Changes in Extent of Bay of Plenty Frost Flats: 2003-2017

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Nicholas Singers
Ecological Solutions
Innovation in conservation

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Author(s): Alana Delich for Nicholas Singers Ecological Solutions Ltd
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Note: This report is an updated version of the original May 2019 report. The figures within the report have been updated to include the 66.9 ha Kokomoka frost flat, which was mistakenly left out of the initial dataset. This frost flat has been classified as a successional monoao frost flat ecosystem (VS8). It was left out of the initial dataset as it was classified as Matai, Hall's totara, kamahi forest (CLF5) in the BOP Potential Ecosystems layer.

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Executive Summary

This report presents the results of a GIS analysis of changes in extent of Bay of Plenty frost flats from 2003 to 2016/17. The analysis examined both changes in predominant landcover of the frost flat polygons, and changes in wilding pine cover within frost flat polygons.

An existing BOP Frost Flat Layer created in 2012 was used as the starting point, and amended to ensure accuracy. This initial layer was then divided into polygons of contiguous wilding pine cover, based on the modified Braun-Blanquet scale, using 2003 aerial imagery. Each polygon was also assigned an overall land cover, whether indigenous frost flat community, wilding pine forest, or a developed landcover. When the 2003 layer was complete, a copy was made, and the polygons were again amended for wilding pine cover based on the 2016/17 aerial imagery, and the overall land cover reviewed. The final datasets were also analysed for land tenure.

The resulting dataset revealed that there has been an overall decline in indigenous frost flat communities from 2003 to 2016/17 of 12.9%. On private land, this decline has been even more pronounced at 25.4%. Frost flat communities were also more highly invaded with the lower cover scores showing a decline in extent of this timeframe, and the higher cover scores showing an increase. The extent of frost flats with <1% cover of wilding pines declined by 8.3%.

The differences in invasion of wilding pines between public and privately owned frost flats is likely to be partly driven by the past fragmentation of the privately owned frost flat areas, which are long and thin and are not buffered by other indigenous ecosystems such as native forest.

The observations made while compiling this report suggest that (without a significant investment) there is little chance of maintaining control of wilding pines in frost flat areas if wilding pine cover is allowed to exceed 5%. Priority should be given to maintaining low density of wilding pines in all areas where this is currently the case.

The following recommendations were made:

- Identify high priority frost flat areas where there is currently low cover of wilding pines (<1% cover).
- Work with the Department of Conservation and private land managers to ensure that a wilding pine control schedule is in place in these high priority areas, so that they are treated every 4 years, and are maintained at <1% wilding cover in the long term.
- Undertake site visits to some of the historically cleared areas, and consider long-term ecological restoration aspirations for these areas, and other frost flat areas that have already become heavily invaded by wildings (>25%).
- Develop a preferred strategy to deal with the current areas of wilding pine forest (467 ha).

In conclusion - Bay of Plenty frost flats are being incrementally lost to wilding pine invasion and development into forestry (usually following irreversible wilding pine invasion). In the 13 years from 2003 to 2016 there was a 12.7% decrease in frost flat area. The extent of frost flats with <1% cover of wilding pines declined by 8.3%. On private land the extent of frost flats decreased by 25.4%.

The results of this report suggest that there is little chance of maintaining control of wilding pines in frost flat areas if wilding pine cover is allowed to exceed 5%. Maintaining those areas which currently have <1% cover of wilding pines is the highest priority.

1. Introduction

1.1. History of Frost flats in the Central North Island

Frost flats are low-lying flat areas at relatively high elevations (400-800 m a.s.l.), where cold air ponds due to the local topography. In these areas frosts can occur in all months of the year, so are commonly referred to as frost flats. Frost flats in the Central North Island have been given the name "Old Tephra Plains", as they were formed after the Taupo eruptions, by water-sorted pumice eroded from the surrounding hillslopes and ranges into basins and valleys.

The deep rhyolite pumice comprising old tephra plains is naturally infertile, so while intense frost (probably at temperatures of in excess of –9°C) is likely to be the primary environmental driver that excludes tall trees, such as silver beech, red beech and matai, which commonly occur on surrounding hillslopes, from the low-lying topography, additional physical stress factors are also important. These potentially include soil nutrient impoverishment, summer drought on free-draining stony or pumice substrates and high-water tables (Singers and Rogers 2014). Old tephra plains are a naturally uncommon ecosystem (Williams et al. 2007), as they have always been of limited geographical extent, and are classified as a critically endangered ecosystem (Holdaway et al. 2012). Plant composition within old tephra plains of the Central Plateau is distinct from 'frost flats' on the frosty, often strongly leached alluvial terraces and plains in the South Island (Wiser et al. 2013).

Intact frost flat sites surrounded by native forest have a distinct zonation of plant species with forest on the upper hillslopes, a band of taller scrub (often of manuka and or kanuka) which grades to the basin floor scrub or shrubland. In many sites there is a mosaic of vegetation types, with monoao vegetation in the cold infertile pumice terraces, wetland and grey scrub ecosystems on alluvial terraces, and grey scrub or short forest communities on only slightly elevated, better-drained soils (Singers and Rogers 2014).
At most frost flat areas of the Central North Island the vegetation is dominated by a low shrubland (<2 m) to scrub (4+ m) of monoao (*Dracophyllum subulatum*). Open shrubland areas typically have a ground cover of coral lichen (*Cladia retipora*), and reindeer lichen (*Cladonia confusa), mountain oat grass (Deyeuxia avenoides*), silver tussock (*Poa cita*), hard tussock (*Festuca novae-zelandiae*), woolly moss (*Racomitrium lanuginosum*), and dainty bristle grass (*Rytidosperma gracile)* (Smale 1990). Introduced cats ear (*Hypochaeris radicata*) and mouse-eared hawkweed (*Pilosella officinarum*) are often common especially where rabbits occur. Other cold tolerant shrubs may also be present in association with monoao including; twiggy tree daisy (*Olearia vigata*) and mingimingi (*Coprosma propinqua*). Manuka (*Leptospermum scoparium*) and kanuka (*Kunzea serotina*) may also occur in frost flat habitats, though more typically in the band on sloping land on hillsides. Locally bog pine (*Halocarpus bidwillii*) and mountain toatoa (*Phyllocladus alpinus*) are present, but primarily in sites long protected from fire. These were likely common components of this ecosystem and at the most intact sites, such as the upper Waipakihi Valley in the Kaimanawa Range and Whenuakura Clearing in the Hauhangaroa Range (Figure 1), both occur as an emergent tier above monoao, and in some locations form a distinct low forest community.

Grey scrub vegetation often occurs in association with monoao along more fertile alluvial stream margins, side slopes of higher terraces and the ecotonal margins adjoining native forest. Grey scrub can also occur on poorly drained soils as many species also grow in wetlands. Grey scrub is named for its greyish appearance and consists of a variety of cold tolerant small-leaved, highly branched shrubs such as mingimingi, twiggy

tree daisy, korokio (*Corokia cotoneaster*), mountain wineberry (*Aristotelia fruticosa*) and *Veronica parviflora*. Climbing vines can also be common scrambling over and through the shrubs. Rare plant species are often found in grey scrub communities, such as the nationally vulnerable *Pittosporum turneri* and *Pimelea tomentosa,* and the declining shrubs *Coprosma wallii* and leafless mahoe (*Melicytus flexuosus*) (de Lange et al. 2018).

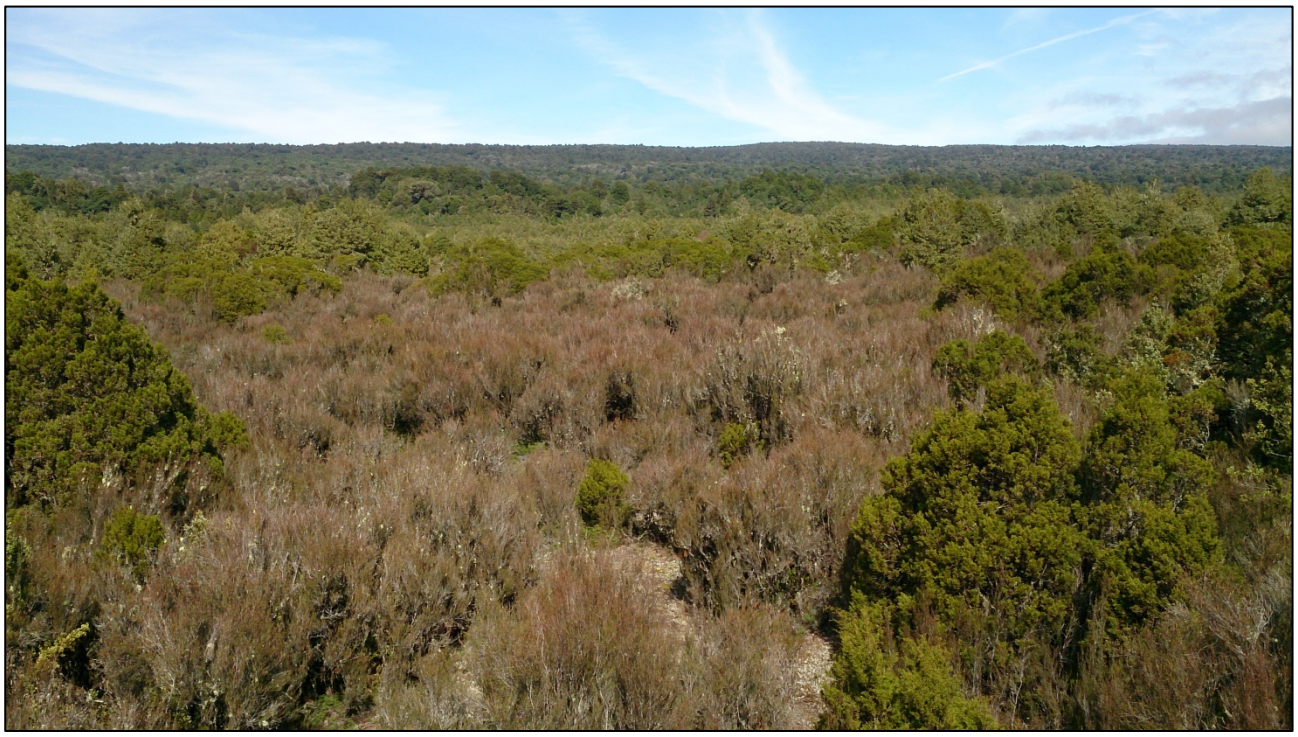

Figure 1: *Whenuakura Clearing, Pureora Forest Park. Monoao frost flat with scattered bog pine and alpine celery pine. One of the most representative examples of intact Central North Island frost flat vegetation remaining.*

Monoao is highly flammable, as the colloquial name for monoao "turpentine bush" implies. It also quickly recolonises from seed after fire and is adapted to harsh growing conditions with its leathery, needle-like leaves, that have a specialised layer of cells with thickened walls, called sclerophyll, which prevent moisture loss in windy, dehydrating environments. Fire has had a significant impact on the distribution, composition and structure of monoao and composition of frost flats in the Central North Island (Rogers & Leathwick 1994). When Europeans first explored the Central North Island (Bidwill 1841) monoao scrub, fern and tussock occurred across the Kaingaroa Plateau, around Lake Taupo and south to Waiouru. Evidence suggests that much of this was induced by anthropogenic fires which caused a decline of forest and the spread of these early succession communities. Much of this vegetation remained similar, up until the establishment of plantation forestry or post WWII agriculture and the application of fertilisers with cobalt. Consequently, some areas of monoao vegetation may be successional.

In true temperature inversion frost flat ecosystems, the stands of monoao tend to be an even aged cohort that recolonised after the last fire, as new seedlings are very rarely recruited due to the thick cover of lichen and moss on the soil surface. Without fire, over time the monoao will eventually senesce, and other cold tolerant species such as bog pine and mountain toatoa will become increasingly dominant. Potentially

heavy snow damage may also result in periodic regeneration cycles of monoao. In many fire induced stands of monoao, the appearance cold tolerant shrubs and trees such as manuka, lancewood and Colenso's kohuhu, and later matai seedlings, indicate that the site may not have ongoing physical conditions to be a permanent frost flat. Over time, this successional monoao vegetation will likely be replaced by shrubland, and ultimately forest (Smale et al. 2011).

1.2 Bay of Plenty Frostflat areas

The frost flats in the Bay of Plenty are in four main areas, shown in the overview map (Figure 2). Rangitāiki Conservation Area is the largest frost flat area (2652 ha) and is public conservation land under Department of Conservation management. There are an additional 313 ha of frost flat on the Karaitiana Blocks on the eastern side of Rangitaiki Conservation Area, making the entire extent of the Rangitaiki frost flat area 2,965 ha. This area is bounded by indigenous vegetation on the eastern side, the Rangitaiki River forms the western boundary, and State Highway 5 form runs along the northern edge.

Tahau and Waione frost flats are located within Public Conservation land of the Whirinaki Te Pua-a-Tane Conservation Park. The combined area of frost flat vegetation is 75 ha. There are an additional 229 ha of manuka surrounding the Tahau frost flat which is an integral part of the vegetation sequence at this site, but this manuka scrub has not been included in the analysis in this report. These frost flats have a largely intact boundary of indigenous vegetation, though there are some regenerating forestry blocks nearby that were within the boundary of the Conservation Park.

The Otangimoana frost flats are located on Alluvial terraces along the Otangimoana Stream and the Otamatea River. Much of this area is public conservation land within Otangimoana Conservation area, and the Otamatea River Marginal Strip. This area is surrounded by pasture on the southern and eastern sides, and forestry to the west and north.

Rangitaiki River scrub frost flats are located on alluvial terraces along the Rangitaiki River downstream of State Highway 5. These frost flats are entirely surrounded by forestry. The uppermost section is public conservation land (Rangitaiki River Conservation Area – 195 ha), but the vast majority of this area is under private management.

Kokomoka frost flat is within public conservation land, in the Kokomoka Forest stewardship area and has 66.9 ha of frost flat vegetation. This frost flat has been classified as a successional monoao frost flat ecosystem (VS8), as it is classified as Matai, Hall's totara, kamahi forest (CLF5) in the BOP Potential Ecosystems layer.

1.3 Wilding Pines

The most invasive wilding pine species is Pinus contorta. P. contorta is a cold tolerant species, so is not prevented from growing in frost flat vegetation. It produces prolific windblown seed, and can produce seed at only 4-5 years old, which means that populations can increase very quickly. The seed can remain viable in the soil for 4 years, meaning that once a tree is removed the site needs to be checked after four years for seedlings.

The other wilding pine species of concern for frost flat vegetation is Douglas fir (Pseudotsuga menziesii). Douglas fir is tolerant to shade, and is not as frost tolerant as P. contorta, so it tends to establish within denser vegetation where it is protected from frost. It is of most concern in grey scrub frost flat communities.

Both of these wilding pine species were used as shelterbelts in the past, and some of the wilding pine invasion centres spread out from these shelterbelts.

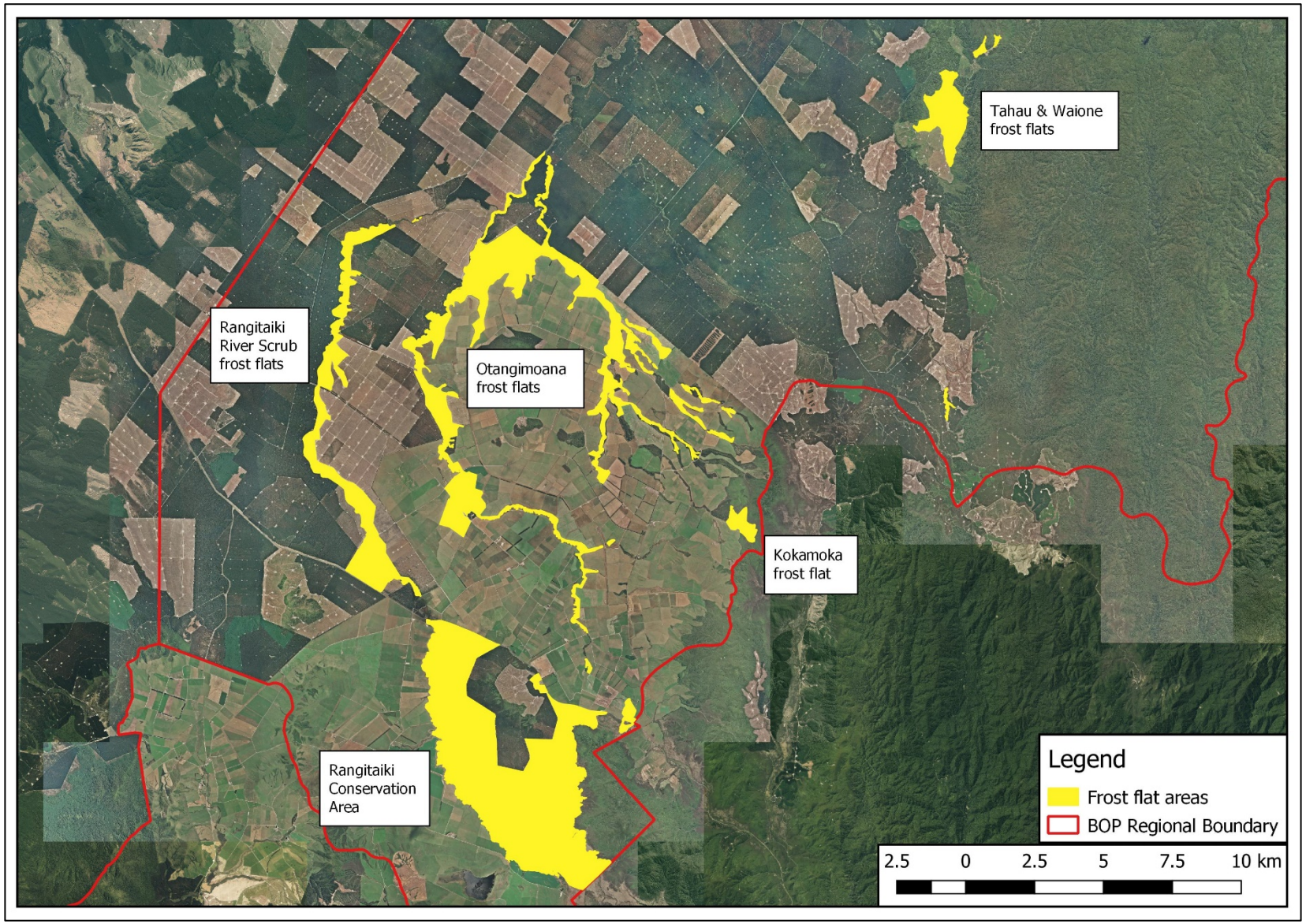

Figure 2: Overview of frost flat areas in the Bay of Plenty Region

2. Methodology

2.1 GIS

An existing BOP Frost Flat Layer created in 2012 was used as the starting point. The landcover of this layer was amended using 2003 imagery, the BOP Potential Ecosystem Layer and existing knowledge to identify areas that were not actually frost flats, for example areas of wetland and indigenous forest. These methods were also used to identify sites which had not been included in the 2012 polygons but should have been.

Vegetation that was excluded from this initial data set included:

- Areas that of developed forestry or pasture that were already present in the 2003 photos.
- Areas of wetland vegetation.
- Areas of low-stature native vegetation that were not identified as a temperature inversion ecosystem on the Singers and Rogers potential ecosystem layer (TI3 and TI4). These were low stature regenerating native forest, of manuka shrubland.
- Areas that were outside the BOP region boundary.
- Narrow areas of riparian vegetation that did map as TI3 or TI4 on the potential ecosystem layer, but on inspection of aerial image were modified grassy river flats which did not include monoao in a significant component of the vegetation (these were the most down-stream portions of the Otangimoana and Rangitaiki River polygons).

This amended layer was used as the starting point for the BOP Wilding Pine Cover 2003 Layer. The polygons in the 2003 layer were divided up into areas of contiguous wilding cover, based on the 2003 aerial imagery. Each of the resulting polygons were assigned a landcover, based on the predominant landcover within the polygon.

On completion of the 2003 layer, a second copy was saved as BOP Wilding Cover 2016/17 Layer. The 2003 wilding pine cover polygons were then edited using the 2016/17 aerial photography layer. Areas of contiguous wilding density were again mapped using the modified Braun-Blanquet scale, and landcover changed if required. (e.g. and area with the landcover of Wilding Pine Forest in 2003 may have changed into Developed – Forestry in 2016/17).

While this mapping was being carried out, a 2011 aerial photography layer was used as an intermediate in order to determine what had happened in the intervening years (e.g. evidence of wilding control, land cleared for forestry, to confirm that changing vegetation was wilding pines rather than another species).

2.2 Analysis

2.2.1 Canopy Cover

The modified Braun-Blanquet scale was used to assign canopy cover of wilding pines within each polygon. This scale uses the cover categories of <1%, 1-5%, 6-25%, 26-50%, 51-75%, >75%. (Figure 2.). The Braun-Blanquet scale is widely used in ecological research and monitoring, and was chosen for this reason, as this increases the likelihood that this dataset will be comparable with other existing datasets.

The cover class "NA" was included in the 2016/17 dataset. This cover class was selected when scoring the cover of wilding pines was not applicable. These were areas that had been developed into forestry and pasture and very recently cleared areas where no wilding pine regeneration was evident, as we felt that the <1% cover score should be reserved for intact frost flat areas, and areas of recently controlled dense wilding pines did not meet this criteria. Cleared areas that were showing regeneration of wilding pines were scored for cover.

Following completion of the GIS datasets the changes in canopy cover of wilding pines, and overall landcover were analysed using pivot tables in Microsoft Excel.

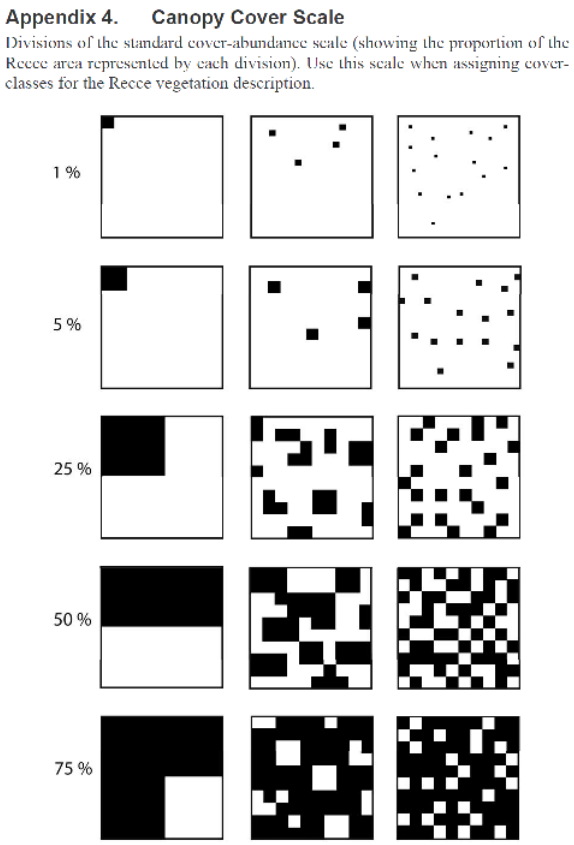

Figure 3: Standard cover-abundance scale used to score cover of wilding pines (modified Braun-Blanquet cover-abundance scale; from Hurst and Allan 2007).

2.2.2 Landcover

The following landcover classes were assigned to each polygon:

TI3 – Frost flat: As defined in Singers and Rogers (2014) – scrub of abundant monoao and lichens, and occasional silver tussock and *Pimelea prostrata*. Also known as old tephra plains.

TI4 – Grey scrub: As defined in Singers and Rogers (2014) – *Coprosma*, *Olearia* scrub – with species including *Carmichaelia*, *Coprosma*, *Olearia*, *Hebe*, *Corokia cotoneaster*. In this report this was limited to alluvial terraces. This is often found in small pockets within larger TI3 areas. This landcover was only assigned where this was the predominant vegetation within a polygon, which was uncommon. Therefore the overall sum presented within this report is not an accurate representation of this landcover within frost flats within the Bay of Plenty.

VS8 – Successional frost flat: As defined in Singers and Rogers (2014) – Monoao scrub often including manuka, kanuka, and commonly within the Central North Island - *Veronica stricta*, *Pittosporum colensoi*, and cabbage trees. This is successional monoao, that has likely been induced by fire in areas that are not true temperature inversion sites. These areas are expected to succeed into forested systems. This landcover was assigned where there was evidence of a decline in dominance of monoao since 2003 within a polygon; and was only assigned where this was the predominant vegetation type. It is likely that with field inspection this landcover would have been more often assigned, as diagnostic regeneration of kanuka and manuka within monoao dominated systems is much more accurate in the field. Therefore as for TI4 – this landcover in not an accurate representation of this landcover within frost flats in the Bay of Plenty.

Developed-Forestry: Areas of indigenous frost flat vegetation that have been developed into forestry since 2003.

Developed – Pasture: Areas of indigenous frost flat vegetation that have been developed into pasture since 2003.

"Cleared" Areas: An extra vegetation class "cleared" is for areas of wilding pine invasion that have been mechanically cleared, or blanket sprayed. Often these areas were greater than 50% wilding pines, and upon being felled the ground surface was covered in wilding pine slash. Following this treatment there is not yet any sign of frost flat vegetation recovery in aerial photographs. This treatment has been ascertained by viewing the intermediate 2011 aerial photography.

2.2.3 Land Tenure

Following the completion of the 2003 and 2016/17 datasets, land tenure was analysed. This was carried out on copies of the final 2003 and 2016/17 datasets. Land tenure was separated into land under Department of Conservation management, private land, and private land under QEII covenants.

Given the nature of the data the resulting dataset has many small shapefiles (known as slivers), where the frost flat vegetation narrowly extends from public to private land along vegetation boundaries etc. Slivers can be a problem for displaying data, however they do not impact on the land tenure analysis, and in this case result in a more accurate dataset.

Following the creation of the 2003 and 2016/17 land tenure analysis layers, a total of four layers were created for this project.

2.3 Limitations

Invasion by weeds other than wilding pines has not been assessed in this report. Many of the aerial photographs used were not taken in the spring – which does not allow us to identify areas that have been invaded by broom and gorse. When these species are not in flower they cannot be distinguished from native shrubland species such as mingimingi and koromiko on aerial photographs. Likewise the aerial imagery does not allow sufficient detail to determine if frost flat areas have been invaded by other weeds such as heaths and herbs such as mouse-eared hawkweed.

The extent of TI4 - Grey scrub communities have not been accurately assessed in this report. These communities are usually small pockets within larger frost flat areas, particularly along riparian margins. These areas were generally not picked out from larger frost flat polygons, and areas classed as grey scrub were those where grey scrub was the predominant landcover within the polygon. Therefore the overall area in hectares of "TI4 - grey scrub" within this dataset is a considerable underestimate of the actual extent of this vegetation type within the BOP.

The minimum size of wilding pines that are evident on these aerial photographs are already likely to be 2 m tall. Therefore areas classed as having <1% wilding cover will not necessarily be free from wilding seedlings. This is part of the reason that wildings seem to spread so quickly when looking at the aerial photographs in sequence, there are already numerous wildling seedlings present, which have then grown large enough to be seen on aerial photographs by the subsequent set of aerial imagery.

3. Results

3.1 Changes in Landcover

Following rationalisation of the 2012 frost flat polygons, using 2003 aerial imagery, there was a total of 5539 ha of frost flat. This was the starting point for examining changes in extent. Of this starting point 261 ha were already classed as 'Wilding Pine Forest' but this area was not excluded from the initial analysis, as much of this was contiguous with less invaded frost flat areas, often on the edges or sometimes forming small pockets within the larger areas, and the subsequent treatment of these areas over the subsequent thirteen to fourteen years provides valuable information. The initial areas under each landcover class in 2003, 2016/17, and the overall change is listed in Table 1, and displayed in Figure 4.

Of the 5539 ha – initially there was 5191 ha of frost flats (including TI3, TI4 and VS8 ecosystems). In 2016/2017 this has decreased to 4529 ha. Overall from 2003 to 2016/17 there was a 12.7% reduction in the area of frost flats in the BOP region. The main losses of frost flat vegetation were due to development into Forestry (309 ha) and invasion by wilding pines forming closed canopy wilding pine forest.

The extent of TI4 and VS8 frost flat communities actually showed a slight increase over this time period, this is partly due to the successional nature of frost flat communities (particularly for the VS8 communities), and also party due the scale at which the areas were examined. As these areas became more highly invaded by wilding pines, and more dissected, some of the smaller polygons were predominantly TI4 – grey scrub vegetation in 2016/17, when this had been only a small proportion of a larger TI3 – frost flat polygon in 2003.

Table 1: Changes in landcover extent of BOP Frost flats from 2003 - 2016/17

Landcover	**Sum of Area (ha) 2003**	**Sum of Area (ha) 2016/17**	**Change** (negative value indicates a decline in extent)
TI3 - Frost flat	5038.6	4325.9	-712.7
TI4 - Grey scrub	67.9	113.5	+45.6
VS8 - Successional frost flat	84.3	89.6	+5.3
Cleared	87.3	216.4	+129.1
Developed- Forestry	0.0	308.9	+308.9
Developed- Pasture	0.0	17.3	+17.3
Wilding Pine Forest	261.2	467.6	+206.4
Grand Total	**5539.1**	**5539.1**	

Of the 309 ha of frost flat that were developed into forestry, between 2003 and 2016/17, 106 ha were already wilding pine forest in 2003. The remaining 203 ha showed varying invasion of wilding pines initially (Figure 5). No frost flat areas with <1% cover of wilding pines were developed. Of concern are the 72.5 ha of frost flats developed for forestry that only had 1-5% cover of wilding pines in 2003. These were almost exclusively small fingers of vegetation within the Otangimoana frost flats.

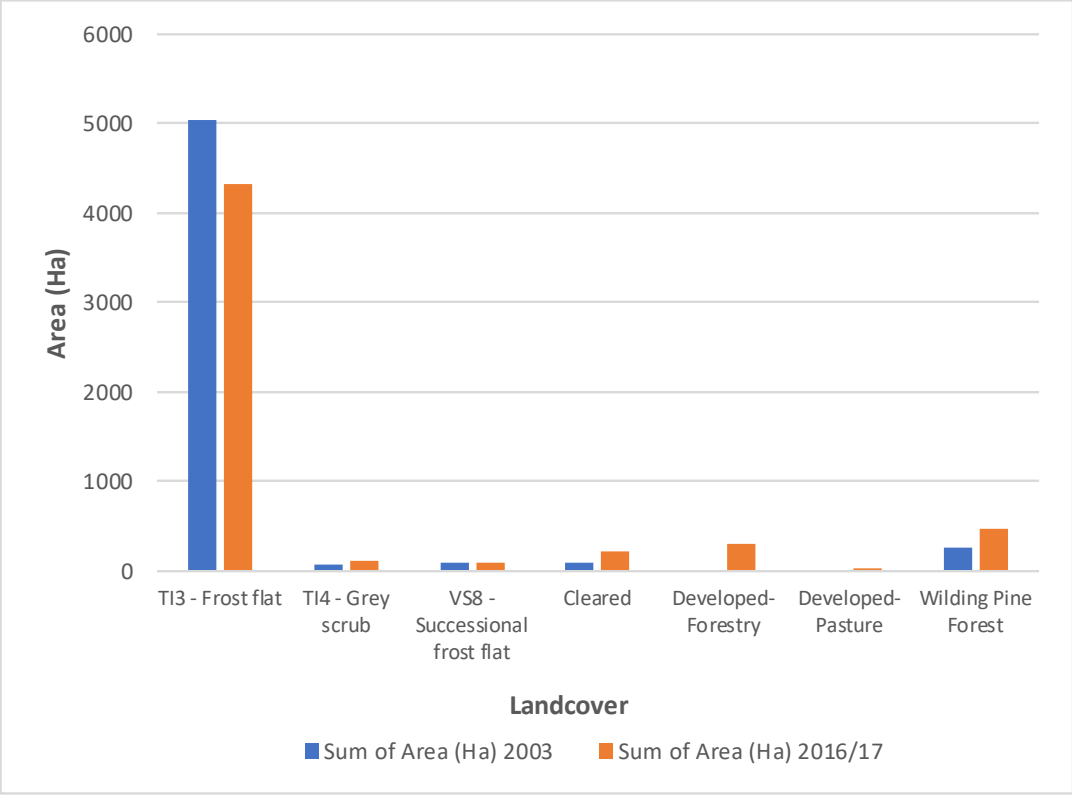

Figure 4: Changes in landcover extent of BOP Frost flats from 2003 - 2016/17

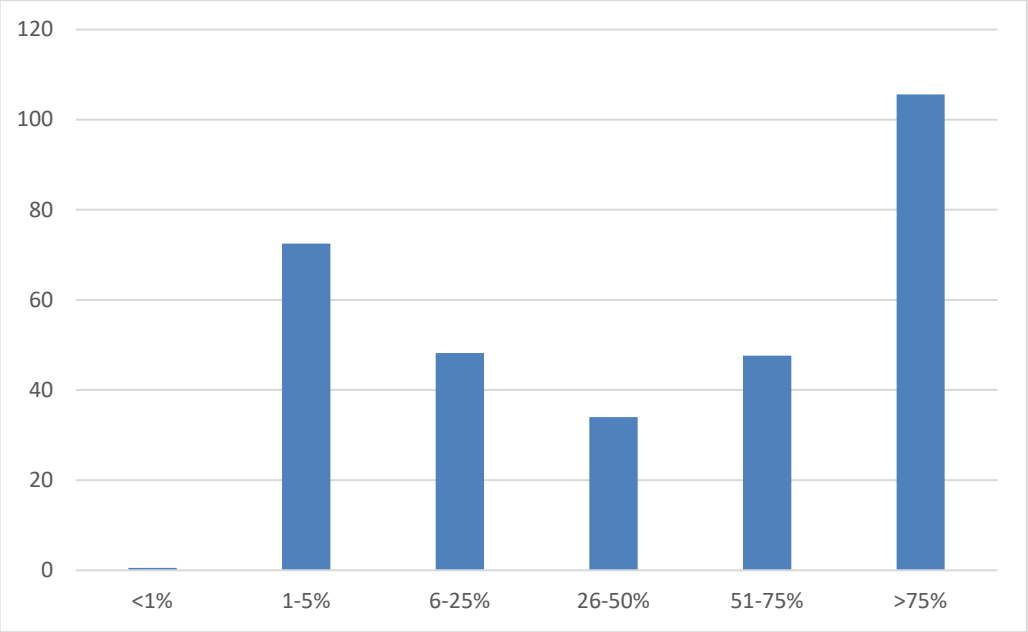

Figure 5: Original cover (2003) of wilding pines of the 308 ha of frost flats that were developed into forestry from 2003 - 2016/17

3.2 Changes in Wilding Pine Cover

Figure 6 shows that the total extent of the three lowest wilding pine cover classes has declined, and the total extent of the three highest cover classes have increased or remained very similar. This demonstrates a trend of increasing wilding pine invasion of frost flats in the Bay of Plenty from 2003 to 2016/17. As expected, (given that wilding pine cover defined the cover class) the area of wilding pine cover of >75% matches the extent of "wilding pine forest" (206.4 ha).

The cover class NA indicates areas where scoring cover of wilding pines is not applicable. These are the areas that have been developed into forestry and pasture (326 ha), and very recently cleared areas where no wilding pine regeneration was evident (38.7 ha), as we felt that the <1% cover score should be reserved for intact frost flat areas, and areas of recently controlled dense wilding pines did not meet this criteria. Cleared areas that were showing regeneration of wilding pines were scored for cover.

Table 2: Changes in wilding pine cover of BOP Frost flats from 2003 - 2016/17 (all landcovers listed in Table 1)

Wilding Pine Cover	**Sum of Area (ha) 2003**	**Sum of Area (ha) 2016/17**	**Change (ha)** (negative value indicates a decline in extent)
<1%	3798.7	3484.6	-314.1
1-5%	261.2	478.8	+217.6
6-25%	593.1	319.5	-273.6
26-50%	162.1	213.0	+50.9
51-75%	168.5	155.5	-13.0
>75%	468.3	467.6	-0.7
NA	87.3	420.1	+332.8
Total	**5539.2**	**5539.2**	

Table 2 reports changes in extent for all the areas, and landcovers reported in Table 1. In 2003 there were 3799 ha of indigenous frost flat ecosystems (TI3, TI4 or VS8 ecosystems) with less than 1% wildling pine cover. By 2016/17 the area of indigenous frost flat ecosystems with <1% wilding pine cover had declined to 3485 ha, a decline of 8.3%.

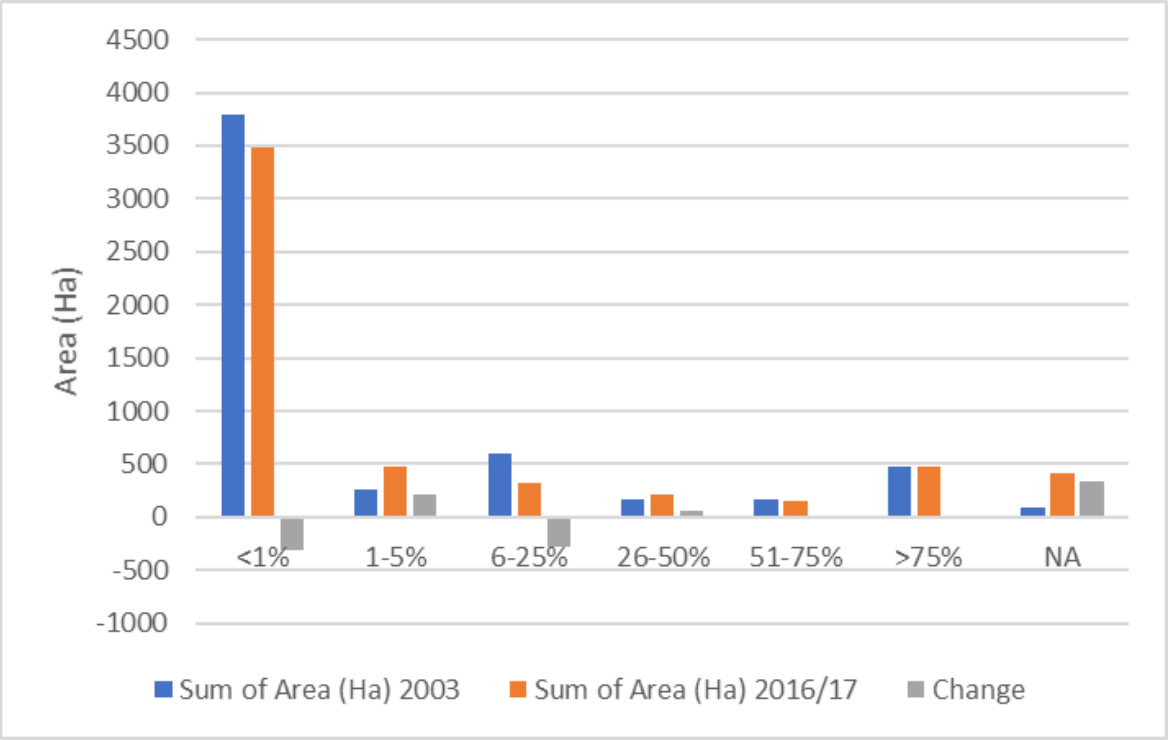

Figure 6: Changes in wilding pine cover of BOP Frost flats from 2003 - 2016/17

3.3 Analysis by Land Tenure

The changes in landcover and wilding pine cover on public conservation land and private land were also examined separately. The patterns demonstrated in the overall dataset become more pronounced when private land is examined separately. There was a 6.2% decline in indigenous frost flat landcovers (TI3, TI4 and VS8 combined) in the Department of Conservation dataset (Figure 7), and a 25.4% decline in the privately owned dataset (Figure 8).

This is likely to be partially attributable to the past fragmentation, and the size and shape of the privately owned frost flat areas, which tend to be long narrow riparian areas, with little ecological connectivity, generally surrounded by forestry or pasture. It should also be noted that the Department of Conservation managed Rangitaiki Conservation Area, at 2,652 ha makes up over half of the initial frost flat area, the very low cover of wilding pines has been maintained at Rangitaiki C.A. over the study period.

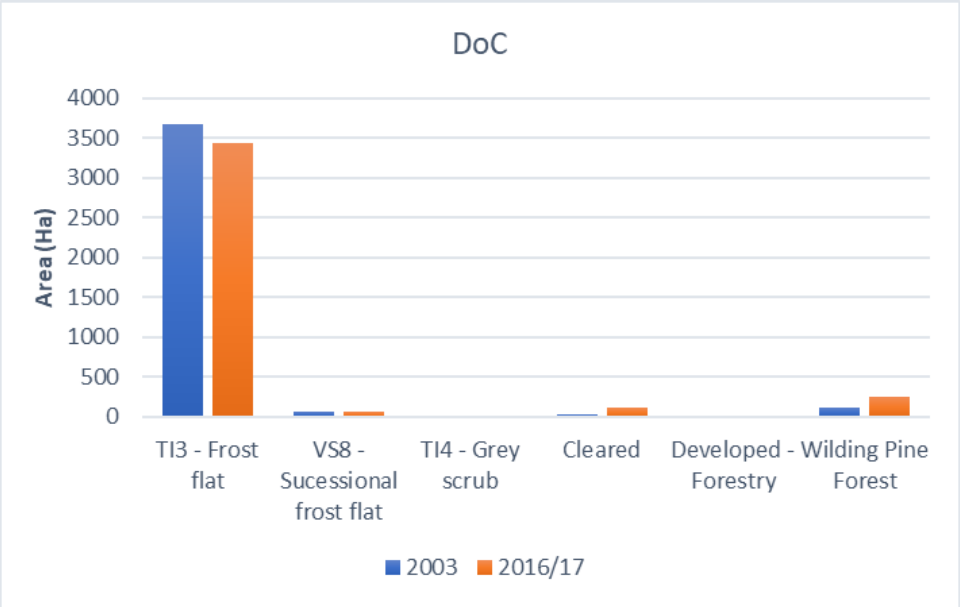

Figure 7: *Changes in landcover extent of BOP Frost flats within public conservation land from 2003 - 2016/17*

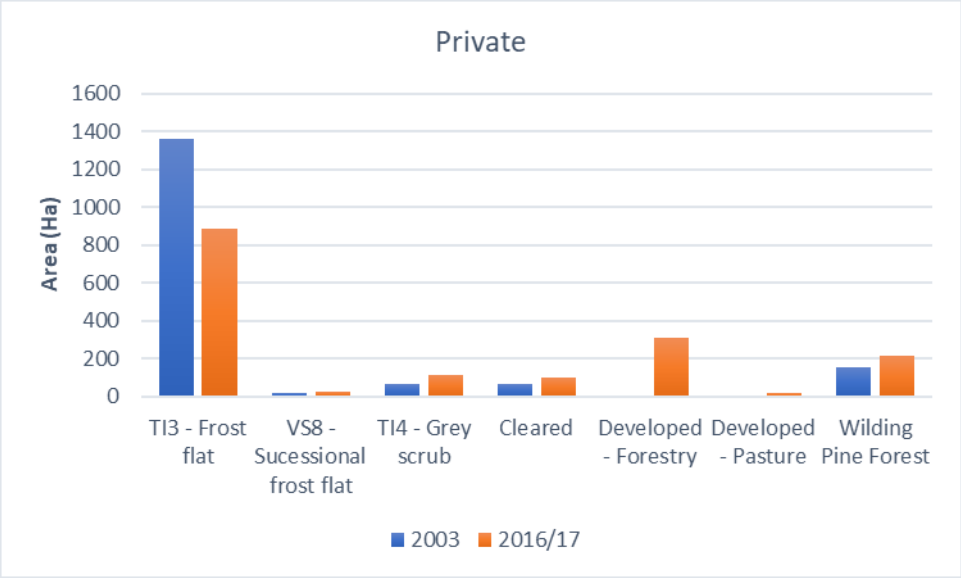

Figure 8: *Changes in landcover extent of BOP Frost flats located on private lands from 2003 - 2016/17*

Likewise the pattern displayed in the overall dataset – with a shift in cover of wilding pines with the lowest three cover classes showing a decline in overall area, and the highest three cover classes demonstrating an increase – was less pronounced in the Department of Conservation dataset (Figure 9) and more pronounced in the privately owned dataset (Figure 10).

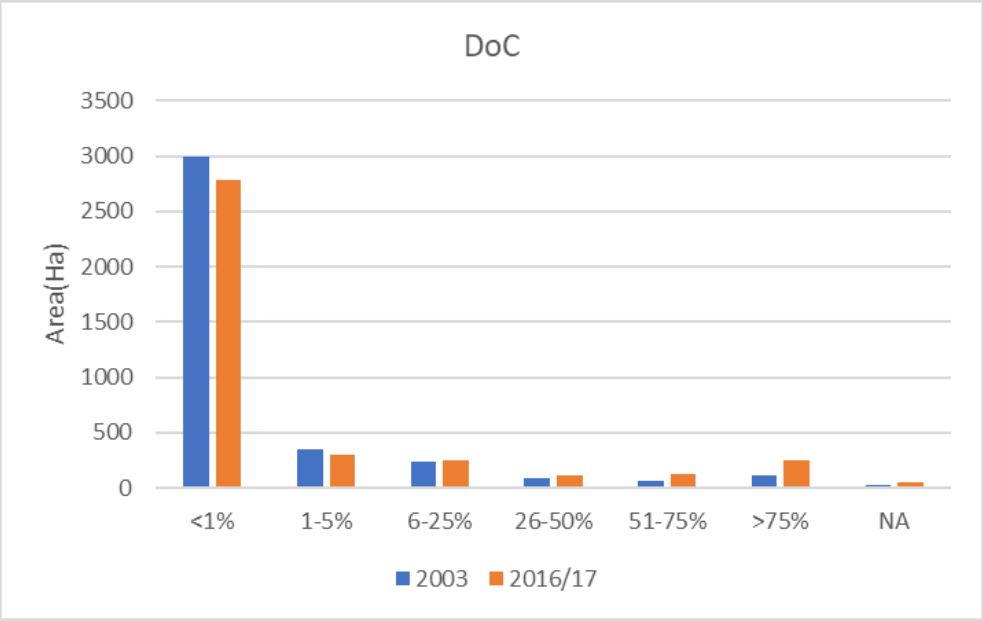

Figure 9: *Changes in wilding pine cover of BOP Frost flats within public conservation land from 2003 - 2016/17*

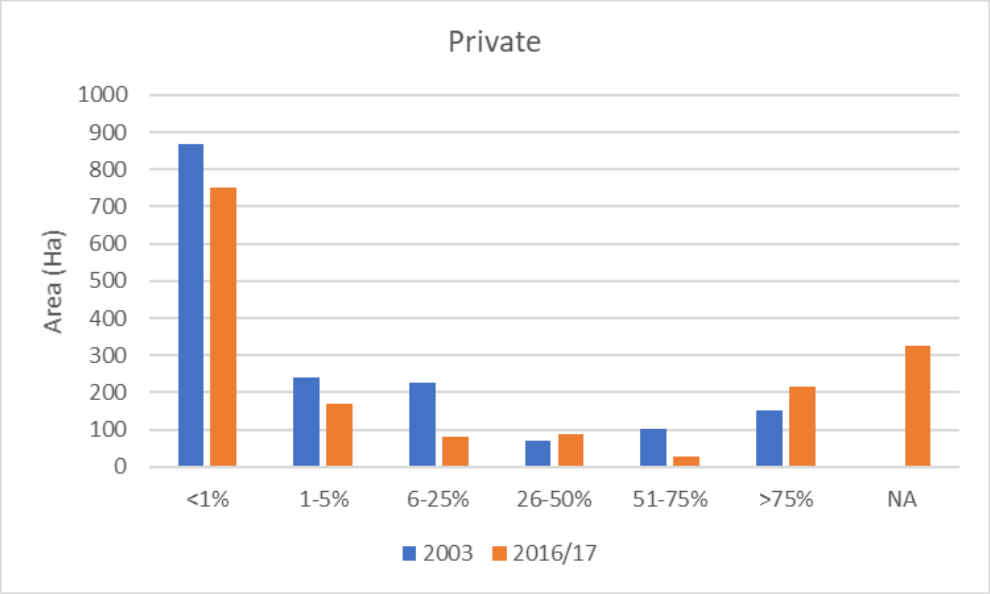

Figure 10: *Changes in wilding pine cover of BOP Frost flats located on private land from 2003 - 2016/17*

4. Discussion

4.1 Changes in Landcover

Development into forestry has primarily happened in areas that were heavily infested with wilding pines, to an extent that is likely to be irreversible. 61% of the 309 ha developed for forestry had an initial wilding pine cover of >25%, for example see progression in Figure 11 a-c. However development has also happened by small increments on various frost flat margins, and particularly in small fingers of vegetation within the Otangimoana frost flat areas, and to a lesser extent with plantation forestry areas encroaching into the frost flat "fire break" areas following harvest and replanting. Of concern are the areas within Otangimoana frost flats that had reasonable low cover of wilding pines (1-5%) that were developed.

Figure 11a. Part Otangimoana Conservation area, 2003, showing areas of wilding pine forest.

Figure 11b *Part Otangimoana Conservation area, 2011, showing that areas of wilding pine forest outside of DOC boundary have been cleared for production forestry.*

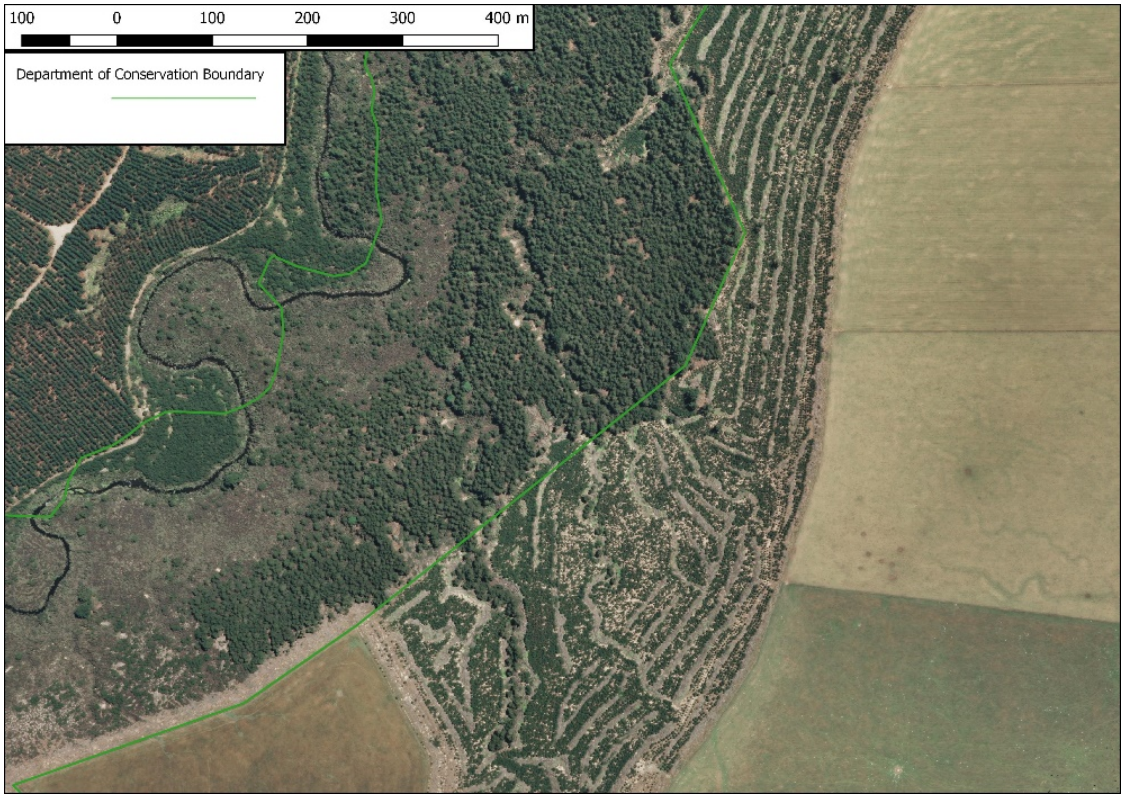

Figure 11c *Part Otangimoana Conservation area, 2016/17, showing continued spread of wilding pines within DOC boundary.*

A few small areas that have been developed to forestry were modified sites — development into pasture had been attempted into the past but abandoned and the land allowed to revert back to semi-indigenous vegetation. In these sites the plantation trees often seem to be doing poorly, which strongly suggests that these sites have climate conditions that would have supported frost flat vegetation in the past.

Development into forestry has not occurred in frost flat areas managed by the Department of Conservation, as in Figure 10 a-c, where development into forestry has occurred only outside the Department of Conservation boundary. However with 256 ha of frost flats under Department of Conservation management now at the stage of wilding pine forest, the question of what to do in these areas should be addressed.

Development into pasture between 2003 and 2016/17 occurred only in one area, adjacent to SH5 that was already a highly modified community. In 2003 Monoao occurred in here in patches, in a mosaic with exotic grasses and dense wilding pines. Following development into pasture the indigenous vegetation values have been lost from this mosaic ecosystem, but this developed area was not considered a pristine frost flat area.

Cleared areas: Examination of the aerial photos in the areas defined as "Cleared" reveals that these practices do not seem to be successful at restoring frost flats. The remaining frost flat vegetation is damaged by the clearance operation, and the extensive wilding seed banks, and the aggressive growth habits of wilding pine species mean that wildings are the main vegetation type to regenerate. For example, in figure 12 a-c within the Otangimoana Conservation Area, note the extent of wildings in 2003, which have been cleared in 2011, and in the 2017 aerial image only wildings seem to have regenerated with bare soil surrounding. There is no evidence of the characteristic reddish monoao and pale coloured lichens growing amongst these wildings.

Anecdotal observations from Rangitaiki River Conservation Area (pers. comm Nick Singers) of some areas that were formerly pine forest (from Rangitaiki River Conservation Area) and wildings were manually controlled, is that these areas typically regenerate into exotic grasslands dominated by Yorkshire fog, brown top and other pasture species, with other exotic herbaceous species such as thistles, *Conyza* sp., catsear (*Hypochaeris radicata)* and hieracium (*Pilosella officinarum*). Common native species such as monoao and silver tussock don't seem to colonise these areas. Speculatively, this may be soil related, either exacerbated by increased nutrients in the soil, due to nutrients brought to the surface from buried paleosol layer – (buried topsoil layer below the Taupo 232AD eruption pumice layer) and or unsuitable mychorrizal associations. These exotic grasses and weeds are palatable species that attract rabbits and hares, and invasion of these species may result in a cyclical loop occurring where higher rabbit populations prevent regeneration of woody native frost flat species. These cleared areas also tend to be invasion sites for heaths and woody legumes if a seed source is present. A few of the areas that were classed as cleared in 2003, showed aggressive regeneration of wildings in 2011, and have now been developed into forestry.

Figure 12a Part Otangimoana Conservation area, 2003, showing areas of wilding pine forest.

Figure 12b Part Otangimoana Conservation area, 2011, showing cleared areas of wilding pine forest.

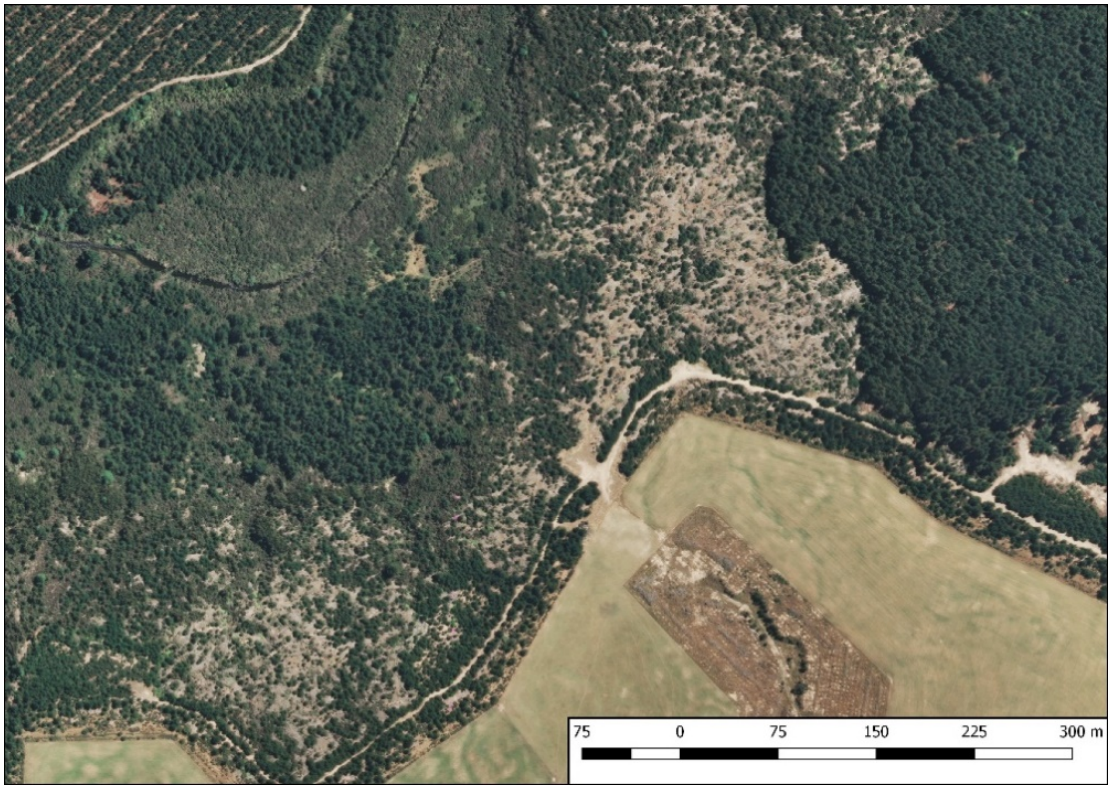

Figure 12c *Part Otangimoana Conservation area, 2016/17, showing cleared areas regeneration in wilding pines, with little regeneration of indigenous frost flat species evident.*

4.2 Further Discussion

As discussed in the introduction, areas of true monoao frost flats are usually even aged-stands, with a dense lichen and moss ground layer. Recruitment of monoao is almost non-existent due to the density of this bryophyte layer. Eventually the monoao becomes senescent, and it is only with fire, that a new cohort of monoao begins to grow. The severity of frosts, and other conditions such as low soil fertility and dry summer conditions means recruitment of forest trees such as matai usually will not occur in these areas. However *Pinus contorta* can germinate in these systems, and if not kept in check, (suggested to be <1% cover by this report) can change them irreversibly.

In the 2016/17 data set only 3,442 ha of frost flat with <1% cover of wilding pines remained. These areas have been mapped in Figure 12. Most of the Otangimoana frost flats now have a wilding pine cover of 5% or higher, and this area is most at risk to being lost to wilding pine invasion completely. Areas at either end of the Rangitaiki River scrubs have been invaded, but a long central area retains low wilding pine cover. (Figure 12). These remaining areas are of the highest priority for further ground survey and vegetation, and a wilding pine control and surveillance regime needs to be established urgently.

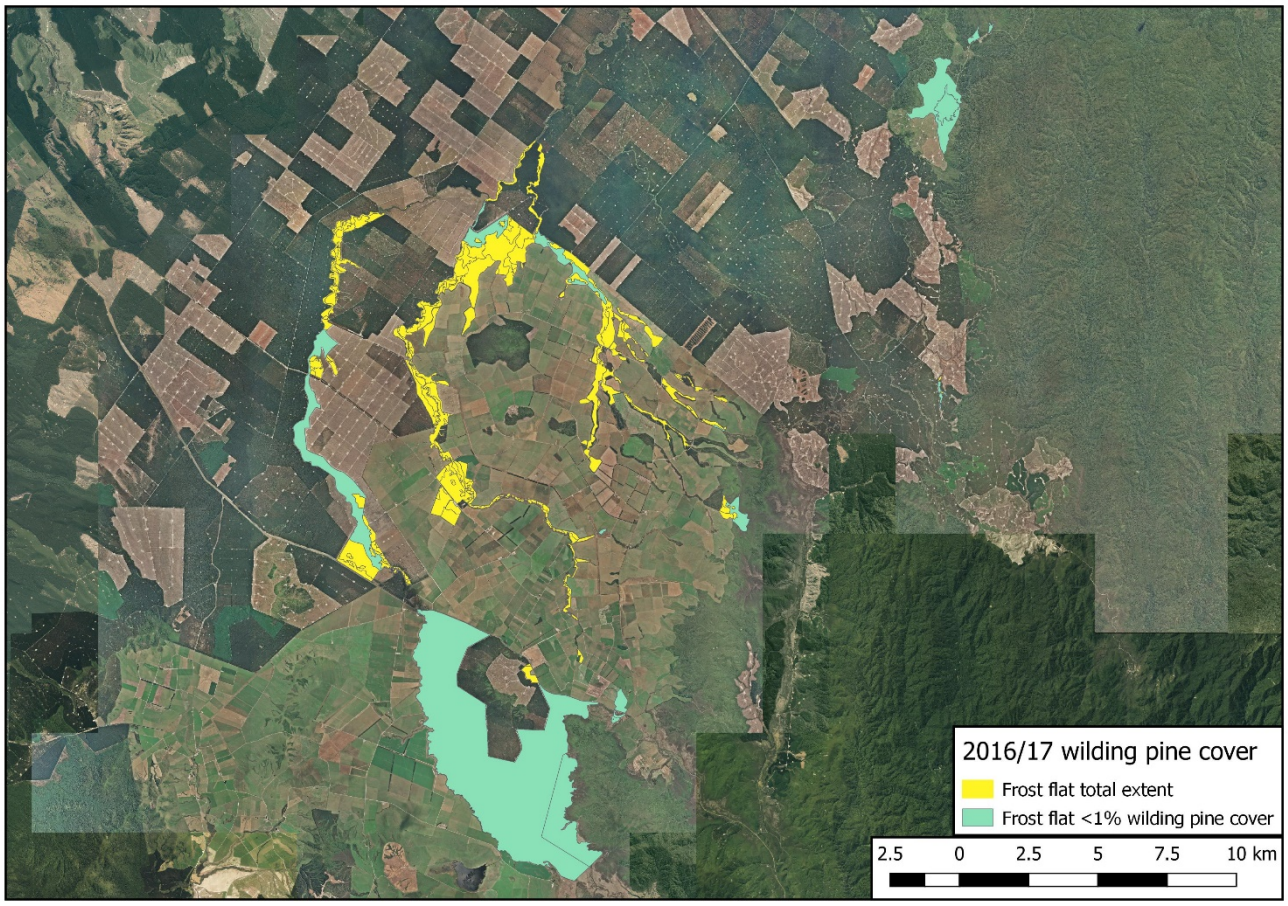

Figure 12 *Extent of Bay of Plenty frost flat areas, with areas that remain at <1% wilding pine cover in pale green.*

The more pronounced invasion of wilding pines into the Rangitaiki River scrublands, and Otangimoana frost flats is in part likely to be an artefact of the lack of ecological buffering at these sites. Only the Rangitaiki, Tahau and Waione frost flats have an intact ecological sequences from native forest, to manuka shrubland, and then frost flat vegetation on the valley floor. Rangitaiki frost flat is buffered along the eastern side, Tahau frost flat is buffered by native vegetation around 75% of its perimeter. The Rangitaiki C.A. and Tahau frost flats are of the highest priority for wilding pine surveillance and control, as they are the largest and most ecologically intact. Both are under Department of Conservation management. Both have remained at very low density of wilding pines (<1%) though a few scattered wildings are visible on aerial photos at both sites. Use of aerial imagery would be a very effective means of finding centres of wilding invasion at these very low density sites, as seedlings are likely to be common around wildings large enough to see on aerial photos.

The remainder of frost flat areas – the Rangitaiki River scrubland, and the Otangimoana stewardship areas have had this natural edge removed, and are now completely surrounded by forestry or pasture. This lack of buffering makes them much more vulnerable to invasion by wilding pines, and of other edge effects – such as impact by hares and rabbits grazing at the pasture edge, or increased fertility due to fertiliser drift or agricultural runoff. These sites have limited seed sources for natural succession, although riparian connectivity for downstream seed dispersal of riparian grey scrub species is largely maintained along the Rangitaiki River.

A pasture edge may further hinder maintenance of a natural frost flat system due to increased fertility due to runoff or overspray from pasture – leading to a change in the low fertility conditions that favour indigenous frost flat species. This is likely to lead to increased invasion of exotic species, which may be exacerbated by rabbits and hares which feed on the pasture but shelter in the frost flat areas, and transport seed and nutrients into the frost flat as a result.

In order to halt the spread of wilding pines, the seed sources need to be addressed, particularly the 467 ha of wilding pine forest that is now present within the Bay of Plenty frost flat areas. Logging the oldest stands maybe periodically an option though aerial spraying is likely to be the cheapest method in the vicinity of $2000/ hectare — requiring an investment of close to $1 million dollars alone for initial treatment. Within privately owned frost flat areas the wilding contorta forest is most commonly being cleared and replanted in production forestry. If this is being carried out, then it is important it is done in a way that removes as much of the contorta seed bank as possible. The wilding contorta should not be simply cleared then immediately replanted in forestry, following the clearing of wilding contorta, a stand down period of at least 18 months should be employed, in order to wait for a large proportion of the seed bank to germinate. The area should then be re-sprayed, and then planted in forestry. If this process is followed then a large proportion of the *Pinus contorta* seedbank will be eliminated.

However, if all the areas of wilding pine forest are developed into forestry the extent of natural areas within the Bay of Plenty will continue to be reduced. On Department of Conservation land, development into forestry is not consistent with the purpose of the land as reserves protected by the Conservation Act. What are the long-term aspirations for these areas? Many monoao dominated frost flats are actually a successional community (VS8), which are actually on a long-term succession to a mixed woody community – with frost tolerant species such as mountain celery pine (*Phyllocladus alpinus*), bog pine (*Halocarpus bidwillii*) and *Coprosma propinqua* – with a prickly shield fern understory. Threatened species such as *Pittosporum turneri*, *Coprosma wallii* are also present in these communities. These communities are much more resilient to invasion by wilding pines than the open monoao community.

In the areas of wilding pine forest on Department of Conservation land the best treatment may be removing wildings and creating temporary exotic grasslands. In a grassland community a selective herbicide could be used to spray regenerating *P. contorta*. These grasslands could be maintained for 1-2 decades, and once the *P. contorta* seedbank is exhausted, the area could then be revegetated into cold tolerant woody species that are largely missing from these systems, such as alpine celery pine and bog pine. .

Finally, it is recommended that site visits are undertaken to frost flat areas that were initially wilding pine forest and which have been repeatedly controlled since. Sites in the Rangitaiki Conservation Area are probably the best examples, where treatment dates back to the late 1980's and were known to have regenerated into a high proportion of exotic grassland, to see first-hand what has happened at these locations since.

5. Recommendations/Conclusions

5.1 Recommendations

The following recommendations have been discussed in this document:

- All frost flat areas where there is currently low cover of wilding pines (<1% cover) are the highest priority for wilding management and should be the priority for management.

- Work with the Department of Conservation and private land managers to ensure that wilding pine control management occurs in these areas every 4 years, and are maintained at <1% wilding cover in the long term.

- Undertake site visits to some of the historically cleared wilding pine forest areas, and consider long-term aspirations for these areas, and other frost flat areas that have already become heavily invaded by wildings (>25%).

- Develop a strategy that targets progressive control of areas with denser wilding pine infestations working from the areas from the areas least affected. This strategy will also need to address management of the current areas of dense wilding pine forest (467 ha).

5.2 Conclusions

Bay of Plenty frost flats are being incrementally lost to wilding pine invasion and development into forestry (usually following irreversible wilding pine invasion). In the 13 years from 2003 to 2016 there was a 12.9% decrease in frost flat area. The extent of frost flats with <1% cover of wilding pines declined by 8.3%. On private land the extent of frost flats decreased by 25.4%.

The results of this report suggest that there is little chance of maintaining control of wilding pines in frost flat areas if wilding pine cover is allowed to exceed 5%. Maintaining those areas which currently have <1% cover of wilding pines is the highest priority.

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