chapter of the global iNaturalist Network (https://www.inaturalist.org/pages/network). iNaturalist is a free website and mobile app for sharing and identifying observations of species. iNaturalist is operated from the California Academy of Sciences and is co-owned by the Academy and the US National Geographic. iNaturalist began in 2008 as an open-source masters project at UC Berkeley’s School of Information. It became

part of the California Academy of Sciences in 2014, and became a joint initiative with National Geographic in 2017.

The New Zealand Bio-Recording Network Trust (a NZ charitable trust) launched a New Zealand optimised version of the iNaturalist codebase in August 2012, with major funding from the NZ Government's Terrestrial and Freshwater Biodiversity Information System (TFBIS). This system was pre-loaded with NZ species and places, along with the observations and users from the Trust's older NZBRN species recording website. After consultation with NZBRN users, some of whom expressed confusion between "naturalist" and "naturist", NZBRN launched its iNaturalist-based system under a different brand name, NatureWatch NZ.

In 2014, NZBRN joined the incipient iNaturalist Network after iNaturalist built the features to allow Mexico to operate a regional site (NaturaLista, https://www.naturalista.mx/) within the global iNaturalist system. This integration maintained the New Zealand focus and vibrant and growing New Zealand community, while contributing to the global iNaturalist database, and it allowed New Zealanders to obtain species identifications from all iNaturalist users worldwide. The NatureWatch NZ brand was retired in June 2018 and replaced with iNaturalist NZ – Mātaki Taiao.

When you use https://inaturalist.nz, you see the New Zealand observations, species, users, and projects, but the whole world of iNaturalist is accessible from any search. By 6 June 2019, 13,669 users had made 743,646 New Zealand observations of 16,336 species and lower taxa, identified by 4,471 users. In the Canterbury region, 3,444 users had made 167,604 New Zealand observations of 7,490 species, identified by 2,059 users. (See below for a closer look at just the Canterbury plant observations.)

All of iNaturalist NZ's wild observations with confirmed identifications ("research grade") are shared weekly with the Global Biodiversity Information Facility (GBIF, https://www.gbif.org), and iNaturalist NZ is now the fifth largest overall contributor of NZ species observations to GBIF. iNaturalist NZ is the second largest GBIF contributor of observations made this century (after eBird) and has contributed 81.5% of NZ's GBIF plant observations made this century.

If you have not used iNaturalist NZ yet, we encourage you to join and share your botanical expertise with other users, and upload your most interesting and important observations. Also, if you are promoting botany with community groups, be sure to mention iNaturalist NZ – Mātaki Taiao as a great way for budding botanists and naturalists to build their knowledge of NZ species and share their observations.

Plant naturalisations in Canterbury

Since European settlement of Canterbury, there has been an ongoing accumulation of naturalised plants, one that shows no sign of slowing. From the PhD research of the late Hazel Gatehouse (Gatehouse 2008) there were 1,312 seed plant species known to have been naturalised in Canterbury by 2010 (Fig. 1, p. 57). The dates of discovery in

Canterbury are not readily available for these species so Dr Gatehouse's national dates of discovery for each species have been used (Fig. 1).

Gatehouse (2008), and independently Mahon (2007), have been one-off efforts to collate all available publication and collection data on wild exotic plants in Canterbury. For her PhD research, Gatehouse (2008) collated an annotated list of all seed plant species naturalised nationally by the end of 2000, including the regions in which each was known, based on all available published sources (e.g., Heenan et al. 2002). She updated this up to the end of 2010 after graduating (H.A.W. Gatehouse, unpublished data), bringing the total to 1,312 full species of naturalised seed plants in Canterbury.

Mahon (2007) collated all naturalised vascular plants in Canterbury prior to December 2005, based primarily on the national list of Howell and Sawyer (2006). Mahon listed 1,367 taxa (species and subspecies) of vascular naturalised plants in Canterbury, including 1,319 full species.

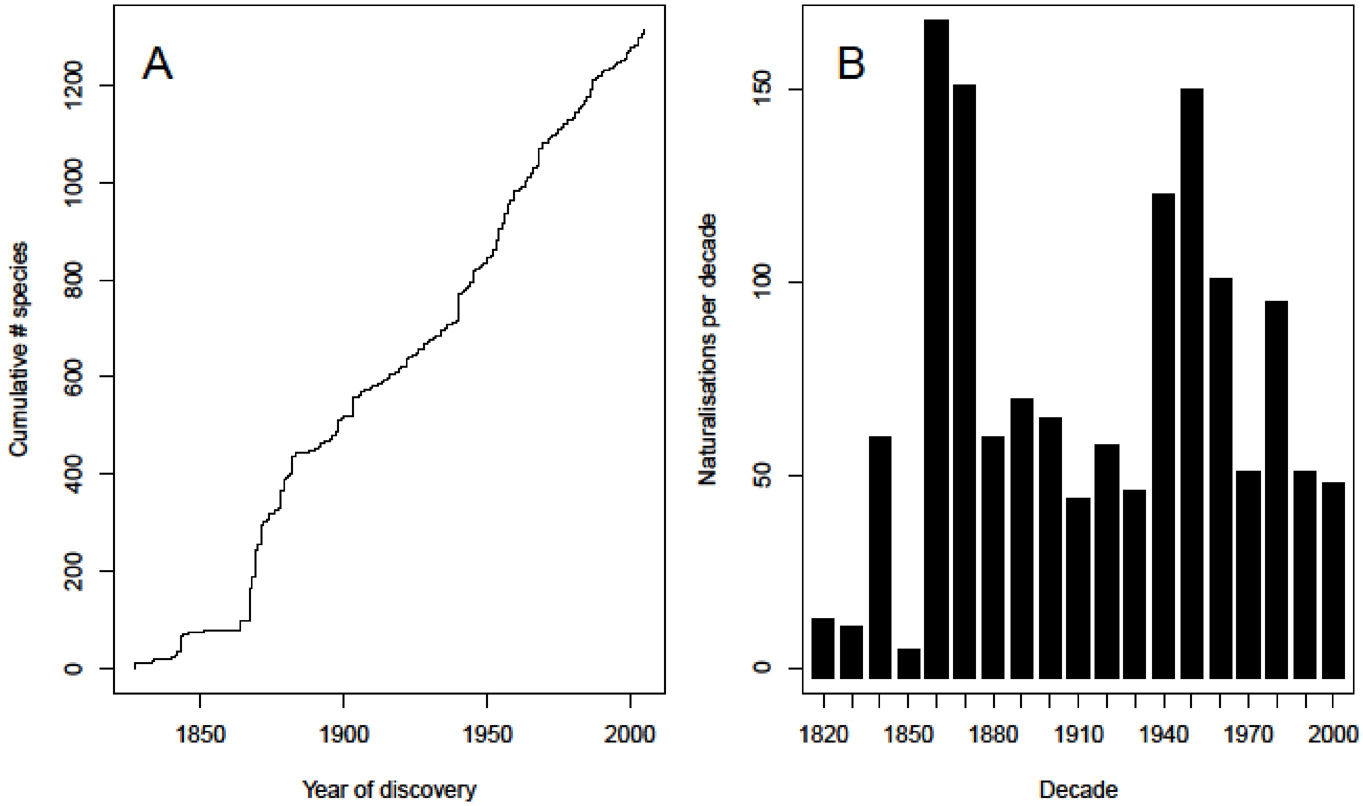

Figure 1. The accumulation of naturalised seed plants (conifers and angiosperms) in Canterbury, plotted against the national date of discovery for each species (based on Gatehouse (2008) and H.A.W. Gatehouse, unpublished data, for naturalisations up to 2010). **A** shows the cumulative naturalisation in Canterbury and **B** shows the same data by naturalisations per decade. Varying collecting effort likely explains most of the between-decade variation in naturalisations in recent decades in **B**, such as the 1980s spike in naturalisations coinciding with the writing of Flora IV (Webb et al. 1988).

The New Zealand Plant Conservation Network (NZPCN) website (http://www.nzpcn.org.nz) also maintains a searchable list of exotic (and native) plant

species in New Zealand, which can be filtered by district. It currently includes 805 wild exotic taxa from all Canterbury districts combined, including 797 species (accessed 5 August 2019).

For plant observations from Canterbury made by users on iNaturalist NZ as at 6 June 2019, a total of 1,834 users had made 80,008 Canterbury plant observations of 3,392 species and lower taxa (Fig. 2). The prominent uptick in species in April 2019 (Fig. 2) is the result of the Christchurch District's participation in the global City Nature Challenge (Australasia's first entry into this global competition). This recent uptick, and the continuing upward trajectory of all observations (Fig. 2), indicate that more Canterbury plant species, of all biostatus categories, have yet to be documented by the iNaturalist NZ community, and likely will be observed over the coming months and years.

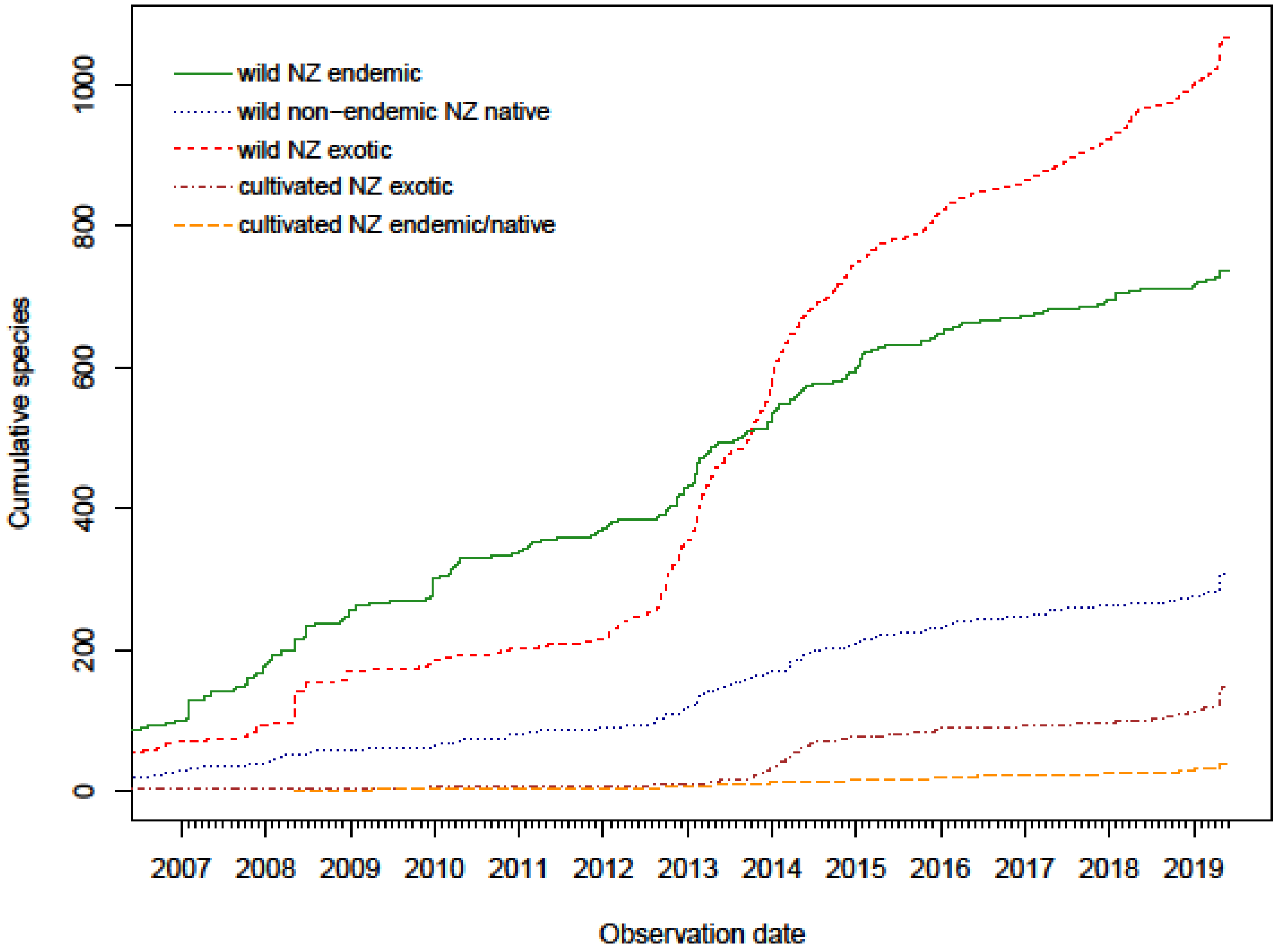

Figure 2. The accumulation of plant species (full species, lumping together subspecies and varieties) observed by users of iNaturalist NZ – Mātaki Taiao, as at 6 June 2019. Species are separated by their national biostatus, based on iNaturalist NZ's edited checklist of biostatus sourced from the NZ Organisms Register (http://www.nzor.org.nz/). Species are additionally separated by whether or not each species has been observed in the wild.

As at 6 June 2019, approximately 1,070 wild, exotic plant species had been observed by iNaturalist NZ users. We say "approximate" due to the ambiguity around whether

some of the species recorded from Canterbury's cities and towns were really wild. Some iNaturalist NZ users have not consistently recorded whether their observed plants are wild or not, and some of these observations have yet to be annotated as such by other users. In an attempt to weed out these observations of cultivated plants, we have applied a 5% threshold, whereby we consider all species with ≥95% of observations noted as cultivated to be only cultivated unless they are also on one of the Canterbury naturalised plant lists, and all species with <95% of observations cultivated we considered to be present in the wild.

We have manually inspected the iNaturalist NZ species lists and our threshold seems to be functioning as expected. However, we have not (yet) carefully looked through all of the observations of all species that have been reported only in Canterbury via iNaturalist NZ. It therefore remains possible that a few cultivated-only species have slipped through.

What proportion of Canterbury's known naturalised plants have been observed by iNaturalist NZ users, and how many first records of naturalised plant species have they documented? Answering these questions proved to be much more complicated than we expected, due to differences in taxonomy and synonymy in the three available lists of Canterbury's naturalised plants. After careful editing of each list to account for (at least some of) the differences in synonyms and formatting, we combined the species lists from Mahon (2007), Gatehouse (2008), and the NZPCN. This produced a total list of 1,545 species.

While this warrants a more in-depth taxonomic look, one thing is immediately apparent: the three existing lists of Canterbury naturalised plants are quite different, both in their lengths and the species they contain. Of the 1,545 species, only 633 (41%) are shared by all three lists, even after our attempt to clean up synonymy. 77.3% are shared by Mahon (2007) and Gatehouse (2008).

Given this taxonomic uncertainly, it is a testament to the tenacity and skills of the iNaturalist NZ community that, in just seven years, observations have been made of 782 (50.6%) of Canterbury's naturalised plant species, as listed on at least one of these three other source lists (Table 1, p. 60). Furthermore, 285 plant species have been observed that were not listed on any of these other lists.

A more detailed exploration and analysis of the iNaturalist NZ exotic plant observations from Canterbury (and New Zealand) would be beneficial. Our preliminary look underscores the importance of iNaturalist NZ, and citizen botanists, as an engine for discovering new naturalisations. It also highlights how difficult it currently is to promptly and accurately determine which Canterbury observations are of plants not previously recorded in the region.

Table 1. Lists of naturalised plants of Canterbury and how many were observed and identified by users of iNaturalist NZ – Mātaki Taiao, as at 6 June 2019.

Source	Total species	Only on this list	Observed on iNat NZ
Mahon (2007)	1,317	59	710
Gatehouse (2008)	1,311	86	678
NZPCN	795	65	550
iNat NZ	1,067	285	

Notable new naturalisations

While there remains uncertainty around exactly how many new-to-Canterbury plant naturalisations have been detected so far on iNaturalist NZ – Mātaki Taiao, there are many, as can be illustrated through examples. The following is an annotated list of examples of some of the new Canterbury naturalisations, or prominent range expansions, detected by users of iNaturalist NZ. This is sorted alphabetically (by Latinised binomial) and is not intended to be comprehensive.

Kiwifruit *Actinidia chinensis* var. *deliciosa* (Mike Lusk, 28 Apr. 2017, Lake Tekapo, https:\\inaturalist.nz/observations/7303478, Mark Bloomberg, 11 Mar. 2018, Lake Pukaki, https:\\inaturalist.nz/observations/10300330)

While wild kiwifruit as an abundant weed is an issue only in more northern parts of New Zealand, it is impressive how cold-hardy it can be. Well-established plants were found growing on the shores of Lakes Tekapo and Pukaki, presumably germinated from discarded fruit.

Madeira vine *Anredera cordifolia* (Jon Sullivan, 10 May 2016, Lincoln, https:\\inaturalist.nz/observations/3148973, https:\\inaturalist.nz/observations/3363469)

Madeira vine is a well-established and problematic weed of the North Island but few observations of it have been made from Canterbury (there are five records on the Australasian Virtual Herbarium, all from Christchurch city). Here it was found aggressively spreading through Lincoln's Mahoe Reserve. How it got there remains unknown, and an attempt is being made to eradicate it from the area.

Cow parsley *Anthriscus sylvestris* (James Mortimer, 26 Jan. 2013, Christchurch, https:\\inaturalist.nz/observations/949961)

James Mortimer made repeat visits to this plant, wild in the Christchurch Botanic Gardens, to confirm its identification. It was one of few records of this species from NZ, but Trevor Partridge (pers. comm.) notes that it is now well established at three sites around Christchurch and he expects to see more of it in the future.

Great masterwort *Astrantia major* (Trevor Partridge, 14 Nov. 2015, Christchurch, https:\\inaturalist.nz/observations/2394683)

This is a potential first record for New Zealand of this species, here found spreading in the Christchurch Residential Red Zone.

Berberis congestiflora (Jon Sullivan, 20 Apr. 2012, Geraldine, https:\\inaturalist.nz/observations/940126 CHR 616308)

This unusual barberry in Geraldine's Talbot Bush was noticed while on a university field trip. It is the first New Zealand record for this species. It has been removed and has not been seen since.

Candy flower *Claytonia sibirica* (William Reinders, 4 April 2018, Christchurch, https:\\inaturalist.nz/observations/10653937)

This was the first record of this species on iNaturalist NZ and, according to the Australasian Virtual Herbarium, there have been eight prior herbarium collections from Canterbury, all from the past 20 years. This is native to Siberia and North America and may be one to watch given how widespread its congener miner's lettuce is becoming, and how widespread this species is reported to be in the UK.

Smokebush *Cotinus coggygria* (David Beukes, 5 May 2017, Lincoln, https:\\inaturalist.nz/observations/6243578)

Three wild seedlings have been found in Christchurch of this long-time garden plant, and there are no records of it wild from Canterbury on the Australasian Virtual Herbarium. Time will tell whether this remains casual in the wild or naturalises fully.

Chilean glory creeper *Eccremocarpus scaber* (various observers, https:\\inaturalist.nz/observations?place_id=8479&taxon_id=401602)

Chilean glory creeper is worthy of mention because it is still very rare in and around the Christchurch District but is being reported by iNaturalist NZ users. It is spreading and is a known weed. Time is running out to control it.

Red Mount Teide bugloss *Echium wildpretii* (William Reinders, 11 Aug. 2017, Tai Tapu, https:\\inaturalist.nz/observations/7444566)

The Australasian Virtual Herbarium lists three previous collections of this species in Canterbury, the earliest from 1998. This could be another one to watch, and potentially stop, given how abundant Echium vulgare now is, and how quickly Echium candicans and Echium pininana are spreading.

Long-flowered veldt grass *Ehrharta longiflora* (Alice Shanks, 9 & 11 Sept. 2018, Christchurch, https:\\inaturalist.nz/observations/16372106 https:\\inaturalist.nz/observations/16413917)

This is a relative of veldt grass (Ehrharta erecta), which was voted New Zealand's worst environmental weed in 2014 by the NZ Plant Conservation Network (Ward 2015). Ehrharta longiflora is already naturalised in Australia, and this was the first

South Island record of the species, growing along a fence line in Christchurch city. It has since been eradicated.

Rough horsetail *Equisetum hyemale* (Sonny Whitelaw, 16 Jul. 2015, Oxford, https:\\inaturalist.nz/observations/1767761, James Ranstead, 12 Nov. 2016, Lincoln, https:\\inaturalist.nz/observations/4533604)

The Australasian Virtual Herbarium lists 12 earlier herbarium collections of this species, all but one from Christchurch city. These iNaturalist NZ observations appear to be the first observations of this species from Lincoln and Oxford. Environment Canterbury was alerted in both cases.

Great willowherb *Epilobium hirsutum* (Jason Butt, 15 May 2018, Pegasus, https:\\inaturalist.nz/observations/10247701 CHR646066, Colin Meurk, 2 Feb. 2019, Christchurch, https:\\inaturalist.nz/observations/20037942)

This was a new-to-New Zealand discovery of a serious wetland weed that triggered a national incursion response from Biosecurity NZ.

Blue eryngo *Eryngium planum* (William Reinders, 19 Mar. 2017, Christchurch, https:\\inaturalist.nz/observations/5886642 CHR644048)

This was the first wild observation of this species in Canterbury and resulted in a vouchered specimen lodged in the Allan Herbarium.

Tussock hawkweed *Hieracium lepidulum* (Jon Sullivan, 12 Apr. 2018, Christchurch Port Hills, https:\\inaturalist.nz/observations/10849005)

Herbarium collections on the Australasian Virtual Herbarium of this hieracium are from the Canterbury high country and (two) from high elevation sites on Banks Peninsula. This was the first observation from the Christchurch Port Hills, and may signal an ongoing expansion of this species through the Christchurch District.

Himalayan balsam *Impatiens glandulifera* (Wie Quan, 18 Mar. 2016, Christchurch, https:\\inaturalist.nz/observations/2807511, Joe Potter Butler, 21 Feb. 2018, Christchurch, https:\\inaturalist.nz/observations/9942039)

This is a notorious riparian weed in the United Kingdom and Europe, which took several centuries to reach its current distribution and abundance (Phil Hulme, pers. comm.). It is known in Canterbury, and already abundant around parts of Hanmer Springs. Several new sites of this species have been observed on iNaturalist NZ across Christchurch city, as well as Temuka, Little River, Rangiora, and Waikuku, indicating its continued spread.

Limonium companyonis (Steve Attwood, 14 Jan. 2014, Christchurch, https:\\inaturalist.nz/observations/983490)

This saltmarsh weed has been observed in Ferrymead, Christchurch, and in Akaroa harbour, complementing the four herbarium collections made in these areas on the Australasian Virtual Herbarium. Attempts are being made to stop this weed.

Garden honeysuckle ***Lonicera × americana*** (Mark Parker, 24 Jan. 2017, Kaikoura, https:\\inaturalist.nz/observations/4996371 CHR644108)

This was a first record of this species for Kowhai Bush in Kaikoura.

Yellow lupin ***Lupinus luteus*** (Trevor Partridge, 16 Dec. 2017, Christchurch, https:\\inaturalist.nz/observations/9181701)

Webb et al. (1988) regarded Lupinus luteus as a casual escape of fodder crops that "seems never to have established except in Northland and on Great Barrier Id". It remains a mystery where this patch in Christchurch came from, and whether or not it was wild.

Gypsywort ***Lycopus europaeus*** (William Reinders, 28 Dec. 2018, Christchurch, https:\\inaturalist.nz/observations/19265182)

The Australasian Virtual Herbarium lists two previous collections of this species in Canterbury, one in Lincoln and one north of Lake Ohau. This observation is the first for Christchurch city.

Nemesia floribunda (Jon Sullivan, 19 Mar. 2014, Lincoln, https:\\inaturalist.nz/observations/990325, William Reinders, 4 Jul. 2017, Christchurch, https:\\inaturalist.nz/observations/6913608)

This widespread weed of Dunedin was previously not recorded from Canterbury. The single plant found at Lincoln was removed before it seeded and none have been seen since. However, since then it has been detected at several locations in Christchurch city, including a dense patch on the Main South Road railway bridge. Port Hills rangers of the Christchurch City Council are eager to keep this from establishing on the Port Hills as it is a potential rock outcrop weed.

Nemesia fruticans (Trevor Partridge, 4 Oct. 2015, https:\\inaturalist.nz/observations/2077698)

This was the first record of this species in Canterbury, and William Reinders has since observed it wild at four other sites in the city.

Apple-of-Peru ***Nicandra physalodes*** (Sue McGaw, 11 May 2014, Kaiapoi, https:\\inaturalist.nz/observations/1000019)

There are nine Canterbury Allan Herbarium collections of this species on the Australasian Virtual Herbarium, eight from Christchurch and one from Ashburton, dating back to the 1960s. However, reports are increasing on iNaturalist NZ of this species in and around Christchurch city.

Antarctic beech ***Nothofagus antarctica*** (Dave Evans, 23 Apr, 2011, Mount Oxford, https:\\inaturalist.nz/observations/944640)

This unusual beech was spotted growing wild part way up Mount Oxford and turned out to be Nothofagus antarctica, which is known wild in just a few places in the Canterbury mountains. This iNaturalist NZ observation was pre-dated by four

herbarium collections on the Australasian Virtual Herbarium, from other areas of Canterbury.

Australian fireweed *Senecio bipinnatisectus* (William Reinders, 10 Sept. 2017, Christchurch, https:\\inaturalist.nz/observations/7913770)

This was the first observation of this Australian naturalised Senecio in Canterbury, and there are now eight observations all around the Wigram area and Christchurch city. It is widespread and abundant further north in New Zealand. It is not known whether its arrival in Christchurch is a result of the warming climate or the ongoing southward expansion of this species. Regardless, it appears to be persisting.

Arsenic bush *Senna septemtrionalis* (Murray Dawson, 1 Oct. 2015, Diamond Harbour, https:\\inaturalist.nz/observations/2621906)

This species had been collected twice wild around Lincoln according to the Australasian Virtual Herbarium. It is a forest weed in New South Wales and Queensland.

Flowering inch plant *Tradescantia cerinthoides* (William Reinders, 22 Jul. 2017, Christchurch, https:\\inaturalist.nz/observations/7185974)

This wild seedling of *Tradescantia cerinthoides* appears to be a first record for Canterbury. It has been recorded wild in the North Island before but there are no herbarium records of it on the Australasian Virtual Herbarium.

Discussion

We see iNaturalist NZ – Mātaki Taiao as a valuable complement to the professional botanical services of the Allan Herbarium. iNaturalist NZ has resulted in many more people in Canterbury making many more plant observations than have traditionally be made by professional botanists. As we have shown, some of those observations have been important, and several of these have resulted in vouchered herbarium specimens and weed control efforts. It is encouraging that many botanists are active identifiers on iNaturalist NZ and are encouraging users to collect the most important finds and send them to the Allan Herbarium.

As well as new naturalisations, iNaturalist NZ users are also reporting the ongoing spread of known naturalised plants in Canterbury. Species like *Eccremocarpus scaber*, *Equisetum hyemale*, *Heracleum mantegazzianum*, and *Impatiens glandulifera*, are well known weeds and iNaturalist NZ users are showing that they are on the move in Canterbury. More can, and should, be done to ensure that detections of such weeds in new areas of Canterbury are dealt with swiftly.

Prompt alerts to new naturalisations have so far been *ad hoc* based on knowledgeable iNaturalist NZ users noticing unusual plant observations and alerting staff at the Allan Herbarium or the appropriate agencies, i.e. regional and local Councils and/or the Department of Conservation. This process could be automated if there was an up-to-date list of known naturalised plants of Canterbury, preferably with names

matching those on the NZ Organisms Register (http://www.nzor.org.nz/), or Kew Gardens' Plants of the World online. There is much to be gained from better streamlining Canterbury's processes for weed detection and follow-up action.

It is important that agencies monitor iNaturalist NZ observations. They can subscribe to get automated emails of all observations of selected taxa from selected places. Decisions can then be promptly made, and actions against new naturalisations are more likely to be both affordable and successful. The eradication of long-flowered veldt grass is an excellent example of early detection leading to successful eradication of a bad weed. However, this discovery triggered no official agency process and its eradication was the result of the right people being told. Canterbury – and indeed all of New Zealand – stands to save a huge amount in weeding expense and ecological and economic impacts if we get better at pouncing on new naturalisations as they are discovered. The clock is ticking.

Acknowledgments

We are grateful to all of those people who have taken the time to upload observations to iNaturalist NZ – Mātaki Taiao. We would like to particularly acknowledge the many important Canterbury plant observations made by Grahame Bell, Joe Potter Butler, Alex Fergus, Kate McCombs, Sue McGaw, Nathan Odgers, Trevor Partridge, William Reinders, Jenny Saito, Alice Shanks, Greg Stanley, Gail Timmerman-Vaughan, and Wei Quan. We would also like to acknowledge Ken-ichi Ueda, Scott Loarie, and the whole team at iNaturalist central for developing and maintaining the iNaturalist platform globally. We also thank the New Zealand institutions (DOC, MPI, MBIE, Brian Mason Trust) that have provided financial support to NZBRN to maintain and grow iNaturalist NZ – Mātaki Taiao.

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Chilean mayten – an increasingly invasive tree in Canterbury

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Introduction

Maytenus boaria (also known as Chilean mayten, mayten or maiten) is a woody South American species becoming increasingly more invasive, especially in the Canterbury region. This tree has real potential to become yet another major environmental weed in New Zealand.

A timeline of known information for Chilean mayten establishment and subsequent concerns raised in New Zealand is:

- 1881: Introduced into cultivation at the Christchurch Botanic Gardens from imported plant material.
- 1929: Male clones sold commercially by Duncan & Davies Nurseries, New Plymouth.
- Mid-1980s: Seed-grown plants started to be sold, including females.
- 1986/1989: Recorded as naturalised from herbarium specimens.
- 2002: Joe Cartman and Kate McCombs (CCC) published their concerns on the emerging invasiveness.
- 2010: Alan McDonald (DOC) published notes on three emerging invasive species for Canterbury, including Chilean mayten.
- 2012: Chilean mayten added to the National Pest Plant Accord (NPPA) list.
- 2016 and 2017: Murray Dawson (MWLR) published articles outlining the emerging threat.
- 2018: Chilean mayten listed in the Canterbury Regional Pest Management Plan (RPMP) 2018–2038 as an "Organism of Interest".
- Present day: iNaturalist NZ – Mātaki Taiao citizen science observations indicate an expanding distribution for Chilean mayten, particularly in Canterbury.
- Present day: ECan are preparing publicity material to raise awareness of the invasiveness of Chilean mayten.

What is Chilean mayten?

Chilean mayten belongs to the Celastraceae family and is native to South America, naturally occurring in Chile and Argentina from about 30°S to 50°S.

This evergreen tree is fairly cold-hardy and drought resistant. It is cultivated as a small to medium sized tree, typically reaching 6–8 m after several decades (Fig. 1, p. 68). However, under optimum conditions and given enough time it can eventually grow up to 20–30 m tall (Fig. 2, p. 68). When mature, this graceful tree develops a straight trunk and pendulous branchlets that sway in the wind. It has fissured grey bark (Fig. 3, p. 69).

Chilean mayten leaves are alternately arranged, glabrous (hairless), glossy and dark green on the upper surfaces, lighter green on the lower surfaces, and shortly petiolate (with leaf-stalks 1.3–6 mm long). The leaves are (15–)20–60(–75) mm long, narrowly lanceolate to elliptic, and with finely serrated margins (Fig. 4, p. 69).

Figure 1. Chilean mayten planted in front of Governors Bay Fire Station, Banks Peninsula, Canterbury. This small tree produces fruit, and self-sown saplings are found nearby. (https://inaturalist.nz/observations/5927646).

Figure 2. Large mature tree of Chilean mayten cultivated at Lincoln University, Canterbury. This tree pre-dates the sale of female (seed-setting) material on the market. (https://inaturalist.nz/observations/26535147).

Figure 3. Close-up of the fissured grey bark of Chilean mayten. From a mature tree planted on a street frontage near Bottle Lake Forest Park, Christchurch. (https://inaturalist.nz/observations/5973295).

Figure 4. Finely serrated leaves of Chilean mayten. From a shrub naturalised in Saint Mary's Anglican Church grounds, Halswell, Christchurch. (https://inaturalist.nz/observations/25860052).

In New Zealand Chilean mayten flowers from late August to October. Its flowers are solitary or arranged in axillary clusters (arising from the stems), about 5 mm in diameter, 5-merous, greenish-yellow and relatively inconspicuous. Separate male (Fig. 5) and female (Fig. 6) flowers are produced.

Figure 5. Close-up of male flowers of Chilean mayten. From a shrub naturalised in the Manaaki Whenua – Landcare Research grounds, Lincoln, Canterbury. (https://inaturalist.nz/observations/4218287).

Figure 6. Close-up of female flowers of Chilean mayten. From a shrub naturalised in the Manaaki Whenua – Landcare Research grounds, Lincoln, Canterbury. (https://inaturalist.nz/observations/4222010).

In New Zealand it is usually described as a dioecious species (having separate male and female plants). However, the sexuality and reproductive biology of Chilean mayten may be more complex. Some overseas accounts suggest that Chilean mayten is monoecious (with male and female flowers together on the same plant) or polygamous (bearing some flowers with stamens only, some with pistils only, and occasionally some with both, on the same or different plants). Closer examination of NewZealand material may be warranted.

Seeds formed on female plants mature from March to June and are surrounded by orange to dark red coloured fleshy arils (Fig. 7, p. 71). The persistent fruit capsules are yellowish-brown in colour (Fig. 8, p.71).

Figure 7. Close-up of fleshy fruit arils of Chilean mayten. From a small tree planted in front of Governors Bay Fire Station, Banks Peninsula, Canterbury. (https://inaturalist.nz/observations/5927646).

Figure 8. Close-up of old fruit capsules persisting on a Chilean mayten tree. This female tree was planted in the Canterbury Agriculture and Science Centre (CASC) grounds, Lincoln, some 30-years ago. It was a likely seed source causing its spread on the campus. This tree has now been cut down and the stump poisoned. (https://inaturalist.nz/observations/a4459816).

Why is it weedy?

Chilean mayten has a wide range of weedy attributes including:

- Long-life.
- Drought resistance.
- Persistent suckering from roots (Fig. 9).
- Resistance to poisoning.
- Shade tolerance, but also an ability to grow in full sun.
- Easily overlooked; as a shrub intergrowing with, and difficult to distinguish from, New Zealand native plantings.
- Flowering and fruiting from an early age (3–5 years, 2 m tall).
- Seeds readily dispersible by birds.

Figure *9*. Persistent suckering from a Chilean mayten tree that was cut down more than 15 years ago in the CASC grounds, Lincoln. (https://inaturalist.nz/observations/5003463).

Chilean mayten was considered relatively benign and was cultivated (clonally through root cuttings) with few issues for more than 130 years in New Zealand. Unfortunately, this all changed from the mid-1980s when seed-grown plants started to appear on the market, and inevitably some of these were female. Birds love to eat the fleshy seed-containing arils and thus Chilean mayten has now gained wings in New Zealand. This has allowed the species to disperse well beyond the original (male) plantings and to colonise new areas.

Chilean mayten can establish in a wide range of habitats including open pasture, shelterbelts, parklands and native plantings. Canterbury is a stronghold for the invasive spread of Chilean mayten, especially in Lincoln, Red Zone land (eastern suburbs of Christchurch City and Kaiapoi), and around the base of the Port Hills.

I've pointed out earlier records of it naturalising near Eastwoodhill Arboretum (Gisborne) and in Bason Botanic Gardens (near Whanganui). More recently, Richard Pender (Wildland Consultants) confirmed it naturalising in Rotorua. No doubt other locations will be uncovered as this species gains a wider foothold.

What is it confused with?

When it's still a shrub, Chilean mayten is easily overlooked and under-reported. Unless in fruit, it is rather nondescript with its small evergreen leaves and few distinguishing features. As a shrub it resembles several native New Zealand plants, such as māhoe (*Melicytus ramiflorus*) and lacebarks (*Hoheria angustifolia* and *H. sexstylosa*).

As a mature tree, Chilean mayten can be confused with several exotics, including weeping willow (*Salix babylonica*) and pepper tree (*Schinus mole*).

What can we do about it?

Thankfully, some regulatory controls have been applied in recent years. Its addition to the National Pest Plant Accord (NPPA) list bans it from sale, distribution and propagation throughout New Zealand. Because Chilean mayten is long lived, numerous trees are still growing in cultivation.

Inclusion in the latest Canterbury RPMP is also a step in the right direction. However, it is listed only as an "Organism of Interest" (RPMP, Appendix 2, p. 90), which means there are no formal control programmes applied to Chilean mayten under that plan.

ECan are currently preparing publicity material to raise awareness of its invasiveness. They are asking for sightings from the public to be added to the iNaturalist NZ platform, to more fully establish presence and scope of spread in Canterbury (Fig. 10)

A project for sightings has been created at https://inaturalist.nz/projects/canterbury-chilean-mayten-mayhem.

To effectively nip the establishment curve of this invasive species in the bud, early intervention is needed. Search-and-destroy of female plants and self-established saplings in particular should be undertaken as soon as possible to mitigate further spread. It is possible to put the Genie back in the bottle, but only if we act now.

Figure 10. Distribution of Chilean mayten in Canterbury. Map generated in August 2019 from iNaturalist NZ (https://inaturalist.nz/taxa/77969-Maytenus-boaria).

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The fern *Polypodium vulgare* as a weed in New Zealand

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The fern *Polypodium vulgare* has been naturalised in New Zealand for several decades. It has increased markedly in abundance. This article outlines the relationships of *Polypodium vulgare*, its distribution in New Zealand, and the threats that it poses to conservation values.

Relationships of *Polypodium vulgare*

Polypodium vulgare was described by Linnaeus in 1753. Its indigenous distribution is wide-ranging, encompassing Europe, Turkey, Russia, China, Mediterranean Africa, southern Africa, and the Kerguelen Islands in the Indian Ocean (Page 1997; Roux 2009; Crouch et al. 2011; Lu and Haufler 2013).

There are a number of similar species in the northern hemisphere that have been segregated from what used to be a broadly circumscribed *Polypodium vulgare*, such as *P. cambricum* (= *P. australe*) and *P. interjectum* of Europe, western Asia, and northern Africa (Page 1997), and several North American species including *P. virginianum* (Haufler et al. 1993). The plants naturalised in New Zealand have been identified as *P. vulgare sensu stricto* (hereafter, *P. vulgare*) based on chromosome number and micro-morphological characters (Lovis 1980; Shepherd & Perrie 2006; Brownsey & Perrie 2014). However, Lovis (1980) considered plants from the Port Hills to have “atypical macro-morphology” for *P. vulgare*, and noted that “it remains possible that our plants have not originated from Europe”. Southern Africa, for instance, is an alternative source.

There are no indigenous species of *Polypodium* in New Zealand, but its family, Polypodiaceae, has native representatives in *Loxogramme*, *Microsorum*, and *Pyrrosia* (Brownsey and Perrie 2014). In New Zealand, *Polypodium vulgare* is most likely to be confused with *Microsorum pustulatum* (Lovis 1980; Wilson 2013; Brownsey and Perrie 2014). They can be distinguished by the frond lamina of *P. vulgare* being dissected right to the rachis to form distinct pinnae, even in the basal third of the lamina, whereas the lamina of *M. pustulatum* is only pinnatifid (i.e., there is always a wing of lamina alongside the rachis) (Figs. 1 and 2, p. 76). Additionally, the frond margins are serrate in *P. vulgare* (sometimes only minutely so) but entire in *M. pustulatum*. *Blechnum deltoides* (previously known in Australasia as *B. vulcanicum*)

is also superficially similar to *P. vulgare*, but easily distinguished by reproductive features; the sori of *B. deltoides* are linear on dimorphic and much-narrowed fertile fronds, while they are circular in *P. vulgare* (Figs. 1 and 2).

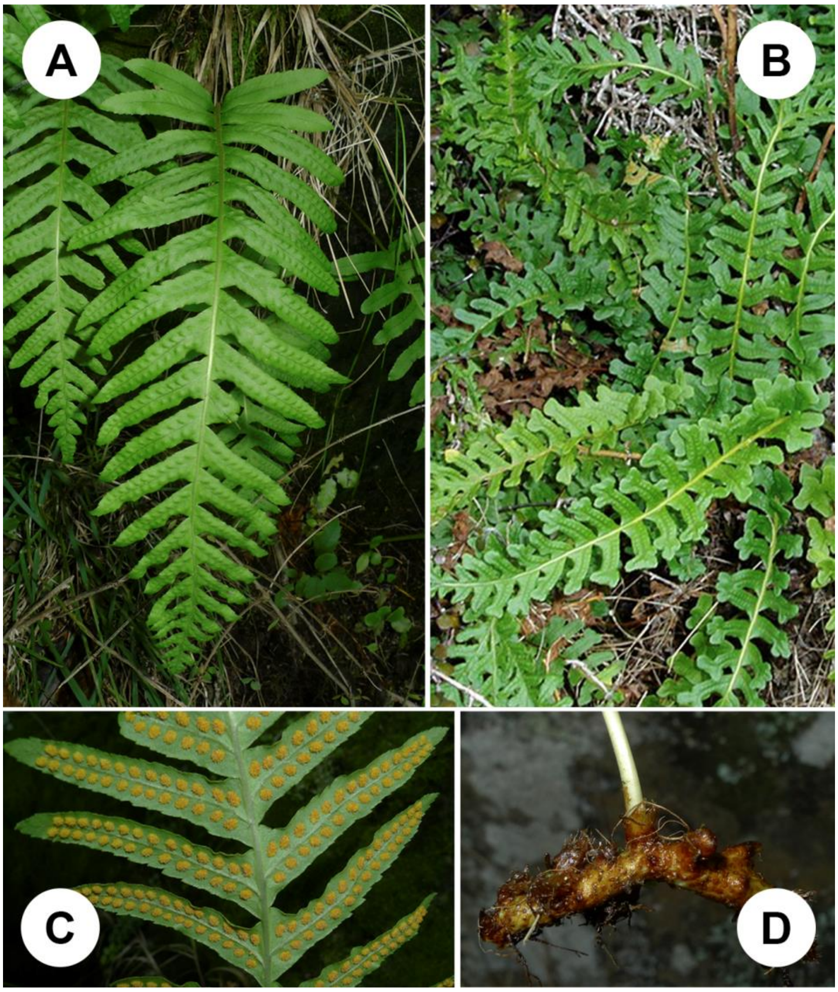

Figure 1. *Polypodium vulgare*. A: Frond, with the lamina dissected to the rachis. B: Crested forms occur rarely in the wild; this is from a northern Canterbury population. C: Underside of fertile frond, showing the unprotected orange sori (clusters of spore-producing sporangia), the lamina dissected to the rachis, and the serrate lamina margins. D: Creeping rhizome. Photos A, C, and D by Leon Perrie; B by Miles Giller.

Figure 2. Native New Zealand ferns superficially similar to *Polypodium vulgare*. A: In *Microsorum pustulatum* the lamina is not dissected right to the rachis, and the margins are entire. B: *Blechnum deltoides* (previously known as *B. vulcanicum*) has distinctive fertile fronds with narrow pinnae (at middle-right and bottom-centre in this image). Photos by Leon Perrie.

Distribution in New Zealand

The first record of *Polypodium vulgare* occurring wild in New Zealand was made by Lovis (1980), who wrote that it "was first discovered…by Yvonne Elder and John Thompson, who saw it in a wall just outside the bottom of the Lyttelton Reserve…sometime between 1966 and 1973". Because of the much larger colonies present in 1980 at Breeze Bay, Lovis thought that this Lyttelton Reserve site may not have been the "original site of introduction, although the possibility of an ultimate origin for *Polypodium* on the Port Hills by escape from a Lyttelton garden cannot be discounted".

Only four populations of *Polypodium vulgare* in New Zealand, all on the Port Hills, were known to Lovis (1980). Three were so limited that it was still practically possible to describe them in detail: Lyttelton Reserve with "six plants…present, but all were juvenile or submature"; Mount Cavendish with seven plants and "three tiny sporelings"; and a roadside between Jollies Bush and Evans Pass, being "of limited extent, (30 metres) but includes one patch of substantial size (100+ fronds) and several smaller clumps". The population at Breeze Bay was the biggest but limited accessibility meant assessing its size was difficult. Lovis (1980) thought it likely that both the Jollies Bush/Evans Pass and Mount Cavendish populations were "of quite recent establishment" as it was "difficult to believe that such a distinctive fern would have gone unnoticed by earlier pteridologists, growing so close to the main station for *Pleurosorus rutaefolius* [≡*Asplenium subglandulosum*] in the Christchurch district".

The subsequent spread of *Polypodium vulgare* in New Zealand has been substantial. It is now abundant on the Port Hills, and it has spread to Banks Peninsula and northern Canterbury, ranging from near sea-level to an elevation of at least 700 m (Brownsey and Perrie 2014). It has also been found wild in the southern North Island (Shepherd and Perrie 2006). A wind-blown origin to the North Island from the eastern South Island seems more likely than human-mediated transfer, at least for the population near Cape Palliser, which is exposed to the south and has few people living nearby.

This spread has been mapped (Figs. 3 and 4, p 78). The data for these maps are from herbarium specimens of Auckland Museum, Manaaki Whenua Landcare Research, and Te Papa, together with observations of the authors and from the iNaturalist citizen-science website (www.inaturalist.nz, accessed 27 August 2019). The large increase in records between 1997-2008 and 2009-2019 reflects presumably both actual increase in plant numbers and the advent of more observers (including those of iNaturalist, along with the work of Christchurch City Council rangers extending to Banks Peninsula around this time).

Even as early as 1980, Lovis noted that *Polypodium vulgare* was exhibiting "a very wide range of ecological tolerance" in New Zealand. It had already colonised Mount Cavendish with "the hottest and driest north-facing rocks on the Port Hills", where "at least in dry summers, it very probably persists…solely through its fleshy rhizome". This was "a dramatic contrast to the damp south-facing rocks above Breeze Bay". We have generally found *Polypodium vulgare* on dry banks, but have seen it

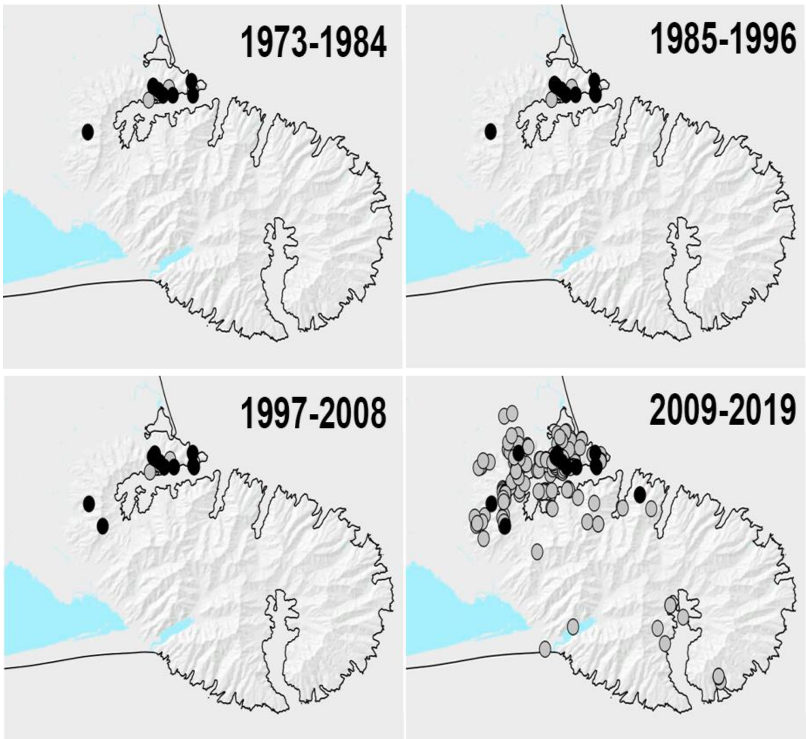

Figure 3. Distribution through time of *Polypodium vulgare* on the Port Hills and Banks Peninsula. The black circles are specimens from the herbaria of Auckland Museum, Manaaki Whenua Landcare Research, and Te Papa. The grey circles are unvouchered observations, by ourselves and from the iNaturalist citizen-science website. Maps from LINZ, CC BY.

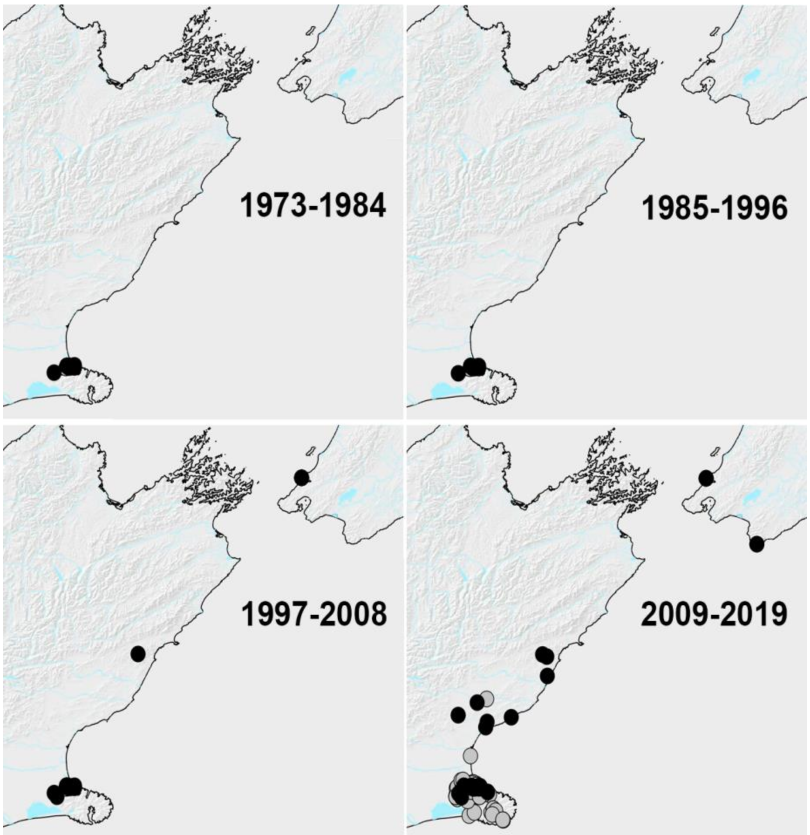

Figure 4. Distribution through time of naturalised *Polypodium vulgare* in New Zealand (north-eastern South Island and southern North Island). The black circles are specimens from the herbaria of Auckland Museum, Manaaki Whenua Landcare Research, and Te Papa. The grey circles are unvouchered observations, by ourselves and from the iNaturalist citizen-science website. Maps from LINZ, CC BY.

even in damp seepages, albeit rarely (Fig. 5). It ranges from full-light, open sites to heavy shade, and has been recorded in both very hot sites and very cold sites. Its ability to drop its fronds and survive as just a rhizome means it is probably most reliably located in spring when it is producing new fronds.

Figure 5. Some of the habitat diversity of *Polypodium vulgare*. Photos top-left and middle-right by Alice Shanks; top-right by Kate McCombs CC BY-NC; middle-left, bottom left, and bottom-right by Miles Giller.

The potential distribution of *Polypodium vulgare* in New Zealand is probably extensive. Although the number of genotypes in New Zealand is presumably very limited, and one genotype is unlikely to have the range of its species, the indigenous distribution of *P. vulgare* is massive, spanning the climates of northern to southern Europe. The current New Zealand distribution of *P. vulgare* falls within the "cool, semi-arid" and "mild, semi-arid" macroclimatic zones of Singers and Rogers (2014),

and these extend along the eastern side of the axial ranges from East Cape to southern Otago (see Figure 1 of Singers and Rogers 2014). The cliffs, banks, and outcrops that the species seems to prefer are readily available northwards to Marlborough, Wairarapa, and Hawke's Bay, westwards to the foothills of the Southern Alps, and southwards into Otago.

The problem of *Polypodium vulgare*

Polypodium vulgare in New Zealand has shown itself to be proficient at occupying a wide range of habitats. It is capable of locally dominating habitats, along with other weeds, to the detriment of indigenous species that are out-competed (including out-shaded). This affects herbs but also the seedlings of larger plants.

On Banks Peninsula and the Port Hills, *Polypodium vulgare* grows at the same sites as the Nationally Threatened species *Anogramma leptophylla* and *Myosotis lytteltonensis* and the Nationally At Risk species *Asplenium subglandulosum* and *Veronica lavaudiana*. In northern Canterbury, *P. vulgare* occurs alongside the Nationally At Risk species *Clematis petriei*, *Daucus glochidiatus*, *Discaria toumatou*, *Leptinella pusilla*, and *Linum monogynum*. As the spread of *P. vulgare* continues, it will probably move into additional rock outcrops and dry substrates in northern Canterbury that are home to other Nationally Threatened and At Risk species, such as *Anemanthele lessoniana*, *Carex inopinata*, *Chenopodium allanii*, *Coprosma intertexta*, *Leptinella serrulata*, *Pseudopanax ferox*, and *Teucrium parvifolium*.

Habitat occupied by weeds such as *Polypodium vulgare* curtails the potential population size of indigenous species. This is especially problematic for species with naturally small populations, such as those with very particular environmental requirements, whose long-term viability may be compromised. Thus, another weed competitor is another issue that requires active management to ensure that native species do not become extinct in the wild.

Page (1997) described *Polypodium vulgare* in Britain as a "weak calcifuge". This may mean *P. vulgare* is unlikely to invade limestone and other calcareous outcrops, which are often home to plant species of conservation concern (Rogers et al. 2018).

Control

Christchurch City Council trialled herbicide control in 2009 and again in 2016-2017. Metsulfuron was the most effective of various options tried, but its long term effectiveness has yet to be established. The rhizome of *Polypodium vulgare* has resistance against at least some herbicides, allowing plants to regenerate their fronds. It was found that spraying in November/December before the summer die-back was more effective than spraying the new growth in March.

Manual removal (including the rhizomes) has seen *Polypodium vulgare* locally eliminated from several covenants in northern Canterbury. Where feasible, manual control seems to be the most effective control option currently available.

Greater Wellington Regional Council attempted in 2010 to manually control the Plimmerton population, but having to dig out the rhizomes from a rocky slope meant it was very disruptive. Plans were subsequently made to use herbicide, but landowner permission has not been forthcoming, and it is expected that the population is persisting. Someone (not Greater Wellington Regional Council) seemingly tried to control the Cape Palliser population, but this has not been completely successful, with an iNaturalist observation of living plants made in August 2019.

Legal status

Polypodium vulgare is listed as an "unwanted organism" by the National Pest Plant Accord, preventing its sale, propagation, and distribution. The National Pest Plant Accord is a cooperative agreement between the Nursery and Garden Industry Association, regional councils, and government departments with biosecurity responsibilities. It makes illegal, via the Biosecurity Act, the sale and distribution of a plant species where either formal or casual horticultural trade is the most significant way of that species spreading in New Zealand. It is worth noting that *P. vulgare* was being recommended for planting in New Zealand gardens as late as 1998 (Auckland Botanic Gardens 1997; Van der Mast and Hobbs 1998). In about 2005 and again in 2010, live plants of *P. vulgare* were transferred from the Port Hills to the Te Mata Road area in Hawke's Bay, to cultivate as a source for herbal medicinal products.

Polypodium vulgare is listed as an "Organism of Interest" in the Regional Pest Management Plan 2018-2038 of Environment Canterbury. Organisms of Interest "are not accorded pest status but future control of them could arise, for example through Site-led programmes". In the Pest Management Plan 2019-2039 of Greater Wellington Regional Council, *P. vulgare* is designated a "Harmful organism" but not a "Pest", which means they do not have to control it, but that it is "watch-listed for ongoing surveillance or future control opportunities". *Polypodium vulgare* is not mentioned in the Regional Pest Management Plans of Otago Regional Council, Marlborough District [Unitary] Council, or Hawke's Bay Regional Council.

Conclusions

GWRC (2019, figure 5) describe an "invasion curve" of pest establishment. The "Lag Stage" involves initial slow establishment where "Pest numbers are low, the rate of population increase is slow and the distribution of the species [in an area] is limited. The most effective option [for pest management] during this stage may be eradication to prevent further establishment". Next is the "Explosion Stage", where "a pest has adapted to its environment and has reached a population base that allows rapid growth in population size and range. At this stage it is not realistic or cost-effective to eradicate the pest, but it may be possible to prevent further spread through containment". Finally is the "Established Stage", which occurs when "the pest fills most of its available habitat. At this stage, pests can only be suppressed to mitigate their impacts".

Based on the observations mapped here, *Polypodium vulgare* appears to be in the Established Stage on Port Hills, and the Explosion Stage on Banks Peninsula and at least parts of northern Canterbury. It is seemingly still only in the Lag Stage in the southern North Island.

Sheppard et al. (2016) state that "Weed management is most cost-effective at the early stages of weed invasion…Best practice weed management is preventative, focusing on eradication of weed species with populations consisting of very small numbers of individuals, while large entrenched populations are best suited to biocontrol programmes and site-led control at high value sites".

In 1980, *Polypodium vulgare* was so uncommon in New Zealand that the four known wild populations, all on the Port Hills, could be described in detail, even to the number of sporelings present. Nobody foresaw its massive spread and no preventative action was taken. Unfortunately, this now means that if the natural values (e.g., rare species) on the Port Hills that are harmed by *P. vulgare* are to be conserved, ongoing weed control will be forever needed (in lieu of biocontrol).

What has happened on the Port Hills provides a strong demonstration to pest managers in other parts of New Zealand: *Polypodium vulgare* should not be left unchecked. It may be possible to contain *P. vulgare* from becoming too abundant in eastern Banks Peninsula. Elsewhere, Environment Canterbury should seek to contain *P. vulgare* within northern Canterbury if it is already too late for eradication, while other pest managers should be actively excluding/eradicating it; this particularly applies to the regions that are probably most at risk of invasion by *P. vulgare*, namely Otago Regional Council, Marlborough District Council, Greater Wellington Regional Council, and Hawke's Bay Regional Council.

Polypodium vulgare has proven its invasiveness in New Zealand. Substantive action is now needed if its spread is to be curtailed.

Acknowledgements

Thanks to Auckland Museum, Manaaki Whenua Landcare Research, and Te Papa for access to collection data, and to the contributors to iNaturalist. We appreciate information from Megan Banks, Biosecurity Officer, about control efforts for populations in the southern North Island.

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The bibliography of Dr AD Thomson: corrections and additions

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Corrections

A number of the contributors to *Canterbury Botanical Society Journal Issue* 49 (2018) would have consulted Dr AD (Andy) Thomson's publications on the life and work of Leonard Cockayne to inspire and inform their articles. We apologise for the occasions when I [JC] might have omitted to include their acknowledgement of Andy's work.

We are grateful to Dr Warwick Harris for pointing out that rather than DSIR Botany Division being reborn as part of Landcare Research, Botany Division was largely absorbed into Landcare Research. We are also grateful to Warwick for reminding us to search the relevant DSIR Botany Division Triennial Reports for additional works authored by Andy Thomson. These and other papers, reports and articles missed from the bibliography published in Issue 49 of the *Journal* are listed below.

Additions

Thomson AD 1974. Russell Morris Allison 1915-1974. Crop Research News 16: 7–12.

Thomson AD 1975. Aspects of the early history of Government-sponsored plant breeding in New Zealand. Crop Research News 17: 12–14.

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Canterbury Botanical Society (NZ) Inc.

Sixty-Sixth Annual Report
June 2018 – May 2019

Officers and Committee

President: Paula Greer
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Committee: Melissa Hutchison (website manager), Bryony Macmillan (journal proof reading & newsletter posting), Dean Pendrigh (newsletters), Alice Shanks (programme co-ordinator) Miles Giller, Geoff Henderson, Sarah Wright and Paul Maurice (who resigned due to ongoing work commitments in August).

Monthly meeting programme

- June – AGM. Paula Greer presented her Masters' thesis on **using earth dams/water storage ponds as restoration sites** for native plants.
- July – Zane Lasare (MSc Ecology, University of Canterbury). **How plant trait diversity influences the success of invasions, and whether community trait composition can predict changes in abundance**. To quote from Alice's review of the meeting "In the end, if you are a plant then it is great to fit in with your environment, but if you are too weird then you may not persist. If the environment changes then a bit of difference can get you ahead." An evening that stretched some brain cells.
- August – Jeremy Rolfe (Department of Conservation). **Changes in the threat status of NZ vascular plants**. The best-attended meeting I have been present at. With many members and a few extras making the effort to hear from Jeremy why the updates to the threatened status of many species has been changed.
- September – Yuriy Malakhov (PhD candidate and BOTSOC student grant recipient). **Benthic microalgae of the Estuary**. A fascinating talk about the differences of benthic microalgae that Yuri found in the Ihutai Estuary, their amazing silica forms that are used for identification, and how his research has developed into a nation-wide programme "Sustainable Seas" involving personel from four other universities, NIWA and Cawthron Institute.
- October – Herman Frank. **The fauna of South Canterbury limestone and the plants they eat**. Herman took us on a trip to his favourite areas of South Canterbury. He gave us a short review of the twenty-odd years he has been working here looking for lizards and watching the landscape changes due to farming practices and new landowners.

- November – Dr Jamie Wood (Manaaki Whenua, researcher Ecosystems and Global Change). **New Zealand birds and the fungi they eat**. Through the use of coprolite (ancient bird droppings) DNA research, Jamie and his team have found a link between the ability of some of our fungi (with closed heads) to spread their spores by digestion. Jamie also told us about how ancient DNA is being researched in New Zealand, and the role of ectomycorrhizal fungi in facilitating exotic plant invasions.
- December – Rowan Hindmarsh–Wall, (Department of Conservation) **Unique habitats and plants of Ata Whenua - Fiordland National Park**. Rowan provided us with an interesting talk about the effects of limited management, increasing pest browsing, and the rarely seen species of Fiordland plants. The photos were incredible and to think this is what he does outside his work as a Tier 1 monitor.
- February – Dr David Glenny (Manaaki Whenua researcher – systematics). **The willow flora of New Zealand: an introduction to the *Salix* key**. This evening provided us with not only a chance to use the new *Salix* key, but to learn about the number of *Salix* in NZ, and the interesting background to *Salix* around the world and its many uses. This key has now gone live.
- March – Dr Pieter Pelser (University of Canterbury). **New research on the herbaceous *Brachyglottis* leads to one species**. Pieter with the support of Rob Smissen (co-author & geneticist) and Timothy Millar (master's graduate, lead author and topic researcher) provided an evening that was filled with discussion and debate about the merits of grouping and splitting species based on resulting genetic differences, or lack thereof.
- April – Colin Meurk. **Native plants are vital to nationhood, not just "nice to have optional extras", and how do we do that?** Colin reminded us that the limited use of natives in the city whether in gardens, private and municipal, or as part of the streetscape, is helping reduce people's recognition and knowledge of our native heritage. To turn this around we all must play a part by increasing the recognition and use of OUR plants.
- May – Lily Brailsford (MSc graduate, UC), **Evidence for Genetic decline within Afromontane forest fragments on the Mambilla Plateau, Nigeria**. Lily provided us with the evidence that the use of common species in fragmented forests can provide the genetic information for decline or ongoing diversity within the biodiversity of the area.

Monthly field trips

- July – Allan Herbarium, Manaaki Whenua, Lincoln. A Friday afternoon was spent enjoying the interesting and amazing collection that makes up the Herbarium. A lesson that it is well worth the effort to collect plants and review what has already been collected, where and when, to remind us of the changes in our country.

- August – Coprosma training in the Port Hills with Coprosma Key creator David Glenny. A well-attended trip, with some new faces of those willing to improve their abilities to use stipule shapes, and hair types and positions to improve their identification skills, whether in open sun or shade.
- September – The Jan Chaffey kowhai garden, Peter Joyce's sculpture garden, and the Rocklands forest restoration project, Taitapu. Jan's kowhai put on a great display for those who were able to make the trip. They were rewarded with being able to see a variety of kowhai species from New Zealand, Lord Howe Island and South America, with some cultivars. Peter and Anabelle have created what is known as the "Taitapu Sculpture Garden", which is open to the public with large and small sculptures for sale in spring. The creation of this garden, although with the intention of starting small, ended up large as a result of ordering by the tray (16) instead of pot as intended. Peter has increased his knowledge of natives and bush rehabilitation under the guidance of Jan, with the revegetation of a common area in the subdivision of the "Rocklands Reserve". This provides a walking track through a smallish bush area on the side of the hill.
- October – Tiromoana Bush, Kate Valley. Miles Giller led a trip through Tiromoana Bush with back-up from Jason Butt who has collected seeds there for many years. It was interesting to see how far a new pest had spread since discovery due to inaction, and the range of experiments being carried out there by the University of Canterbury.
- November – Spring camp around the Conway River area. Day trip to join those at Conway River and visit a rare patch of alluvial podocarp forest. Two trips that saw a variety of sites that have been created by river and earth movements. Some rare and naturally uncommon plants were found while enjoying a great weekend.
- December – Coringa Limestone outcrop. A trip that went through pasture to jumbled limestone outcrops with appropriately gnarled trees and kowhai that tried to confuse with a variety of leaf forms on top of the hill, and then down to the river for a preview of a possible later trip.
- January – Summer holiday trip to Murchison. A week that showed there is more to the Murchison area than many thought. The discovery of new areas and a larger variety of species than expected created a trip that was considered well worth the effort by everyone that went.
- February – Ataahua Government Purpose (wildlife management) reserve, on the shores of Te Waihora/Lake Ellesmere. A wet and wild day was spent finding the new reserve and comparing it to the surrounding lake shore and previously reserved areas.
- March – Lake Coleridge wetlands. Paula, Margaret and George, Miles, Graeme, Jane, and James (from USA) and Alice had an enjoyable day out testing their identification skills in a series of wetlands in the Lake Coleridge district.

- April – Rakaia Gorge Walking track. A small and enthusiastic group headed up the gorge looking for climbing broom. We found potatoes growing wild, but no broom.
- April again – Nature City. This was an extra trip where Melissa guided us to spots on Banks Peninsula to add some rare species to the Nature City competition on iNaturalist. Several of our members made the top 10 for species found and number of species identified.
- May – To Sue and John Steven's The Tors Farm. This trip produced some amazing photos of lichen and being cut off by the clouds, with 15 people enjoying the day.

Submissions and Correspondence

In May the Botanical Society made a submission to the Waimakariri District Council in support of employing a Biodiversity Officer for terrestrial systems. Gillian Giller, who also made a submission, has been told that the council is in progress of employing this Officer. There have also been submissions to ECAN, Christchurch City Council and The NZ Biodiversity Strategy.

Awards

Sally Tripp was awarded the Bledisloe Award for her achievements in the conservation of flora in both Governors Bay and on Banks Peninsula.

Both the Senior and Junior Science Fair Awards were given in the 2018 Westland/Canterbury Science Fair. As part of their prizes both students were given membership of the Society for the year. The Senior winner has come to several Monday meetings and is enjoying his first year at UC studying Botany.

Membership

There are currently 193 members, with 19 new members and 19 leaving. Our current average age has decreased this year.

Ron Close one of our Life Members died this year. Several of you will have memories of trips with Ron. His widow has donated several of his books to the Society to pass on to members who are interested.

The Journal

The 49th Journal based around Dr Cockayne, with several of the articles from the *Leonard Cockayne at Large* seminar in 2013, has been successfully received with enquires for copies from non-members. The 50th journal is in progress and is based around the issues of pests and biosecurity. Thank you to John Clemens for editing our Journal issues and chasing up article authors.

Committee

The committee started this term short of a President. I volunteered after a couple of meetings. Paul Maurice stepped down in August due to ongoing work commitments – hopefully we will see you back when you finally get the retirement you deserve, Paul. Geoff Henderson handed his notice in in April after realising the joy in retirement of being able to travel when and where you want due to fewer ties.

We have had a good year with our trips being well attended and some enjoyable meetings. They both stretched our minds, and gave us some amazing pictures to look at.

I am looking forward to the next year participating in this committee.

Paula Greer