Alpine Treeline Ecotone Monitoring Program

Within the Tasmanian Wilderness World Heritage Area

Jenny Styger and Jayne Balmer

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Front Cover Photograph: Treeline on the eastern slopes of the Snowy Range looking north-east across the upper Russell River Valley.

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Summary

This is the establishment report for the alpine treeline monitoring program for the Tasmanian Wilderness World Heritage Area. The purpose of this report is to describe the sites at which monitoring has been established, document the methods used and the objectives of the research. The introduction sets out a brief justification for the establishment of the treeline monitoring program while the discussion proposes possible processes of vegetation change that may occur based on ecological theory and research results already published for other sites. Complementary research and possible ways in which the data collected may be used to assist in developing management strategies to conserve the natural values of the alpine ecosystem are also discussed.

1.0 Introduction

The principal natural values management objective of the Tasmanian Wilderness World Heritage Area (TWWHA), is to "identify, protect, conserve, present and, where appropriate, rehabilitate the World Heritage and other ... [natural] values ..., and to transmit that heritage to future generations in as good or better condition than at present" (p 31 of the Tasmanian Wilderness World Heritage Area Management Plan, Parks and Wildlife Service 1999). Human induced global climate change could make this difficult for land managers. A number of strategies are needed to combat the threat of climate change on biodiversity values, including more detailed climate-modelling, theoretically-based predictions of impacts and risk assessments, and management strategies that incorporate values-based priority settings. Strategic monitoring and survey work is also needed to measure ecosystem responses to climate change. With survey and monitoring data it will be possible to determine if ecosystems are conforming to theoretical predictions of ecosystem processes and whether our knowledge of these systems is sufficient to accurately predict responses across the landscape. Sound knowledge of ecosystem processes is needed to develop appropriate mitigation measures to manage for the conservation of biodiversity.

The alpine ecosystem (together with its constituent biodiversity) is considered to be one of the natural values of Tasmania's Wilderness World Heritage Area at risk from climate change (Australian National University 2009). The values represented within this ecosystem include the presence of bolster-heath species, which provide a superb example of both convergent evolution and scleromorphic evolution in response to low nutrients and a maritime climate; universally outstanding natural aesthetic values, and a rich diversity of endemic species. More details about the flora of this ecosystem and its conservation significance can be found in Kirkpatrick (2003) and Balmer et al. (2004).

The climatic treeline, sometimes referred to as the alpine treeline, occurs where the average temperature of the warmest month is 10°C. Above this altitude temperatures are too cold for trees to persist due to the limited ability for plants to photosynthesize sufficient carbon to produce woody growth at low temperatures (Daubenmire 1954, Kirkpatrick 1997, Smith et al. 2003).

By definition alpine vegetation is the vegetation that occurs between the climatic treeline and below the nival zone. However treeless vegetation with the same or similar structural and floristic characteristics also occurs widely in subalpine areas of Tasmania. Trees are excluded from these areas because of factors other than average summer temperatures such as frequency and severity of frost, fire, water-logging, extreme exposure to wind and grazing (Kirkpatrick and Brown 1987, Gibson and Kirkpatrick 1989, Kirkpatrick 1997). Even including the treeless communities of the subalpine zone the area of vegetation with alpine affinities occupies less than 2% of Tasmania, and only 6% of the TWWHA (Balmer et al. 2004). Less than half of this mapped area is likely to be true alpine habitat.

One of the predicted vegetation responses to increased temperature is that trees will expand their range as the climatic treeline moves uphill (Australian National University 2009). However, climate change may also impact on the other processes currently causing the exclusion of trees in subalpine areas. This may
markedly restrict the extent of treeless highland communities in Tasmania with alpine floristic associations. Even where trees do not expand their range, woody shrubs may develop in height and cover leading to an increased exclusion of herbs, graminoids, cushions and mat heaths associated with alpine communities and a concomitant loss in biodiversity.

Predictions based on preliminary climatic modelling suggest that by 2040 mean minimum temperatures will be 0.3°C warmer than 2005 (Macintosh et al. 2005, Hydro Tasmania et al. 2006). The limited and incomplete temperature data recorded at the summit of Mount Wellington (1260 m above sea level) since 1962 indicates the possibility that a warming trend has already commenced, with the mean maximum and minimum temperatures for the decade 1962–1971 being 1.1°C and 0.5°C respectively cooler than the means of those recorded for the last decade (Bureau of Meteorology data). However differences in the averages are within the standard deviation of the mean for both decades and so the differences observed can be accounted for by chance variation. Nevertheless, if a rise of 0.2°C is presumed to have taken place prior to 2005, which coupled with the 0.3°C predicted, then it is probable that by 2040 the climatic treeline will be about 80 m higher than its historical location. This presumes an adiabatic lapse rate of 0.6°C (the average for Mount Wellington), but in some regions the lapse rate may be steeper (Kirkpatrick 1997).

More recent and detailed modelling suggests that Tasmania’s climate is likely to increase in temperature by an average of at least 1.5°C by 2100 compared with the historical period leading up to climate change (Greg Holz pers. comm. University of Tasmania, Climate Futures project, August 2009). This suggests that by the end of this century the climatic treeline will be 250 m higher than its historical location, a result that is likely to completely remove all true alpine habitat in Tasmania.

Some modelling suggests that 10,000 years before present, temperatures were actually 1–2°C warmer than present (Sikes et al. 2002). Forest expansion was relatively rapid during the early Holocene in Tasmania (Macphail 1979), but by 10,000 years ago it would certainly not have reached its current distribution so that treeless plant communities were able to prevail despite the warmer conditions. Trees and forest are now more geographically proximate to treeless vegetation, making highland treeless plant communities more vulnerable to tree invasion than at any time in the past.

Due to the extreme vulnerability of the alpine zone to climate change it was considered expedient to establish long-term monitoring transects across some climatic treeline sites in the Tasmanian Wilderness World Heritage Area where the vegetation response to increasing temperature at this critical ecotone can be measured. The climatic treeline is just one location at which rapid change might be expected to take place, signalling the commencement of broader impacts across the ecosystem.

1.2 Definitions

For the purposes of this report the following definitions apply:

**Alpine zone:** the zone between the treeline and the upper limit of closed vegetation (where vegetation is a significant part of the landscape and its physiognomy).

**Alpine obligate species:** species only ever located above the treeline. In Tasmania these species include: *Carpha rodwayi*, *Phyllachne colensoi*, *Dracophyllum minimum*, *Gaultheria depressa*, *Celmisia saxifraga* and *Oreomyrrhis sessiliflora*.

**Altitudinal treeline:** the line above which large patches of tree species no longer occur.

**Climatic treeline:** the upper limit of tree growth located where the mean temperature of the warmest month is 10°C. Above this isotherm temperatures are too cold for the long-term persistence of trees. Note that the climatic treeline may occur above the actual limit of tree growth.
**Forest**: vegetation with >30% cover of trees taller than three metres, within patches of at least 0.1 ha (greater than ~32 m by 31 m).

**Forestline**: also known as the timberline, the lower limit of the treeline ecotone. Above the forestline trees greater than three metres in height occur only with a patchy discontinuous distribution. Below the forestline forests may occur.

**Inverted-treeline**: any boundary between tree dominated and treeless vegetation below the climatic treeline and caused by factors other than summer temperatures, which inhibit tree growth such as frost, water-logging and grazing.

**Treeline ecotone**: the zone between the forest line and the tree species line.

**Tree species**: woody plant taxa with the potential to reach heights greater than five metres. In the Snowy Range these include *Eucalyptus coccifera, Nothofagus cunninghamii, Eucryphia milligiani, Atherosperma moschatum, Phyllocladus aspleniifolius, Orites diversifolia, Cenarrhenes nitida, Richea pandanifolia* and *Tasmannia lanceolata*. Note that *Eucalyptus vernicosa* does not typically reach heights greater than five meters and is able to flower and set seed at heights of less than a metre and so might reasonably be excluded from being considered as a tree.

**Tree species line**: the altitudinal limit beyond which no adult tree species, including shrub forms, occur.

### 1.3 Project aims

The purpose of this report is to document the three research sites and the specific locations where long-term monitoring plots have been established. The methods used to collect the baseline data are described. The first collections of baseline data are documented in this report and are used to describe the composition and structure of the current vegetation within the treeline ecotone. Later monitoring at these sites will enable future researchers to assess the impact that changing conditions may be having on these communities and determine whether an upward shift of the climatic treeline is occurring and how this is affecting the biodiversity of areas previously located above the forestline.

In particular the data collected were assessed here to provide information on:

- The nature of the structural transition in the vegetation between forest and alpine areas.
- Whether the forestline, treeline and tree species line are identifiable and what methods might best be used to monitor changes in their locations over time.
- Was there a corresponding change in species composition, richness or diversity above and below a) the forestline, b) the treeline or c) the tree species line?
- Were there any changes observed in tree density, height, health, and dominance that could be correlated with increasing altitude?
- Was there evidence that the treeline has been moving?
2.0 Site selection and establishment

2.1 Site selection

Three sites were selected for treeline monitoring within the Tasmanian Wilderness World Heritage Area for a combination of pragmatic and historical reasons.

Forestry Tasmania and the Department of Primary Industries, Parks, Water and Environment (DPIPWE) together established a series of Ecotone and Permanent Baseline Monitoring Plots (BAMPs) within the Warra Long Term Ecological Research Site (Barker 1998, Brown et al. 2001, Grove et al. 2004). This joint project resulted in the establishment of an altitudinal plot 50 m by 20 m along the contour at 1100 m on Mount Weld, which coincidentally happened to lie within the treeline ecotone. The establishment report for the project (Grove et al. 2004) details the methods for the BAMPs project and some of the Climatic Treeline Ecotone Transects. However the Climatic Treeline Ecotone Transect was only established in April 2005 and is not referred to in Grove et al. (2004). The Climatic Treeline Ecotone Transect was established perpendicular to the altitudinal plot at this site, to better sample the variation within and across the treeline ecotone. However the vegetation transition in this ecotone is extremely gradual and the location of the treeline is obscure because of the presence of other factors inhibiting tree growth in the area (e.g. boulderiness, frostiness, exposure) and the lack of a steep altitudinal gradient. A 100 m transect line through an inverted-treeline ecotone at 950 m elevation was therefore established instead of a replicate transect within the climatic treeline ecotone.

Nick Lewis, working for a private company, ES Link, established six treeline monitoring transects (each 100 m in length) along an eastern ridge of Mount Rufus in consultation with staff in DPIPWE. An establishment report titled “Monitoring Manual: Mount Rufus Treeline Monitoring Project” was prepared (ES Link 2006). In 2007 ES Link ceased their interest in managing this permanent research site and the flora data for the site (‘RufusMonitoringData’ access database, DPIPWE M-Drive) was given to DPIPWE for future management and monitoring. For more detailed descriptions of the monitoring protocols for the Mount Rufus treeline monitoring site please refer to ES Link 2006 (DPIPWE files, Doc One).

Monitoring transect lines is time consuming and expensive. The treeline site at Mount Weld is remote and the gradual nature of the transition may make interpretation of results more challenging. The site at Mount Rufus, while apparently robust, was burnt in 1965 and on its own the results may not be applied confidently to the TWWHA more generally. A third site for treeline monitoring was therefore sought.

The criteria for a third treeline monitoring site were:
- easily and cheaply accessible from Hobart,
- within the Tasmanian Wilderness World Heritage Area,
- possessing a well defined treeline which includes *Eucalyptus* as a dominant.

The two closest alpine areas are Hartz Mountain and the Snowy Range. Hartz Mountain National Park, while having good vehicular access onto the top of the mountain, is an undulating plateau with no sharply defined eucalypt dominated climatic treeline easily apparent. The Nevada Peak area of the Snowy Range was therefore chosen because the treeline is accessible in a day trip from Hobart.

Suitable sites within the Snowy Range were identified from aerial photographs and site visits. An initial site visit for suitable treeline sites was conducted in May 2008, with the location and establishment of the sites finalised in February 2009.
2.2 Transect access

2.2.1 Snowy Range
Two treeline ecotone transects were established in the Snowy Range, located within the South-West National Park. The transects are located on the eastern slopes below Nevada Peak about 300 m apart (Figure 2.1). The most efficient route to the study sites is along the Nevada Peak Walking Track accessed from the Russell State Forest. Transect A is reached by leaving the main Nevada Peak track where it reaches the treeline and heading south for about 100 m. The central point on the transect is located at GDA Easting 472547 and Northing 5248152. Transect B is reached by continuing up along the main Nevada Peak walking track above the treeline for about 200 m, before heading north along the contour for about 150 m. The mid-upper stake is the most likely first point of contact with this transect located at GDA Easting 472374 and Northing 5248406.

To get to the walking track drive from Hobart to Judbury and then take the Lonnavale/Russell Road to Lonnavale and continue along the Russell Road. Continue to the left (main Russell Road) at the junction with Dolerite Road and continue along the main Russell Road (past North Russell Road and back over the Russell River) continuing on until the Russell Spur 3 Road is reached. Drive up the Russell Spur 3 Road uphill, taking the left hand road at an unmarked track junction. Continue uphill until a logging coupe with an obvious turning circle/car park at the end of the road is reached. Cairns mark the walking track which heads towards the forest edge on the western side of the logging coupe. The drive to the track head takes approximately 2 hours from Hobart.

The walk to the treeline from the road takes approximately 2½ hours with full packs. Uncomfortable and informal camping is possible at the track junction to Woolley’s tarn, where there is a good water supply in the nearby creek or in the open *Gleichenia* bog a little further up along the main track. There are no suitable locations for camping at the treeline due to the absence of water and the camping on Nevada Plateau is exposed in bad weather.
2.2.2 Mount Weld
The Climatic Treeline Ecotone Transect is reached via the main walking route up the eastern ridge of Mount Weld, which commences partway along the walking track known as the ‘Gahnia Track’, an old disused logging track (Figure 2.2). The Climatic Treeline Ecotone Transect is on the southern side of the part-cairned north-east ridge crest leading to the summit of Mount Weld. It is about five metres north of the ridge crest and away from the usual track route, which ascends from the nameless lake to meet this ridge further upslope at a dell. The Inverted-Treeline Ecotone Transect is just southwest of the nameless lake located at 955 m elevation, south of the main ridge up Mount Weld. The lake can be reached by taking an alternative ‘pad’ south from the main ridge line when it reaches a treeless opening at about 950 m elevation. Walk through open bog-vegetation skirting around the northwest side of a hill marked on the map as being 975 m in elevation. Continue around the hill to the southeast to find the lake.

The drive to the start of the Gahnia Track takes approximately 2 hours from Hobart. The Mount Weld track is a relatively clear taped route, but it is a long and arduous walk (~7 to 8 hours), especially when carrying field gear. A campsite can be located at the nameless lake located at 1089 m that feeds into Trout Lake below. This site is recommended for measuring the BAMPs (Grove et al. 2004) 1300 m and 1200 m elevation plots and is a reasonable point from which to measure the Climatic Treeline Ecotone Transect and the BAMP’s 1100 m plot, which are located together. But for measuring the subalpine
Inverted-Treeline Ecotone Transect and the 1000 m, 900 m or 800 m BAMPs plots, a campsite is better located at the other nameless lake, south of the main ridgeline walking track at 955 m elevation.

To date, most survey work on the BAMPs and treeline transects at Mount Weld has been done by organising a helicopter to pick up scientists from the head of the South Weld Road (start of the Gahnia track) and dropping them on the upper slope of Mount Weld at a suitable camp site. The scientists then walk back out via the walking track to their car at the road head after the survey work has been completed.

**Figure 2.2 Location map for the Mount Weld Climatic Treeline Ecotone and Inverted-Treeline Ecotone Transects, as well as the walking track access route. Grid coordinates GDA 94 UTM (Tasmap 1:25,000 Topographic series Weld Sheet 4623).**

### 2.2.3 Mount Rufus
Six treeline ecotone transects were established on the eastern ridgeline of Mount Rufus, three on the northern aspect of the ridge and the other three on the southern aspect (Figure 2.3). The transects are reached by taking the main walking track to Mount Rufus from Lake St Clair. An informal campsite can be made in a patch of treeless vegetation along the track edge, next to a creek at about 1070 m elevation. This is about a kilometre before reaching the eastern ridgeline on which the transects are located. After
climbing up ‘the steps’ onto the first peak of Mount Rufus, turn left (south-east) and proceed along the eastern ridge for approximately 500 m. After passing rocky ‘peaks’, you should reach or pass Transect 6. The walk to the transects takes about 2½ hours from Cynthia Bay with day packs.

Figure 2.3 Location map for the Mount Rufus Treeline Ecotone Transects, as well as the walking track access route. Grid co-ordinates GDA 94 UTM (Tasmap 1:25,000 Topographic series Rufus Sheet 4233, 1988).

2.3 Transect design and layout

2.3.1 Snowy Range Transect A and Transect B
Each treeline site consists of a 200 x 10 m belt transect that spans part of the treeline ecotone. Each transect is divided into 10 x 10 m plots numbering 1 to 20 from the bottom. A nested 1 x 1 m subplot at 5-6 m from the bottom of each plot is located along the southern (Transect A) and south-eastern (Transect B) edge of the plot where the main measuring tape is runout (Figure 2.4). Figure 2.5 shows the treeline ecotone transect locations in relation to each other and the current treeline.
Figure 2.4 Snowy Range transect design. The diagram shows a 50 m length of each 200 m long belt transect. Plots were each 10 x 10 m and were labelled 1 to 20 from the bottom (20 was the uppermost plot). Nested subplots 1 x 1 m were located between 5.0 m and 6.0 m uphill from the bottom of the transect on the southern (Transect A) south-eastern (Transect B) side of each plot. Permanent markers were placed on the southern or southeastern side of each Transect (A, B respectively). The Transects are orientated uphill (the direction of the arrow).

Figure 2.5 Transects A and B with location of surrounding outlying tree species and the approximate position of the current tree species line.
Galvanised steel fence pickets have been used to mark the central top and bottom points of both transects. Rocks required that some transect stakes be displaced one metre from the plot corner requiring care in checking for short stakes at the real location of plot corners. Additional curly wire markers have been placed at some quadrat corners and very short galvanised pickets have been located at one end of most 1 x 1 m monitoring and photo points for each 10 x 10 m plot to assist in laying out the transect tape in the same position next time. Table 2.1 provides the grid locations of the main posts along each transect. The main galvanised fence picket is located one metre above the start of the bottom of Transect A where it could be seen. A wire curly stake marks the real bottom of the transect but it is obscured by vegetation.

Table 2.1: Snowy Range transect locations and stake co-ordinates.

<table>
<thead>
<tr>
<th>Transect</th>
<th>Co-ordinates Top Stake (200 m)</th>
<th>Co-ordinates Upper-mid Stake (150 m)</th>
<th>Co-ordinates Mid Stake (100 m)</th>
<th>Co-ordinates Lower-mid stake (50 m)</th>
<th>Co-ordinates Bottom Stake (0 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. (Aspect 70°)</td>
<td>0472448 E 5248152 N</td>
<td>0472498 E 5248153 N</td>
<td>0472547 E 5248152 N</td>
<td>0472595 E 5248153 N</td>
<td>0472642 E 5248147 N</td>
</tr>
<tr>
<td>B. (Aspect 20°)</td>
<td>0472298 E 5248287 N</td>
<td>0472322 E 5248326 N</td>
<td>0472348 E 5248366 N</td>
<td>0472374 E 5248406 N</td>
<td>0472400 E 5248447 N</td>
</tr>
</tbody>
</table>

2.3.2 Mount Weld Climatic Treeline Ecotone Transect and Inverted-Treeline Transect

At Mount Weld there was only one climatic treeline ecotone transect established. It was 100 m long and established perpendicular to the contour. It is located so that it crosses over the top of the 1200 m altitude BAMP plot (50 m by 20 m established parallel with the contour). The two would be best monitored concurrently. The plot nomenclature and transect layout of the Climatic Treeline Ecotone Transect is shown diagrammatically in Figure 2.6. Stake locations and transect details are located in Table 2.2.

A high altitude inverted-treeline transect was established in a location where frost and waterlogging have excluded trees from a plateau, the slope below which trees are present. This Transect was established to determine the extent to which trees will expand their range within areas of the treeless subalpine zone. This Transect was 100 m long and consisted of 10 contiguous 10 x 10 m plots numbered 1 to 10, with the bottom plot being labelled number 1 and top plot labelled number 10. Stake locations and transect details are located in Table 2.2. It should be noted that the top stake was located one metre beyond the top of the Transect. Stakes were also placed on all four corners of the belt transect and either side of the boundary between plots 5 and 6. The co-ordinates were provided only for the stakes on the western side of the Transect.
Figure 2.6 Transect layout and design for the Mount Weld Climatic Treeline Ecotone Transect which is orientated with the slope and crosses the BAMPs altitudinal plot, which is orientated along the contour.
## Table 2.2 Mount Weld transect locations and stake co-ordinates.

<table>
<thead>
<tr>
<th>Transect</th>
<th>Top-Stake Label</th>
<th>Co-ordinates</th>
<th>Mid-Stake Label</th>
<th>Co-ordinates</th>
<th>Bottom Stake Label</th>
<th>Co-ordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatic Treeline Ecotone Transect (100 m) North-East Aspect</td>
<td>1—0 m</td>
<td>0466530 E 5238424 N</td>
<td>Stake at Top (5th corner) of BAMPS plot TAG=A111 &amp; Stake at bottom left (east corner) of Lower mid Plot=BAMPS plot 10.</td>
<td>Bottom left corner BAMPS plot 10: 0466580 E 5238453 N Only 5 cm showing above ground level.</td>
<td>Bottom left corner (east) of Lower plot 4. Tag=A65</td>
<td>0466607 E 5238481 N</td>
</tr>
<tr>
<td>Inverted-Treeline Transect (100 m) Southern Aspect</td>
<td>Top stake is located one metre above the top of the corner of plot 10.</td>
<td>0467199 E 5238074 N</td>
<td>Stake located at the corner between plot 5 and plot 6.</td>
<td>04467202 E 5238122 N</td>
<td>Bottom southwest corner of Plot 1. Tag= A66 at base of stake.</td>
<td>0467204 E 5237972 N</td>
</tr>
</tbody>
</table>

### 2.3.3 Mount Rufus Treeline Ecotone Transects 1 to 6.

Six Treeline Ecotone Transects were established on the eastern ridge of Mount Rufus. Three on the northern aspect and three on the southern aspect of the ridge. The transects are 70 to 100 m in length. Details of their layout and location are provided in the Monitoring Manual report prepared by ES link (2006) the diagram for which is copied here in Figure 2.7. Table 2.3 provides details of the stake locations and labels.
Figure 2.7 The layout of plots within each transect at Mount Rufus.
<table>
<thead>
<tr>
<th>Transect</th>
<th>Top-Stake Label</th>
<th>Co-ordinates</th>
<th>Mid-Stake Label</th>
<th>Co-ordinates</th>
<th>Bottom Stake Label</th>
<th>Co-ordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (100 m) Southern Aspect</td>
<td>1—0 m</td>
<td>0427469 E 5335727 N</td>
<td>1—50 m</td>
<td>0427469 E 5335685 N</td>
<td>1—100 m</td>
<td>0427443 E 5335643 N</td>
</tr>
<tr>
<td>2. (100 m) Southern Aspect</td>
<td>2—0 m</td>
<td>0427539 E 5335684 N</td>
<td>2—50 m</td>
<td>0427529 E 5335635 N</td>
<td>2—100 m</td>
<td>0427524 E 5335593 N</td>
</tr>
<tr>
<td>3. (100 m) Southern Aspect</td>
<td>3—0 m</td>
<td>0427594 E 5335700 N</td>
<td>3—50 m</td>
<td>0427593 E 5335653 N</td>
<td>3—100 m</td>
<td>0427610 E 5335590 N</td>
</tr>
<tr>
<td>4. (80 m) Northern Aspect</td>
<td>4—0 m</td>
<td>0427780 E 5336016 N</td>
<td>4—50 m</td>
<td>0427791 E 5336057 N</td>
<td>4—80 m</td>
<td>0427805 E 5336087 N</td>
</tr>
<tr>
<td>5. (80 m) Northern Aspect</td>
<td>5—0 m</td>
<td>0427716 E 5336032 N</td>
<td>5—50 m</td>
<td>0427736 E 5336074 N</td>
<td>5—80 m</td>
<td>0427740 E 5336107 N</td>
</tr>
<tr>
<td>6. (70 m) Northern Aspect</td>
<td>6—0 m</td>
<td>0427640 E 5336039 N</td>
<td>6—50 m</td>
<td>0427658 E 5336101 N</td>
<td>6—70m</td>
<td>0427641 E 5336107 N</td>
</tr>
</tbody>
</table>
3.0 Data collection methods

3.1 Species composition and environmental variation

For all treeline ecotone transects measuring tapes were laid out to mark both sides of each belt transect. Additional tapes were used to mark the edges of each 10 x 10 m plot along the contour as well.

Vascular plant species cover was visually estimated for each vascular plant taxa present, to the nearest percentage, with sparsely occurring species of less than one percent cover recorded as “<1” OR “+” on the score sheets. Species occurring as a single individual of less than one percent cover were recorded as R (rare). Within the access database these scores were ascribed the values 0.5 and 0.01 respectively.

In addition to projected foliage cover estimates for each species the average maximum height for each species was estimated or measured.

Other parameters recorded for each plot included:
- Aspect
- Slope
- Percentage cover of
  - Rock
  - Bare ground/soil
  - Litter
  - Non-vascular plant cover

3.1.1 Snowy Range

In addition to the above, vascular plant species cover was visually estimated for each 1 x 1 m subplot by laying a collapsible quadrat frame with a 100 square grid (10 x 10 cm squares) over the vegetation. The frame was made from polypipe and the grid created using stretchy shot-cord.

Two soil depths were also measured from random locations (but where rock was not evident at the surface) within each of the 1 x 1 m subplots.

3.1.2 Mount Weld

Percentage cover of standing dead vegetation was recorded in addition to other parameters.

3.1.3 Mount Rufus

Notes on the drainage, landform and geology were recorded for each plot/transect as appropriate.

3.2 Tree species mapping

All observed individuals of tree species (irrespective of their height or dimension) were mapped within each 10 x 10 m plot that they occurred in, using a standard cartesian grid co-ordinate system to identify the location of the main stem at ground level. The X co-ordinate being the distance measured along the contour from the staked side of the belt transect, and the Y co-ordinate being the distance measured up or down the main transect line (downhill) from the start of the transect (Figure 3.1). Transects differed in which directions the plots were numbered (Mount Rufus was from top to bottom while Mount Weld and Snowy Range plots were numbered from bottom to top).
3.1 Illustration of tree co-ordinate determination for the Mount Rufus Treeline Ecotone Transects where the X co-ordinate is the distance east from the western (staked) side of the belt transect and the Y co-ordinate is measured from the top of the transect down, so that the tree shown in this illustration would be recorded at X = 6.8 m, Y=13.3 m.

In addition to the location of each stem, the height of each tree was measured as the highest living part of the tree above ground level.

3.2.1 Snowy Range
The tree species observed and recorded within the Snowy Range transects were *Eucalyptus coccifera*, *Nothofagus cunninghamii*, *Eucryphia milliganii*, *Athrotaxis selaginoides* and *Phyllocladus aspleniifolius*.

In addition to the heights of each tree species, the stem circumference was measured at ground height, or as near to ground height as possible. If the tree was growing as an epicormic shoot off a seemingly dead trunk, then a measurement of the circumference of the largest live branch was also taken. Trees taller than breast height had their diameters at breast height recorded in some cases.

For each plot in which a tree species was recorded, an estimation and map of the projected foliage cover was also made. The projected foliage cover of each individual was recorded by laying a 1 x 1 m grid, subdivided into 100 10 x 10 cm squares, over the tree species, and counting the number of cells in which any live foliage and branches occurred as well as the number of cells in which dead foliage occurred. Where cover was fairly continuous the grid was systematically moved along each 1 x 1 m grid in the plot and the number of cells of each tree species counted and recorded. This data was used to map an approximate distribution of tree canopy’s across the plot (Figure 3.2).
The location of outlying tree species was also recorded adjacent to each transect, with a handheld differential GPS capable of submetre accuracy. For Transect A, tree species were recorded roughly 50 m either side of the transect line from the treeline up. *Eucalyptus coccifera* and conifer species were recorded with a single point whereas approximate location of the outer perimeter of large clumps of *Nothofagus cunninghamii* and *Eucryphia milliganii* were recorded by measuring four locations around the perimeter (upper most, lower most and across slope dimensions).

There were a greater number of outlying tree species in the 50 m vicinity of Transect B and time restraints required that the method of recording be refined. Hence only trees greater than one metre tall were recorded above the treeline (Figure 2.5). It appeared that the trees were restricted to altitudes below the top of the established treeline ecotone Transect B but further searching in the area in the coming summer would be expedient to confirm this observation.

### 3.2.2 Mount Weld

*Eucalyptus coccifera* and *Nothofagus cunninghamii* trees were observed and recorded on the Inverted-Treeline Ecotone Transect on Mount Weld while only *E. coccifera* was located on the Climatic Treeline Ecotone Transect.

The Y co-ordinates were measured from the bottom of the transect while the X co-ordinates were the distance east across the slope from the western side of the plot for both treeline transects on Mount Weld. No trees were located in the upper plots of the Climatic Treeline Ecotone Transect, which were all above the tree species line. An over sight resulted in the lack of collection of the tree map data for the two mid plots along this transect and will be collected at the next visit to the site.

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**Figure 3.2** Tree mapping. The 10 x 10 m plots were divided into 1 x 1 m subplots, with a 1 x 1 m grid divided into 100 squares laid over each subplot.
3.2.3 Mount Rufus
The only tree species mapped and recorded on the Mount Rufus Treeline Ecotone Transects were *Eucalyptus coccifera*. Their locations were recorded (X, Y coordinates) together with their heights (not circumferences) in the plots above the treeline (plots 1 to 5 only). The Y co-ordinates were recorded as the distance down slope from the top of the transect. The X co-ordinates were recorded as the distance away from the western edge of the plot (Figure 3.1).

The floristic data collection for all plots provided an estimate of the total cover, average height and height range of live *Eucalyptus coccifera* trees and notes were also made about the heights of dead trees within each plot.

3.3 Photographic monitoring

3.3.1 Snowy Range
Profile photographs of each plot were taken from the northern side of Transect A looking back to the southern boundary of the plot, where possible. Similarly, the photographs were taken from the north-western side of the transect looking back towards the south-eastern side of the plots on Transect B. Where tall vegetation or the topography was such that the view across the plot was obscured a photograph from an alternative position was taken and the details noted.

Photographs of each 1 x 1 m subplot were taken looking down at the vegetation from above whilst standing outside the plot on the southern side (Transect A) or south-eastern side (Transect B) of the transect line. Two photos were taken of these subplots one with, and one without, the 1 x 1 m quadrat frame over the top of the vegetation.

3.3.2 Mount Weld
No photo monitoring was established for the ecotone transects at Mount Weld at their establishment. Future monitoring should include the establishment of photo monitoring points.

3.3.3 Mount Rufus
At Mount Rufus the photographic monitoring points were established along each transect, as indicated in Figure 2.7 showing the transect design (ES Link 2006). These were marked with a 50 cm steel dropper (not labelled). These photographic monitoring points are outside the transect plot area and care needs to be taken not to confuse these for plot corner stakes. Photo points have been located 10 m “above” each permanent stake and 10 m to the west of each permanent stake on Transects 1 – 3. Following the same procedure, photo points were established at the 0 m and 50 m marks of Transects 4 – 6.

Photographs are taken while standing over each photo point and using a digital SLR camera, the photographer held the camera at 1.75 m above the ground. Focusing upon a red, 25 cm diameter disc suspended 1.4 m above the permanent stake, a photo was taken. The general approach is illustrated in Figure 3.3 for a photograph taken looking straight down the transect line from above. Vegetation profile photographs taken looking across the plot perpendicular to the slope are also taken from the western side of the transect looking east.
Figure 3.3 Photo monitoring method for the Treeline Ecotone Transects at Mount Rufus.
4.0 Results

4.1 Structural variation along an altitudinal gradient

4.1.1 Snowy Range structural data

The detailed transect measurements of tree covers provided the data analysed here. No tree species occurred above the 100 m mark within belt Transect A (~altitude 1137 m), and the occurrence of tree species below 100 m showed no obvious changes in cover with increasing altitude (Figure 4.1). A patch of *Nothofagus cunninghamii* and individual *Athrotaxis selaginoides* were present at higher altitudes than occurred within the belt transect but trees such as these were of very rare occurrence and were limited to altitudes below ~1160 m. *N. cunninghamii* and *Eucryphia milliganii* were the tree species that occurred at the highest altitudes along Transect A (plot 10, ~1136 m). *Eucalyptus coccifera* only occurred in plot 2 (~1118 m) and 4 (~1122 m) and *A. selaginoides* only occurred in plot 1 (~1115 m) and 2 of the transect. While cover of some tree species was extensive in the first 100 m of Transect A, plant heights were less than three metres in all but the plots 1, 2, 4 and 5. *E. coccifera* was present in the vicinity of Transect A up to an altitude of about 1145 m.

![Figure 4.1 Tree cover by species for each plot along Transect A on the Snowy Range. Plot 1 (lowest ~1115 m) to plot 20 (highest ~1158 m).](image)

In terms of the definitions provided for this report, the altitudinal treeline within the belt transect was positioned at the boundary between plot 10 and plot 11 (~1137 m altitude). Beyond Transect A, the location of the altitudinal treeline varied somewhat above and below the position observed on Transect A by a variation in elevation of less than 10 m. For example a substantial patch of trees occurred adjacent to plot 11 to the south at a slightly higher elevation. The tree species line was located beyond the altitudinal maximum of Transect A. The sparse distribution of trees above the altitudinal treeline makes defining a tree species line difficult, but might be achieved by determining the highest elevation of a tree species for each aspect on the mountain slope. The elevation at which trees reached an average of three metres was at about the boundary between plot 2 and plot 3 on Transect A (~1119 m elevation).

The percentage cover of tree species in Transect B showed some apparent decline with increasing altitude but the trend was inconsistent. No tree species were recorded above plot 16, 160 m up the
transect (altitude ~1180 m) and no tree species were observed higher than this in the general vicinity (Figure 4.2). *Eucalyptus coccifera* occurred at the highest altitudes in Transect B, with the exception of one immature individual of *Phyllocladus aspleniifolius*, which occurred in plot 15. The percentage cover of *Nothofagus cunninghamii* was considerably larger than that of all other tree species. *Eucryphia milliganii* also occurred occasionally along the lower half of Transect B (Figure 4.2). No trees with heights greater than three metres were recorded along Transect B.

![Figure 4.2 Tree cover by species for each plot along Transect B on the Snowy Range. Plot 1 (lowest ~1140 m) to plot 20 (highest ~1190 m).](image)

In terms of the definitions in this report, the altitudinal treeline was located on the boundary between plots 5 and 6 on Transect B (~1149 m). Above this, trees occurred only in small discontinuous patches with a total cover of less than 30 percent. The forestline was located an estimated distance of less than 50 m below Transect B at about 1118 m altitude. The tree species line was located at about the boundary between plot 15 and plot 16 on Transect B, an elevation of about 1180 m.

The mean height of *Eucalyptus coccifera* for each plot shows a steady increase below the altitudinal treeline at plots 5 and 6 (Figure 4.3), however, there are insufficient plots below the altitudinal treeline for this to be considered meaningful. Above the altitudinal treeline there is a dip followed by a rise in the mean height of *E. coccifera*, before they cease altogether at plot 14. The maximum height of *E. coccifera* above the altitudinal treeline is 185 cm, occurring in plot 12, whereas the maximum height of *E. coccifera* below the altitudinal treeline is 270 cm occurring in plot 1.
Figure 4.3 The average height of *Eucalyptus coccifera* occurring along Transect B, Snowy Range. There were only two individuals of *E. coccifera* in Transect A, which were 600 cm (plot 2) and 380 cm (plot 4) tall.

There was no discernible pattern in the diameters at ground height for *Eucalyptus coccifera* along Transect B (Figure 4.4). The largest mean diameter was for plot 3, however this was due to the presence of just two individuals, (48.05 and 33.41 cm in diameter). The minimum diameters were similar for all plots that had an *E. coccifera* individual. The diameters of *E. coccifera* were not measured along Transect A.

Figure 4.4 Maximum, minimum and mean stem diameter for *Eucalyptus coccifera* along Transect B for the Snowy Range. The error bars show the standard error of the mean for each plot.

4.1.2 Mount Weld structural data

Estimated tree cover data for the Climatic Treeline Ecotone Transect showed that only the lower 50 m of the transect had any *Eucalyptus coccifera* although there were some *Nothofagus cunninghamii* individuals located intermittently along the transect up to the second plot from the top (Figure 4.5). Both species were sparsely covered. Tree heights along the transect were all less than 150 cm, with the
average height of *E. coccifera* varying from 40 and 70 cm in height (Figure 4.6). The boundary between plot 5 and plot 6 (1103 m) is approximately located along the limit of *E. coccifera* on Mount Weld. No records were made at the time of survey of the presence or absence of *N. cunninghamii* above that altitude away from the transect. The lower limit of the transect appears to be located above the altitudinal treeline. The treeline ecotone appears to extend over a wide geographic extent on Mount Weld.

Between plots 1 – 5, the Mount Weld Inverted-Treeline Ecotone Transect consisted of *Eucalyptus coccifera* woodland vegetation with live trees reaching a height of six metres (Figure 4.7). Beyond the transect eucalypts were less than one metre in height and rare above the boundary between plots 5 and 6 (~933 m altitude), only one occurring within the transect above this altitude (Figure 4.7). *Nothofagus cunninghamii* occurred throughout the transect length but was less than two metres in height in the upper 50 m section (Figure 4.7) and averaging about one metre tall (Figure 4.10). Total tree cover was less than 20 percent in all plots and less than five percent in all but plot 7 of the upper 50 m of the transect (Figure 4.8), while stem density for *N. cunninghamii* declined with altitude (Figure 4.9).
Figure 4.9 Stem density of *Eucalyptus coccifera* along the Mount Weld Inverted-Treeline Ecotone Transect.

Figure 4.10 Average measured heights of all trees along the Mount Weld Inverted Treeline Ecotone Transect.

4.1.3 Mount Rufus structural data

The Mount Rufus transects were placed subjectively so that the first 50 m were above the apparent altitudinal treeline. Measurements suggest that the altitudinal treeline and forestline, as defined in this report, were actually further down slope in some instances. The data in Figure 4.11 shows the cover of all tree species present in the Mount Rufus transects and therefore includes *Leptospermum lanigerum, Nothofagus cunninghamii, Orites diversifolia* and *Tasmannia lanceolata*. However 97 percent of the total cover was contributed by *Eucalyptus coccifera*. Tree cover was minor in plots 1 to 5 (the top 50 m of each transect) for all but Rufus Transect 6 (RT6). On RT6, plot 5, tree cover reached nearly 10 percent and had a height of about two metres (Figure 4.11). More substantial tree cover corresponding with vegetation below the altitudinal treeline was observed in plots 6 for Rufus Transects 1, 2, 4 and 6. Rufus Transect 3 (RT3) and Rufus Transect 5 (RT5) only had substantial tree cover consistent with areas below the altitudinal treeline in plot 8 and 7 respectively. The forestline (line below which trees were three metres in height or more) was located in plots 6 for RT1 and RT2, in plot 7 for RT4 and RT5, and plot 8 for RT3 (Figure 4.12). Rufus Transect 6 was only 70 m long and did not extend to the forestline.

Figure 4.11 Estimated total tree cover (all species) and average live tree height (*Eucalyptus coccifera*) for plots 1 to 10 for six transects on Mount Rufus (the treeline is positioned between plots 5 and 6 on each transect). Note plot 10 is at the lowest point on the transect.
Figure 4.12 Estimated maximum tree heights for live *Eucalyptus coccifera* for plots 1 to 10 for six transects on Mount Rufus (the treeline is positioned approximately between plots 5 and 6 on each transect). Notes: dead trees about 25 m tall occurred at RT5, while dead trees 10 and 12 m in height were present in RT2 and RT3 respectively.

This data confirms that plots 1 to 5 are above both the altitudinal treeline and forestline on five transects. However plot 5 on Rufus Transect 6 has 10 percent tree species cover (more than 80 plants) which are all under two metres (Figure 4.15). On the northern aspects (Transects 4 and 5) the altitudinal treeline was at about 1228 m (±10 m) altitude and the forest line was at about 1220 m. On the southern aspect (Transects 1 to 3) the altitudinal treeline was about 50 m lower at 1172 m (±5 m) and the forestline was only one to two metres lower in elevation. *Eucalyptus coccifera* occurred above the altitudinal treeline on both aspects, although extended higher up above the transect on the northern aspect (Figure 4.13). Tree densities declined with altitude but heights were variable (Figure 4.13). Tree densities above the treeline were higher on the northern aspects (Transect 4 to 6) than on the southern aspects (Transect 1 to 3). The treeline ecotone being more contracted on the south-facing slope compared with the north-facing slope.

The current forestline is not far below the altitudinal treeline at this site with trees more than three metres in height in plot 6 for Transect 1, 2, 3 and 6. On the southern transects the forestline was only one to two metres below the altitudinal treeline whereas on the northern transects it was from one to five metres lower in elevation. No data on maximum tree height was collected for plot 6 on Transect 5, and the maximum tree height on Transect 4 was less than three metres. Trees taller than three metres were present in plot 7 for all transects (Figure 4.12).

Dead *Eucalyptus coccifera* up to 10 m and 12 m in height occurred below the treeline where live trees were less than eight metres tall on RT2 and RT3. On RT5 a dead tree of about 25 m was present below the forestline where live trees only reached up to 12 m in height.
4.2 Species richness along the altitudinal gradient

No relationship between plant species richness and altitude was observed along any of the treeline ecotone transects.

Species richness on the Snowy Range averaged 19 species per plot for Transect A, whereas the average species richness per plot in Transect B was 22 (a more northerly aspect). The greatest recorded species richness was 28 species for both transects, with this value being recorded in plot 11 for Transect A and plot 17 for Transect B. The lowest recorded species richness for the 10 x 10 m plots was 12 species in plot 8 of Transect A and 17 species in plots 2 and 19 of Transect B.

Species richness on the Mount Weld Climatic Treeline Ecotone Transect varied from 25 to 33 species with a mean of 29. The mean for the lower 50 m was 28 species, while for the upper 50 m it was 30 species per plot. Species richness varied from 29 to 39 plant species per plot on the Mount Weld Inverted-Treeline Ecotone Transect. The average for the upper plots was 37 species per plot while the average for the lower plots was 33.

At the Mount Rufus treeline transects the variation in species richness was from 18 to 44 with the mean across all plots on all transects being 32. The average species richness for plots in the top 50 metres of all transects was 31, while plots lower down the slope had a mean of 33 species.

When the Mount Rufus species richness data set was tested using Analysis of Variance the results provided strong evidence that there is a relationship between species richness and aspect and the probability that the results were due to chance variation was small (p< 0.001). The mean species richness was highest on the northern slopes (an average of 35 species per plot) compared with plots on the southern aspects (an average of 30 species per plot).

4.3 Species composition along the altitudinal gradient

There was a floristic change associated with change in cover and height of tree species. This will be the subject of future papers describing the floristic variation along the ecotone and is not reported here in detail. However, in summary, the top 50 m of the Mount Rufus transects were floristically distinct from plots in the lower parts of the transects. Species with significantly higher covers in plots in the upper 50 m of the six transects on Mount Rufus included *Baeckea gunniana*, *Bellendena montana*, *Boronia citriodora*, *Carpha alpina*, *Epacris serpyllifolia*, *Euphrasia gibbsiae*, *Orites acicularis*, *Orites revoluta*, *Pentachondra pumila* and *Poa gunnii*. Species associated with plots more than 50 m down each transect included *Coprosma nitida*, *Eucalyptus coccifera*, *Leptospermum rupestre*, *Planocarpa sulcata*, *Podocarpus*
lawrencei, Rubus gunnianus and Tasmannia lanceolata. There was also a relationship between aspect and plot floristic composition.

4.4 Tree mapping

The tree mapping results are not contained with this report but are filed within separate data sets for each site location.

4.4.1 Snowy Range
Tree mapping data for the Snowy Range can be found by searching the DPIPWE M drive for “Treeline.mdb”

4.4.2 Mount Weld
Tree mapping data for Mount Weld can be found by searching the DPIPWE M drive for “WarraWHAEcotoneTransectData2005.xls”

4.4.3 Mount Rufus
Tree mapping data for Mount Rufus can be found by searching the DPIPWE M drive for “RufusMonitoringData.mdb”

4.5 Other casual observations

4.5.1 Snowy Range
There were large dead trees and stumps present along the lower part of Transect B on the Snowy Range showing that more substantial trees have occupied this zone in the past than are presently occupying the site. *Eucalyptus coccifera* plants generally arose from substantial woody stems at ground level, suggesting that they are not young plants despite their diminutive size and that they probably regularly resprout from epicormic buds after dieback events caused by drought, frost and browsing. The relative ages of the tree from the lower to the upper parts of the slope should not be judged by their heights since growing conditions are progressively harsher and more exposed with increasing distance upslope. Older trees at the lower end of the transect surviving the last fire in the area have prostrate trunks with branches forming vertical leaders.

4.5.2 Mount Weld
The transects at Mt Weld were established above the alpine treeline, across the tree species line for *Eucalyptus coccifera*. The second transect was established across an inverted-treeline, where frost and cold-air drainage and water-logging have combined to eliminate trees. Both transects are still recovering from a wildfire, which possibly occurred at about the turn of the century between 1898 and 1906 but no accurate disturbance history has been determined for the sites (Hickey et al. 1999, Doran et al. 2003, Grove et al. 2004).

4.5.3 Mount Rufus
No investigation of stem circumference at the base of plants was attempted in the initial data collection for Mount Rufus but substantially taller trees were present in the lower part of transects prior to the 1950 bushfire as evidenced by the presence of large dead trees and stumps, and some surviving trees.
5.0 Discussion

Evidence in Tasmania and elsewhere suggests that tree expansion with warming does not always occur as a linear migration of the forestline (leading edge colonisation). Rather the migration of the treeline is likely to be episodic and almost certainly will lag behind the movement of the treeline isotherm (Grace et al. 2002, Smith et al. 2003, Miliar et al. 2004, Green 2009). In the case of post-glacial forest expansion in Tasmania, relictual vegetation patches probably existed above the forestline where micro-climates were mild enough to enable the persistence of frost-tolerant tree species in the form of shrubs (Macphail and Colhoun 1985, Kirkpatrick and Fowler 1998). Plants within this ‘forest species refugia’ would have been able to re-establish their tree form and so establish small forest islands following deglaciation. Expansion from such refugial forest patches was likely to have occurred in pulses resulting from the occasional successful recruitment of a tree species into surrounding treeless vegetation, which would lead to the amelioration of the micro-environmental conditions at these sites, making them more suitable for tree establishment. Detailed models of treeline expansion are provided by Smith et al. (2003) suggesting feedback mechanisms between tree establishment and the improved suitability of site for future recruitment.

The rate of forest expansion is likely to be dependent on the time taken for tree species to reach tree stature and sexual maturity, which in the upper limits of the subalpine environment is likely to be much longer than for more lowland areas. The many barriers and limits to seed production, seed dispersal, seed germination and seedling recruitment are likely to further inhibit rates of forest expansion well after average summer temperatures are warm enough to support tree growth. For these reasons the spread of forest was, and is probably still, most rapid downhill into forest gaps from highland refugia/ or upland tree outliers and slower uphill (Green 2009).

Even in the current situation where global warming seems likely to occur on a relatively dramatic scale worldwide, the migration of trees remains limited by the dispersal capacity, age of sexual maturity and seedling recruitment requirements of each tree species. *Eucalyptus coccifera* remains absent from northeast and southwest Tasmania despite the prevalence of suitable habitat for the species (Williams and Potts 1996). At most transects monitored for this report, the presence of immature shrubs of *E. coccifera* above the current position of the altitudinal treeline provide points from which *E. coccifera* might be able to establish tree cover relatively quickly in the event of a sustained increase in average summer temperature. Recruitment of seedlings surrounding these trees, especially downhill from them, might reasonably be expected to occur over a longer period since conditions suitable for recruitment may not be immediately available but should improve with the presence of an established tree canopy. The expansion uphill from the existing limit of *E. coccifera* might be expected to be extremely slow since it will be dependent on chance dispersal events uphill.

*Nothofagus cunninghamii* too is likely to increase in height as temperatures increase and radial expansion of its current occupancy can reasonably be expected to occur slowly over time. The movement uphill of the species is likely to be much slower than invasion into treeless patches adjacent and below shrubberies/forest patches in which this species is already present.

Examination of seedling establishment above and below the *Eucalyptus pauciflora* subsp. *niphophila* treeline species in the Snowy Mountains, mainland Australia, in burnt and unburnt sites following the 2003 bushfires revealed that most trees responded by resprouting from lignotubers and seedling establishment was greater in areas below the treeline with relatively little seedling establishment above the treeline in either burnt or unburnt plots (Green 2009). The treeline sites were selected on the basis that there were no mature trees uphill of the treeline at the site and the study was undertaken only five years after the fire. The treeline represented the forestline at these sites since trees averaged a height of 7.5 m. A study by Ferrar et al. (1989) has shown that *E. pauciflora* subsp. *niphophila* is able to establish, grow and produce viable seed at altitudes 200 m above the current treeline where seed is artificially brought to the site. It appears from these studies that the current limit of tree distribution in the Snowy Mountains is a result of the inability of the species to disperse uphill. Estimates by Slatyer (1989) of the rate of treeline movement from natural seed release from trees at the treeline would be about...
three metres per century on a slope of 15 percent. Green (2009) suggests that stochastic dispersal of branches with capsules in strong winds during fires or winter storms may result in the establishment of isolated trees well above the main treeline, but dismisses these events as a major mechanism for treeline movement.

Like *Eucalyptus pauciflora* subsp. *niphophila*, *Nothofagus cunninghamii* and *E. coccifera* in ordinary circumstances have a capacity to disperse their seed only very short distances. Flowering is episodic rather than annual for *N. cunninghamii*, with flowering limited to mast years. Furthermore, it has been observed that the overall productivity of mast years is less in highland areas compared with lowland forests (Read 1999). Dispersal distances for this species are thought to be limited to the distance of one to two times the tree canopy height (Hickey et al. 1982). Sexual maturity is reached within 25 years, suggesting upward migration rates of less than 24 m per century. Chance dispersal events by birds, animal vectors or strong winds are likely to increase the possible migration distances beyond this.

*Eucalyptus coccifera* is also likely to flower only intermittently, with seed production correlating with higher temperatures as observed for other highland eucalypt species (Green 2009). Fire events may result in the chance dispersal of some branches with seed bearing capsules in upward wind currents from the fire fronts. However, for successful recruitment of dispersed seed, suitable conditions for seed germination and recruitment would also be needed, lowering the probability of successful migration of trees further.

Unlike the Snowy Mountains, no tree establishment trials have been undertaken above the treeline in Tasmania. Hence the relative position of the treeline isotherm relative to the current treeline is not known. However, the structural transition of vegetation at all the treelines studied for this project appear to occur over a relatively wide geographic range with a gradual reduction in tree height. Tree growth at the treeline is very stunted in most areas of Tasmania suggesting the species is closer to its limit than on mainland Australia. However, the presence of taller dead trees in the vicinity of the current treeline at the Snowy Range and Mount Rufus may suggest that tree heights have not yet reached their height potential at these locations and so potentially may begin to resemble the more abrupt transition from treeless vegetation to woodland more than seven metres tall reported by Green (2009) for the Snowy Mountains. Certainly the presence of large trees within a short distance of the current altitudinal boundaries at Mount Rufus and the Snowy Range transects suggests that trees have occupied this current ecotone for at least one and probably more than two centuries.

The wide variation in the density and distance of tree saplings above the treeline suggest that there are factors that are inhibiting tree establishment that vary between sites. The greatest density of *Eucalyptus coccifera* saplings appeared to be associated with the more northerly aspects. This may be a result of the inability of these saplings/shrubs to persist in areas of more persistent snow-lie, or may relate to fire history at these sites.

No analysis of shrub cover and height along the ecotone transects was undertaken here but future changes in climate may favour woody shrub growth over herbaceous species, resulting in thickening of treeless communities. These ecotonal transects will provide an opportunity to observe and measure such changes.
6.0 Conclusions

The baseline data collected for this study suggests that the treeline has the capacity to move relatively rapidly in situations where immature saplings are already present above the main treeline. Baseline data collected from the transects reported here, as well as tree mapping and tree distributions observed from aerial photographic data, suggest that the treeline on the Snowy Range is located between 1135 m and 1150 m varying with aspect. At Mount Weld it is located at approximately 1100 m. On Mount Rufus it was at about 1230 m on the northern aspect and 1170 m on the southern aspect.

Large dead trees and stumps were located below the current treelines in all locations suggesting that trees have occupied these sites for hundreds of years. Saplings/shrub forms of tree species were located above the treelines for 50 to 100 m distance above the current treeline, but the potential of these plants to become trees and establish a treeline further above the current one is not clear. The circumferences of shrubs and saplings suggest that the trees have been established above and below the treeline for a long time and are not simply the result of recent (last two to three decades) seedling establishment coinciding with changes in climate observed in Tasmania since 1978.

6.1 Future research possibilities

This treeline monitoring data set requires some additional measurements to complete the existing data set so that it can be fit for the purpose of measuring changes in tree species movement and associated floristic changes in the vegetation community:

1. Photo monitoring is required for the Mount Weld transects.
2. Tree circumference measurements at ground level should be recorded for all trees less than breast height at Mount Rufus and Mount Weld.
3. Absolute percentage cover data for the middle two plots of Climatic Treeline Ecotone Transect on Mount Weld is required to supplement the cover index data recorded in 2000.
4. Further survey work should be undertaken at Mount Weld to establish where the forest line and treeline are with consideration to establishing plots above and below each of these lines if locatable.
5. Further survey work at the Snowy Range is required to confirm the location of the forestline.
6. Further survey work at Mount Rufus is required to confirm the location of the tree species line for all transect areas.
7. Establishing some temperature and other climatic monitoring such as soil and air temperatures along the transect lengths, the forestline and tree species line, in order to determine the relative differences in temperatures between plots and transects.
8. Consider establishing a long term temperature data logger/weather station at one of the sites (eg. Snowy Range) that can be used to measure variation of temperatures at the treeline.
9. In addition to what has been collected, additional tree mapping in the vicinity of all transects may be useful.
10. The likely age of saplings with distance along the transect might be surmised by cutting sample stems in an adjoining area to see if establishment is random, sequential with youngest plants at the highest altitudes and oldest plants at the forestline, or appears to be associated with particular events (eg. following fire).

Given the likelihood that movement of the treeline is likely to be slow, repeated monitoring events could be spaced by relatively long time intervals (10 to 20 years). However a check of the transects after five years from the date of establishment may be warranted to take photographs and check stakes and labels, replacing rusted posts if necessary. Consideration should also be given to a partial remeasurement of one south and one northern transect at Mount Rufus, one transect at the Snowy Range and one transect at Mount Weld at five years after establishment. This would assist in determining if there is any evidence that shrub cover and height is increasing at the expense of herbaceous species.
Other research that might complement the treeline monitoring transects already established would include an analysis of a time series of aerial photography and detailed digital photography to determine if the limit of the treeline or forestline can be detected over time and to map the extent of fire damage caused by the most recent fire in older aerial photographs when the damage was fresher and more obvious. High resolution digital photographic monitoring should be investigated for its potential to monitor other aspects of alpine community floristics and structure.

At Mount Weld, Lidar data coverage taken for the Warra LTER site should be investigated to determine if it can be used to verify the location of the altitudinal treeline on Mount Weld.

Consideration should also be given to undertaking some dendrochronology work to analyse the change in tree growth rates in the forest, at and below the current treeline, to determine if there has been a change that might be coincident with climate change. Such a study could compare several different altitudes and aspects to determine any patterns in changes to growth rates that might be present. Tree growth rates with age would need to be considered. Studies in Switzerland revealed a dramatic increase in recent growth rates and provides a model for such a study (Paulsen et al. 2000).

Doran et al. (2003) noted that climate change might result in range shifts at the boundary between montane forest and the subalpine woodland/forest (~900 m ASL) where there is a sharp increase in the number of species typical of alpine vegetation and a marked increase from typically species poor lowland forests to relatively rich subalpine communities. This boundary is thought to be associated with the average position of cloud base, a location that is likely to shift with climate change. Consideration to establishing monitoring across this ecotone on roaded slopes such as Hartz mountain, Mount Field, or Ben Lomond could be considered as part of a biodiversity monitoring strategy.

More targeted monitoring surveys are also required within the alpine zone to determine if highly valued communities such as cushion moorlands and snow patch herbfields are changing in species composition. Of particular value would be monitoring communities dominated by relatively rare alpine obligate species such as *Phyllachne colensoi* cushion communities, which are possibly the most vulnerable to increasing temperature and competition.

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### 8.0 References


