Review of Karioi Forest *Pinus contorta*

Management Plan 2006-2021

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Summary

Project and Client

A review of the Winstone Pulp International Forestry *Pinus contorta* Management Plan 2006-2021 was undertaken for Horizons Regional Council by Landcare Research.

Objectives

- Review the probable effectiveness of the 'WPI Forestry *Pinus contorta* Management Plan 2006-2021' for Karioi Forest.
- Suggest alternative or additional actions that will increase the effectiveness of this management plan.

Methods

With staff of WPI Forestry, we inspected areas containing *P. contorta* within Karioi Forest on 11 and 12 June 2007 and discussed the management plan. Relevant literatures on plant eradication strategies and *P. contorta* biology and control were then used to analyse the management plan with respect to strategies for detection, containment, extirpation, commitment, and restoration.

Results

The management plan sets out to provide a basis for future management of *P. contorta* within Karioi Forest. It proposes management based on (1) dividing 69% of the forest into 3 areas for detection and removal of new seedlings on a 3-year cycle; (2) prioritising removal of mature stands; (3) prioritising removal of *P. contorta* within wetland sites; (4) containing *P. contorta* seed rain within large *P. radiata*/*P. contorta* blocks as an interim measure; and (5) establishing a monitoring programme.

Analysis of the management plan with respect to detection, containment, extirpation, commitment, and restoration suggested several ways in which the plan could be improved or supplemented. The plan does not specifically detail a programme of detection but we assume this is part of the 3-year 'sustained control' activity and the programme needs to be extended to completely fulfil this role. Containment of *P. contorta* is difficult because of its abundantly produced, light, wind-dispersed seed. The order of removal of mature stands should focus on reducing the number of seeds being released, reducing exposure of cones to high winds, and reducing the possibility that dispersed seeds will find suitable establishment sites. More information is needed to assess whether the containment measures suggested will be effective. The methods implied for killing *P. contorta* individuals are appropriate and will be effective. The many conditional statements included in the management plan undermine the perceived commitment of WPI Forestry to undertaking actions in the plan and should be reduced. Possible restoration measures are not included in the plan.

Conclusions

The management plan includes many actions that will reduce *P. contorta* extent and abundance within Karioi Forest and will limit further spread both within the forest and onto neighbouring areas. Although it provides a foundation for *P. contorta* control, uncertainties on the outcomes of some proposed actions and on the commitment by WPI Forestry to carry

out these actions reduce the perceived effectiveness of the plan. However, a number of improvements to the management plan could be made, and these form the basis of the recommendations below.

Recommendations

We recommend that WPI Forestry revise the proposed management plan to consider specifically strategies for detection, containment, extirpation, commitment, and restoration. Specific recommendations are:

- Provide a clear statement of goals and establishment of specific milestones within the management plan.
- Include the entire forest within the 3-year detection and control programme for newly established seedlings immediately, and design this programme to concentrate strategically on high-risk sites, and to monitor progress.
- Prioritise stands at high altitude, on windy sites, near the eastern boundary, outlying stands, and 'green' *P. contorta* first for removal.
- Carry out the planned removal of *P. contorta* around the edge of the central *P. radiata/P. contorta* stands but increase the depth of the buffer on the eastern boundaries of these stands, and establish a monitoring study so that its effectiveness can be assessed.
- Identify any stands of *P. contorta* on neighbouring land that may pose a risk of reinfestation of Karioi Forest and negotiate their removal.
- Consider use of herbicide to control stands of *P. contorta* in compartment 20.
- Carry out an economic study comparing relative costs of different control scenarios including cutting *P. contorta* to waste.
- Stakeholders should explore whether cooperative actions are possible to address this problem.
- Identify sites where appropriate revegetation could occur following *P. contorta* removal.

Introduction

A review of the Winstone Pulp International Forestry *Pinus contorta* Management Plan 2006-2021 was undertaken for Horizons Regional Council by Landcare Research.

1. Background

1.1 *Pinus contorta* and Karioi Forest

Pinus contorta was first introduced to New Zealand about 1880 but was not planted in large quantity until the late 1920s (Miller & Ecroyd 1987). This included 2000 ha planted at Karioi Forest between 1928 and 1933 (Jamieson 1974). Two varieties were planted there: the 'green' or coastal form (*P. contorta* ssp. *contorta*) and the 'yellow' form (*P. contorta* ssp. *murrayana*). Subsequently, seed from planted *P. contorta* invaded unplanted higher altitude areas and other open areas such as firebreaks, leading to an additional 1300 ha within Karioi Forest being covered in naturally established *P. contorta* by 1974 (Jamieson 1974).

As well as seeding into Karioi Forest itself, *Pinus contorta* from Karioi spread onto substantial areas to the east, invading the volcanic landscapes of the Tongariro National Park (Graeme 1997), the Waiouru Military Training Area (Burns et al. 2001), and the Kaimanawa Ranges. Control programmes for *P. contorta* in these areas have now been active for over 40 years (Weedbusters 2005) and have been large in scale and cost. "Escapees from Karioi Forest [have] led to the largest ongoing weed control operation (apart from agricultural weeds) in New Zealand" (Williams & Cameron 2006). Total costs of control outside of Karioi Forest are unknown but undoubtedly now extend to many millions of dollars (N. Singers and J. Mangos, pers. comms.). Although current control operations on the Tongariro National Park and Defence Force lands have been reducing *P. contorta* populations on these areas, the most significant seed source outside these lands still occurs on Karioi Forest and continues to compromise the success of these operations.

There has also been active control of both planted and wilding *P. contorta* within Karioi Forest. Winstone Pulp International have harvested 1419 ha of *P. contorta* since 1990 at a cost of approximately $7.95 million (WPI Forestry 2006). In addition, a further $2.56 million has been spent since 1990 on controlling *P. contorta* wildlings (WPI Forestry 2006).

The weedy nature of *P. contorta* is a result of its ability to produce cones precociously (sometimes after only 3 years), abundant light-weight, wind-dispersed seed, and the ability to establish on non-forested exposed, frosty, wet and/or high elevation sites where competition from other species is low (Miller & Ecroyd 1987). It is currently recognised as an environmental pest plant by Horizons Regional Council (Horizons Regional Council 2007), with a control objective of containment across the region (although aiming for zero-density management within defined control areas), and a containment plant pest by Environment

Waikato, who require the occupier to destroy all *P. contorta* on their land (Environment Waikato 2007).

Karioi Forest comprises 10, 554 ha on the southeast slopes of Mt Ruapehu (Jamieson 1974). It covers an altitudinal range from 640 to 1160 m asl of terraces and fans of gentle slope. Forests planted within Karioi are now predominantly *Pinus radiate*, although some of the original plantings, including *Pinus ponderosa, Pinus nigra, Pseudostuga menziesii* and *Pinus contorta*, are still extant.

1.2 General principles of weed eradication

Eradication is the elimination of every single individual of a species from an area in which recolonization is unlikely to occur (Myers et al. 1998). We suggest five critical factors are necessary for successful weed control where eradication is a goal: detection, containment, extirpation, commitment, and restoration.

Detection

Delimitation of extent of a weed incursion is fundamental for eradication success (Panetta & Lawes 2005), because undetected infestations will expand and spawn further loci for invasion. All individuals of a weed need to be located to ensure success (Williams 1997), which requires detection of individuals even at low densities (Myers et al. 2000). The ability to detect a weed is a function of its visibility and of search effort, experience, and method (Harris et al. 2001). Detectability also has a temporal component because of the persistence of plants in seed banks. Even if all vegetative plants are destroyed, new plants can arise from seed banks (Mack & Lonsdale 2002). Repeated surveying, particularly in the vicinity of known occurrences or on the site of former occurrences, is essential. Surveying should also concentrate on sites susceptible to invasion and along dispersal routes (Zamora et al. 1989). Determining the extent of a weed invasion is also necessary to estimate the resources required for control programmes (Panetta & Timmins 2004).

Containment

Once the spatial extent of an invasion is known, successful eradication programmes require the prevention of further spread (Panetta 2007). Actions that support containment are the destruction of outlier populations (Zamora et al. 1989; Williams 1997), particularly those that are pre-reproductive, reducing the dispersal potential of extant populations through consideration of the biology of the species, and preventing reinvasion from outside the area to be eradicated.

Destroying outlier populations "remain[s] amongst the most important lessons learned from attempts to eradicate potentially invasive species" (Mack & Lonsdale 2002). A species with many widely separated foci is much more difficult to eradicate than a single infestation (Mack & Lonsdale 2002). So efforts to reduce the number of areas of high infestation will be rewarded.

The dispersal potential of an infestation can be reduced by strategically prioritising treatments to remove those populations with the highest probability of causing spread (Zamora et al. 1989). For example, populations of a wind-dispersed species that occur on sites subject to high winds would be prioritised for early removal.

Containment will only be effective if re-entry from outside the eradication area is prevented. Any undetected populations on adjacent land can lead to reinvasion and these threats need to be identified. Also, quarantine for the focal species should be in place over the eradication area to stop the reintroduction of the weed by people (Zamora et al. 1989).

Extirpation

Successful weed eradication will only occur when practicable control measures are available (Williams 1997). These include using hand tools, mechanical equipment, chemicals, fire, biological control, or passively waiting for natural processes. Selection of a method or combination of methods varies according to the life form of the weed, its response to treatment, the size of the infestation, and the presence and types of non-target species associated with the weed (Williams 1997). A key factor is whether the a target plant will regenerate once cut or damaged, and therefore require revisiting and the reapplication of treatments at sites.

Eradication requires the rate of weed removal to exceed the rate of weed increase at all population densities (Panetta & Timmins 2004). Therefore extirpation is concerned both with removing individuals and preventing recruitment, e.g., halting seed production. Decreases in population size will be highly influenced by the dynamics of soil seed banks, the effectiveness of control measures in removing new recruits before they can reproduce, and in removing early those individuals contributing most to seed rain (Zamora et al. 1989; Panetta 2007). In order to deplete soil seed banks, critical information is the length of time seed remains viable in the soil for the species involved. If new inputs of seed can be prevented, this will provide the time over which an area needs to be resurveyed in order to pick up newly germinated seedlings. Another critical piece of information is the length of time the plant spends in the pre-reproductive phase. If plants can be controlled before seed production, the time required for eradication can be drastically reduced (Panetta 2007).

Commitment

Eradication of weeds from an area usually requires long-term and consistent financial and institutional commitment (Simberloff 2003; Panetta & Timmins 2004). There are significant financial benefits and time savings in detecting and controlling weeds early compared with delayed control because of the exponential rate of weed population increase (Williams 1997; Simberloff 2003; Harris et al. 2001). Eradication also often requires cooperation across a number of groups with different interests, e.g., different landowners (Simberloff 2003). Having resources sufficient to fund a programme to conclusion, and a lead agency with the mandate to carry out all required procedures at all affected sites, are essential factors in successful eradication programmes (Myers et al. 2000). Because of the exponential rate of population increase, unnecessary delays in control can lead to substantial setbacks in the eradication progress. Eradication programmes can be delayed due to conflicts of interest arising when a species is considered weedy in one context but a valuable resource in another (Panetta & Timmins 2004).

Restoration

Weeds are such because they cause ecological or economic costs as a result of their presence. The goal of eradication is therefore to prevent these costs. Sometimes eradication of a weed

facilitates the entry of another unwanted species in the void left by its removal (Myers et al. 2000; Simberloff 2003). Successful eradication may require revegetation or restoration of sites to prevent such secondary weeds from using the opportunity created by the removal of the target weed (Mack & Lonsdale 2002). Such revegetation can also reduce the chances of reinfestation of sites by the target weed by making them unavailable for seed establishment.

2. Objectives

- Review the probable effectiveness of the 'WPI Forestry *Pinus contorta* Management Plan 2006-2021' for Karioi Forest.
- Suggest alternative or additional actions that will increase the effectiveness of this management plan.

3. Methods

The management plan was reviewed with respect to the 5 key factors identified for successful weed eradication (detection, containment, extirpation, commitment, and restoration). Relevant literatures on plant eradication strategies and *P. contorta* biology and control were used to inform our analysis. We supplemented this review with an inspection of areas containing *P. contorta* within Karioi Forest on 11 and 12 June 2007 and discussions of the plan with staff of WPI Forestry.

4. Results

4.1 Summary of WPI Pinus contorta Management Plan 2006-2021 (WPI Forestry 2006)

The plan sets out to provide a basis for future management of *Pinus contorta* within Karioi Forest. We identified three high-level goals of management discussed at different points within the document:

- Achieve zero-density control of *P. contorta* within Karioi Forest (p. 9).
- Reduce and then eliminate *P. contorta* seed spread within Karioi Forest (p. 5) and onto neighbouring properties (pp. 2, 5).
- Be cost effective, keep within budget constraints, and sell as much felled *P. contorta* wood as possible to offset costs (p. 5).

The plan purports to provide a basis for management from October 2006 to October 2021. However, the plan details actions only over a 3-year period (2006–2009) with more "general direction" given for 2010–012 (p. 4). It therefore provides direction for only 6 years rather

than 15. The plan is to be reviewed and updated at 3-year intervals to specify activities for the next 3-year period.

To achieve its objectives, the plan prioritises the following actions:

1. The perimeter of the forest has been divided into 3 zones: southwest (2765 ha); north (1895 ha); and east (2575 ha). Each year one of these zones will be subject to "sustained control". What "sustained control" entails is not specified in the plan, but from discussions with WPI staff we interpret this to mean that the area under focus in any year will be systematically searched for outlier *P. contorta* seedlings and these will be destroyed (e.g., pulled out or cut at ground level) when found. This action excludes core infestation sites. Each of the zones will be increased after 3 years to include more of the total forest area until by 2012 all the forest is contained within one of these zones.
2. Remove stands of 'mature' *P. contorta* trees when "harvest is cost-effective and trees are of a harvestable age". Of these stands, prioritise removal of 'green' *P. contorta* over 'yellow' *P. contorta*, originally planted stands over regenerated stands, higher elevation or wind-prone sites over lower elevation or less windy sites, and sites closer to the boundary over those further into the interior of the forest.
3. Remove existing *P. contorta* from wetland areas within the forest between 2007 and 2009.
4. Remove *P. contorta* from a 30-m-wide strip around all edges of blocks of *P. radiata* mixed with *P. contorta* that occur in the centre of Karioi Forest.
5. Establish a monitoring regime to measure success (pp. 2, 9). In particular, monitor whether the *P. contorta* population within Karioi Forest and its seed rain have been reduced as a result of actions undertaken. Details of the monitoring plan are not given.

4.2 Distribution of *P. contorta* within Karioi Forest in 2006

Five different types of high-infestation areas contained *Pinus contorta* in Karioi Forest in 2006 (Fig. 1):

1. Stands planted between 1928 and 1933 (approximately 93 ha, Fig. 1). The last planted stand of 'green' *P. contorta* in compartment 47 (approximately 10 ha) was recently harvested. Other remaining planted stands are 'yellow' *P. contorta* in compartments 36, 31, and 28 (Appendix 1).

2. Stands of 'green' *P. contorta* arising from wilding spread into wetland areas (Fig. 1, Appendix 1). These occur mainly in the centre of the Karioi Forest Estate (compartments 14, 21, 22, 27, 28, and 31). Estimated area of wetlands containing *P. contorta* is 232 ha.

3. Pure stands of 'green' *P. contorta* arising from wilding spread into non-wetland areas. The main area of this type remaining is in compartment 20 (approximately 29 ha, Fig. 1, Appendix 1). *P. contorta* also occurs scattered in the scrub west of compartment 20, although most of this has recently been poisoned.

4. An approximately 16 ha stand of *Pinus nigra* and *Pseudostuga menziesii* (Douglas fir) in compartment 65 also contains *P. contorta* that has entered this stand through wilding spread (Fig. 1, Appendix 1).

5. The largest areas of *P. contorta* occur mixed with stands of *P. radiata* at high to mid-elevation. The majority of these areas were planted with *P. radiata* between 1990 and 1995 with *P. contorta* entering the stands through wilding spread and establishing between the rows of *P. radiata*. These stands combined total approximately 658 ha (Fig. 1, Appendix 1).

Further *P. contorta* individuals occur as isolated trees or seedlings scattered throughout Karioi Forest. In our visit of June 2007, we noted a few such seedlings along road corridors and streambanks.

4.3 Consideration of management plan against weed eradication principles

Detection

The management plan does not specifically detail a programme of surveillance and detection for *P. contorta*. As discussed above, however, we interpret the sustained control that will be undertaken within 3 perimeter buffer zones on a 3-year rotation to include systematic searches for this species, although a search method (e.g., searching on grids, transects, random walks, or some form of stratification) is not specified. These buffer zones will be gradually increased until by 2012 they cover the entire forest. However, this implies that a significant central section of the forest (31%) will not be subject to search effort until that time. This provides a window of opportunity for newly established seedlings to reach coning age before detection within this area.

Pinus contorta is a precocious seeder with some trees producing cones as early as 4 years old and many trees by 5 years old (Miller & Ecroyd 1987; Burns et al. 2001). As 1-year-old and sometimes 2-year-old seedlings can be difficult to find during surveillance, repeat surveillance and control more than 3 years apart greatly increases the chance that seedlings will produce seed before removal (Burns et al. 2001). Therefore, we agree that areas within Karioi Forest should be searched for new seedlings of *P. contorta* every 3 years to ensure new recruits are removed before they seed. However, the whole forest should be brought into this 3-year rotation immediately, to remove the opportunity for undetected infestations to establish and reach coning age.

This programme of surveillance should be carried out to focus strategically on areas adjacent to high-infestation sites, previously infested sites (where seed banks may still occur), and open habitat in which *P. contorta* is more likely to establish, e.g., on roadsides.

Containment

Pinus contorta produces abundant small (3-5 mm long, 2-2.5 mm wide) wind-dispersed seeds (Miller & Ecroyd 1987). Seed is mostly released from cones in autumn, although small quantities of seed remain in cones until the following spring (Ledgard 2001). A study on the central Plateau observed that most *P. contorta* seed were released in May (Ledgard 2001). Most seed falls within 60 m of the parent tree (Schmidt & Alexander 1985), but there are records of wildings occurring many kilometres away from seed sources (up to 40 km) suggesting very long-distance dispersal (Ledgard 2001).

Cremer (1971) examined the dispersal characteristics of *P. contorta* seed and determined its terminal velocity at 1.4 miles per hour (2.25 km per hour). This value allows prediction of

the distance of dispersal given the wind velocity and height at which the seed is released. For example, *P. contorta* seeds released at 30 m height in 100 km per hour winds are predicted to travel 1.3 km (Cremer 1971). Air turbulence, and particularly updrafts, could substantially increase this distance.

Strong winds are a feature of the climate of the Ruapehu area, commonly recorded in the mountains at 55–111 km per hour, with gusts up to 148 km per hour (Potton 1995). The prevailing wind is westerly with gale force winds blowing about 10% of the time in the mountains (Thompson 1984). Wind strong enough to blow down trees is known to be a common factor in the forest dynamics of nearby indigenous forests (Lusk & Ogden 1992). Therefore, winds that could disperse *P. contorta* seed across the eastern boundary of Karioi Forest occur regularly.

P. contorta is a shade-intolerant species with seedlings establishing best on bare soil and in open vegetation types, e.g., tussockland, open shrubland (Burns et al. 2001; Ledgard 2001). As the western boundary of Karioi Forest (Fig. 1) abuts dense indigenous forest whilst the northern and eastern boundaries abut open pasture or tussocklands, there is a much greater probability and threat of *P. contorta* spread to the east and north of Karioi Forest than to the west.

Although these considerations suggest that the presence of any coning *P. contorta* within Karioi Forest can lead to seed dispersal within the forest itself and on to adjacent land under extreme weather conditions, strategies to reduce seed dispersal under more normal conditions would be to first remove coning stands nearest to the eastern boundary (therefore increasing the distance seeds need to travel to reach adjacent, vulnerable land downwind), remove coning stands at highest elevations (frequency and intensity of wind increases with elevation) or 'take-off sites' (Ledgard 2001), and to remove stands of larger, taller trees before smaller, shorter trees (assuming larger trees produce more seeds and taller trees release seeds from higher so they can travel further). The management plan does recognise most of these priorities.

Experience on weed containment noted above (section 2.2) also emphasises the benefits of controlling outlier populations and reducing the numbers of control foci (Mack & Lonsdale 2002). This principle also needs to be encapsulated in the management plan by targeting removal of the smallest coning stands by area earlier than larger stands. The largest population of *P. contorta* remaining is that mixed with *P. radiata* in the centre of the forest (compartments 41, 42, 43, and 51) and, by this principle, this should be treated last.

The plan to remove *P. contorta* from a 30-m strip around the edge of the central *P. radiata*/*P. contorta* stands is a strategy designed to reduce *P. contorta* seed dispersal from these stands until harvest planned for 2020 and 2025. This strategy assumes that (1) *P. contorta* occurring > 30 m from a boundary will not disperse seed further than this edge, (2) that the *P. radiata* will grow taller than the *P. contorta* therefore suppressing it and forming an upper canopy so that the *P. contorta* are protected from wind (seed dispersal distance is dependent on wind velocities experienced, Nathan & Muller-Landau 2000), and (3) that competition with the *P. contorta* still allows *P. radiata* to grow to harvestable age within the time frame envisaged.

This strategy is experimental and there are no data available to assess whether this strategy would be effective, and in particular, that the assumptions listed above are valid. Evidence on which to assess this strategy could be gathered through (1) studying seed dispersal (using

seed traps) from forest edges from which *P. contorta* has been removed to different buffer widths, and (2) establishing permanent forest plots to investigate the competition and growth of *P. radiata* and *P. contorta* in these stands.

Assuming that this strategy may be effective, possible refinements to this model would include (1) creating deeper buffers at eastern boundaries than western to recognise the predominant westerly airflow across Karioi Forest, (2) killing those *P. contorta* growing closest to *P. radiata* individuals to reduce any competitive effect and facilitate *P. radiata* dominance.

The management plan should also evaluate the risk of reinvasion of *P. contorta* from neighbouring land on to Karioi Forest. Continued representation on the *P. contorta* Coordinating Committee, as recommended in the management plan, would help identify any risks that could occur and assist neighbours in control where practical.

Extirpation

The management plan does not stipulate its proposed method of *P. contorta* control. However, conventional control occurs by either hand-pulling seedlings or cutting adult trees at ground level (or at least below the bottom whorl of branches), and our contact with WPI staff suggests these techniques will continue to be used at Karioi. The strategic use of herbicides, either injected into trees or aerially applied, could be considered for particular areas, e.g., in compartment 20, where a mature stand of *P. contorta* is isolated from current production stands of other species.

The length of time seed remains in the seed bank is an indicator of how often sites on which *P. contorta* has been removed need to be revisited. In New Zealand, trials of *P. contorta* seed longevity have shown that most seed germinates in the first year following release, with no seed germinating after the fourth year (Ledgard 2001). Therefore, sites from which *P. contorta* is removed will require revisiting to ensure that seedlings germinating from the seed bank do not reach coning age. The proposed 3-year rotating programme of surveillance will adequately cover this need, with areas from which *P. contorta* has been removed specifically targeted for detailed inspection.

Commitment

The management plan is persistently conditional with regard to the commitment of WPI to undertake the eradication measures proposed. It stipulates that harvest of mature stands will only occur "as economic conditions allow", and other forms of activity, e.g., sustained maintenance control, will only occur "as budget allows". This purports to recognise the uncertainties of budgeting within a commercial environment, but does not recognise the increased long-term costs of control that arise as a result of delays or interruptions in such a control programme (Harris et al. 2001). The interruption in *P. contorta* control in the 1990s that allowed the invasion of the *P. radiata* stands with wildings now form the most serious and costly infestation remaining in Karioi Forest. The management plan also does not recognise the additional costs neighbouring landowners will face as a result of delays in controlling *P. contorta* within Karioi Forest through having to prolong their own control programmes as a result of continued seed dispersal from there. We urge WPI to take a less conditional commitment to *P. contorta* control within Karioi Forest.

WPI still recognise *P. contorta* as a resource rather than a weed, so there is potential for conflict of interest. Removal of stands may be delayed if no market exists at that time. We suggest that an economic analysis be commissioned to compare the commercial gains in harvesting *P. contorta* for sale as hog fuel, firewood or timber against the increased costs of wilding control caused by any delays in that harvesting. Financial models similar to those used in Harris et al. (2001) may be useful. Cutting mature *P. contorta* to waste may prove to be the most economically viable option.

Although landowners need to be responsible for weeds existing on their own property, the scale of the *P. contorta* infestation within Karioi Forest and the adverse influence this infestation has on neighbouring lands suggests that support and assistance from the Regional Council and other stakeholders should be considered.

Restoration

Management on sites from which *P. contorta* is removed could include revegetation with desirable species (non-plantation) to prevent subsequent invasion by other weed species, or to make the sites less susceptible to reinvasion by *P. contorta* (*P. contorta* requires high light conditions to invade). The management plan does not but possibly could indicate sites on which particular vegetation management could occur to achieve these ends.

5. Conclusions

We conclude that the management plan includes many actions that will reduce *P. contorta* abundance and spread within Karioi Forest and neighbouring areas, and provides an excellent foundation. It establishes a 3-year rotation for detecting and removing newly established seedlings and infestations over most of Karioi Forest. This is an appropriate timeframe to ensure new recruits are removed before they seed, and to deplete the seed bank. It also prioritises removal first of mature stands that pose the greatest risk of producing seed that may disperse long distances, i.e. those at highest elevation, on the windiest sites, closest to boundaries, and 'green" *P. contorta* over 'yellow' *P. contorta*. The management plan recognises the importance of wetlands by prioritising removal of *P. contorta* from those areas early, and also recognises the importance of establishing a monitoring programme to measure the progress of the control activities.

The management plan, however, could be improved in a number of areas. It was difficult to identify the specific goals of the plan as they were dispersed throughout, and these should be clearly stated at the start. There were also no specific time-related milestones for the plan, particularly in terms of which infestations would be removed and when. Although most of the forest would be surveyed for removal of new recruits on a 3-year cycle, a central portion of the forest would not be completely part of this surveillance for at least 6 years. This provides an unnecessary opportunity for new infestations to establish. The surveillance should also be strategic in first searching locations where *P. contorta* are most likely to be found, e.g., sites of previous infestations, sites downwind of remaining infestations, and open habitat most suitable for *P. contorta* seedling establishment. In the prioritisation of which infestations to target first for removal, the removal of outlying populations and sites close to the eastern boundary should also be included as factors along with those already identified.

The measures suggested to contain *P. contorta* seed dispersal from the central large *P. radiata/P. contorta* stands are a novel approach and we do not have any data on which to assess their possible effectiveness. The management plan could include the establishment of monitoring to provide these data by measuring seed dispersal from forest edges at which *P. contorta* has been removed to different depths, and following the effects of competition between *P. radiata* and *P. contorta* on growth using repeated measure permanent plots.

Although establishment of a monitoring programme is suggested, no details are given of how this might proceed. Monitoring could be incorporated as part of the surveillance and control activity on a 3-year cycle. During this operation, sites where new individuals are discovered would be located using GPS and the number of seedlings or trees counted. Progress could then be reported in terms of numbers of individuals encountered per man hour search effort per unit area.

There are two further aspects of control of *P. contorta* that are not covered by the management plan. First, any risks of reinfestation from neighbouring properties are not identified. Are there any *P. contorta* stands on adjacent land that could seed into Karioi Forest and could these be controlled? Second, once infestations are removed, are there any sites where appropriate revegetation could occur that would reduce the ongoing risk of these sites being reinfested by *P. contorta* or other weeds?

Finally, although the amount of control effort that can be expended per year is obviously subject to available resources, we emphasise that significant benefits and savings would accrue to WPI Forestry, neighbouring landowners, and Horizons Regional Council in carrying out control measures for *P. contorta* as early as possible. An economic study comparing relative costs of different control scenarios could quantify these benefits.

6. Recommendations

We recommend that WPI Forestry revise the proposed management plan to specifically consider strategies for detection, containment, extirpation, commitment, and restoration. Specific recommendations are:

- Provide a clear statement of goals and establishment of specific milestones within the management plan.
- Include the entire forest within the 3-year detection and control programme for newly established seedlings immediately, and design this programme to concentrate strategically on high-risk sites, and to monitor progress.
- Prioritise stands at high altitude, on windy sites, near the eastern boundary, outlying stands, and 'green' *P. contorta* first for removal.
- Carry out the planned removal of *P. contorta* around the edge of the central *P. radiata/P. contorta* stands but increase the depth of the buffer on the eastern boundaries of these stands, and establish a monitoring study so that its effectiveness can be assessed.
- Identify any stands of *P. contorta* on neighbouring land that may pose a risk of reinfestation of Karioi Forest and negotiate their removal.
- Consider use of herbicide to control stands of *P. contorta* in compartment 20.

- Carry out an economic study comparing relative costs of different control scenarios including cutting *P. contorta* to waste.
- Stakeholders should explore whether cooperative actions are possible to address this problem.
- Identify sites where appropriate revegetation could occur following *P. contorta* removal.

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Appendix 1 Photographs of *Pinus contorta* within Karioi Forest

Figure 2. Planted stand of 'yellow' *P. contorta* in Karioi Forest

Figure 3. *P. contorta* within wetland areas in Karioi Forest

Figure 4. Pure stand of 'green' *P. contorta* in compartment 20

Figure 5. Interior of *P. nigra/P. contorta* stand

Figure 6. *P. radiata/P. contorta* stand at high altitude

Figure 7. Wilding *P. contorta* on roadside in Karioi Forest