Effect of Salix spp. in Styx Mill Conservation Reserve

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Executive summary

- Styx Mill Conservation Reserve is a wetland area that holds cultural, social, and ecological value. Invasive willows can threaten the ecological health of wetlands and are present within Styx Mill Conservation Reserve.
- Willow removal techniques are labour and cost intensive. Is willow removal worthwhile to restore the natural environment?
- Our research question is: What are the impacts of willow tree presence on native plant regeneration at Styx Mill Conservation Reserve?
- Quantitative data collection method was used to compare native regeneration between three site categories: native vegetation, controlled willows and live willows.
- Site category had no significant effect on density of native regeneration. Level of herbivory, distance from stream, and willow size also had no effect on native regeneration.
- Our main recommendation is that willow management using glyphosate continues.
- Specifically, we recommend that willows are not completely cleared and that removal of willows closest to waterways is prioritised.
- We would encourage New Zealand Conservation Trust to develop a relationship with mana whenua due to the similarity of intentions and to encourage the preservation of mahinga kai and growth of native species.
- A major limitation of this research was time. This decreased the amount of data we could collect, decreased the spatial scale of the project, and meant we could not physically study the effect of willows on other areas of biodiversity.

Introduction

Restoration ecology is becoming increasingly important as anthropogenic stressors increase at an unprecedented rate, causing severe degradation and alteration to the natural environment (Suding, 2011). Severe habitat loss, increased fragmentation, and an influx of invasive species has resulted in a dramatic loss of native species. (Saunders & Norton, 2001). Given New Zealand's (NZ) unique geological background, landscape, and climate; there is a vast amount of endemism*. This increases the importance of restoration (Maranhão & Sant'ana, 2017). Wetlands have been severely impacted by these stressors. A considerable proportion of low-lying wetlands have been converted to farmland, and the remaining wetlands face increasing pressure from invasive species (Myers et al., 2013). Restoring these wetlands is critical as they create habitat for a variety of native biodiversity and provide essential ecosystem services (Maranhão & Sant'ana, 2017). Globally, wetlands contribute up to half of the world's ecosystem services including carbon sequestration, pollutant filtration, flood control, and important social and cultural resources (Myers et al., 2013). Māori value wetlands as mahinga kai sites and provide habitats for many taonga species (Anderson, 2008).

Styx Mill Conservation Reserve, hereafter referred to as Styx Mill, is a low-lying wetland located in Northwood, Canterbury. Significant conservation work at Styx Mill has improved the wetland environment, however, more work is required. *Salix spp* (willows) are an invasive species thought to be hindering native biodiversity. For this reason willow trees are being removed from Styx Mill to improve native biodiversity. We will explore the relationships between willow tree presence and native plant regeneration to determine whether this should be a leading factor in management decisions, and we will discuss other factors impacted by the removal of willows.

Wider brief from New Zealand Conservation Trust

Our brief was to determine whether willow trees were helping or hindering native (flora or fauna) regeneration, using Styx Mill as a case study.

Aim

To identify the impacts from willow trees on native biodiversity at Styx Mill Reserve to inform recommendations for future conservation.

Question

What are the impacts of willow tree presence on native regeneration at Styx Mill?

Literature review

Introduced and native plant interaction

There is conflicting research about if some invasive plants help specific natives establish in differing environments. Although the majority of research indicates a negative interaction. The treatment of willows with glyphosate increases native plant dominance after three years (J. Griffiths, Armstrong, Innes, & Terry, 2018). This is because willows decrease the diversity of native plant communities by reducing light availability and nutrients (J. W. Griffiths & McAlpine, 2017).

Some researchers have suggested that the interaction between introduced and native species can be positive. For example, shade tolerant native species can outcompete gorse. This is dependent on herbivory, seed source, and climate (Wilson, 1994). Invasive pecies in alpine ecosystems can help native plants establish by creating favourable environmental conditions (Cavieres et al., 2014). This concept could be applied to Styx Mill. However, the benefits of nurse plants on species richness may be exclusively correlated with harsh environments (Callaway, Brooker, Choler, Zaal, & et al., 2002).

How invasive mammals impact native regeneration

Brushtail possums (*Trichosurus vulpecula*), European rabbits (*Oryctolagus cuniculus*), and two rat species (*Rattus norvegicus*, *Rattus rattus*) are small invasive mammals consume native vegetation at Styx Mill (The Styx, 2020). There is limited information on the interaction between invasive mammals and willows, and how this impacts native plant regeneration (Wilson, 2003).

Possums and rats consume large quantities of native plant material such as seeds, flowers, fruits, and leaves, and in the absence of ungulates consume seedlings (King & Forsyth, 2021; Wilson, 2003; Clayton, 2008). At high densities *R. norvegicus* can alter the recruitment and composition of native plant communities (Allen, Lee, & Rance, 1994, Wilson, 2003). In native forests adjacent to pasture, damage caused to native plant seedlings was likely due to rabbits. Further away from pasture into the forest, seedling damage is reduced, as rabbits were less common (Gillman & Ogden, 2003).

The physiology of willow trees, invasive traits, and removal techniques

Willows tend to grow in well-watered environments or around damp/swampy areas (Weih et al., 2006). Their invasive traits enable them to survive in the water tract of highly disturbed sites with low native vegetation. The growth patterns of willows are the leading cause for invasive tendencies in willows as their access to waterways enables them to spread on large scales. Invasive tendencies include high dispersal rates through breakable branches dropping into waterways (Lewerentz et al., 2019). Researchers also found willow's complex root systems and higher growth rates in juveniles than natives, also contribute to invasive growth trends (Lewerentz et al., 2019).

Due to these invasive traits' willows require extensive removal techniques to target growth and reinvasion. Through a before-after control-impact experiment the application of drilling glyphosate into roots significantly reduced willow cover and reinvasion rates. This method is desirable for willow control as it provides accurate results with low collateral damage in non-targeted vegetation (Burge et al., 2017). Overall, results showed willows treated with glyphosate allow for increased native regeneration.

The effects of willow trees on native fauna biodiversity

The effects of willows on native biodiversity are varied. Willows in waterways positively effect native benthic invertebrates* and had no effect on native fish (Glova & Sagar, 1994).

Negative trends were also observed in terrestrial biodiversity. Native arthropod abundance and diversity decreased with the presence of invasive plants (Litt et al., 2014). Native beetle abundance and diversity decreased with grey willow presence (Watts et al., 2012).

Avian biodiversity peaked in areas of native vegetation, decreased with willow presence and was lowest in sites with no vegetation (Holland-Clift et al., 2011). This highlights the importance of strategic removal plans. A meta-analysis conducted by Schirmel et al., (2015), looked at native animal biodiversity responses to invasive plants across ecosystems. In 56% of studies invasive plants had a reducing effect on animal biodiversity and the remaining 44% of the time there was a neutral effect. No increasing effects were found. These studies illustrate that although results are not clear cut; invasive plants and willows specifically tend to have negative effects on native biodiversity.

Historic wetland flora of Canterbury

Prior to 1250 AD wetlands were dominated by native species such as kahikatea, rimu, and beech (Wood et al., 2018; Moar, 2008). After Polynesian settlers arrived in 1250 AD, much of the woody canopy was burnt off to allow for water, nutrient, and sediment flow into the wetlands. This created more productive ecosystems where wetland birds, freshwater fish, and eels became abundant (McGlone, 2009). The wetland community composition changed and species such as: sedges, raupō, tī kōuka and harakeke; became dominant (McGlone, 2009; Pawson & Holland, 2005). These wetlands remain important to Māori for mahinga kai (Anderson, 2008). Importantly, there was a reduction in endemic biodiversity as the wetlands transitioned from swamp forest to more open wetland communities (McGlone, 2009).

A restored wetland community reflecting pre-1250 AD conditions would support more endemic biodiversity. However, would be less equipped to provide cultural ecosystem services (McGlone, 2009). This poses the question; should restoration goals reflect the ecosystem before or after Polynesian settlement?

Methods

General plan and mapping

We sampled at twelve sites in Styx Mill: four sites with controlled willows, four sites with live willows and four sites with native regeneration (called 'No Willows' in Figure 1). Potential sites were recorded with a GPS waypoint which were then collated into a map on Google Earth Pro (Google, n.d.a). This enabled us to mark out areas within Styx Mill that could be used for different treatments.

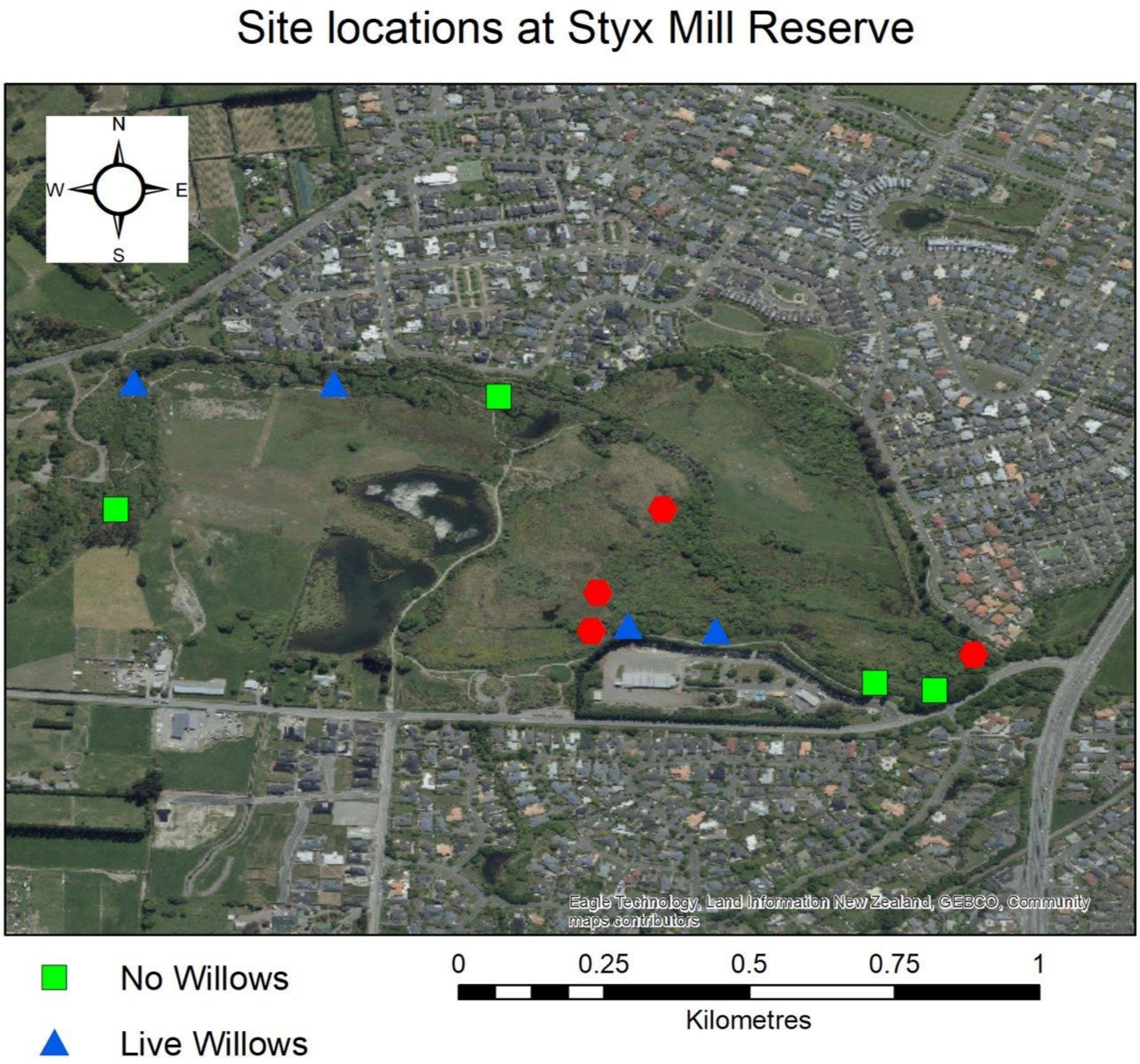

Figure 1: Map of sampling site locations within Styx Mill (Google, n.d.b).

We planned to sample four different willow treatments from Styx Mill. However, we found that there were only two potential sites where willows had been partially controlled, and this treatment was abandoned.

We were limited by the availability of potential sites within Styx Mill. This reduced the spread of sampling sites, making random sampling a challenge. For example, on the west side of Styx Mill there were few live willows. Therefore, at live willow sites the quadrat could not be randomly placed. In addition, accessibility also limited our ability to randomly sample sites. Some of the areas contained thick impassable undergrowth or deep mud that made it difficult to sample.

Data collection

We created a data collection sheet to record features of the site and density and size of native regeneration. Features recorded included site category, distance from stream and herbivory. At each site location, a 2m^2 quadrat was pegged out using a measuring tape. Initially, a 1m^2 quadrat was going to be used. However, a larger quadrat was decided on to represent the sites more accurately. Herbivory was judged by the abundance of lacerations to leaves. We used stem counts to identify density of native regeneration.

We identified species within our plots using iNaturalist (www.inaturalist.org; Nugent, 2018). When iNaturalist could not give us an accurate identification; we then photographed labelled seedlings and sent images to Professor Dave Kelly to identify any remaining species.

Data analysis

Our data was analysed using a generalised linear model (GLM) due to the non-normal distribution of count data. The original Poisson model failed the overdispersion assumption, so we changed to a multi-factor quasi-Poisson model. Data analysis was completed using R version 4.0.3, implemented in RStudio version 1.2.5033 (RStudio Team, 2019; R Core Team, 2020).

Results

A multifactor quasi-Poisson GLM tested relationships between native plant density and predictor factors; site category, willow abundance, level of herbivory and distance from stream (Figure 2). Site category did not significantly affect native plant density (Figure 2 & Figure 3). Willow abundance also had no significant effect on native plant density (Figure 2 & Figure 4). Level of herbivory had no significant effect on native plant density (Figure 2 & Figure 5). Finally, distance from stream also had no significant effect on native plant density (Figure 2 & Figure 6).

```
> glm.styx <- glm(total ~ willows + stream + willow.abundance + herbivory,
  family = quasipoisson, data = styx)
> anova(glm.styx, test = "F")
Analysis of Deviance Table

Model: quasipoisson, link: log

Response: total

Terms added sequentially (first to last)


                 Df Deviance Resid. Df Resid. Dev      F  Pr(>F)
NULL                                11     437.67
willows           2    3.826         9     433.85 0.0560 0.94600
stream            1   12.430         8     421.42 0.3641 0.56833
willow.abundance  1  191.247         7     230.17 5.6022 0.05576 .
herbivory         1   18.009         6     212.16 0.5275 0.49499
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 2: Analysis of deviance table from a multi-factor quasi-Poisson run testing the response variable of native plant density against predictor variables; site category, willow abundance, level of herbivory and distance from stream.

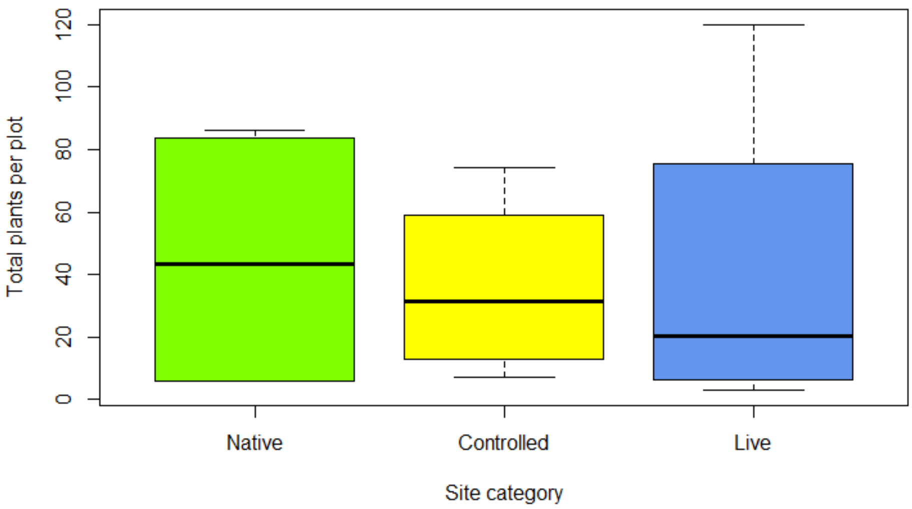

Figure 3: Boxplot showing density of native plants (stem count) between different site categories; native vegetation, controlled willows and live willows.

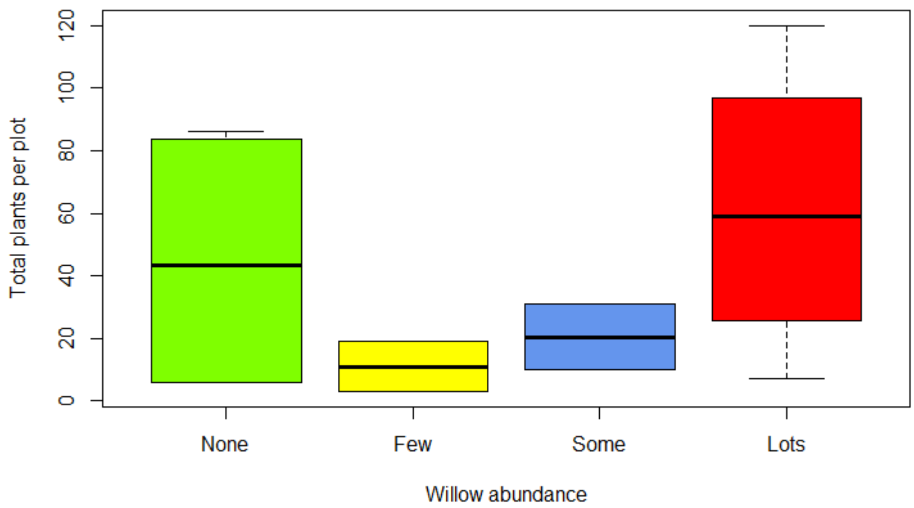

Figure 4: Boxplot showing density of native plants (stem count) between plots with varying amounts of willows; none, few, some and lots of willows.

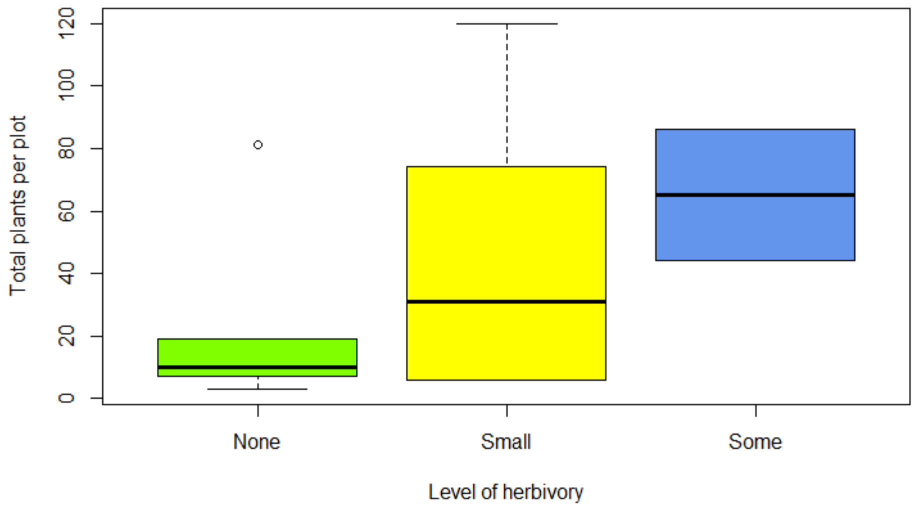

Figure 5: Boxplot showing density of native plants (stem count) between plots with varying levels of herbivory; none, small and some herbivory. No sites had large amounts of herbivory.

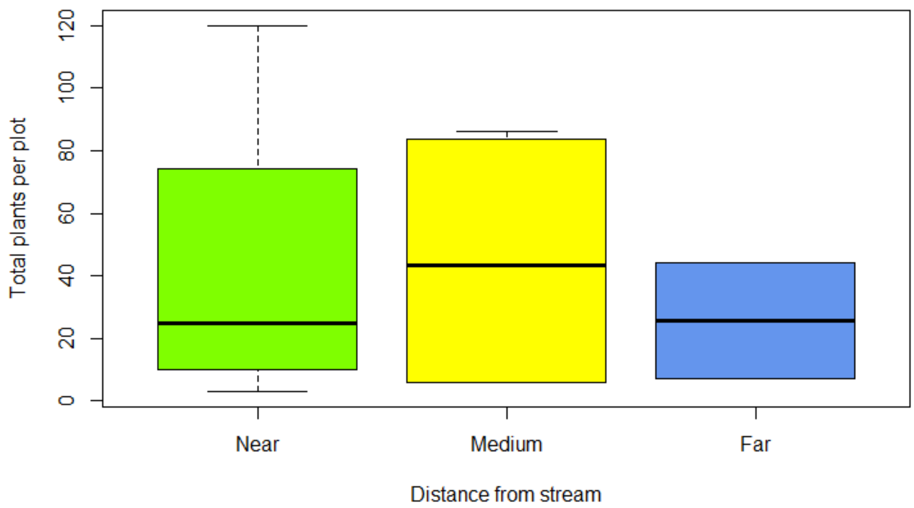

Figure 6: Boxplot showing density of native plants (stem count) between plots found at varying distances from the stream; near (<2m), medium (2-7m) and far (>7m).

Discussion

Our analysis shows that willow trees have no significant effect on native plant regeneration at Styx Mill. However, conclusions gathered from recent literature have stated that willows and other factors can have an impact on aspects of native biodiversity.

Herbivory

Our results show herbivory had no significant effect on native plant regeneration. This is because the ten native species recorded within our plots are not proven to be highly preferred by rabbits or possums (Appendix A). Additionally, the absence of species such as mahoe (*Melicytus ramiflorus*) and hinau (*Elaeocarpus dentatus*) from Styx Mill could be because they are highly palatable to possums (Nugent, Fraser, Sweetapple, & New Zealand. Department of, 1997). This suggests that herbivory may be altering species richness. Species richness is the total abundance of species present in our sample and the absence of some species could imply an unhealthy ecosystem (Whittaker, Willis, & Field, 2001).

However, Figure 5 shows that when native plant density is highest so is herbivory. One reason for this result is that possums and rabbits are not commonly caught in Styx Mill. These species consume native vegetation in spots where it is most dense (The Styx, 2020).

Willow abundance

The results show that at Styx Mill there is no significant relationship between willow abundance and the density of native plants. One explanation for this is that most of the sampled sites only had establishing natives that were less than 50 cm tall and there were limited mature natives. Willows provide a sheltered area for seedlings to germinate by protecting them from stressful environmental conditions such as wind and flooding. One study showed that there was higher mortality of seedlings in open plots compared to beneath willows (Dona & Galen, 2007). This research is supported by our results (Figure 4) as the highest mean number of total native plants per plot was in the ‘lots of willows’ category.

The relationship between willow abundance and native regeneration is likely to be more apparent as the native trees mature. This is because as plants mature, they need higher levels of light and nutrients. Willows will compete with natives for resources and prevent them from reaching full maturity (J. W. Griffiths & McAlpine, 2017). Over the next 10 to 20 years the competitive relationship between willows and natives at Styx Mill can be observed in more detail.

Willow size

Sites with high abundance of willows tended to have smaller willow trees compared to sites with lower abundance where they were often larger. Although both willow abundance and willow size do not affect native plant density, they could prevent the establishment of native plants over time. This is likely because smaller willows do not provide the same sheltering effects to native plants. Furthermore, the increased abundance of maturing willows is likely to compete more vigorously with native plants for resources.

Seed source

At Styx Mill native plant establishment is more likely to be dependent on seed sources than willow abundance. Seed source is the best predictor of species diversity and the regeneration of later successional species (McClanahan, 1986). The closer a site is to a seed source the higher the tree and shrub density. This relationship is strongest at the early stages of native plant establishment (Kepfer-Rojas, Schmidt, Ransijn, Riis-Nielsen, & Verheyen, 2014). At Styx Mill, our results show that there are strong seed sources for *Comprosa, Pittosporum* and *Griselinia*. For example, 182 *Comprosa*'s were recorded whereas there was only one of *Dacrydium cupressinum* and *Plagianthus regius*. The frequency of *Comprosa* and *Pittosporum* species could also be attributed to their fast root and shoot growth allowing them to be a well-known early successional wetland plant (Marden, Rowan, & Phillips, 2005; Tulod & Norton, 2020). Styx Mill also has ideal conditions for non-woody plants such as *B. montanum* and *C. secta* found within our plots. This is because they can grow quickly in poorly drained organic peat soils common in wetland environments (Wehi & Clarkson, 2007).

Willows effect on native fauna

As there was no evident effect of willow tree presence on native regeneration, other factors should be considered in deciding whether the willows should be removed. Understanding the interactions that willows have with other native species is a crucial factor for conservation.

A meta-analysis conducted by Schirmel et al., (2015), looked at the effects of invasive plants on native animal diversity through a range of countries, ecosystems, and taxa. Majority of the time the impact on native animals was negative (56%) and the rest of the time there was a neutral effect (44%). This shows that on a wider scale, invasive plants tend to hinder native animals.
More specific studies corroborated these trends. Another meta-analysis conducted by Litt et al., (2014), examined interactions between invasive plants and native arthropod communities. Finding reducing effects most common (62%) and increasing effects least common (15%). Exhibiting the general trend of invasives negatively impacting biodiversity.
Willows specifically are also shown to negatively impact native animals. Willows reduced diversity and abundance of native beetle species in a New Zealand study conducted by Watts et al. (2012). A negative effect was also seen in Australian native bird communities in response to willow presence. Diversity was highest in areas of native vegetation, dropped with willow presence and was lowest in areas that were completely cleared of vegetation (Holland-Clift et al., 2010). Looking at how willows impact avian biodiversity was important for this project as NZCT works heavily on trying to conserve native bird diversity. However, there was a gap in the literature looking at how willows impact native

birds. When looking at instream diversity, willows had a positive impact on native benthic invertebrates, and no effect on native fish communities (Glova and Sagar, 1994).
When studying these impacts, it is clear that in general, native animals are negatively impacted by invasive plants including willows. These interactions should be of utmost importance in management decisions, as if these studies are applied to Styx Mill, this would provide sufficient reason for the continuing removal of willow trees.

Bank stability

New Zealand is an erosion-prone country due to its geological setting with hilly and mountainous topography. Studies have shown that poplar (*Populus spp.*) and willow trees are widely used in soil conservation to prevent shallow landslides. Willows are especially good because of their lateral root development, high evapotranspiration rates, and tolerance to wet soils (Phillips et al., 2014). The installation of live willow posts as a bioengineering technique is also dominating bank stability efforts internationally. A study found the willow posts strengthen stream banks, reinforce soil stability, enhance sedimentation, and trap debris and soil blocks from upslope landslides (Watson et al., 1997).

Research suggests that although willows provide benefits for bank stabilization in larger catchments, their influence on smaller scale fluvial areas is too extensive for them not to be removed. Invasive willows can influence catchment water budgets through transpiration and interception in riparian areas which induces low-flow conditions (Marttila et al., 2018). Willows are unique as their roots spread into the bed of the watercourse, slowing the flow of water, and reducing aeration. This can divert water outside the main catchment channel, causing flooding and erosion where the banks are vulnerable (Marttila et al., 2018). Removal of these willows is an option to mitigate these effects but will depend strongly on the water-use characteristics of replacement vegetation (Marttila et al., 2018).

Willows at Styx Mill are inadequate to stabilise banks as it is a small-scale wetland area were changes in the channel morphology and accumulation of sediment are common. Therefore, the removal of willow trees at Styx Mill are necessary to support native regeneration growth and protect the natural river flow morphology.

Future research

Our research was limited since we only sampled twelve sites over a week period and only at Styx Mill. As a result, our analysis has low statistical power and only provides a small snapshot as to how willows affect native plant regeneration in NZ. We recommend that further research is conducted to better understand this.

A study by Williams (2011) concluded that replacement of woody, weed species such as willows by natives may be possible, but without long-term studies such as the one conducted by Hugh Wilson at Hinewai Reserve (Wilson, 1994), a conclusive answer cannot be provided. Therefore, future research should sample native plant regeneration in the presence of willows over the course of multiple years. It would be interesting to see whether native plants could outcompete willows over time. Future research should also focus on the effects of willows on native plant regeneration on a landscape scale. This is important because of the ability of willows to act as a nursery plant for native plants may depend on the native successional species that are present.

Recommendations to New Zealand Conservation Trust

We recommend that the current management of willows at Styx Mill continues. Although our study found that native plant regeneration was not affected by willow presence, the literature tells us that there are other crucial factors that should be considered. Wider biodiversity of animals is negatively impacted by invasive plants including willows (Schirmel et al., 2015; Holland-Clift et al., 2010)). Aspects of bank stability are important to consider as it differs with stream velocity. The Styx River is slow flowing through Styx Mill, and in areas with willows present it is known to encroach and push the water up over the banks. This is common with willows on the banks of slow flowing rivers (Marttila et al., 2018). This influences our recommendations, as we suggest prioritising control of willows near the river to avoid encroachment.

We also recommend maintaining the removal strategy that is occurring at Styx Mill currently which avoids clear-felling. Native biodiversity of animals, especially native birds, responds poorly to areas with no vegetation (Holland-Clift et al., 2010). Thus, drilling glyphosate into the base of the trunk and keeping the controlled willow trunk provides habitat for birds, invertebrates and keeps some shelter for native regeneration.

In addition to the continued management of willows, we also recommend the continued planting of natives. While this was not something we tested for, we found that native seedlings within sites had mature versions of those species close by. This suggests that seed source plays a significant role in native regeneration. This suggestion is corroborated by a study from Cordell et al., (2009) that also recommends management of non-natives and planting of natives to incentivise native regeneration.

A native species that has been shown to be capable of regeneration following willow control is kahikatea. (Griffiths & McAlpine, 2017). We would recommend planting more kahikatea to promote native regeneration growth reflecting similar elements from the historic wetland of Canterbury.

Future plans for native plant regeneration within Styx Mill should be mindful that invasive mammals have preferences for specific plant parts from certain species. Therefore, we recommend incorporating the control of possums and rabbits alongside rats within Styx Mill. This will benefit the regeneration of existent natives and establish others. This recommendation is supported through research conducted by Wilson et al., (2003) who reported that including invasive mammals such as rats increased native regeneration.

Conclusion

This project investigated the effect that willow trees have on native plant regeneration near waterways at Styx Mill Conservation Reserve. In association with the NZCT, we aimed to provide an insight into the effects willow management could have when restoring Styx Mill into a thriving wetland ecosystem.

Native plant size and density were sampled from four sites from the three categories: live willows, controlled willows, and native regeneration. Observations of herbivory, distance from a stream, willow abundance and willow size were also recorded. Analysis of this quantitative data using a multi-factorial quasi-Poisson model revealed that none of these factors had a significant effect on native plant density. However, future research sampling more sites could provide stronger conclusions.

Investigations into the literature do suggest that willows significantly affect other ecosystem components such as bank stability and avian habitat. Therefore, after assessing the findings from this project and the literature we have several willow management suggestions for the NZCT. Firstly, we recommend that treatment of willows with glyphosate continues, prioritizing willows near streams. Planting of wetland plant species should be maintained to create a stable seed source for continued regeneration. In areas with willows kahikatea is preferable. Furthermore, pest control should continue to aid the establishment of native plants.

Further research is required to investigate if native plants can eventually outcompete willows. As the vegetation at Styx Mill matures the interaction between the native plants and willows will become clearer. The scope of further research should also include other areas around Christchurch and New Zealand.

Acknowledgements

The authors of this report would like to thank Hadee Thompson-Morrison for her guidance throughout this project and Dave Kelly for his advice on species identification and data analysis. We are also appreciative of Justin Harrison for the use of sampling equipment. Thank you to Andrew Christie, David Rate-Smith, Yvette Williams' whose knowledge of Styx Mill Reserve was invaluable to our research approach. Finally, thank you to Daniel Leadbeater and the New Zealand Conservation Trust for facilitating the project.

Appendices

Appendix A.

List of native plant species recorded in our plots at Styx Mill Conservation Reserve

Species:
Blechnum montanum (kiokio)
Carex secta (makura)
Coprosma propinqua (Mingimingi)
Coprosma robusta (Karamū)
Dacrydium cupressinum (Rimu)
Griselina littoralis (Kapuka)
Phormium tenax (Harakeke)
Pittosporum eugenioides (Tarata)
Pittosporum tennifolium (Kōhūhū)
Plagianthus regius (Manatu)

Appendix B.

Data collection sheet used at each sample site.

Site Number:	**Site Location:**	**Date:**	**Category:** LW DW N
Weather: *(circle).* Sunny/ Overcast Raining Windy Other:			
Distance from stream: *(circle).* <2m <7m >7m		**Herbivory:** none small some lots	
Average willow size: 0-5cm 5-20cm 20+		**Willow abundance:** few some lots	

Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	
Species name:	**Size**	**Density**
	<20cm	
	20-50cm	
	50cm-1m	
	1m+	

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