Restoring Exotic Plantation Clear-Fells: Guidance for Northern South Island Districts

Contract Report Prepared for Nelson City Council by Dr Adam Forbes

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Cover photograph:

Exotic plantation clear-fells and standing plantations, Port Underwood, Marlborough Sounds (February 2021).

1.0 INTRODUCTION

1.1 Report Purpose and Scope

Nelson City Council engaged Dr Adam Forbes (affiliated with Forbes Ecology Limited & University of Canterbury School of Forestry | Te Kura Ngāhere) to provide a review and practical guidance on restoration of exotic plantation clear-fells in the context of conditions found in the top of the South Island. The work is needed as many landowners harvest exotic plantations with the intention of establishing native vegetation. However, clear-fell restoration is normally required at landscape scales and the types and levels of management required to successfully achieve restoration can be difficult to determine in the absence of practical expert guidance. The purpose of this report is to provide practical expert guidelines to landowners wishing to restore plantation clear-fells in the top of the South Island.

This report presents a review of published and grey literature on the forest ecology effects of plantation clear-fell. The review concludes with a synthesis of the key considerations which we recommend for clear-fell restoration. To illustrate our guidance, the key considerations are then applied to four clear-fell case study sites located in the Marlborough District, Nelson City, and Tasman District.

Clear-fell restoration is an important aspect of forestry and restoration in Aotearoa New Zealand which requires further research as well as substantial policy and financial support.

2.0 The Forest Ecology Effects of Plantation Clear-fell in Aotearoa New Zealand

This section presents a review and synthesis of the ecological effects of plantation clear-fell as they relate to the management of clear-fell restoration.

2.1 Macroclimate and Microclimate

The loss of the forest canopy causes increased variability in the microclimate on the clear-felled land (Pawson et al., 2006; Spittlehouse et al., 2004; Zheng et al., 2000; Keenan, 1993). Canopy loss affects the radiation balance which alters temperature and moisture dynamics of the air and soil. This is important as temperature and moisture (of both air & soil) are variables which regulate physiological processes that determine plant survival and growth (Keenan, 1993). In moderate climates (e.g., coastal), increased daytime temperatures can drive increased rates of photosynthetic growth in clear-fells compared to surrounding forest. However, at dry and sunny sites, levels of radiation might create stressful microclimate conditions that are detrimental to seedling survival and might cause mortality (Hawkins & Sweet, 1989), which would be one explanation of regeneration failure of native tree species in clear-fells. At elevated inland areas, increased night-time long-wave radiation on low-elevation landforms may increase frost effects on vegetation in clear-fells compared to levels of frost effect on vegetation in the adjacent forest.

From these findings we can expect the performance of native tree species to be affected by both the macroclimate, the resulting microclimate, and the level of shelter available in each clear-fell. Warm day-time and night-time temperatures might favour growth of native seedlings in moderate macroclimates. Native seedling establishment might be limited on hot dry sites, especially in dry macroclimates.

The altered radiation balance resulting from canopy loss also affects soil temperature. Due to the buffering effect of air trapped in the soil profile, soil has strong insulating properties, and this means that effects of increased radiation are greatest at the ground surface and diminish rapidly with increasing soil depth (McIntosh & Sharratt, 2001). Wind flows will be more variable and potentially greater in clear-fells compared to adjacent plantation forests (Spittlehouse & Stathers, 1990) and air flow is an important means of both dissipating soil surface temperatures (Keenan, 1993) and spreading the seed of wind dispersed species. Where soil has been compacted and its porosity reduced, the insulating ability of the soil will be reduced thereby affecting the soils temperature and moisture regime.

2.2 Vegetation Response

Clear-fell results in an abrupt change in important plant growth resources (e.g., increased light availability & soil resources; Nybakken et al., 2013). A release of nutrients from decomposing harvest residues is known to occur following clear-fell (Ouro et al., 2001).

Clear-fell leads to an initial dominance by pioneering flora with light-demanding life-history traits (Zenner & Berger, 2008) and in some cases a preference for elevated soil nutrients (Prescott, 1997) and soil disturbance (e.g., wind-dispersed species; McIntyre et al., 1995). Species commonly found in recent New Zealand clear-fells include pampus grass, inkweed, buddleja, blackberry, poroporo, rangiora, hangehange, and karamū (Allen et al., 1995; Forbes, 2021), with total species richness being initially high (Allen et al., 1995; Smith & Ashton, 1993) before subsequently declining through competitive interactions (Kasel et al., 2015). Species with good abilities to persist in the soil seed bank will be well represented (e.g., native hangehange, Moles & Drake, 1999; exotic gorse, for which up to 40,000 seeds m^{-2} can remain viable for c. 30 years, Broadfield & McHenry, 2019). The high rates of seedling establishment in recent clear-fells might lead to rapid seed bank depletion (Eycott et al., 2006). Species that are dependent on long-distance dispersal from seed sources elsewhere in the landscape are likely to hold lower representation in short-term regeneration (Moles & Drake, 1999).

Amongst clear-fells in the central North Island (Forbes et al., 2021) and Tairāwhiti (Forbes, 2021), native woody angiosperm seedling densities were positively associated with distance to native seed source, with this positive effect being greatest within 80-100 m of the native forest edge (Forbes et al., 2021; Forbes 2021). These results are consistent with dispersal distances cited in the existing literature (Canham et al., 2014) highlighting the need to protect existing native seed sources in and adjacent to clear-fells. Species might also be present in clear-fells having survived plantation harvest (Ogden et al., 1997). In combination, these factors will lead to early structural and compositional differences among and within clear-fells.

Near Minginui in the central North Island, a survey across 206 ha of clear-fells up to 14-years-old found the most abundant woody native species to be kōtukutuku, makomako, and kānuka (Forbes et al., 2021). These three native tree species possess the life history traits of fast growth and ready seed dispersal (by frugivory & for kānuka, by wind). The levels of natural regeneration by woody species on higher-elevation hill country indicated a passive approach to canopy establishment was likely to work in these areas. However, on flat, low-elevation sites, very high levels of weed cover (mainly by wilding conifers, blackberry, buddleja, & Spanish heath) occurred meaning that some form of weed control would be necessary to achieve restoration.

In southern Tairāwhiti, clear-fells <2-years-old held native woody stem densities of 7,085±1,446 stems ha^{-1}, and native tree densities of 3,790 stems ha^{-1} (Forbes, 2021). The three most abundant native tree species were makomako, māhoe, and karamū. Each of these species produce seeds that are readily dispersed, are likely to have occupied mature plantation understories prior to clear-fell (Forbes et al., 2019; thus, building a seed bank in the soil), and are known to frequently hold considerable representation in radiata pine plantation seed banks (Moles & Drake, 1999). Woody native stem density peaked within several years of clear-fell indicating relatively rapid colonisation of clear-felled land by native woody species in both Minginui and Tairāwhiti clear-fells (Forbes et al., 2021; Forbes 2021). The only weed species of concern in vegetation plots were wilding conifers. Inkweed occurred but showed only a weak negative association with native woody stem density.

These sites represent good climate and seed source contexts which will not be represented at all clear-fells across Aotearoa. In dry or cool climates, and where natural seed sources are lacking, natural regeneration will be limited and an active approach to restoration will be required (e.g., forest restoration planting to establish a canopy).

2.3 Regeneration and Control of Plantation Species and other Weeds

Most conifer species grown in plantations have the potential to grow as wildings, however the most abundant in clear-fells is radiata pine. Radiata pine exhibits the life history traits of a light-demanding pioneer, showing rapid establishment and rapid growth in open sites (McDonald & Laacke, 1990). On average, radiata pine is coning significantly by year ten, although some coning will commence earlier (Ledgard & Langer, 1999). Wilding conifer species have been measured at densities of 1,214±389 stem ha^{-1} in clear-fells of <2 years age (Forbes, 2021) and stem densities of several thousand per hectare are likely where dense post-harvest regeneration occurs. Forbes et al. (2021) found no relationship between the site factors elevation, slope, slope aspect and wilding pine stem density, which is consistent with the view that many Pinaceae have wide edaphic tolerance (Pauchard et al., 2015) and together these results indicate that factors other than landform influence wilding establishment following clear-fell.

Soil disturbance creates favourable microsites for undesirable weeds such as radiata pine and pampus (West, 1996), meaning that soil disturbance associated with harvest might make sites more susceptible to subsequent weed invasion. Recurrent disturbance (e.g., from repeated herbicide control) maintains sites in a state of vulnerability to weed invasion (McAlpine et al., 2018) and, specifically, fire can stimulate conifer regeneration (Ledgard, 2009) which makes burning an unsuitable weed control method in New Zealand's clear-fells.

Experience from wilding control shows that control is more effective at the earlier stages of the invasion (Nuñez et al., 2017) and in clear-fells it follows that control should occur before the wildings commence coning. Ledgard (2009) describes a method for determining appropriate wilding conifer control techniques based on (1) assessment of wilding tree frequency and size (Table 1) and (2) selection from 14 control techniques arranged in five categories (Table 2).

Table 1. Classes of wilding tree frequency and size. Reproduced from Ledgard (2009).

	Wilding tree size		
Wilding tree frequency	Small	Medium	Large
Lone wildings or widely scattered individuals	Diameter: <2 cm at base	Diameter 2-20 cm at 1.4 m	Diameter >20 cm at 1.4 m
Dense trees – often with touching crowns	Height: most <0.5 m tall	Height: most >0.5 m tall	Height: often 10+ m tall

Table 2. Categories and techniques for wilding removal. Reproduced from Ledgard (2009).

Wilding control category	Wilding control techniques
Site management	Burning, grazing, and fertilising
Hand removal	Pulling, tools, ring-barking
Power tools	Chainsaw, scrub-bar
Machine	Mulcher, digger/dozer
Chemical	Foliar, cut-stump, stem poisoning, soil injection

Control methods include ground-based removal by pulling or cutting individual trees. Hand pulling is feasible for seedlings up to 50 cm tall. Cutting must be below any green foliage and can be via loppers, small saws, axes or using either chainsaw or scrub-bar (Ledgard, 2009). Cutting presents least impact to surrounding vegetation but requires relatively high labour inputs (Nuñez et al., 2017). Although in some cases it might be that the higher labour inputs are partly offset by the ecological benefits of retaining non-target vegetation (i.e., achieving native forest cover sooner and avoiding or reducing the need to plant a native forest).

Chemical methods have been refined (see https://www.wildingconifers.org.nz/publications/) and range in their potential for damage to non-target vegetation. Native vegetation exhibits a range of sensitivities to herbicide types and selection of the most appropriate herbicide is important where broadcast spraying is required to address wilding invasions (e.g., Harrington & Schmitz, 2007; Harrington & Gregory, 2009).

2.4 Soils

Many of the effects on soils from clear-fell originate from forest floor removal and soil compaction (Simcock et al., 2006; Keenan, 1993). Compaction results from use of heavy machinery and is variable depending on the techniques and machinery used and on soil attributes (e.g., texture, moisture content, & organic matter content). Compaction leads to increased soil strength, reduced porosity/air content, and decreased hydraulic conductivity and infiltration rates. As a result, tree establishment and growth can be severely reduced due to decreased water availability and in-plant water deficits, a spatially compromised rooting zone, poor soil aeration and anaerobic respiration by roots, reduced nutrient mineralisation and plant uptake, and imbalances in hormonal growth regulators (Kozlowski, 1999; Keenan, 1993; Wert & Thomas, 1981; Foil & Ralston, 1967).

Compaction can be avoided or minimised through choice of silvicultural techniques (e.g., aerial rather than ground-based methods), minimising and confining the extent of compacting activities. Options for remediating soil compaction are of variable success (Kozlowski, 1999) and include, amending or replacing soil (Jim, 1993), loosening soil/ripping (Unger & Kaspar, 1994), installing soil drainage (Harris, 1992), or soil fertilisation (Sheriff & Nambiar, 1995). Avoiding or minimising compaction is the best strategy and measures to achieve this should be investigated prior to clear-fell.

Following plantation harvest, the stabilising effect of the remnant root systems of the plantation trees diminishes over several years (Watson et al., 1999). This reduces the shear strength of the soil, exposing landslide-prone areas to a period of vulnerability, particularly where there is a probability of slide-inducing weather events (Griffiths et al., 2020).

Vegetation cover, particularly by tall trees, has a stabilising effect on soils. Inherent soil stability attributes are an important consideration, so too is the role of vegetation in stabilising soil in clear-fells.

2.5 Selecting an Approach for Forest Restoration

Where to take an active or passive approach for forest establishment in clear-fells is a critical decision which needs to consider key criteria. Active approaches include interventions such as tree planting to establish a forest canopy. Intermediate on the active to passive continuum are moderate interventions which require a medium level of active input, such as interventions to create heterogeneity (e.g., mechanical soil mounding, creating canopy gaps or enrichment planting) or to reduce the impact of threats on natural processes. At the other end of the continuum, passive approaches to forest restoration (sensu DellaSala et al., 2003) involve relying on natural processes, such as occurs from spontaneous forest regeneration, to reach the desired result (Holl & Aide, 2011; Prach & Hobbs, 2008).

The degree of projected success is a major consideration in determining whether a passive approach should be followed (Prach et al., 2020). Spatially explicit prioritisation of active to passive restoration needs to be assessed across spatial scales (DellaSala et al., 2003) and this assessment might result in a mix of approaches across a given restoration area.

Passive approaches are generally advantageous when restoration is proposed at landscape scales (Prach et al., 2020; Holl & Aide, 2011), where the forest ecosystem is resilient (Forbes et al., 2021; Norton et al., 2018), where the forest context is amenable to spontaneous regeneration (Wilson, 1994) and when site degradation has not been too severe (Lamb et al., 2012; DellaSala et al., 2003; Fig. 1). Due to the generally lower associated costs, passive restoration is desirable when resources are insufficient to support active restoration (Meli et al., 2017) and a passive approach might result in improved biodiversity and greater ecological function, in the long term, compared to an active approach (Prach et al., 2019).

Dealing with processes that are leading to degradation in the first place (DellaSala et al., 2003; Lamb et al., 2012; Hobbs & Norton, 1996; e.g., feral goat browsing or structurally dominant weeds) should be a top management priority and the restoration process should include setting realistic goals and measures of success, along with methods for implementing those goals (Lamb et al., 2012).

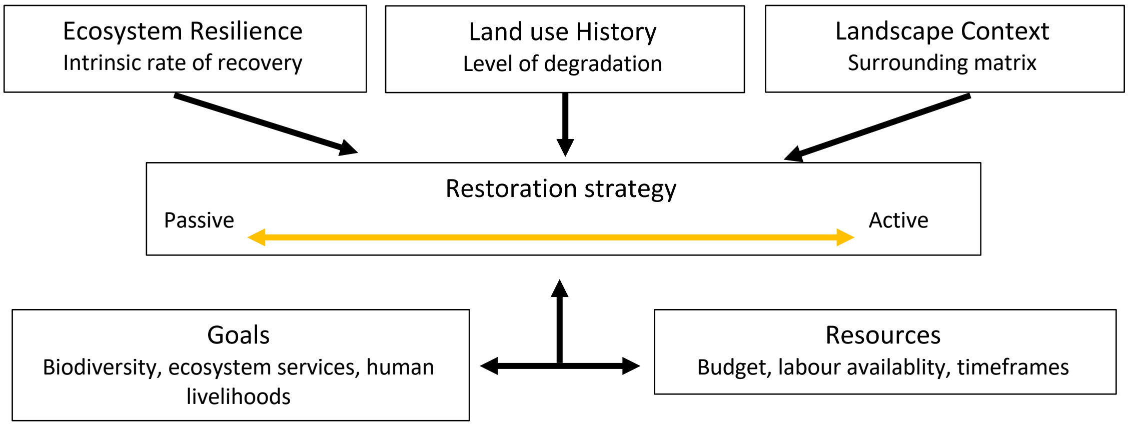

Figure 1. Factors that should be considered when planning management strategies for recovering/restoring degraded lands (reproduced from Holl & Aide, 2011).

In a similar vein to Holl and Aide (2011; Fig. 1), Prach et al., (2020) analyse which conditions support passive restoration and list these as:

1. Abiotic site conditions,
2. Intensity, extent, and type of the initial disturbance,
3. Biotic interactions, competition, and grazing,
4. Landscape matrix, presence of target species, invasive species, dispersal vectors.

Prach et al. (2020) point out that biotic interactions are difficult to predict and focus on the remaining groups of determinants of estimating restoration success. Experimental manipulations are needed to provide empirical evidence on the circumstances in which exotic species facilitate or inhibit recruitment of native woody species (Forbes et al., 2021). However, principles are available to help support predictions over competitive interactions between woody weeds and native woody species in Aotearoa's forest context (McAlpine et al., 2021). The ability of native woody species to establish in stands is determined by the landscape context and climate factors (Holl & Aide, 2010; Prach et al., 2020), as well as stand characteristics (Forbes et al., 2019; Burrows et al., 2014; Sullivan et al., 2007). The shade tolerance of the plantation canopy species provides some guidance as to whether the plantation species will persist through self-replacement or whether future stand composition is more likely to be determined by recruitment of other species through regeneration (McAlpine et al., 2021).

Some invaders will become structurally dominant and/or are shade tolerant, which are both attributes that indicate a need for weed control (Peltzer, 2018; Barrs & Kelly, 1996). Examples of structurally dominant vegetation includes wilding conifers (Peltzer, 2018; which form dense stands and attain heights of tens of metres), Old Man's Beard (an aggressive climbing vine that smothers vegetation, thereby starving the invaded vegetation of sunlight). Examples of shade-tolerant or semi-shade tolerant weeds include cotoneaster (Weedbusters, 2021), Darwin's barberry (McAlpine & Jesson, 2007), tutsan (Groenteman, 2013), and blackberry (Balandier et al., 2013).

Several examples exist of large-scale restoration of plantation clear-fells. At Maungataniwha, Hawke's Bay, the Forest Lifeforce Restoration Trust is restoring over 4 000 ha of clear-felled land to native forest. The project has been reviewed by Marlborough District Council (2016) and Lambie and Marden (2020). The project's restoration approach following clear-fell could be summarised as follows:

- Land is left without management for at least three years following clear-fell,
- Then metsulfuron herbicide (with penetrant) is applied via boom spray to the densest wilding conifer infestations,
- Manual rather than herbicide control of pines is undertaken in gullies and other areas where natives predominate.

The Maungataniwha landscape context includes large tracts of adjacent native forest and an avian forest-seed disperser community. Ecosystem resilience is supported by climatic conditions which are clearly favourable for temperate rainforest regeneration. This case study indicates that, in this environment and landscape context, the levels of disturbance associated with plantation clear-fell and the subsequent boom-spraying of wilding pine regrowth do not fundamentally exceed the level of resilience of the forest ecosystem. Although, it should be acknowledged that the actual compositions and successional trajectories of forest regeneration in the Maungataniwha plantation clear-fells (& the effect of herbicide on these compositions & trajectories) are yet to be formally examined.

A second large-scale project seeking to restore native forest cover in plantation clear-fells is the Waingake Transformation Project. The project aims to restore 1 100 ha of native cover on land that will have plantations harvested between 2018 and 2027. Mean annual rainfall is 1 490±319 mm and mean annual air temperature is approximately 13-14°C.

A plot survey in clear-fells aged 0.5- to 2-years-old indicated mean native woody stem densities in clear-fells of 7 085±1 446 stems ha^{-1}, mean native tree species stem densities in clear-fells of 3 790 stems ha^{-1}, with eight native tree species occurring at >100 stems ha^{-1}. When ranked by combined cover, of all native and exotic woody species surveyed in clear-fells, native tree species comprised >50% of life forms.

Native woody tree density for individual species occurring at >100 stems ha^{-1} (i.e., 10 x 10 m spacing) was occupied by eight species with a combined density of 3 790 stems ha^{-1} (i.e., *c*. 1.5 x 1.8 m spacing) and species specific densities of: makomako (1 271±525 stems ha^{-1}), māhoe (931±201 stems ha^{-1}), karamū (434±275 stems ha^{-1}), patē (406±193 stems ha^{-1}), putaputawētā (303±150 stems ha^{-1}), kōhūhū (174±150 stems ha^{-1}), whauwhaupaku (114±150 stems ha^{-1}), kōtukutuku (114±150 stems ha^{-1}).

Animal pest control, especially goat control, is professionally implemented which is an essential intervention in this location for successful forest restoration. Radiata pine densities in clear-fells aged 0.5-2 years in the Waingake restoration area were 1 214±389 stems ha^{-1} indicating a clear need for a comprehensive programme of wilding pine control.

These early results of native forest regeneration in plantation clear-fells provide promising early signs of the project's restoration objectives being met passively, largely by natural forest regeneration.

A third large-scale forest restoration project in plantation clear-fells is Ngāti Whare's Project Whirinaki which has the goal of enhancing the mauri of Whirinaki Forest and the mana of Ngāti Whare. The project is restoring native forest with a combination of planting and natural regeneration across 592 ha and is taking research-led approach in determining restoration methods. Modelling of native woody stem densities and weed cover indicates a range of active and passive approaches will be required across different elevation and landforms (Forbes et al., 2021).

2.6 Synthesis - Key Considerations for Clear-fell Restoration

Based on the above review, below are key considerations to guide planning of clear-fell restoration.

Table 3. Key considerations when planning clear-fell restoration.

1. Goals - define goals in consultation with stakeholders. Some examples include:
• Restore tree cover, • Restore a biodiverse mature forest composition, • Restore cultural values, • Carbon storage, • Soil conservation, • Employment or income, • Education, • Native timber, • Reconnect people with the land.
2. Ecosystem resilience – the intrinsic ability of forests to recover
• Rainfall regime/soil moisture, • Temperature, • Landform, • Soil quality, • Tree species traits, • Dynamics between desirable and undesirable plant species.
3. Land use history – the level of degradation
• Intensity and duration of past land use, • Availability of native propagules within clear-fells, • Retention and intactness of embedded or adjacent remnant native ecosystems, • Level of soil degradation (e.g., compaction, topsoil loss, altered soil hydrology),

- Crossing of abiotic or biotic thresholds.

4. Landscape context – positive and negative influences from the surrounding landscape
• Amount and configuration of adjacent native forest seed sources and disperser habitats,
• Disturbance sources from landscape matrix (e.g., invasive plant or animal species, fire).
5. Resources – financial, human, and intellectual
• Understanding actual restoration costs,
• Accessing funding (amount & timeframes),
• Availability of people to implement restoration interventions,
• Access to accurate restoration knowledge.

3.0 CLEAR-FELL RESTORATION CASE STUDIES

3.1 WHATAROA BAY, PORT UNDERWOOD, MARLBOROUGH DISTRICT

3.1.1 Background

The owners bought the land at Whataroa Bay with the objective of restoring native forest cover following plantation clear-fell. The plantation areas were radiata pine and are held in two blocks, 37 and 31 ha. The 37-ha block is currently being felled; the 31-ha block was felled four years ago. Plantations were harvested by hauling up the face to the ridge top, which resulted in a lot of sediment runoff initially.

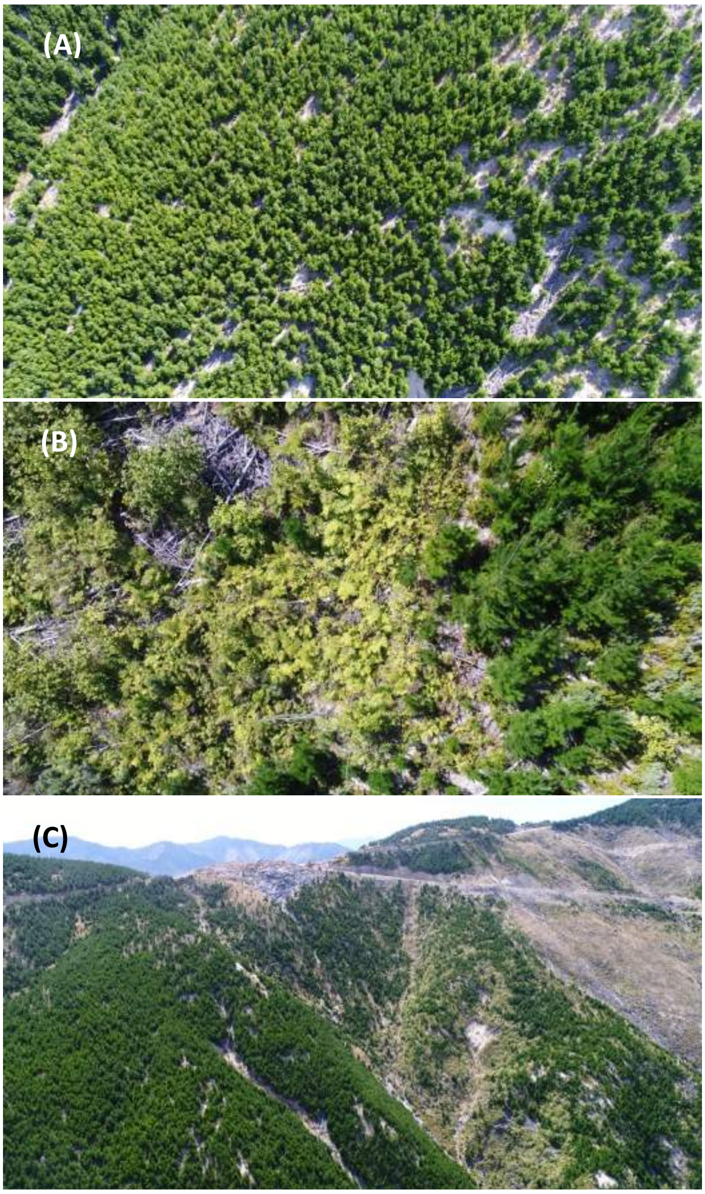

Figure 2 A-C. (A) Four years after clear-fell, the exposed upper slopes feature dense regeneration of wilding radiata pine. (B & C) Native regeneration occurring amongst wilding pine stands can be spared through delineation and adopting low impact wilding control methods in these sensitive areas.

The approach to restoration to date has been to give whatever is there a chance to get away while managing regrowth of radiata pine. Pine control has involved ringbarking, cutting, and poisoning with X-tree. Enrichment planting with natives is also planned.

The owners have been developing their own restoration knowledge based on what works well on their sites. The previous owners yielded income from the plantation harvest. There is no intention by the current landowners to yield income from the land. The focus going forward is purely on restoration.

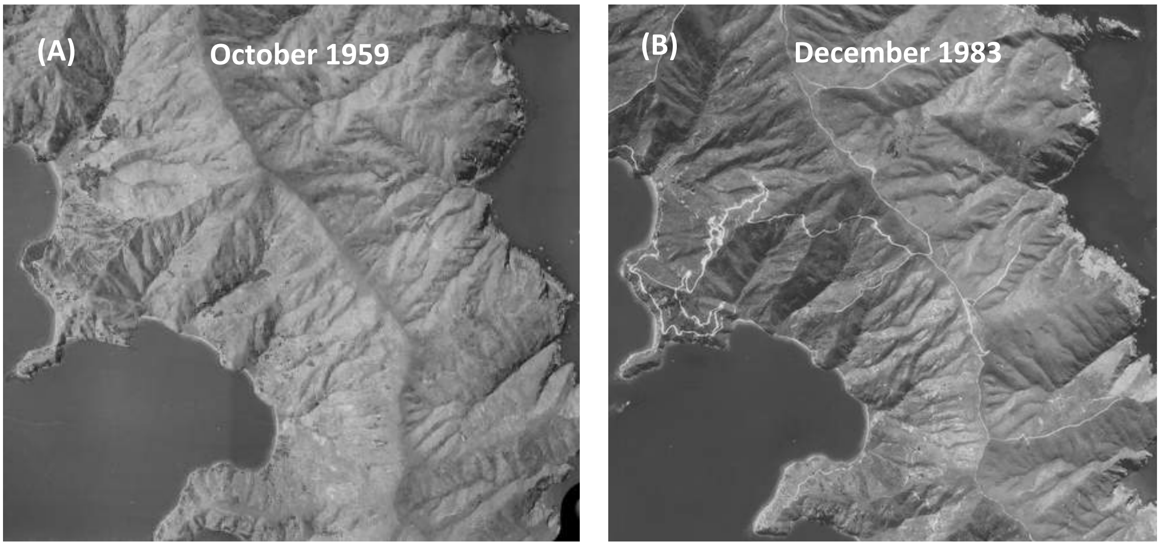

Figure 3 A & B. (A) Predominant grassland coverage of the case study land in 1959. (B) Planted pine seedlings are visible at Whataroa Bay in 1983. Unplanted areas which today feature native seral forests were still denuded in 1983, with this observation providing a timeframe (c. 40 years) for forest regeneration at the case study site.

3.1.2 Case study analysis

Below (Table 4) is an analysis of the Whataroa Bay case study against key considerations in the clear-fell restoration process.

Table 4. Analysis of Whataroa Bay case study against key considerations in the clear-fell restoration process.

Goal(s)		
• To restore a healthy native forest cover on clear-felled land.		
Ecosystem resilience		
Topic	Data/analysis	Conclusion/Advice
• Rainfall regime/soil moisture.	• Mean annual rainfall = 1411±229 mm, • Mean January rainfall = 93±55 mm, • Mean July rainfall = 131±77 mm, • Mean annual days of deficit (AWC 150 mm) = 53±32.	• Plentiful rainfall, • One to three months of soil moisture deficits per year.
• Air temperature.	• Mean annual = 12.9±1.2°C.	• Moderate temperature regime (coastal).
• Landform.	• 0-402 m a.s.l, • Northwest-Southeast ridgeline, • Steeply sloping, • Gully microsites.	• A variety of landforms, • Upper slope and ridge sites will need more management than gully microclimates and south facing sites.
• Soil quality.	• Unknown soil type	• Unknown

• Tree species traits.	• Natives, • Weeds.	Native: • Karamū • Kōtukutuku, • Makomako, • Putaputawētā, • Tauhinu, • Tutu.	Exotic: • Gorse, • Radiata pine, • Spanish heath.
• Dynamics between desirable and undesirable plant species.	• Radiata pine regrowth is vigorous on upper slopes and on exposed sites. In these sites radiata pine will require broadscale control. • Native regeneration is strong on south-facing gullies. Radiata pine control will be required in these locations but to avoid damage to regenerating native forest this control should be ground-based.	• The native species listed above are good at colonising and forming a forest canopy. • Due to its fast growth rates and tall stature, radiata pine is the main weed of concern (Fig. 2 A). A balance needs to be found between the lower financial expenses of broadscale control and higher cost ground based control so as to minimising damage to areas featuring regenerating native species (Fig. 2 B & C). • Where it establishes following pine control, gorse provides an opportunity to establish canopy cover rapidly at no cost with a long-term transition to native forest. Gorse is preferable to a cohort of pines as gorse can be reliably outcompeted in time. Rainfall and seed sources are adequate for this strategy at this location and the transition is likely to take 10-40+ years depending on location within the site. • Spanish heath is known to form dense and persistent stands, so should be controlled at the same time as wilding pines.	
Land use history			
Topic	Data/analysis	Conclusion/Advice	
• Intensity and duration of past land use.	• Aerial photography shows the land was grassland prior to 1959 and planted in pines around 1980 (Fig. 3 A & B).	• Native forest was removed more than 60 years ago (Fig. 3 A). Plantations were being established in the 1980s (Fig. 3 B). Since plantation establishment, unplanted gullies and coastal buffers have regenerated in southern and eastern aspects (over a period of c. 40 years; Fig. 3 A & B).	
• Availablity of propagules within clear-fells.	• Several unplanted gullies above Whataroa Bay and the coastal buffer on the Cook Strait side have regenerated and provide valuable	• Seral forest seed sources are present in several areas of the clear-felled land (Fig. 4 A & B). However, many areas are remote from seed sources and this will reduce the rate of natural regeneration in many locations of the site (Fig. 4 C).	

	seral forest seed sources.	
• Retention and intactness of embedded or adjacent remnant native ecosystems.	• Native forest in unplanted areas has been retained through clear-fell.	• Approximately 40 years of regeneration progress has been made in unplanted sites (Fig. 4 A & B).
• Level of soil degradation.	• Unknown.	• Unknown.
• Abiotic or biotic thresholds crossed.	• Apparently not.	• Apparently not.
Landscape context		
Topic	Data/analysis	Conclusion/Advice
• Amount and configuration of adjacent native forest seed sources and disperser habitats.	• The surrounding seaward land has been deforested for many decades. The nearest significant seed sources are located across the bay 6 km+ to the west, on the Robertson Range (Fig. 5). • Korimako are occasionally seen, tūī and kererū are absent.	• Diverse seed sources are spatially remote from the site (Fig. 5). • Native avian dispersers are not abundant.
• Disturbance sources from landscape matrix (e.g., pests, fire).	• Wilding pine establishment occurs following clear-fell. Pine stands on adjacent land will present an ongoing seed source. • Goats and possums are present.	• Wilding invasion and goat populations are essential to acheive restoration. Possum control will support forest regeneration.
• Neighbours views of restoration.	• Property on market. • Allowing pines to regenerate for second crop. • Further afield there is strong interest in restoration.	• There appear to be mixed views toward clear-fell restoration, but the peninusla presents a unique opportunity for restoration and the pest issues (wildings & browsing mammals) will be best addressed through a collaborative landscape-scale approach.

Resources		
Topic	Data/analysis	Conclusion/Advice
• Known costs.	• Aerial spraying c. $3K for 68 ha.	• Repeated control will be required coupled with monitoring of regeneration of desirable and undesirable vegetation cover.
• Funding available (amount & timeframes).	• External funding is not readliy available.	• Keep abreast of upcoming reforestation, biodiversity, or erosion control grant schemes.
• People to implement restoration interventions.	• Landowners.	• Landscape collaborations on goat and possum control, wilding control, and revegetation would be highly beneficial.
• Access to restoration knowledge.	• Landowners.	• Marlborough Sounds Restoration Trust https://marlboroughsounds-restora.squarespace.com • New Zealand Wilding Conifer Group https://www.wildingconifers.org.nz

3.1.3 Recommended Restoration Approach

The climate is amenable to native forest regeneration. Regeneration will occur at variable rates across the varied topography of the site. Readily dispersed native tree species have colonised unplanted areas over a 40-year timeframe, indicating the likely timeframes of forest recovery.

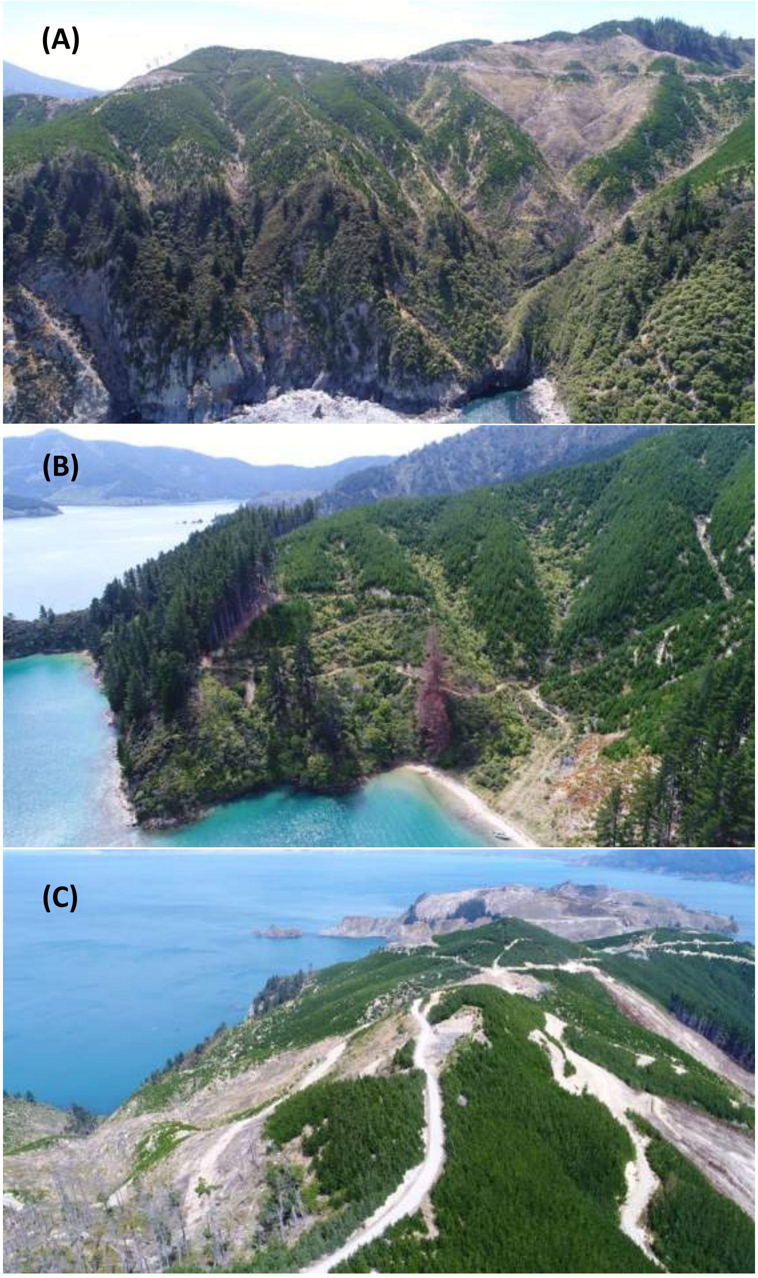

Figure 4 A-C. (A) c. 40 years of regeneration in the unplanted coastal buffer on the Cook Strait side of the case study area. (B) Native broadleaved regeneration in south facing unplanted gullies present sites for low impact wilding control and enrichment planting with old-growth species. (C) Exposed upper face and ridge landforms are most distant from seed sources and are landform units which will naturally regenerate more slowly compared to gullies and sheltered lower slopes.

Minimising disturbance of native regeneration processes while still addressing weed (wilding pines) and animal (goats & possums) threats is the most critical aspect of restoration management at Whataroa Bay. This will start with mapping areas of native regeneration where broadcast spraying would be detrimental and where low-impact ground control methods are achievable.

Ongoing monitoring will be required to determine the least impact and most cost-effective methods of wilding control over the next couple of decades. Gorse or other short-statured light-demanding weeds might provide favourable interim landcover (competing with wilding pines thereby reducing maintenance), and where it occurs, consideration should be given to retaining gorse to allow it to mature and facilitate native forest regeneration.

Goat control is essential for healthy native forest regeneration on the peninsula. Professional advice should be sought on the best approach for goat control, however experience elsewhere indicates that ongoing quarterly control by a professional culler across the entire peninsula (with costs shared by all landowners) would likely constitute a reasonable control effort. Possum control should be implemented across the peninsula also.

Enrichment planting (with old-growth tree species) should be undertaken in areas of advanced native regeneration and methods of broadcasting native seed (e.g., mānuka, kānuka or tutu) could be trialled on exposed upper slopes and ridgelines where native regeneration is naturally slowest.

Figure 5. The nearest mature native forest seed sources are located approximately 6 km to the west on the Robertson Range (here photographed above Kakapo Bay).

3.2 CABLE BAY ADVENTURE PARK, HIRA, NELSON DISTRICT

3.2.1 Background

The vision for the clear-felled area at the Cable Bay Adventure Park (hereafter, Park; Fig. 6A) is to revert the land cover back to what it would have been prior to human disturbance. The Park takes a very long-term (many centuries) intergenerational view on restoration. In addition to forest restoration, the vision includes continued recreational access, integration with the community and leading by example regarding land use and management of clear-felled land. The Park sees commercial and marketing benefits coming from successful restoration.

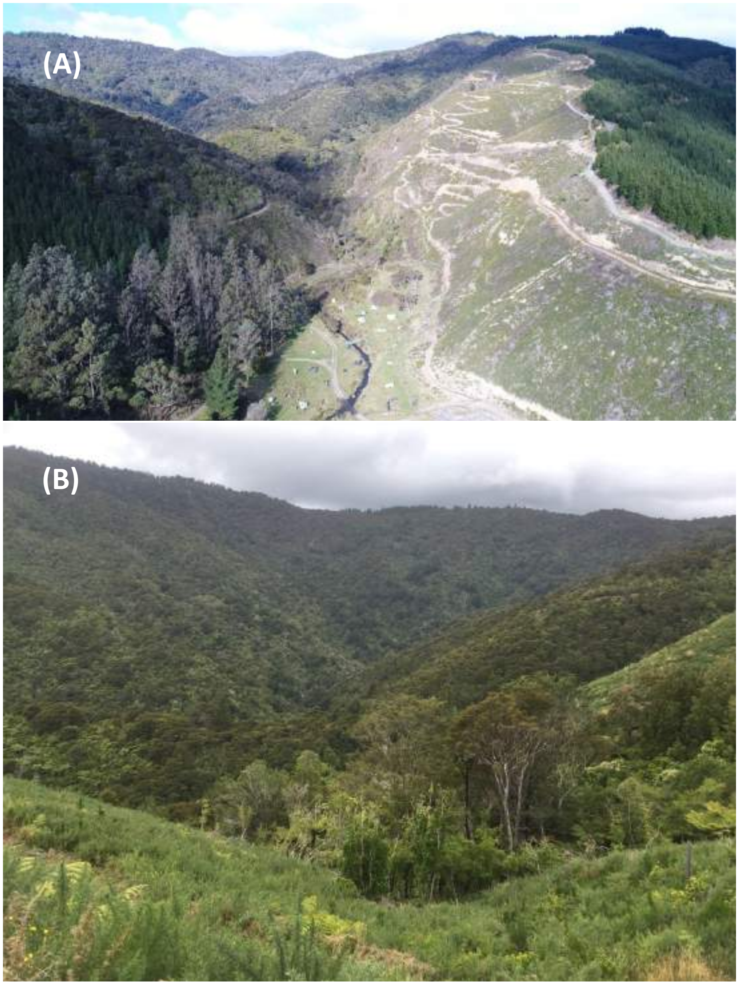

Figure 6 A & B. (A) The clear-fell is bounded by native forest to the south and east. The area is already used recreationally through the provision of mountain bike tracks. (B) The clear-fell is adjacent to a massive tract of native forest that extends eastward to the Marlborough Sounds and south-east to Richmond Range and beyond.

The clear-fell occurs next to a substantial tract of native forest (Fig. 6B) which is both a source of ecological processes and a reference and inspiration for the clear-fell restoration project.

The restoration approach to date has involved active planting of kānuka with the balance of the clear-felled land being left and observed to see what management is required and to determine at what point management intervention is required. Management has been looking at the effect of certain land aspects and has some concerns about erosion. Also, management has observed that natural regeneration is patchy.

The Park has recently started their own on-site plant nursery to provide staff education and upskilling and to provide a local source of native tree seedlings. While the objective is not commercial, the park is interested in the clear-fell serving as a permanent forest carbon sink, thereby offsetting organisational emissions.

3.2.2 Case study analysis

Below (Table 5) is an analysis of the Cable Bay Adventure Park case study against key considerations in the clear-fell restoration process.

Table 5. Analysis of Cable Bay Adventure Park case study against key considerations in the clear-fell restoration process.

Goal(s)		
• To revert the clear-felled land back to fully self-sustaining native forest which will endure in the long term for the benefit of the environment and future generations.		
Ecosystem resilience		
Topic	Data/analysis	Conclusion/Advice
• Rainfall regime/soil moisture.	• 1 100 mm year^{-1} (estimate); 40-50 days of deficit.	• It is likely that regeneration is partially constrained by low summer soil moisture.
• Air temperature.	• Median annual air temperature 11-12°C (estimate)	• Good temperature regime, coastal influence (4 km to the sea).
• Landform.	• Hillslopes of predominately eastern aspects.	• Good relief with microsites in shallow gullies. Eastern aspects will be protected from the brunt of incoming solar radiation and the predominantly western and southern wind directions.
• Soil quality.	• Unknown.	• Unknown.
• Tree species traits.	• Natives. • Weeds.	Native: • Māhoe, • Mapau, • Rarauhe. Exotic: • Radiata pine, • Old Man's Beard, • Himalayan honeysuckle, • Gorse, • Exotic broom, • Inkweed.
• Dynamics between desirable and undesirable plant species.	• Gorse has rapidly covered most of the clear-fell. • Native trees are establishing sporadically amongst young gorse. • Wilding pine invasion is patchy. Old Man's Beard has invaded in places. • Other exotic species are localised. • The site is an excellent candidate for forest establishment via passive	• Gorse is providing valuable shade and will facilitate native trees given enough time (Fig. 8A). The dense gorse also apprears to be providing a physical barrier to goat and deer reaching embedded regenertaion. • Wilding pines (Fig. 8B) and Old Man's Beard (urgent weeds) will both become structurally dominant and must be addressed through low-impact control as soon as possible. • Himalayan honeysuckle, broom, and inkweed are not currently a priority

	means with the management focus on addressing plant and animal pests and enrichment planting.	for control as they can be addressed indirectly through outcompeting by rapidly growing gorse and native regeneration. • Māhoe and kānuka both show fast growth rates at this site and are good choices for planting. • The gorse provides an ideal nursery to support a programme of enrichment planting of old-growth tree species. • Addressing the urgent weeds with minimim intervention to support a trajectory towards heavy shade is the best approach for restoration.
Land use history		
Topic	Data/analysis	Conclusion/Advice
• Intensity and duration of past land use.	• Native forest has been cleared for >72 years (Fig. 7). The plantation was harvested in 2018 and was the 1st rotation. Tracking caused localised disturbance in the 1980s.	• Native forest has been absent for many decades and over this time exotic species have occupied the site. In particular, gorse has rapidly colonised the disturbed ground.
• Availablity of propagules within clear-fells.	• One significant gully of secondary forest has been retained (Fig. 8C). Other seed sites are adjacent.	• Most of the site is dependant on seed dispersal from adjacent forest. The forested gully would be a good site for enrichment planting of old-growth tree species, such as native conifers, beech and broadleaved trees.
• Retention and intactness of embedded or adjacent remnant native ecosystems.	• One very large adjacent seed source exists with a high level of intactness.	• The adjacent seed source is a major ecological asset to clear-fell restoration.
• Level of soil degradation.	• Unknown.	• Unknown.
• Abiotic or biotic thresholds crossed.	• Apparently not.	• Apparently not.
Landscape context		
Topic	Data/analysis	Conclusion/Advice
• Amount and configuration of adjacent native forest seed	• Good population size of kererū, tūī, korimako. • Excellent seed source context at landscape scale.	• Biotic attributes are conducive to passive restoration.

sources and disperser habitats.		
• Disturbance sources from landscape matrix (e.g., pests, fire).	• Feral goat numbers are high in this landscape. Education and culling required. Feral deer and possum will require ongoing control. • The soil holds a high load of gorse seed which will be viable for decades. Treatments that disturb and expose the soil will result in gorse establishment. Minimial disturbance is important. • Old Man's Beard is a significant threat and is one of the key management priorities for forest restoration.	• Management of browsing and smothering pests is the main management priority.
• Neighbours views of restoration.	• Discussion on the topic is growing. The Park has provided an alterative land use example, highlighting new ways of doing things. One riparian restoration collaboration is underway with a neighbour.	• Continued work to develop collaborations on pest issues and restoration will be benefital.
Resources		
Topic	Data/analysis	Conclusion/Advice
• Known costs.	• 2 000 native seedlings have been planted with spot spraying of planting sites. • Native nursery being established on site. • Restoration supported by pro bono expert restoration advice and volunteer labour.	• Building local capacity to maximise restoration cost effectiveness.
• Funding available (amount & timeframes).	• Unknown.	• Unknown. Keep abreast of emerging funding sources.
• People to implement	• Park staff will be trained and work in the plant nursery.	• Contine to build local expertise, engage with the wider community, and local restoration experts.

restoration interventions.		
• Access to restoration knowledge.	• Local restoration expert.	• Local restoration expert.

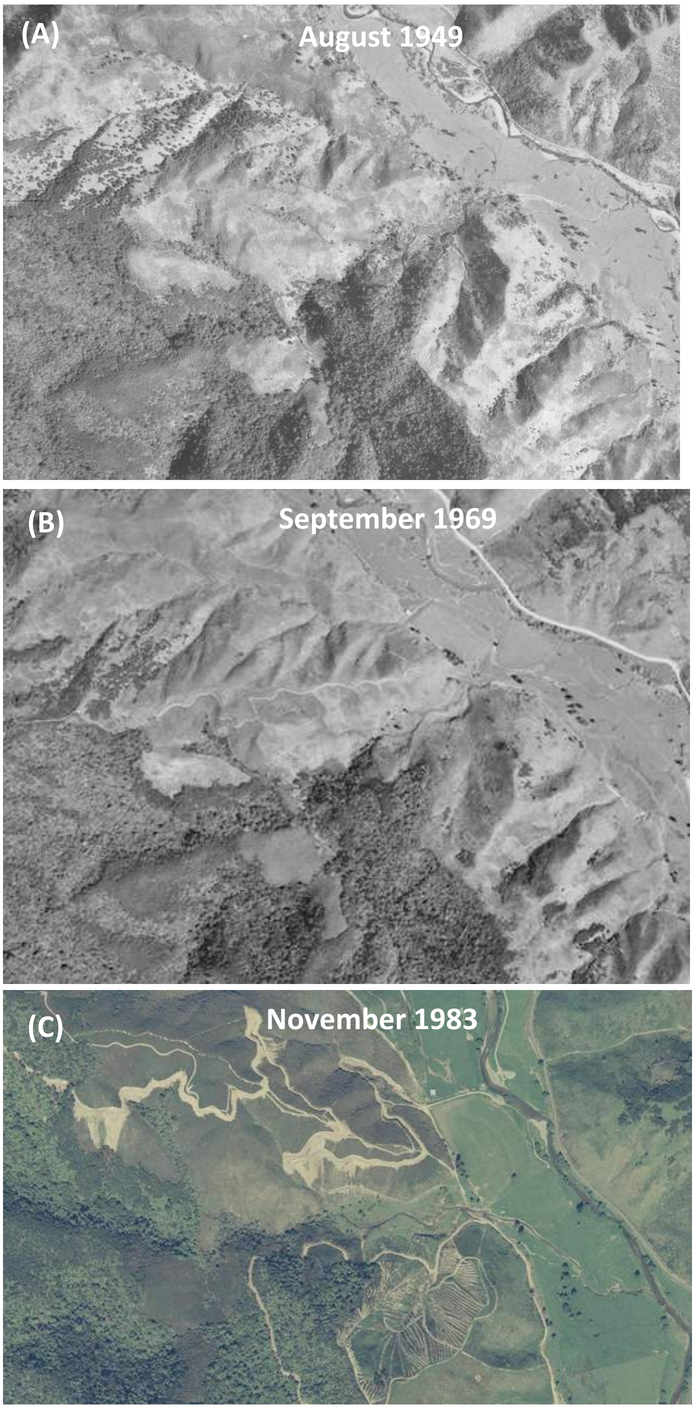

Figure 7 A-C. Land cover in (A) 1949 grassland with light regeneration, perhaps bracken fern, (B) 1969, grassland, (C) 1983, light woody cover, perhaps gorse, earthworks disturbance from tracking.

3.2.3 Recommended Restoration Approach

The site has a good context for passive forest establishment. The dense gorse infestation is beneficial in that it occupies the site limiting establishment of more persistent weeds, creates a microclimate in time for native tree establishment, limits access by browsing mammals. Old Man's Beard on the other hand is a serious threat that must be addressed to reduce the local seed sources and level of threat. Biocontrol of Old Man's Beard has in recent years undergone further research and progress on biocontrol agents should be monitored and adopted where appropriate. Wilding pines should be removed by low impact targeted approaches that do not disturb the wider vegetation cover.

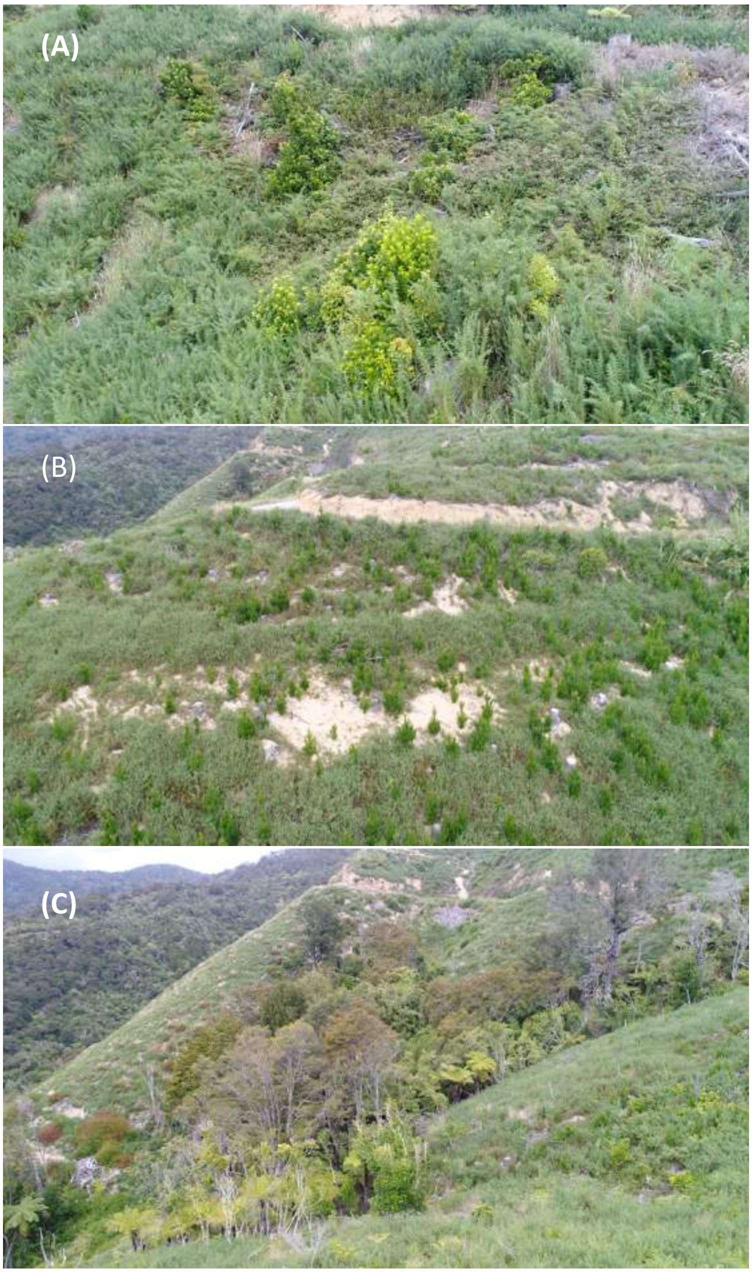

Figure 8 A-C. (A) Māhoe and mapau regenerating amongst gorse three years following clear-fell. (B) Wilding pine seedlings establishing amongst gorse, (C) secondary native forest retained through clear-fell in a prominent gully provides an important proximal seed source.

Browser management is another critical management intervention required to support reforestation. A landscape-scale project led by professional cullers should be initiated to reduce the pressure by browsing mammals on existing and regenerating forest.

Enrichment planting can be carried out in gorse, the aim being to return old-growth tree species to the clear-felled land. Enrichment planting can be configured in various ways, for instance, along gorse edges, or into cut and pasted rows or clearings in gorse.

Continue building capacity to deliver restoration interventions. Establish photopoint monitoring to track and demonstrate restoration progress.

3.3 MAITAI VALLEY ROAD, NELSON DISTRICT

3.3.1 Background

Ngāti Koata own clear-felled land located near Sharland Hill and the Maitai River valley, on the outskirts of Nelson city (Fig. 9A). Rather than re-establishing exotic plantations, Ngāti Koata are interested in permanently transitioning the land to native forest while also yielding social, recreational, cultural, and economic benefits and returns. At less than 3 linear km to Nelson city, the land is within easy reach of the people of Nelson city and the cultural and natural values of native forests have potential to directly benefit many residents and visitors to the city.

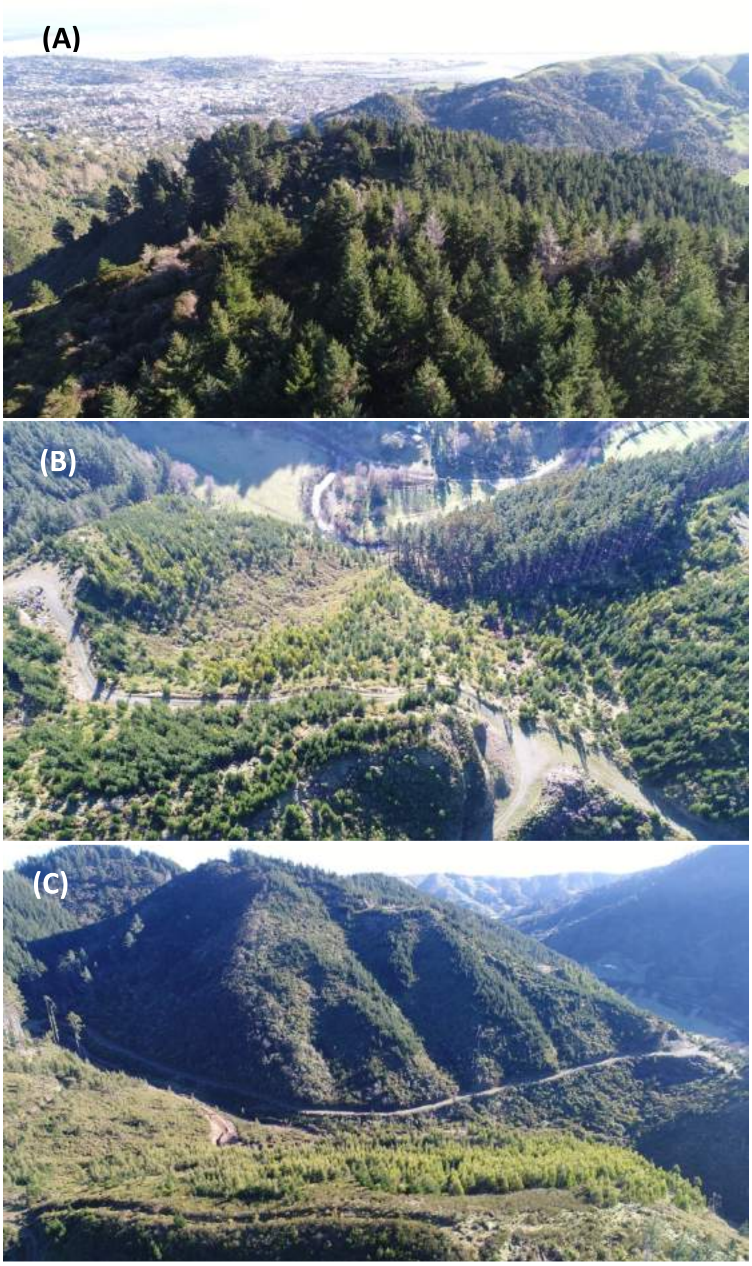

Figure 9 A-C. (A) Four years after clear-fell, the exposed upper slopes feature dense regeneration of wilding radiata pine. (B & C) Native regeneration occurring amongst wilding pine stands can be spared through delineation and adopting low impact wilding control methods in these sensitive areas.

Plantations were cleared from the land around 2013/2014 and much of the area has received no management over the intervening 7–8-year period. As such weed issues have built and plantation species have regenerated at a range of densities (Fig. 9 B & C). The climate is warm and relatively dry, and seed sources are scarce in the landscape. Animal pest numbers have also built over past years. These factors together mean a threat-led approach to native forest management will be essential.

With this management, long term native forestry options are very viable for this area of Ngāti Koata land.

3.3.2 Case study analysis

Below (Table 6) is an analysis of the Maitai Valley Road case study against key considerations in the clear-fell restoration process.

Table 6. Analysis of Maitai Valley Road case study against key considerations in the clear-fell restoration process.

<table>
<tr><th colspan="3">Goal(s)</th></tr>
<tr><td colspan="3">• Restoration of healthy diverse native forest cover.
• Generating income streams from native forestry.</td></tr>
<tr><th colspan="3">Ecosystem resilience</th></tr>
<tr><th>Topic</th><th>Data/analysis</th><th>Conclusion/Advice</th></tr>
<tr><td>• Rainfall regime/soil moisture.</td><td>• Mean annual rainfall = 971±181 mm,
• Mean January rainfall = 77±55 mm,
• Mean July rainfall = 85±77 mm,
• Mean annual days of deficit (AWC 150 mm) = 84±31.</td><td>• The climate is a constraint on forest regeneration and performance of native planted seedlings.
• Aspect likely to be an important consideration in native tree performance.</td></tr>
<tr><td>• Air temperature.</td><td>• Median annual air temperature 12-13°C (estimate)</td><td>• Warm climate.</td></tr>
<tr><td>• Landform.</td><td>• Varied aspects, slopes, and landform units.</td><td>• Diverse range of landforms, some requiring specific consideration.</td></tr>
<tr><td>• Soil quality.</td><td>• Unknown.</td><td>• Unknown.</td></tr>
<tr><td>• Tree species traits.</td><td>• Natives,
• Weeds.</td><td>Native:
• Kānuka,
• Māhoe,
• Kōhūhū,
• Mapau.
Exotic:
• Exotic broom,
• Gorse,
• Himalayan honeysuckle,
• Inkweed,
• Old Man's Beard,
• Pampus,
• Wilding conifers,
• Wilding eucalyptus.</td></tr>
<tr><td>• Dynamics between desirable and undesirable plant species.</td><td>• Wilding plantation species have regenerated vigorously and form both scattered and dense stands.
• A large number of weed species are present, some are in high abundances in the clear-fell. Structurally dominant and shade tolerant weeds will need to be addressed.</td><td>• Land aspects provide a useful means of determining management units and modes (active or passive) for reforestation.
• Structurally dominant and shade tolerant weeds must be addressed.
• Options for using existing cover to shelter native plantings on northern aspects should be considered.</td></tr>
</table>

	• South faces of the adjacent hillsides (e.g., Sugar Loaf; Grampians; Fig. 10) have regenerated well, although this has taken many decades (Fig. 11 A-C). These adjacent faces provide a reference for southfaces located in the clear-fell where passive restoration is more likely to be successful (Fig. 12 A). • Native regeneration is weaker on northfacing sites and weeds are likely to be more dominant (for longer) on these aspects.	• Timeframes for native restoration are multiple decades and ongoing management of competing vegetation (& browsing pests) will be required to attain widespread native dominance.
Land use history		
Topic	Data/analysis	Conclusion/Advice
• Intensity and duration of past land use.	• Native forest has been absent across most of the case study site for >72 years (Fig. 11 A-C). • Rotational forestry commenced on the land after 1983. Land use prior appeared to be pastoral farming (Fig. 11 A-C). • Several patches of native forest have been present on site over this time (Fig. 11 A-C).	• Native forest has been largely absent from the land for many decades. Exotic grassland and exotic woody species (plantation & naturalised) have occupied the land during this time. • Remnants of secondary native vegetation are present.
• Availablity of propagules within clear-fells.	• Very little native seed source remains within the clear-felled land.	• Very little propagule availablity.
• Retention and intactness of embedded or adjacent remnant native ecosystems.	• One sizable remnant of secondary forest exists west of site (Figs. 11 A-C & Fig. 12 A). Canopy cover appeared to decline in this area between 1949 and 1960, perhaps indicating persistent grazing of the forest over those years.	• One secondary seed source exists. Much of the site lacks proximal seed sources.
• Level of soil degradation.	• Unknown.	• Unknown.
• Abiotic or biotic thresholds crossed.	• Apparently not.	• Apparently not.
Landscape context		
Topic	Data/analysis	Conclusion/Advice

• Amount and configuration of adjacent native forest seed sources and disperser habitats.	• One proximal seed source exists.	• One proximal seed source exists.
• Disturbance sources from landscape matrix (e.g., pests, fire).	• A range of plant pests are present in the surrounding landscape. • Goat and deer numbers are high and this is detrimental for native forest restoration. Other threats such as possums and pigs will require attention.	• Pests are a landscape scale issue.
• Neighbours views of restoration.	• Nelson City Council holds adjacent forestry estate.	• Nelson City Council is a logical collaborator for complementary forest management interventions (e.g., pest control).
Resources		
Topic	Data/analysis	Conclusion/Advice
• Known costs.	• Unknown.	• Unknown.
• Funding available (amount & timeframes).	• Unknown.	• Unknown.
• People to implement restoration interventions.	• To be determined.	• To be determined.
• Access to restoration knowledge.	• Ngati Koata Environmental representitive (in house).	• In house.

Figure 10. Seventy (plus)-year-old secondary forest on the pictured shaded south-facing slope located directly west of the clear-felled land.

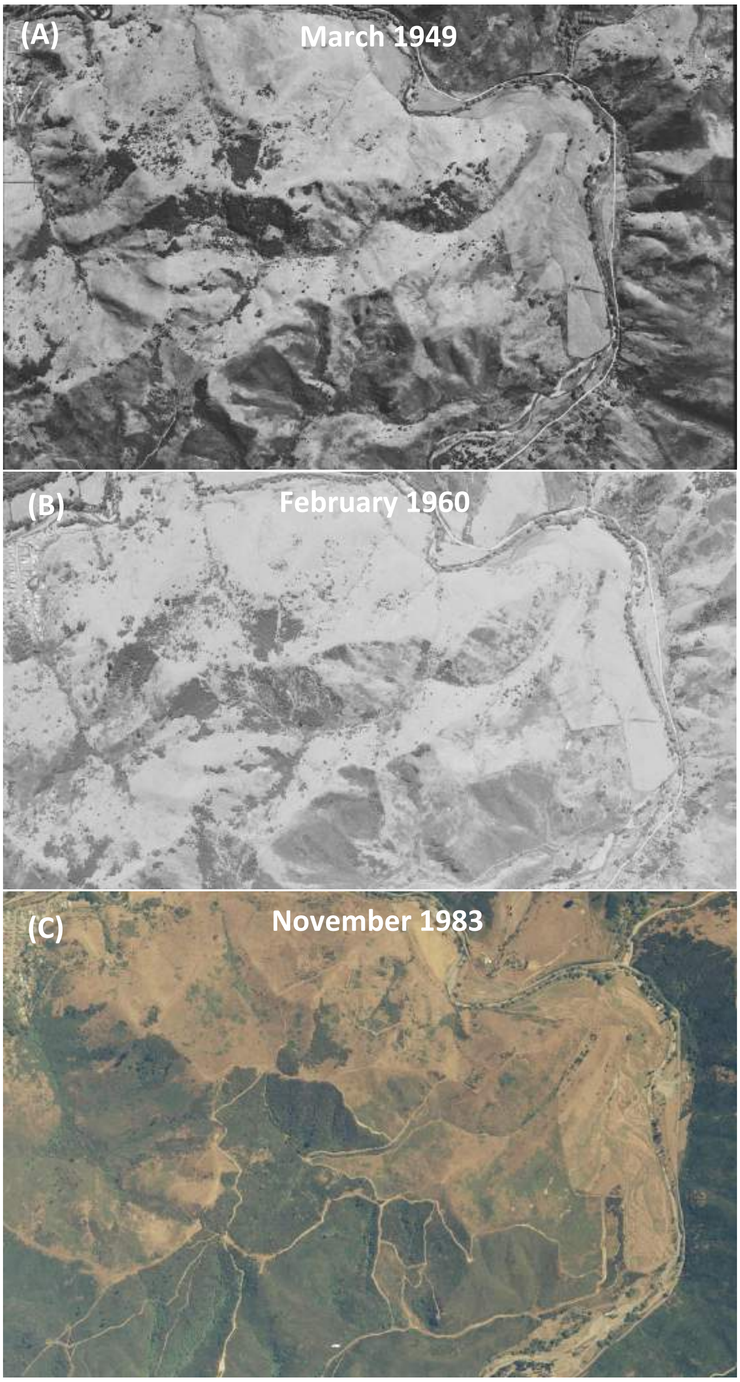

Figure 11 A-C. Land cover in (A) 1949 grassland with patches of secondary forest, possibly kānuka, (B) 1960, grassland with secondary forests persisting, (C) 1983, predominantly grassland with light woody cover, perhaps gorse, and some areas of secondary forest persisting.

3.3.3 Recommended Restoration Approach

A collection of management approaches will be essential for any mode of forestry involving native forest species. These essential management interventions are:

1. Browser control at landscape scales. Feral goats and deer must be effectively eliminated. Other animal pests (possums & pigs) must also be controlled.
2. Control of critical plant pests. Wilding conifers and Eucalyptus (where not used as a nurse), Old Man's Beard, and other structurally dominant or shade tolerant weeds must be managed to allow native tree regeneration and growth.

With these two management interventions in place, the following approach is recommended:

The southern aspects as identified in Figure 13 (southern areas B & D) present the best opportunities for passive native reforestation based on a combination of natural regeneration, enrichment planting, and the above plant and animal pest control.

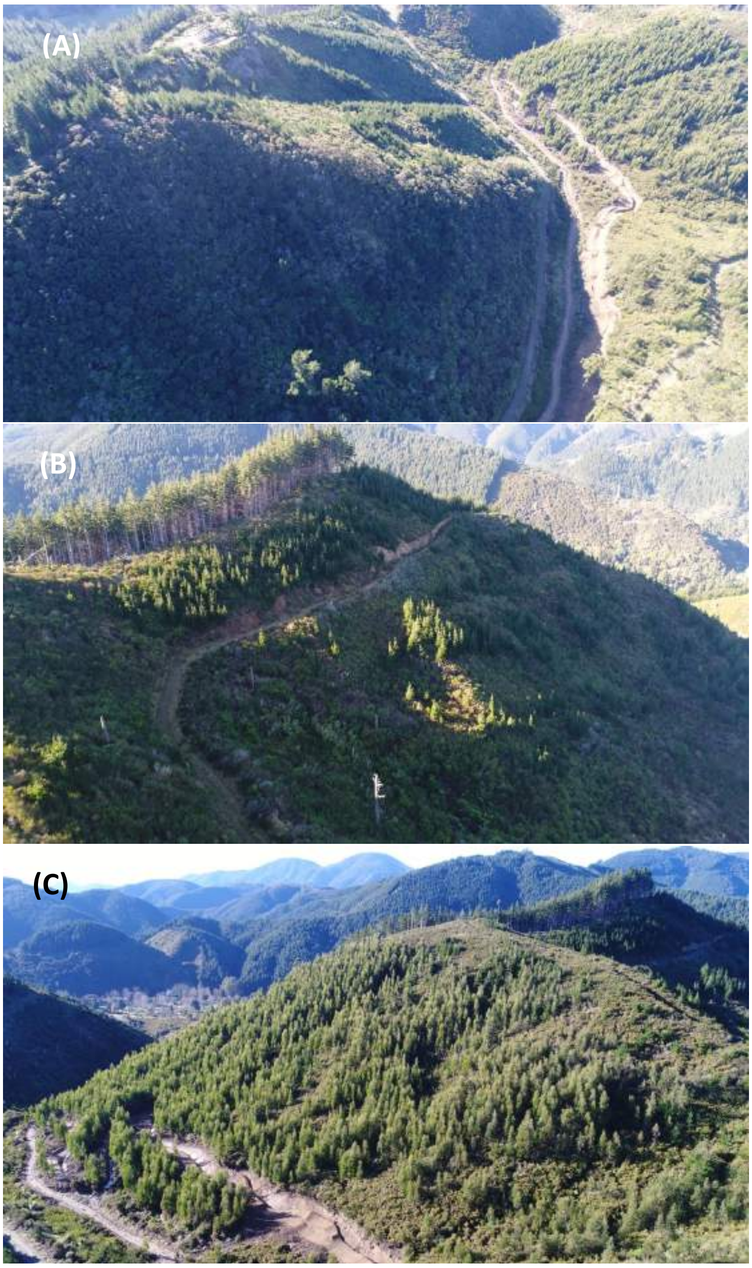

Figure 12 A-C. (A) A remnant secondary forest patch has occupied this south facing slope for >72 years. (B) south facing aspects such as this are the most viable sites for passive reforestation. (C) Eucalyptus is regenerating on this north facing site and can be incorporated in native reforestation as a nurse for planted native timber trees.

An active approach will be required to establish native vegetation on northern aspects. Area A (Fig. 9 B & Fig. 12) has been harvested in 2014 and over seven years has built a significant weed infestation. Addressing the weed infestations via low impact means will be expensive and there is little natural regeneration to protect. For these reasons, aerial broadcast spraying to eliminate the existing vegetation cover followed by oversewing in exotic grass and planting with native tree seedlings is recommended. Depending on the objectives, this area could be planted in mānuka (at 1.5 × 1.5 m spacing/3 333 stem ha^{-1}) for commercial honey, and this planting should include a successional component (e.g., tōtara, horoeka, & tītoki at c. 800 stems ha^{-1}) to ensure permanent native forest cover.

Area C (Fig. 12) could be a multi-use native plantation, with stands established for Whakairo (e.g., tōtara; maori wood carving), firewood (rotational kānuka) and continuous cover native timber. The area of Eucalyptus regeneration could be used through manipulations as a nurse to assist native tree establishment. Beyond this, site preparation should be determined on a site and forestry treatment basis.

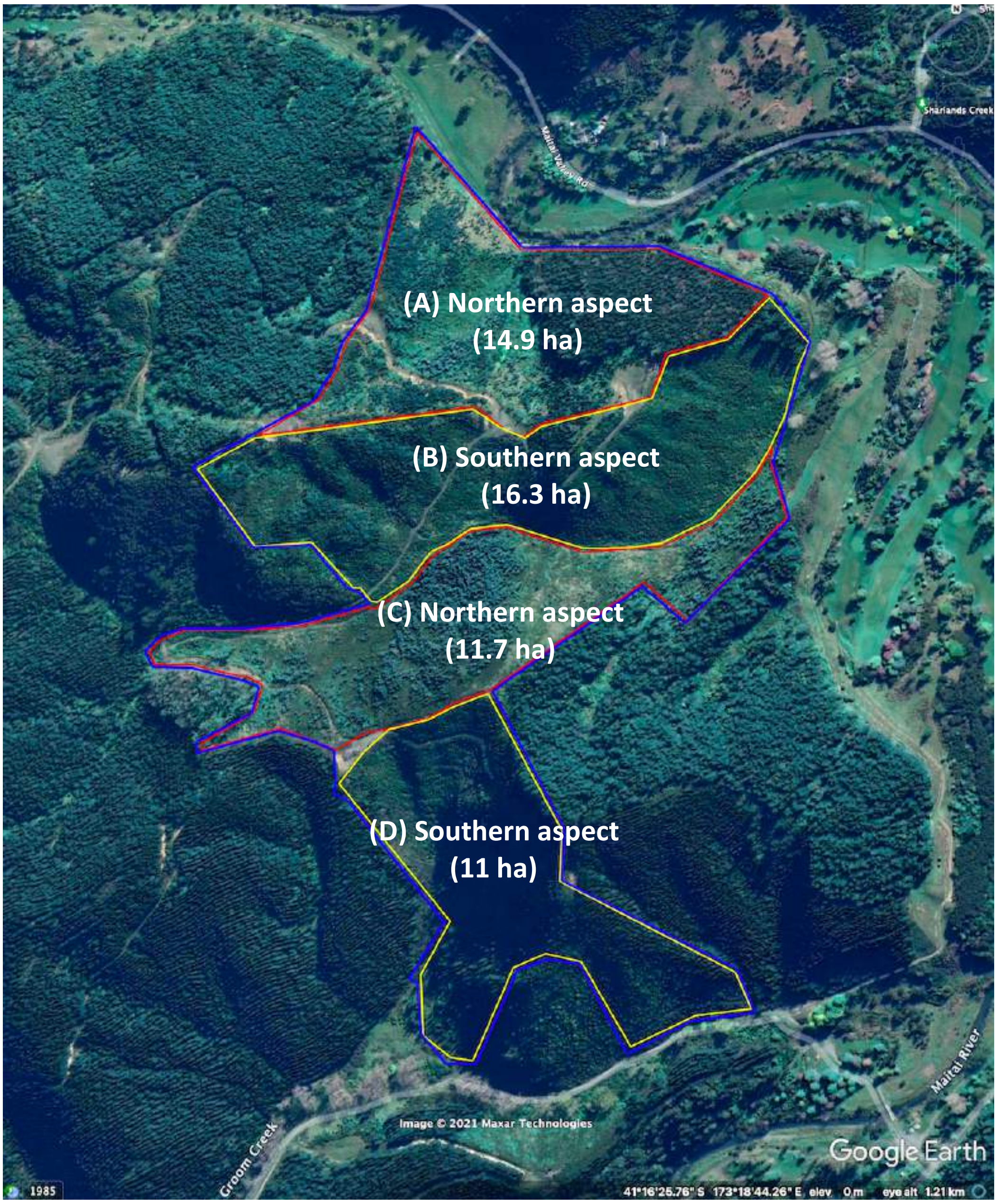

Figure 13. Recommended forest management units based on aspect, Ngāti Koata land, Nelson.

3.4 LIGAR BAY, GOLDEN BAY, TASMAN DISTRICT

3.4.1 Background

In 2011, the Ligar Bay hills received approximately 600 mm of rain in 24 hours. As a result, the land which was covered in mature radiata pine suffered extensive damage with debris dams formed by the destruction of the forest. Most property owners suffered damage; 30 m pine logs littered the landscape with numerous houses damaged. Post flooding investigations were undertaken on the event and on forestry options (Bloomberg, n.d.; Page et al., 2012). Whilst some the land was deemed suitable for exotic production forest, it was concluded that the best option for the land was permanent forest cover.

The landowners purchased the 45 ha clear-fell with a short-term plan and long-term vision of restoring native forest for the benefit of future generations (Fig. 14 A; Fig. 15). The aim in the short term was, through restoration, to set up a trajectory to native forest cover. Management aimed to eliminate all wilding radiata pine from the site within 5 years. The owners are realistic that they will only be guardians of the land for their lifetime so to ensure the land remains as a permanent indigenous forest

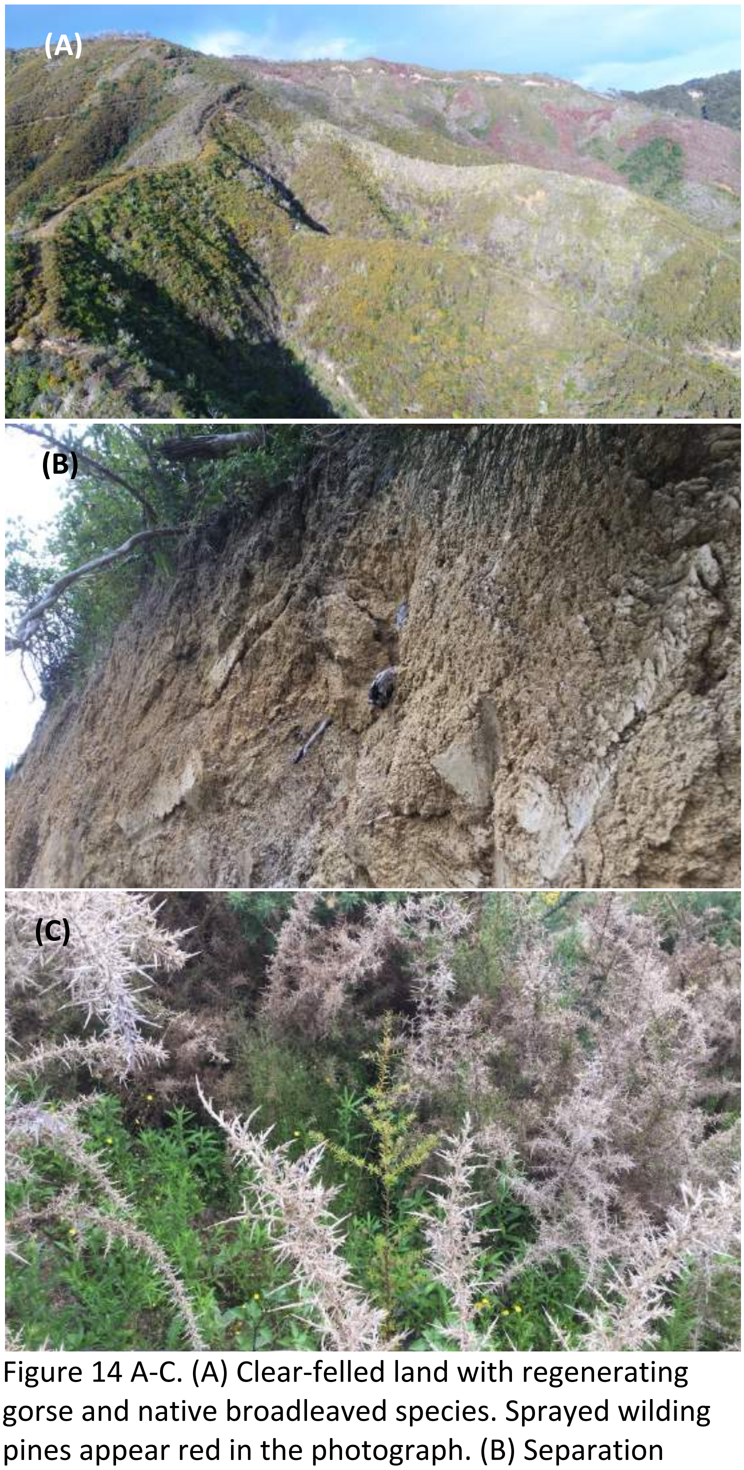

Figure 14 A-C. (A) Clear-felled land with regenerating gorse and native broadleaved species. Sprayed wilding pines appear red in the photograph. (B) Separation Point Granite soils are unconsolidated and highly vulnerable to erosion when the vegetation cover is lost. (C) Tōtara planted into spot sprayed gorse prevents gorse overtopping the tōtara and allowing the seedling time to emerge above the gorse canopy.

the management has been focused on achieving protection under a QEII National Trust covenant.

Being located on Separation Granite soils (Fig. 14 B), when denuded of vegetation cover, the site is highly vulnerable to soil erosion making permanent forest cover desirable from both soil conservation and biodiversity perspectives (Fig. 16).

The project has adopted a passive approach to forest establishment, mainly by nurturing natural regeneration through gorse. Wilding pine control and enrichment planting have been the main management interventions. To accelerate successional development, 10 000 native tree seedlings (mainly tōtara, kahikatea, & rimu, with smaller numbers of beech & rata) have been planted amongst gorse and early native regeneration, and along track edges.

Figure 15. The Ligar Bay case study property with boundaries demarcated.

3.4.2 Case study analysis

Below (Table 7) is an analysis of the Ligar Bay case study against key considerations in the clear-fell restoration process.

Table 7. Analysis of Ligar Bay case study against key considerations in the clear-fell restoration process.

<table>
<tr><th colspan="3">Goal(s)</th></tr>
<tr><td colspan="3">• To return the land to diverse native forest similar to mature local forests.
• Setting up the site for long-term restoration of the forest ecosystem to be continued by later generations.
• In 200 years, seeds from the property will help to establish regenerating native forests across Ligar Bay hills.
• For the land to be pine free within 5 years so that the land can be legally protected through conservation covanent, to ensure protection as a native forest in perpertuity.</td></tr>
<tr><th colspan="3">Ecosystem resilience</th></tr>
<tr><th>Topic</th><th>Data/analysis</th><th>Conclusion/Advice</th></tr>
<tr><td>• Rainfall regime/soil moisture.</td><td>• Mean annual rainfall = 1 270-1 778 mm (estimate).</td><td>• Rainfall is adequate for native forest regeneration.</td></tr>
<tr><td>• Air temperature.</td><td>• Median annual air temperature 12-13°C (estimate).</td><td>• Warm climate.</td></tr>
<tr><td>• Landform.</td><td>• Steep hill country. The main ridge runs north-south and steep spurs run from the main ridge approximately east-west. North and south aspects are dominant (Fig. 17 A).</td><td>• A range of landforms are present. North and south aspects dominate.</td></tr>
<tr><td>• Soil quality.</td><td>• Separation Point granite soils. Highly risk for erosion with a recent history of severe soil erosion.</td><td>• Highly erodable soils. Poor soil of limited depth.</td></tr>
<tr><td>• Tree species traits.</td><td>• Natives,
• Weeds.</td><td>Native:
• Māhoe,
• Tree fern spp.,
• Patē.
• Coprosma spp.
• Putaputawētā,
• Kānuka.

Exotic:
• Gorse,
• Radiata pine,
• Pampus,
• Himalayan honeysuckle,
• Banana passionfruit,
• Buddleia.</td></tr>
<tr><td>• Dynamics between desirable and</td><td>• Wilding pines have required widespread control. Gorse has colonised many areas</td><td>• Pines are the main structually dominant weed that must be addressed.</td></tr>
</table>

undesirable plant species.	and will reliably transition to native broadleaved forest. • Native regeneration has been faster in gullies and south faces compared to north faces and ridgelines. • Recommend leaving to year 5 so the more mature pines protect underlying natives from spray.	• Landform is a main driver of rates of native regeneration.
Land use history		
Topic	Data/analysis	Conclusion/Advice
• Intensity and duration of past land use.	• Forest was cleared from most of the land prior to 1952 (Fig. 17 A). • Regeneration through gorse, similar to the current regeneration pattern, was apparent in 1980, prior to plantation establishment (Fig. 17 B).	• The current pattern of native regeneration through gorse has occurred on this site before. • Distrubance from clear-fell is not precluding native reforestation (Fig. 16).
• Availablity of propagules within clear-fells.	• A large old-growth remnant adjoins the site. • Native conifers are naturally establishing indicating natural dispersal of forest seed is viable in this landscape.	• Local seed source is present.
• Retention and intactness of embedded or adjacent remnant native ecosystems.	• Seed sources embedded in the clear-fell do not exist. • The adjacent seed source appears to be intact and provides critical support for passive restoration at this site.	• The main seed source is from adjacent forest over the ridge in Wainui Bay.
• Level of soil degradation.	• Significant.	• Prior to planting in pines in 1983 the area was root raked and burnt with significant soil loss.
• Abiotic or biotic thresholds crossed.	• Apparently not.	• Apparently not.
Landscape context		
Topic	Data/analysis	Conclusion/Advice
• Amount and configuration of	• A large native seed source is close.	• The local forest context is good with QEII land and Abel Tasman National

adjacent native forest seed sources and disperser habitats.	• The adjacent forest is substantial enough to provide local nesting habitat for kererū, tūī, and korimako.	Park in close proximity and will support passive forest restoration.
• Disturbance sources from landscape matrix (e.g., pests, fire).	• Wilding conifers have been agressively controlled by the landowner. • Animal pest control is difficult due to the inaccessible nature of the site (steep, dense vegetation) and lack of control by neighbours. • The site is prone to significant soil erosion, however with vegetation cover this risk is at least partially mitigated.	• Pests present the most pressing form of disturbance at the landscape scale with pests present in adjoining properties making control an ongoing activity. • The formation of a local group to undertake volunteer conservation work is underway with funding for a part time administrator. • Revegetation erosion and slip sites with planting of colonising species and Lotus major to provide interim cover and prevent weed establishment.
• Neighbours views of restoration.	• Prior to purchase the local community, DOC and TDC were consulted. All were very supportive except for one who consided pines were the best solution and one considered the project would not be achievable. Helicopter spraying does concern some property owners.	• Community supportive volunteers assist with weed, pest control and track maintenance. • Regular communication when spraying is occuring and ensure all property owners are addressed in relation to spraying.
	Resources	
Topic	**Data/analysis**	**Conclusion/Advice**
• Known costs.	• Expecting to have spent about \$100K (excluding time) on wilding spraying when finished. • There has been very little financial support. • At this site, by area, hand removal is three times more expensive than aerial spray.	• Wilding control costs are projected to be \$2 200 ha^{-1}, excluding time.
• Funding available (amount & timeframes).	• The project received some funding from Council for tracking and a One Billion Trees Direct Grant provided about \$45K for enrichment planting.	• It has not been the amount of money, but rather the level of support that has been important.

	• Project Devine (local weed control project) and Trees That Count have provided support with weed control and native seedlings for planting, respectively.	
• People to implement restoration interventions.	• Landowners, restoration expert, local groups.	• Volunteer time. • Formation of local conservation and land care group will give access to volunteers and funding for projects.
• Access to restoration knowledge.	• Local restoration expert. • Spraying has been the biggest learning curve.	• Local expert.

Figure 16. Photopoint comparison showing 6.5 years of forest recovery between March 2015 (left) and November 2021 (right).

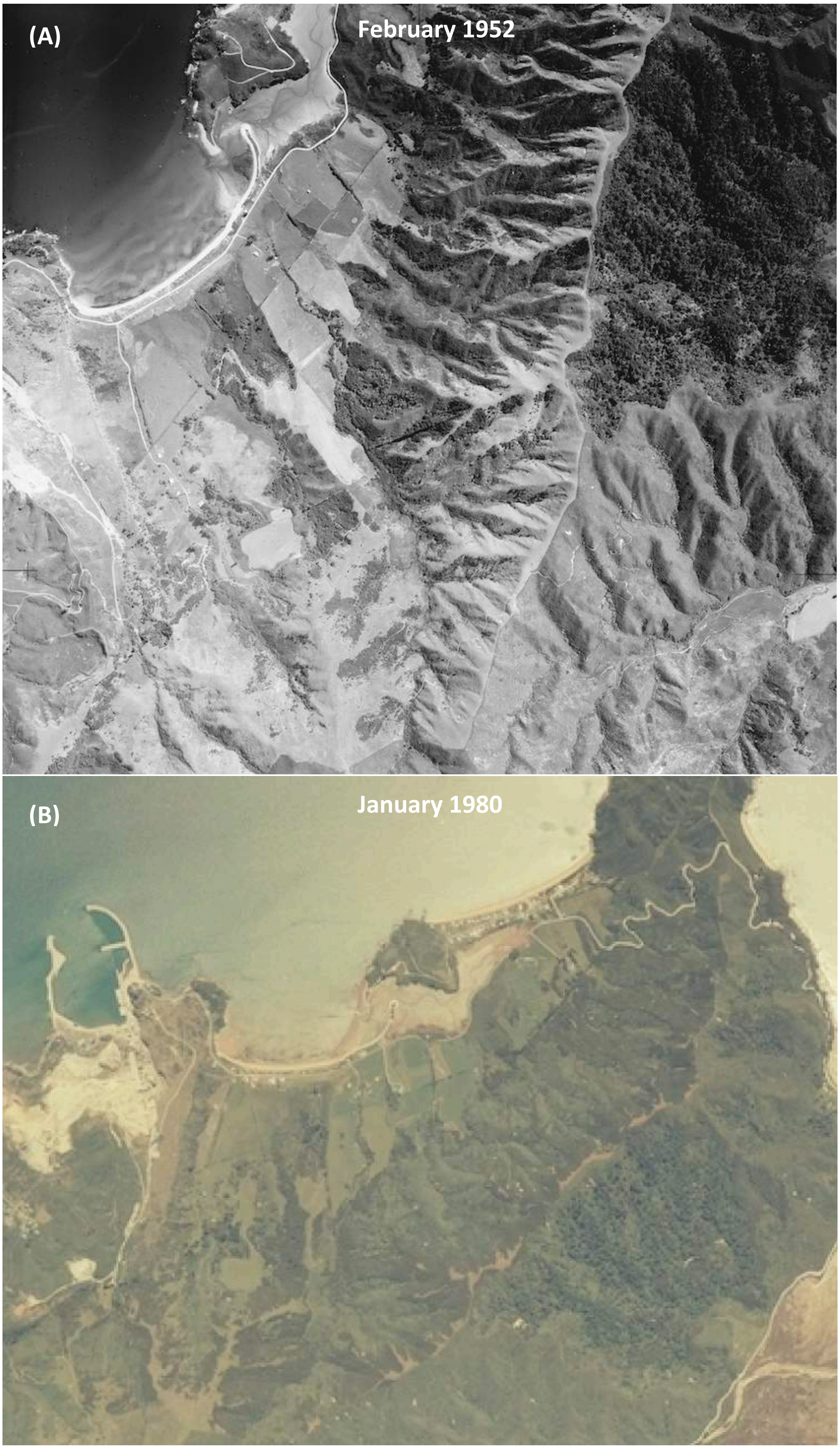

Figure 17 A & B. Aerial views of landcover at Ligar Bay in (A) 1952 and (B) 1980. In 1980 it appears natives were regenerating through gorse, similar to the current vegetation pattern.

3.4.3 Recommended Restoration Approach

The area has a good climate for regeneration and the local seed sources help support a passive restoration approach. Native forest at this site demonstrates a high level of resilience following clear-fell. This is evidenced by prolific māhoe regeneration, which establishes either in the open (Fig. 18 A) or amongst a nurse of gorse. Native conifers are establishing naturally at low densities which is a positive sign, confirming the ability for natural dispersal of forest tree seeds to the site from adjacent forest.

A balance has been found between aerial and ground based wilding control. The preference has been to implement wilding control with low impact ground-based cutting as much as possible, to avoid damage to natives and avoid creating establishment sites for weeds, such as pampus. Although, at this site ground-based cutting is about three times the cost of helicopter-based control.

The timing of helicopter control has been important, where pines are sprayed too early (<3-years-old) weeds (e.g., pampus) tend to establish at the control sites. If control is left too late, the decaying root ball presents an avenue for soil erosion (Fig. 18 B). The best results come from spraying small areas over an approximate 5-year duration.

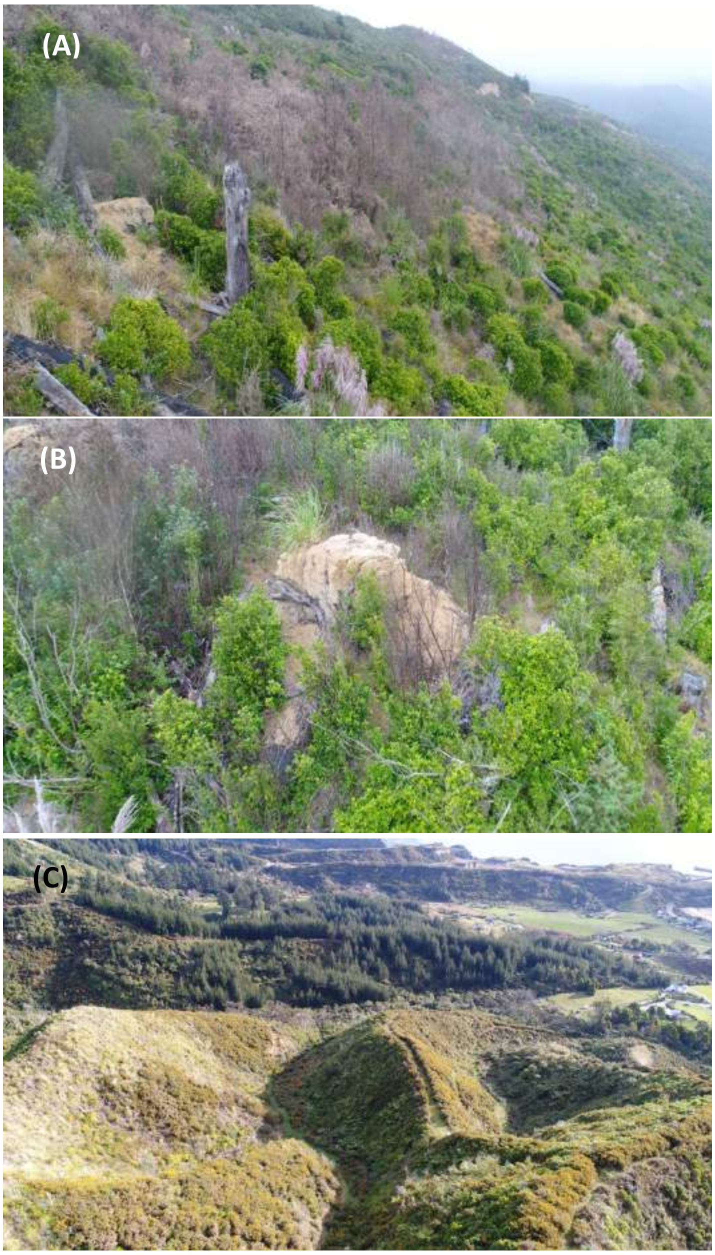

Figure 18 A-C. (A) Māhoe establishing on upper slopes around a wilding pine aerial spray site. (B) An upturned radiata pine root ball, which has become unstable as it decays and results in an avenue for erosion. (C) The shaded face is south facing and has greater native regeneration then the adjacent north facing site.

Regeneration is strongest on south facing slopes (Fig. 18 C). Planted tōtara has proven to be very hardy and has been resistant to herbicides and to browsing mammals. Planted tōtara has grown at rates of up to around 0.8 m height growth per annum over 3-4 years. Planted kahikatea and rata have also performed well. Planting individual native trees into spot-sprayed gorse has proven to provide sheltered microsites from which native seedlings can emerge above the gorse canopy.

To date, browsing mammals have been difficult to control as neighbouring properties are lacking active control. As the vegetation opens with age it will become more accessible by ungulates and more vulnerable to browse.

Ongoing browser management will be an important restoration intervention in the long term. Legal protection is proposed and this, along with ongoing management, will help to ensure that the forest will be secure into the future.

4.0 CONCLUSIONS

The forest ecology effects of clear-fell restoration were reviewed with the results synthesised into key considerations for restoration of clear-fells. Key considerations were grouped by the following topics:

1. Setting goals,
2. Evaluating ecosystem resilience,
3. Considering the effects of land use history,
4. Determining the influence of landscape context, and
5. Resourcing the restoration project.

Application of the key considerations to four clear-fell restoration case study sites illustrates the range of ecological issues that are likely to be encountered when restoring clear-fells in the top of the South Island Districts and how management options can have the most beneficial impact.

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ATTACHMENT 1: NOMENCLATURE USED IN THIS REPORT

Flora

Scientific name	**Maori/common**	**Family**	**Life form**	**Native/Exotic**
Alectryon excelsus	Tītoki	Sapindaceae	Trees & shrubs	Native
Aristotelia serrata	Makomako	Elaeocarpaceae	Trees & shrubs	Native
Berberis darwinii	Darwin's barberry	Berberidaceae	Trees & Shrubs	Exotic
Brachyglottis repanda	Rangiora	Asteraceae	Trees & shrubs	Native
Buddleja salvifolia	South African buddleja	Buddlejaceae	Trees & shrubs	Exotic
Carpodetus serratus	Putaputawētā	Rousseaceae	Trees & Shrubs	Native
Clematis vitalba	Old man's beard	Ranunculaceae	Lianes	Exotic
Coprosma robusta	Karamū	Rubiaceae	Trees & shrubs	Native
Coriaria arborea	Tutu	Coriariaceae	Trees & Shrubs	Native
Cortaderia spp.	Pampas grass	Poaceae	Grasses	Exotic
Cotoneaster spp.	Cotoneaster	Rosaceae	Trees & Shrubs	Exotic
Erica lusitanica	Spanish heath	Ericaceae	Trees & shrubs	Exotic
Fuchsia excorticata	Kōtukutuku	Onagraceae	Trees & shrubs	Native
Geniostoma rupestre var. ligustrifolium	Hangehange	Loganiaceae	Trees & shrubs	Native
Hypericum androsaemum	Tutsan	Hypericaceae	Herbs	Exotic
Kunzea sp.	Kānuka	Myrtaceae	Trees & shrubs	Native
Leycesteria formosa	Himalayan honeysuckle	Caprifoliaceae	Trees & shrubs	Exotic
Lotus uliginosus	Lotus major	Fabaceae	Herbs	Exotic
Melicytus ramiflorus	Māhoe	Violaceae	Trees & shrubs	Native
Myrsine australis	Mapau	Primulaceae	Trees & Shrubs	Native
Ozothamnus leptophyllus	Tauhinu	Asteraceae	Trees & Shrubs	Native
Passiflora 'Tacsonia' subgroup	Banana passionfruit	Passifloraceae	Lianes	Exotic
Phytolacca octandra	Inkweed	Phytolaccaceae	Trees & shrubs	Exotic
Pinus radiata	Radiata pine	Pinaceae	Trees & shrubs	Exotic
Pittosporum tenuifolium	Kōhūhū	Pittosporaceae	Trees & Shrubs	Native

Podocarpus totara	Tōtara	Podocarpaceae	Trees & shrubs	Native
Pseudopanax arboreus	Whauwhaupaku	Araliaceae	Trees & Shrubs	Native
Pseudopanax crassifolius	Horoeka	Araliaceae	Trees & shrubs	Native
Pteridium esculentum	Rarauhe	Dennstaedtiaceae	Ferns	Native
Rubus fruticosus	Blackberry	Rosaceae	Trees & shrubs	Exotic
Schefflera digitata	Patē	Araliaceae	Trees & Shrubs	Native
Solanum sp.	Poroporo	Solanaceae	Trees & shrubs	Native
Ulex europaeus	Gorse	Fabaceae	Trees & shrubs	Exotic

Fauna

Scientific name	**Maori/common**	**Family**	**Native/Exotic**
Anthornis melanura	Korimako	Meliphagidae	Native
Capra hircus	Feral goat	Bovidae	Exotic
Cervus spp. or *Dama dama*	Deer	Cervidae	Exotic
Hemiphaga novaeseelandiae	Kererū	Columbidae	Native
Prosthemadera novaeseelandiae	Tūī	Meliphagidae	Native
Trichosurus vulpecula	Common brushtail possum	Phalangeridae	Exotic