Ecological risks of pasture diversity in regenerative agriculture

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Executive Summary

- Given the need to transition towards a more sustainable future and the global issue of climate change, regenerative agriculture (RA) has become increasingly common in New Zealand. RA aims to improve soil and ecosystem health via minimal soil disturbance, reduced synthetic inputs, and diverse pastures. Although RA is gaining increased attention, there are limited scientific studies on it in a New Zealand context.

- Our research question was '*What are the ecological risks of pasture diversity in regenerative agriculture across a variety of habitats in Canterbury?'*. Our research aimed to determine common species used in diverse pastures, investigate the risk of these species becoming invasive, evaluate how this risk may vary between ecological regions and lastly, determine strategies to avoid and mitigate invasive species.

- This study used a mixed-methods approach. Data was collected through semi-structured interviews from people across a range of disciplines relevant to our research question. Common species used in diverse pastures were identified based on species present on two RA seed lists, which were not present on conventional agriculture seed supplier websites. These species were assessed by conducting a Weed Risk Assessment (WRA). Data collection for this was completed via literature analysis.

- Interview responses highlighted that there are a range of factors that will influence whether a species will become invasive, such as management and its surrounding environment. The risk of species becoming invasive is also not confined to regenerative farming systems. Interviews and literature analysis suggested invasive species generally would not get the chance to dominate on the Canterbury Plains, however, if something was to become invasive this would have high consequences for the indigenous remnants.

  Eight RA-specific species were identified and investigated in our WRA. Russell Lupin had the highest total score of 17.5/21. Timothy and Sunflower had the second highest score of 15/21. Russell Lupin was discussed in interviews and is present on both Environment Canterbury (ECan) and Department of Conservation (DOC) weed lists, therefore was investigated further. Literature analysis highlighted that

Russell Lupin is well adapted to braided rivers, and seeds rapidly spread via waterways. Therefore, braided rivers in both the Canterbury Plains and Mackenzie Basin were considered high risk environments for Russell Lupin invasion.

- The scope of our research is limited to the Canterbury region and only investigates one practice within RA; diverse pastures. A key limitation of the research was the number of RA seed lists used to identify 'common species'. Whilst these lists gave us an understanding of the range of species used in diverse pastures, they did not provide insight into the frequency of which these species are used in Canterbury. Furthermore, our own scoring system was developed for four variables within our WRA. Scores were generated for each species based on literature analysis rather than primary observations, which may be limiting.

- Future research could expand the study beyond the Canterbury region to investigate how species of concern vary across other regions in New Zealand. Enhancing the validity of results through more expansive data collection of regenerative seed lists is recommended.

1. Introduction

Our project explored the risks and opportunities of regenerative agriculture (RA). RA is broadly defined as agricultural practices that improve and restore soil health, enhancing their capability of carbon sequestration (Gosnell, Gill, & Voyer, 2019). Recently, RA has gained traction across New Zealand's agricultural scene and the mainstream media. Many of the positive claims about RA are anecdotal, which whilst hold value, are not always supported with scientific evidence (McGuire, 2018). Given the positive focus on RA, we decided to investigate its possible adverse impacts. Our research question was: *What are the ecological risks of pasture diversity in RA across a variety of habitats in Canterbury?* Our research focused on one practice in RA, diverse pastures, as RA was too broad to cover holistically, especially with the timeframe and resources available.

Our research aims were to:

1. Establish the most common species used in RA diverse pastures, which were not considered to be used in conventional agriculture.
2. Investigate the ecological risk of species sown in diverse pastures becoming invasive.

3. Examine the vulnerability of the Mackenzie Basin (MB) and Canterbury Plains (CP) and how the risk of species becoming invasive may vary between these ecological regions.
4. Determine strategies to mitigate or avoid the risk of invasive species.

This report outlines the methods used for data collection and analysis, as well as the results that ensued, and their meaning in the broader context of RA. Our research highlights the potential risks of pasture diversity in RA, whilst still acknowledging the benefits of regenerative practices.

2. Literature Review, Theory & Concepts

To improve our initial understanding of RA, we researched its benefits concerning soil carbon sequestration, soil water retention and filtration, soil erosion, the implications of increased pasture diversity, and on-farm practices involved in RA.

The literature review regarding pasture diversity aligned most with our research question. Diverse pastures improve soil health, and enhance carbon sequestration, thus influencing climate change mitigation (Tickell, 2020). Farmers benefit economically due to increased yield and production stability, which is crucial under a changing climate (Buzdhygan et al., 2020; Isbell et al., 2015; Weisser et al., 2017). This leads to greater financial stability and farmer wellbeing. Furthermore, nutritional quality of products increase (Buzdhygan et al., 2020), which has ripple effects on human health both nationally and internationally.

The other literature reviews were not as useful as they did not directly align with our research question. However, they still provided context which helped to situate relevant knowledge and refine both our research focus and design. For example, initially we considered focusing our study on soil carbon sequestration, however, methodology used in existing studies highlighted how primary data collection for soil carbon sequestration is resource intensive and requires observation of up to two years (McNally et al., 2015). Such methods would not be viable considering the twelve-week timeframe of this project.

Other aspects of the literature aided method formation regarding secondary data collection. Gosnell et al. (2019) used semi-structured interviews and snowball sampling to gather a sample of farmers who practiced RA. This influenced our methodology refinement.

The literature review focussing on the practices used in RA helped to develop the definitions for this project. RA exists on a continuum, therefore is hard to define. RA was not defined for any other purpose than this research project. Based on literature reviews, RA considers anyone who is conducting one of more of the following practices; minimal soil disturbance, diverse pastures, reduced/no synthetic inputs, integrated livestock, and utilising cover crops. For our study, we considered diverse pastures as having more than five pasture species. We acknowledge that 'conventional agriculture' also exists on a continuum, therefore we considered 'conventional farms' as those which fall outside our RA definition.

The definition we used for invasive species was "Invasive species are non-native species that arrive in a new area, establish and increase in density and distribution to the detriment of the recipient environment." (Brenton-Rule et al., 2016, p. 17). Weeds were analysed from a conservation and environmental perspective, rather than a productive or economic one.

3. Methods

3.1 INTERVIEWS

Interviews were conducted to gain an in-depth knowledge of RA and the broader topics within our research question. Snowball sampling was used to gather interview participants relevant to the subject in question (Gomez & Jones, 2010). Participants had a variety of backgrounds; we spoke to people such as consultants, ecologists, scientists, and regenerative farmers. Random sampling would not have been relevant for the study as RA is still a niche farming system in New Zealand.

Contacts of potential participants were retrieved from our community partner, and contact was made via email. If participants registered their interest, an ethics email was sent. This outlined the context of their participation, how the information was going to be used, a withdrawal date whereby they could refuse participation in the research project and therefore the inclusion of any information they provided, and the option to remain anonymous. Interviews were conducted via Zoom or phone call, and were recorded for transcription. Interviews were semi-structured which allowed us to explore ideas that we may not have thought about or incorporated into our questions, and ensured similar themes could be identified when analysing the interviews (Lewis-Beck et al., 2004). To analyse the qualitative interview data, responses were separated into five themes: RA perceptions/personal definitions, benefits of RA, grazing and management, invasive species, and other points of interest.

3.2 QUALITATIVE RESEARCH

In order to select the RA species to look into further, we collected seed lists from a RA consultant and Symbiosis, a RA seed supplier (J. King, personal communication, August 21, 2020; Symbiosis, 2020b). These were compared to conventional agriculture seed lists sourced from PGG, Carrfields, and Agricom websites (Agricom, n.d.; Carrfields, 2020; PGG Wrightson Seeds, 2020) Only species present on both of the RA seed lists were investigated, as shown in Appendix A. Importantly, we are not claiming that the species investigated are used exclusively in RA, but for the purpose of this research, species were selected that were not present on any of the conventional seed lists analysed. The species selected were further investigated through literature analysis, with the aim of conducting a Weed Risk Assessment (WRA). Literature analysis was also used to investigate the vulnerability of CP and MB to invasive species.

3.3 QUANTITATIVE WEED RISK ASSESSMENT

A WRA was devised to assign a number that represents the potential invasiveness of the selected plant species. The WRA score was adapted from the Department of Conservation (DOC) *New Conservation Weed Risk Assessment* (NCWR) (Williams & Newfield, 2002). Scores for plant attributes had a range of 0-2 and equal weighting was given to each score to ensure an unbiased result. Higher scores indicated attributes that are more favourable for invasiveness.

Hazard was defined as the impact of the plant species of interest, which the NCWR assessment explained can be determined by the biomass of the plant and how well it persists in certain locations (Williams & Newfield, 2002). The impact score was calculated based on maximum plant height relative to natives, optimal growing conditions, (generalist vs. specialist species), and root structure, which was described rather than scored. Height was based on assessing the maximum height of the species of interest compared to the maximum height of prominent native vegetation species of the Mackenzie; *Fescue norae-zelandiae*, *Chionochloa rubra*, *Chionochloa rigida* and *Poa colensoi* (Connor & Vucetich, 1964; Molloy et al., 1998; Norton et al., 2006). Exposure was defined as the chance of the plant species spreading. This was determined by the plants dispersal method, seed viability, palatability and average regeneration time. Seed viability was scored based on whether the plant had a soft or hard seed coats. Hard seed coats protect the seed, increasing seed longevity (Becquerel, 1906, as cited in Mohamed-Yasseen et al., 1994). Average regeneration time was based on whether the plant is an annual or perennial. Perennial species scored higher as they produce seed more frequently than annual species, and over consecutive years. Their seeds are also more likely to germinate than those of annual species which produce seed once a year, then die (USFWS, 2008). Scoring systems for both hazard and exposure attributes are shown in Appendix B.

To calculate the total risk score, the hazard score was multiplied by the exposure score. To assess the validity of the scoring, weed risk was also qualitatively assessed by determining if the species investigated were present on the Environment Canterbury (ECan) *Declared Pests for Canterbury* list and the *DOC Weed Species* list (Environment Canterbury, n.d.-a; Howell, 2008).

4. Results

4.1 INTERVIEW FINDINGS

Overall, RA was perceived as positive. One interviewee believed that it could improve the environment by increasing soil health and mitigating climate change (W. Shaw, personal communication, September 1, 2020). Specific quotes from interviews are outlined in Table 1. Multiple interviewees acknowledged the lack of formal definition for RA (D. Norton, personal communication, August 14, 2020; T. James, personal communication, August 19, 2020). One interviewee believed this to be suited to RA as it exists on a continuum (D. Norton, personal communication, August 14, 2020).

Several interview participants believed there would only be a risk of species becoming invasive if regenerative farmers were importing new species. The Ministry for Primary Industries closely regulates what plant species can be imported into New Zealand, and several interviewees emphasised how difficult it would be to import something new (G. Bourdôt, personal communication, August 19, 2020; T. James, personal communication, August 19, 2020). Participants also pointed out that regenerative farmers are no more likely than conventional farmers to create a weed risk if they are using species already established in New Zealand (G. Bourdôt, personal communication, August 19, 2020).

Interviewees acknowledged the complexities of determining whether a species will become invasive. Invasiveness is based on a large range of factors, and therefore is difficult to predict. It was concluded that the practice of diverse pastures would not directly lead to invasiveness; instead it depends on the surrounding environment (e.g. soil conditions), and management (C. Buddenhagen, personal communication, August 19, 2020; G. Bourdôt, personal communication, August 19, 2020; J. Frew, September 1, 2020).

Participants mentioned two species of concern: Russell Lupin and Hieracium (B. Allan, personal communication, August 26, 2020; T. James, personal communication, August 19, 2020). Whilst we thoroughly investigated Russell Lupin, we did not look into Hieracium. Although Hieracium is a weed in the MB, it is not a species used in RA[1], and therefore was irrelevant to our research question.

Table 1: Key quotes from interviews separated into sub-themes.

Regenerative Agriculture (RA)	Invasive Species	Grazing & Management	Mackenzie Basin & Canterbury Plains
"One of the big criticisms of RA is that it doesn't have a definition, but this is the whole point of it - it doesn't need a definition because it is on a continuum…"	"RA people might be sowing species that are already in NZ, then **if these things present a risk, then that risk is already here**, so sowing these things is **probably not going to increase the risk of weediness**"	"Never going to come down to the plant on what actually happens. It's **going to come down to the management**."	"**Depends on the plant**, what its **origins** are and how they **function** in their natural environments and then **what they encounter** when they are put into a new place. It's **not as simple** as being just able to say things are potentially highly invasive or otherwise because they **change over time.**"
"There are some really fundamental issues here about how we deal with the environment and our carbon footprint going forward. RA will help these problems…"	"It's **not only RA farmers who are likely to create a weed risk…** all agriculture does that and we shouldn't contemplate the idea that RA is necessarily going to be a much riskier system then any of our other farming systems…"	"**…considering the landscape** is important in whether you consider something to be invasive or not and **some landscapes are much more susceptible or prone to invasion by species**"	"The **MB** is potentially at **greater risk** because of **open habitat**, 800 years of degradation, but the **consequences on the Canterbury plains would be much higher** if something did get out and get into a bankside/reserve because it's all we have."

[1] Hieracium was accidentally introduced to NZ as a seed mix contaminant in the late 1800s

4.2 SEED LISTS

The eight RA species investigated in regard to their risk of becoming invasive are shown in Figure 1. These species were chosen using the seed lists outlined in Appendix A.

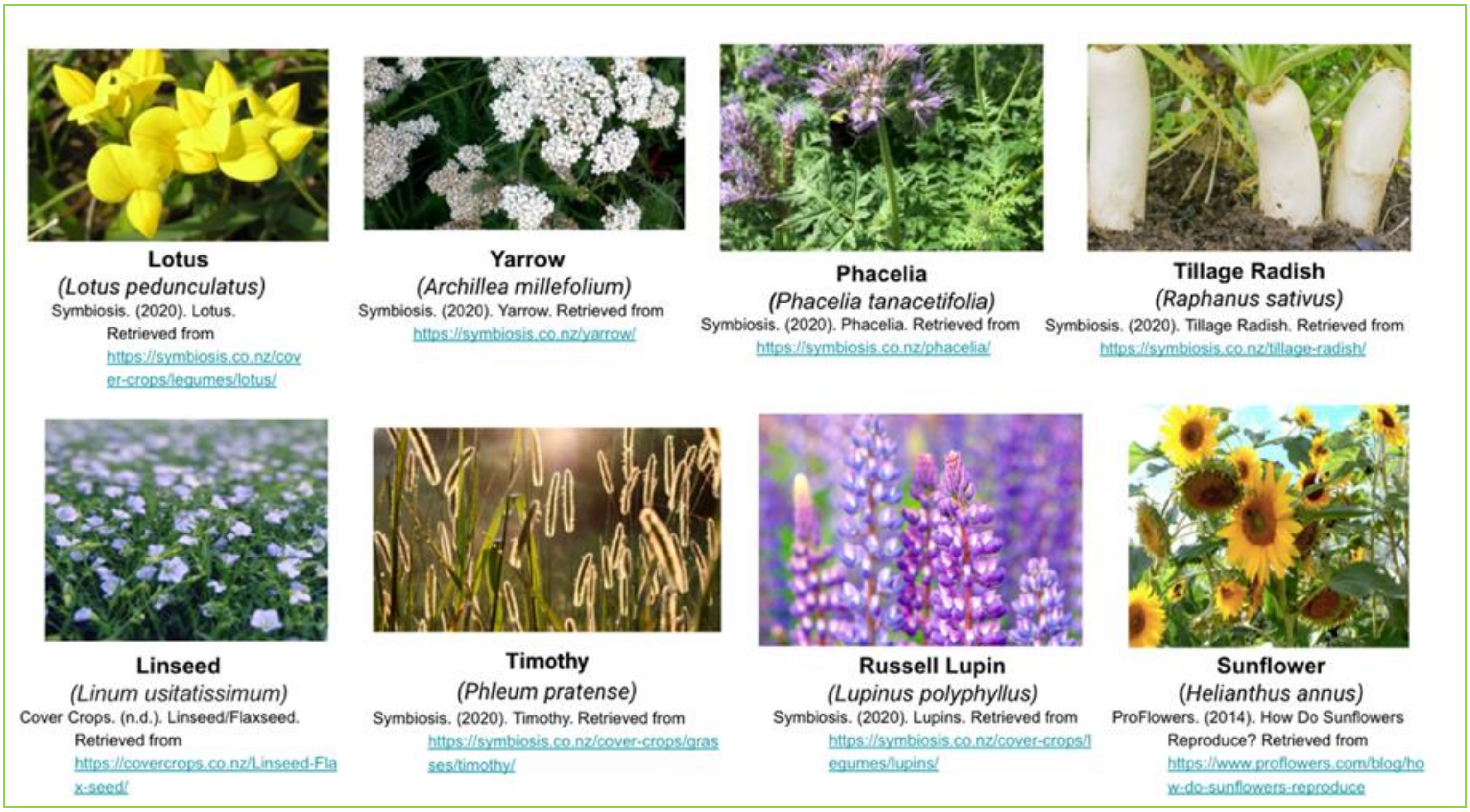

Figure 1. Images and scientific names of the eight species chosen based on their presence on the two regenerative agriculture seed lists analysed and non-presence on conventional agriculture lists.

4.3 WEED RISK ASSESSMENT

4.3.1 Hazard Scoring: Plant impacts

Table 2 shows that Lotus had the lowest hazard score (1), whilst Sunflower had the highest (3). Sunflower has a maximum height of 182cm, and was considered a generalist as it grows in a variety of soil types and climates (Putnam et al., n.d.; Warrick, n.d.).

Timothy and Russell Lupin had the second highest hazard score (2.5). ECan (2016) explained that Russell Lupin can grow up to 150cm. It was scored 1.5 for optimal growing conditions as although it grows well in low fertility soils, because it fixes nitrogen and tolerates aluminium toxicity, it does not grow well in clay soils and prefers damp, gravel soils (DOC, 2010; Scott, 1989).

Timothy has a maximum height of 150cm (CABI, 2020; Cotswold Grass Seeds Direct, 2020a). Timothy was scored 1.5 for optimal growing conditions as it grows in silt, loam, clay, and gravel soils (Wasser, 1982, as cited in Fire Effects Information System, 2020). Additionally, it grows well in shade and can withstand winter flooding (Copper, 1973, Mudd & Mair, 1961, as cited in Charlton & Stewart, 2000). However, Timothy prefers moist, fertile soils and does not tolerate drought (Molyneus & Davies 1983, Langer, 1953, Sampson et al., 1951, as cited in Charlton & Stewart, 2000). Initial literature analysis produced an optimal growing conditions score of 2 for Timothy, based on its ability to withstand a variety of soil types according to an American study (Fire Effects Information System, 2020). However, upon further literature analysis of a New Zealand study, we scored optimal growing conditions for Timothy as 1.5 based on its intolerance to drought and preference of moist, high fertility soils (Charlton & Stewart, 2000). As a result, Timothy's overall risk score was changed from 18 to 15.

Literature analysis of Yarrow highlighted that it has a rhizome root structure (Massey University, 2016). Consequently, Yarrow is difficult to kill as it spreads rapidly via these rhizomes (Massey University, 2016). Although root structure was not quantitatively scored due to lack of literature, the fact Yarrow has rhizomes is important to consider when evaluating its potential invasiveness.

4.3.2 Exposure Scoring: Chances of spreading

As shown in Table 2, Tillage Radish and Phacelia had the lowest exposure score (3) whilst Russell Lupin had the highest score (7). Russell Lupin's primary seed dispersal method is via waterways, it has hard seed coats, and is a perennial plant (ECan, 2016; Bass, 1980, as cited in Mohamed-Yasseen et al., 1994). They contain alkaloids, making them bitter at certain times of the year, and therefore less palatable, thus scoring a 1 (Wink, 1987, as cited in Berenji et al., 2018; Scott, 1989).

Timothy and Linseed had the second highest exposure score (6). Timothy is primarily dispersed by wind and livestock, possesses hard seed coats, and is a highly palatable, perennial grass (CABI, 2020; Fire Effects Information System, 2020). Linseed is an annual species with low palatability, and hard seed coats (Cotswold Grass Seeds Direct, 2020a;

Smith & Froment, 1998; Symbiosis, 2020a). There was limited literature on seed dispersal methods. Therefore, it was scored a 2 as the DOC NCWR assessment explained higher scores are given when there is lack of information for certain attributes (Williams et al., 2005).

4.3.3 Total Scores & Comparison to DOC and Environment Canterbury Seed Lists

Overall, Table 2 shows that Russell Lupin, Sunflower and Timothy had the highest total scores (17.5, 15 and 15, respectively). Russell Lupin was the only species present on both the ECan *Declared Pests for Canterbury* list and the *DOC Consolidated Weed List*, therefore was investigated further (ECan, n.d. - a; Howell, 2008; Williams et al., 2002). None of the species were present on the *MPI Pest and Disease Search* (MPI, 2020).

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Table 2: Quantitative Weed Risk Assessment (WRA) results for the eight selected species and qualitative weed risk results from ECan and DOC weed list comparison.

SPECIES		Phacelia	Sunflower	Lotus	Yarrow	Timothy	Linseed	Russell Lupin	Tillage Radish
***Hazard* = Plant Impacts**	Max Height of plant*	92cm 0	182cm 1	80cm 0	60cm 0	150cm 1	100cm 0	150cm 1	92cm 0
	Root structure*	Tap root + Fibrous	Tap root	Fibrous Central tap Shallow	Rhizome	Shallow and fibrous – up to 120cm deep	Shallow Tap root Lateral roots	Deep Tap Root	Tap root
	Optimal growing conditions*	2	2	1	2	1.5	2	1.5	2
HAZARD TOTAL SCORE:		2	3	1	2	2.5	2	2.5	2
***Exposure* = Chances of spreading**	Dispersal method	1	2	1	2	2	2	2	1
	Seed viability	1	2	2	1	2	2	2	1
	Palatability*	0	0	1	0	0	1	1	0
	Average regeneration time*	1	1	1	2	2	1	2	1
EXPOSURE TOTAL SCORE:		3	5	5	5	6	6	7	3
TOTAL RISK SCORE: ***Risk = hazard x exposure***		**6**	**15**	**5**	**10**	**15**	**12**	**17.5**	**6**
Present on ECan declared pests for Canterbury? (Y/N)		N	N	N	N	N	N	Y	N
Present of DOC Weed species list? (Y/N)		N	N	Y	N	N	N	Y	N
Present on MPI pest and disease search? (Y/N)		N	N	N	N	N	N	N	N

4.4 AREA VULNERABILITY

One of our interview participants discussed that invasive species generally would not get the opportunity to dominate in the CP as opposed to the MB. They further explained that management in the area contributes to this (B. Allan, personal communication, August 26, 2020). Furthermore, the CP is a highly modified system where exotic species dominate and limited indigenous biodiversity remains (Bowie et al., 2016; Cieraad et al., 2015). *Statement of evidence* (2016) discussed the ecological significance of the MB. The MB contains up to 81 at-risk or threatened plant species, some of which are unique to the dryland environment of the MB (Forest & Bird, 2018; *Statement of evidence*, 2016). This may increase the vulnerability of the area in terms of native biodiversity loss if something was to become invasive.

One of our interview participants highlighted that whilst there is a lower risk of invasive species becoming dominant in the CP, if something was to become invasive, this would have high consequences for the patches of remaining indigenous vegetation, due to the rarity of these ecosystems (Ecroyd & Brockerhoff, 2005; D. Norton, personal communication, August 14, 2020).

While these factors contribute to the vulnerability of an area to an invasive species, it is difficult to definitively say whether one area is more vulnerable than another. As one of our interview participants explained, this depends on other factors such as management (P. Barrett, personal communication, August 14, 2020).

4.5 RUSSELL LUPIN

Russell Lupin grows well in soils within the MB which have a low pH and high levels of aluminium (Berenji et al., 2018; David, 1981, as cited in White 1995). Rhizobia enable them to withstand high concentrations of aluminium (Ryan-Salter et al., 2014, as cited in Berenji et al., 2018, Scott 1989). Furthermore, Russell Lupin are nitrogen fixers, thus can overcome nitrogen deficiencies in soils (Moot 2012 as cited in Berenji et al., 2018; DOC, 2010; Peat & Patrick, 2001 as cited in Javernick, 2013)

Russell Lupin primarily disperses seed via waterways, thus transporting them large distances from the parent plant (ECan, 2016). Concerns of Russell Lupin invading river beds was also discussed in multiple interviews (B. Allan, personal communication, August 26, 2020; T. James, personal communication, August 19, 2020). Although Russell Lupin is well adapted to MB soils, land that is distant from waterways has a low risk of it becoming invasive as seed is unable to be effectively dispersed (ECan, 2016). For example, a study at the Mt John field site observed no accidental spread of Russell Lupin at trial sites distant from waterways (ECan, 2016).

Based on these findings and utilising Canterbury Maps Viewer (n.d.), areas that should be considered high risk environments to Russell Lupin include land adjacent to the three major braided rivers within the CP. Additionally, Wilson (2001) as cited in Javernick (2013) identified that 32,308ha in the Upper Waitaki Basin within the MB is riverbeds. Therefore, these areas are also high risk environments.

Russell Lupin is considered a weed as it removes nesting space and provides cover for predators which is detrimental to endangered native birds (Otago Regional Council, 2019; Wardle, 2016). Furthermore, dense cover of Russell Lupin traps silt, stabilising river banks, which can result in channels transitioning from braided to meandering (Holdaway & Sparrow, 2006; Javernick, 2013). Lastly, according to Wardle (2016) control of Russell Lupin in braided river systems is expensive, costing DOC up to $150,000 (NZD) annually.

4.6 MITIGATION & AVOIDANCE

Grazing can be used to control the spread of Russell Lupin as it is palatable to livestock. Russell Lupin should only be planted in areas where grazing can be utilised in order to minimise unwanted spread, such as pastures distanced from waterways (ECan, 2016). According to Frost & Launchbaugh (2003), grazing management must consider plant ecology and plant-animal interactions in order to be successful. Species should be grazed when they are most palatable to livestock and therefore most susceptible to defoliation. The time of grazing should also be considered. As the growing season progresses, plants invest more resources into seed production rather than growth, therefore grazing at this time inhibits dispersal and does not allow for their regrowth. Furthermore, to reduce harm to desired plant species, grazing should be implemented when they are at their greatest tolerance to grazing pressure. Seed predation by livestock also greatly reduces the risk of spread.

Though the principles of RA aim to reduce synthetic inputs, chemical control is a possible mitigation option. There are herbicides which are suitable for controlling Russell Lupin that do not kill native grasses and are safe around waterways (ECan, 2016).

Other mitigation methods for Russell Lupin include hand pulling, which is suitable when removing small patches, and shading, as Russell Lupin is intolerant to moderate shade (ECan 2016; ECan 2018, ECan, n.d.-c).

Monitoring is crucial in order to ensure the implementation of mitigation methods (ECan, 2016). However, success of monitoring depends on the regularity and thoroughness of it. In some cases, it may be more appropriate to avoid planting Russell Lupin altogether. As shown in Table 3, ECan (n.d.-c) and the Otago Regional Council (2019) have outlined that Russell Lupin cannot be present in buffer zones adjacent to waterways. Avoidance may therefore be the best option, as management and mitigation efforts may not stop Russell Lupin becoming invasive.

Table 3: Required buffer zones when planting Russell Lupin near waterways. Source: Adapted from Environment Canterbury (n.d.-c) & Otago Regional Council (2020).

Waterway size	Required buffer zone
Large braided river: 100m + in width	200m
Smaller streams: <100m wide	50m
Farm drains flowing into rivers	5m
Any artificial watercourse	10m
An adjoining property boundary	10m

5. Discussion

In exploring our research question *"What are the ecological risks of pasture diversity in regenerative agriculture across a variety of habitats in Canterbury?"* we did not find a straightforward answer.

A key finding from this research is that the invasiveness of a pasture species comes down to its environment. For example, despite the prevalence of Russell Lupin in interviews and academic literature, we found from the WRA that it is only of great risk on land adjacent to rivers, particularly in the MB where soils are acidic and high in aluminium (Berenji et al., 2018; ECan, 2016).

Consequently, management plays a large role in reducing the likelihood of a plant species becoming invasive. We have identified three potential management practices:

1. Do not plant a species in an area where it is likely to become invasive due to its characteristics and the complementarity of that environment. For example, do not plant Russell Lupin near waterways.

2. Grazing management. Species used within RA pastures are palatable to livestock. Therefore, grazing livestock can reduce or eliminate the dispersal of the potentially invasive species when carried out successfully.

However, the issue posed for these two strategies is enforcement and sustained monitoring to ensure that these management practices are being implemented correctly.

3. Sow species that occupy the same niche as the invasive species. This is about removing the opportunity for the invasive species to grow; e.g. planting a usable non-invasive tap root species which occupies the niche of an invasive tap-root species. For example, an early study conducted in Geraldine, New Zealand, showed that a diverse species mix including chicory, a tap-rooted plant, reduced the invasion of Californian thistle, an 'invasive species' or 'weed' which is also tap-rooted (Musgrave & Daly, 2004). This was in comparison to a rye-grass monoculture. Alternatively, this may be more complex in regard to addressing underlying soil issues, such as an imbalanced C:N ratio or nutrient deficiencies, that are providing the opportunity and environment for the invasive species to thrive (J. Frew, personal communication, September 1, 2020).

An additional conclusion is that there is no greater risk of the species used within RA becoming invasive than the ones used in conventional agriculture (G. Bourdôt, personal communication, August 19, 2020). The species used within RA are already in New Zealand, therefore any threat of a pasture species becoming invasive comes down to the management of them. This can also be applied to conventional agriculture. Furthermore, species used in conventional monocultures are just as likely, if not more, to become invasive due to the sheer abundance of a single species; "Everything can dominate, but it comes down to how much of it you put in the environment" (P. Barrett, personal communication, August 14, 2020). In RA the diversity of pastures does not allow for such dominance.

5.1 LIMITATIONS

Upon critical analysis of our research and associated results, we identified three main limitations:

1. The number of seed lists we used to identify species used in RA. We had only two regenerative seed lists, and though this gave us an idea of the type of species used in RA, it is not representative of how commonly used these species are in Canterbury.

2. We adopted our own WRA. Due to time restrictions, we assigned scores based on literature reviews, rather than primary observations. As literature was from a variety of sources, there may be inconsistencies between how the attributes within our WRA were measured (e.g. how plant height was measured or palatability was assessed). Individual perception of literature findings may have also influenced the scoring within our WRA categories, despite having a defined criteria for our scoring system (Appendix B). Furthermore, some attributes were difficult to allocate a score to, such as root structure, as information on how this impacts species invasiveness was limited. Thus, scores may over/underestimate species invasiveness.

3. The definitions we used are specific to our study. Both 'regenerative agriculture' and 'invasive species' do not have widely accepted definitions. RA is a relatively new concept, therefore no definition has been constructed, whilst invasive species has a variety of definitions of which one cannot be agreed upon.

5.2 BROADER CONTEXT

We found that many of the goals of RA align with the mana whenua value of kaitiakitanga in regard to the environment: protecting and improving the land and mahinga kai for the current generation and those that follow. Additionally, some goals of Ngāi Tahu, as outlined in the Iwi Management Plan (Jolly et al., 2013), align with the ideals of RA, thus may promote partnership and further engagement with mana whenua in implementing regenerative practices.

RA is gaining significant traction in being recognised for its far-reaching benefits. Academic literature highlighted that implementing diverse pastures has substantial positive consequences; such as improved soil structure and water use efficiency, as well as greater ecosystem biodiversity, stability, and function (Buzdhygan et al., 2020; Isbell et al., 2015; Weisser et al., 2017). Examples of what ensues include reduced nitrogen losses into waterways, resilience against climate extremes, increased financial stability, and improved health and wellbeing of both farmers and consumers (Finger & Buchmann, 2015; Isbell et al., 2015; Weisser et al., 2017). Of most prominence, RA sequesters carbon, thus highlighting it as a key player towards mitigating or reversing climate change (Lange et al., 2015).

6. Conclusion

In summary, there is no straightforward answer to our research question. However, our research has identified species of concern in terms of becoming invasive, as well as management strategies for these. Russell Lupin poses the greatest risk of becoming invasive near waterways based on both interview findings and WRA results. When assessing ecological risk across a variety of habitats in Canterbury, whether a species within diverse pastures becomes invasive depends on the surrounding environment and management of that area.

For future research, it would be beneficial to expand this study beyond the Canterbury region to investigate how species of concern vary spatially. More extensive collection of seed lists from regenerative farms is also needed to gain a robust understanding of which species are most commonly used in diverse pastures.

Given that the potential adverse impacts of pasture diversity can be prevented or mitigated, and do not apply to RA alone, it is difficult to overlook the positive effects RA has on the environment, human health and wellbeing, as well as the benefit it can provide to New Zealand's economy due to our significant dependence on agriculture.

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view of RA and the effects it may have. This knowledge was vital due to the lack of scientific literature available on this subject.

Disclaimer

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Appendices

APPENDIX A: Species list crossover between RA seed lists from supplier and consultant with conventional seed lists from PGG, Carrfields and Agricom. Seed list #1 and seed list #2 represent lists provided by Symbiosis (seed supplier) and a regenerative consultant.

Seed list #1	Seed list #2	Crossovers
Tillage radish	Barley	**Tillage radish**
Rape	Beans	**Sunflower**
Yellow mustard	Birdsfoot trefoil	**Linseed**
Brown mustard	Chicory	**Lotus**
Turnip	Cocksfoot	**Lupins**
Kale	Tillage radish	**Yarrow**
Alyssum	Grazing brome	**Timothy**
Swede	Italian ryegrass	**Phacelia**
Arugula	Kale	
Phacelia	Linseed	
Sunflower	Lotus	
Safflower	Lucerne	
Buckwheat	Lupins	
Black oats	Maize	
Grazing corn (maize)	Millet	
Cereal rye (ryecorn)	Oat	
Triticale	Pea	
Barley	Perennial ryegrass	
Quinoa	Phacelia	
Lamb's quarter (fat hen)	Plantain	
Chia	Prairie grass	
Faba beans	Red clover	
White clover	Sunflower	
Balansa clover	Tall fescue	
Berseem clover	Timothy	
Crimson clover	Turnip	
Lentil	White clover	
Red clover	Yarrow	
Lucerne		
Peas		
Persian clover		
Linseed		
Vetch		
Alsike clover		
Cowpeas		
Hairy vetch		
Caucasian clover		
Lotus		

Lupins		
Arrotas clover		
Subclover		
Medics		
Sweet clover		
Strawberry clover		
Sorghum sudan		
Annual ryegrass		
Millet		
Prairie grass		
Cocksfoot		
Tall fescue		
Perennial brome		
Festulolium		
Perennial ryegrass		
Crested dogstail		
Yorkshire fog		
Timothy		
Phalaris		
Chicory		
Plantain		
Borage		
Parsley		
Sheep's burnett		
Yarrow		

Key:

[green box] = Not present on any of the three conventional seed lists

APPENDIX B: Scoring system for Weed Risk Assessment adapted from NCRW weed risk assessment.

IMPACT SCORE:

- **Height of plant:***
  < (or equal to) 1m = 0
  >1m =1

- **Root structure:**
  Descriptive

- **Optimal growing conditions:***
  Specialist = 1
  Generalist = 2

EXPOSURE SCORE:

- **Seed dispersal method:**
  Large birds or accidental =1
  Small birds, wind or water =2

- **Seed viability:**
  Not viable = 0
  Soft seed coat = 1
  Hard seed coat = 2

- **Palatability:***
  Will eat = 0
  Might eat/ parts of plant = 1
  Will not eat = 2

- **Average regeneration time:***
  Perennial = 2
  Annual = 1

TOTAL WRA SCORE = IMPACT X EXPOSURE

**own score system developed otherwise from DOC NCWR*