Establishment Report for Tasmanian Wilderness World Heritage Area
Climate Change Monitoring Program

Montane Conifers
Pencil pine \((\text{Athrotaxis cupressoides})\)
King Billy pine \((\text{Athrotaxis selaginoides})\)
Dwarf pine \((\text{Diselma archeri})\)
Drooping pine \((\text{Pherosphaera hookeriana})\)

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Montane Conifer Monitoring Program Summary

Responsible officer
Jennie Whinam (Senior Ecologist, Resource Management and Conservation, DPIPWE)

Project team
Jennie Whinam (Senior Ecologist, Resource Management and Conservation, DPIPWE)
Nick Fitzgerald (Project Officer, Resource Management and Conservation, DPIPWE)
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Species targeted for monitoring
Pencil pine (*Athrotaxis cupressoides*)
King Billy pine (*Athrotaxis selaginoides*)
Dwarf pine (*Diselma archeri*)
Drooping pine (*Pherosphaera hookeriana*)

Adjunct species recorded by the monitoring program
Hybrid pencil pine (*Athrotaxis X laxifolia*)
Creeping pine (*Microcachrys tetragona*)
Mountain plum pine (*Podocarpus lawrencei*)
Huon pine (*Lagarostrobos franklinii*)
Deciduous beech (*Nothofagus gunnii*)

Aims/objectives of monitoring program
1. Using a field observation protocol, determine the condition (condition status) of four endemic cool-climate conifer species: *Athrotaxis cupressoides*, *A. selaginoides*, *Diselma archeri*, *Pherosphaera hookeriana*.
2. Develop a long-term (multi-decadal) monitoring program to test whether the condition, distribution and extent of these species is changing at the stand scale to landscape scale.
3. Determine if there is demographic change in *Athrotaxis* species.

Justification/rationale/drivers for monitoring
The four conifer species have been chosen for monitoring because of observed dieback in some populations of *Athrotaxis* species and *D. archeri* and because of concerns about the vulnerability of *P. hookeriana*. In order to achieve an effective monitoring program given available resources it is better to target a subset of montane conifers rather than trying to establish adequate monitoring sites for all species. These other species (*Microcachrys tetragona* and *Podocarpus lawrencei*) are considered a lower priority since they are rarely dominant in montane communities.
**Athrotaxis** are iconic species which represent Tasmania’s Gondwanan history and are the dominant trees (keystone or foundation species) of unique and distinctive vegetation communities.

Conifer species have been identified as priority taxa for monitoring climate change impacts in the Tasmanian Wilderness World Heritage Area (TWWHA) on the basis of several criteria including endemism, iconic species, keystone/dominant species (Brown 2010). That report also identifies coniferous shrubberies as a priority alpine community for ground-based monitoring.

Monitoring conifers addresses some of the key research areas identified in ‘TWWHA Research Needs for Management 2007-2012’ (DPIW 2007).

This project will also contribute to recovery actions identified in the Threatened Flora Listing Statement for *Pherosphaera hookeriana* (TSS 2009).

All six vegetation communities dominated by *Athrotaxis* are listed as Threatened Native Vegetation Communities under Schedule 3A of the Tasmanian *Nature Conservation Act 2002*.

More details and specific recommendations from the above reports are provided in Appendix 1.

**What parameters are monitored?**

The condition of conifers is monitored using observations of apical dieback and a general condition score, ranging from 1 (dead) to 4 (healthy). For trees (*Athrotaxis* spp.), observations relate to individual, relocatable trees. For shrubs, a single assessment is made for all individuals of a species in the plot area. Reproduction and recruitment is monitored by observing cone production and presence of immature plants. Other relevant factors such as disease and browsing damage are observed.

**How will monitoring information be used by management?**

Incidences of dieback identified by the monitoring should be investigated to determine likely causes and appropriate management responses. Monitoring will inform climate change adaptation measures, e.g. ex situ conservation, translocation, grazing mammal exclosures.

This information will contribute to prioritisation of conifer sites for fire protection in the PWS Bushfire Risk Assessment Model (e.g. conifer vegetation displaying resilience to climate change may be a higher priority than sites declining in health).

**Year monitoring started**

2011 (January-June).

**Year monitoring completed**

Ongoing.

**Geographical extent of survey**

Central Highlands and southwest Tasmanian mountains, from Black Bluff in the north to the Southern Range in the south, from Mt Read in the west to Mt Field and Pine Lake in the east (Figure 1, Table 1).

IBRA V bioregions: Central Highlands, Southern Ranges, West.
Figure 1. Conifer monitoring locations.

Extent of Tasmanian populations covered by survey
Approximately half of the major populations for each species, with a particular focus on the most significant populations (largest populations, best examples of the vegetation community, geographic range limits).

Frequency of survey
Decadal (every ten years).

Timing of survey
Ideally January to March, subject to weather.
Table 1. Conifer species monitored at each location.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>CODE</th>
<th>A. cupressoides</th>
<th>A. selaginoides</th>
<th>D. archeri</th>
<th>P. hookeriana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Bluff</td>
<td>BB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cradle Plateau</td>
<td>CP</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Cradle Valley</td>
<td>CV</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Central Plateau – Pine Lake/ Mickeys Creek</td>
<td>PL/MC</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Great Western Tiers – Lake Mackenzie</td>
<td>LM</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Great Western Tiers – Mount Ironstone</td>
<td>MI</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Mt Anne – North East Ridge</td>
<td>MA</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Mt Field – Mawson/ Tarn Shelf</td>
<td>MF</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Mt Read</td>
<td>MR</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Southern Range</td>
<td>SR</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Walls of Jerusalem</td>
<td>WJ</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Source of funding for program

Commonwealth Government through World Heritage Area funding arrangements.

Are other organisations, community groups involved in the monitoring program?

University of Tasmania (School of Plant Science) – Field Botany classes to undertake annual monitoring of Athrotaxis at Mt Field; also Dr Tim Brodribb undertaking complementary research on ecophysiological limits of Tasmanian conifers.

Earthwatch Institute – operates ClimateWatch website which features A. cupressoides and A. selaginoides as target species for which the public can submit observations on condition and phenology. Species profiles and observation types have been devised by DPIPWE to support the Montane Conifer Monitoring Project. Data will be managed by Earthwatch and available to researchers via the Atlas of Living Australia.

Interest groups (e.g. field naturalists groups, Australian Plants Society, bushwalking clubs) encouraged to participate in ClimateWatch project.
Break-down of resources required to undertake all aspects of the monitoring program

**Field Surveys**
- RMC staff X2 (or 1 staff plus 1 volunteer): 60 person days (30 days fieldwork)
- Helicopter travel is useful for access to Mt Anne and Southern Range sites
- Helicopter or fixed-wing aircraft for aerial transect at Mt Anne
- Accommodation for approx. 10 nights; plus camping of 9 nights
- RMC vehicle: 30 days

**Equipment**
- GPS
- digital SLR camera
- laser rangefinder
- compass
- mensuration (diameter) tape
- camera post and sighting post (each 1.5m plastic conduit)
- satellite phone
- first aid kit
- clothing and camping equipment for remote area work

**Field work planning and coordination**
RMC staff: 1 person for 5 days

**Data entry, analysis and reporting**
RMC staff: 1 person for 5 days

**Statistical advice**
RMC staff or external expert: 1 day

**Aerial photography or satellite image analysis**
RMC staff or external expert: 10-30 days

**Key stakeholders**
- Tasmanian Government – DPIPWE
- Land managers (Tasmanian Parks and Wildlife Service, Forestry Tasmania)
- TWWHA Consultative Committee
- University of Tasmania (School of Plant Science)
- ClimateWatch (Earth Watch Institute)

**Project methods**

**Permanent monitoring plots**

For trees (*Athrotaxis* spp.), a variation on the point-centred quarter method (PCQM) is employed. This involves permanently marking a centre-point with an aluminium stake and sampling the nearest three *Athrotaxis* individuals over 2 metres tall in each quarter defined by cardinal points of a compass (i.e. NE, SE, SW, NW quadrants).
**Athrotaxis** sampling involves recording the following details for each tree:

- distance and direction from marker post to centre of stem (or centre of cluster for multi-stemmed individuals; to base of trunk for leaning trees),
- DBH at 1.3 metres for each stem trunk,
- chlorosis or death of apical foliage (present/absent),
- overall condition score:
  1. dead
  2. very unhealthy (e.g. >50% foliage brown or lost)
  3. mostly healthy (may be some browning and thinning of foliage)
  4. very healthy (minimal browning and loss of foliage)
- cones (absent, present on <50% of branches, present on >50% of branches, note if from last season),
- other observations (e.g. fungal infection, insect attack, browsing damage).

For coniferous shrubbery, 10x10 metre permanent plots are marked out using four aluminium stakes. For each conifer species present the following variables are recorded:

- average and maximum height,
- projected foliage cover (Braun-Blanquet scale),
- overall condition score:
  1. dead
  2. very unhealthy (e.g. >50% foliage brown or lost)
  3. mostly healthy (may be some browning and thinning of foliage)
  4. very healthy (minimal browning and loss of foliage)
- cones (absent, present on <50% of branches, present on >50% of branches),
- recruitment (none, seedlings, suckers, indeterminate),
- other observations (e.g. evidence of browsing or disease).

**Site description for each plot:**

- easting/northing of centre-post (for tree plots) or north-east corner post (for shrubbery plots),
- elevation,
- slope and aspect,
- landform,
- geology,
- TASVEG community,
- fire history,
- vegetation structure and floristics (height, percentage cover and dominant species for each stratum),
- details of photographs.

**Permanent photo-points and historical photography**

Permanent photo points have been established at conifer monitoring plots.

A 1.5 metre length of plastic conduit (comprising 1 m and 0.5 m lengths and a joiner) is used as a camera post to position the camera, while another 1.5 m post with a reflective disc attached is used as a sighter post (see Photo 1).

For **Athrotaxis** plots, the camera post is placed at the plot centre-post at a height of 1 m or 1.5 m and the sighter post is positioned on a permanent 0.2 m sighter peg marker post.
For coniferous shrubbery plots, each corner post is used as a photo-point with the sighter post located at the diagonally opposite corner, resulting in four views (NE, NW, SW, SE).

For each photo-point, the camera is positioned on top of the sighter post and aligned so that the sighting disc is in the centre of the viewfinder, then 3 bracketed exposures are made (typically an auto-exposure bracketed 2/3 stop either side, but the correct exposure and bracketing range will depend on conditions as determined in the field). While it is not essential to use the same lens, it is preferable for consistency to use a lens with a field of view equivalent to 20 mm focal length on a typical digital SLR (Focal Length Modifier of 1.6, i.e. equivalent to a 32 mm lens on a 35mm film camera).

**Photo 1.** Example of a photo-point in king billy pine subalpine scrub. Note the temporary sighting post.

Historical photographs showing montane conifers have been collated from various sources and archived as scanned images. These will provide an opportunity to relocate and rephotograph some of these scenes to investigate historical change in conifers.

**Aerial photography or satellite image analysis**

Visual assessment of time series of aerial photographs will record presence of dieback and change in extent of conifer vegetation for select sites.

Locations of monitoring sites are detailed in Appendices 3 and 4.

**Limitations or critical issues relating to the project methods**

Field assessment of plant condition is necessarily subjective and is prone to observer bias. This can be compounded by situations where differences in appearance do not necessarily indicate poor health, due to factors such as senescence, weather damage and atypical growth habits. Measures to reduce the potential bias include: using a simple scale with only four categories, clearly defining the categories,
reference photographs of conifers in each condition category in different situations, assigning scores based on consensus among two or three field workers.

Data analysis

Permanent monitoring plots

Trees will be classified into size classes based on DBH. The data collected will allow analysis of total basal area/percentage live basal area for trees.

Sites can be classified according to environmental factors such as elevation, geology or drainage class.

Tree condition characters and recruitment can be analysed statistically in relation to environmental variables and stand structure.

Permanent photo-points and historical photography

Visual assessment of time series photographs will determine changes in stand density and condition over time. These will be recorded as: increase, decrease, or no change. This dataset will allow statistical analysis of spatial and temporal change in conifer condition.

Aerial photography or satellite image analysis

Visual assessment of time series of aerial photographs will record presence of dieback and change in extent of conifer vegetation for select sites. This dataset will allow statistical analysis of spatial and temporal change. Alternatively, or additionally, satellite image analysis methods may be employed to determine presence of dieback and change in extent of conifer vegetation.

Oblique aerial photography using a handheld digital camera has been trialled at Mt Anne and will be repeated opportunistically. This technique should be employed in other locations to provide a time series of high resolution images of conifer vegetation, particularly for A. selaginoides rainforest in inaccessible terrain.

Has statistical advice been provided?

Advice on experimental design from Dr Mick Brown.

Are there metadata descriptions of databases?

No.

Where is the data stored?

Original data sheets from monitoring plots are stored in the RMC office. Digital data and reports are stored on the RMC server:

\RMC_Resources\BCO_Biodiv_Conser\VCS_Vegetation\Montane_Conifer_Monitoring

Photographs are stored on the RMC server:

\RMC_Images\Vegetation\Photo Monitoring\conifer monitoring

Aerial photographs are stored on the RMC server:

\RMC_Images\Vegetation\Aerial photography\Montane conifer sites 1-5000 photos
How will the results of monitoring be made available to stakeholders?

A report will be prepared following each full monitoring season (every ten years, unless modified) and made available publicly via the DPIPWE website. Reports will be provided to the World Heritage Area Consultative Committee. Data will be made available to stakeholders upon request.

Where are reports stored?

Digital versions of reports are stored on the RMC server: \RMC_Resources\BCO_Biodiv_Conserv\VCS_Vegetation\Montane_Conifer_Monitoring

Have the results of the monitoring been published?

No, but it is intended to publish a preliminary analysis of the data in 2012


Yes. Note that under the Lake Johnston Nature Reserve Management Plan 1999 permission from PWS is required for access to some monitoring sites within the restricted area at Mount Read.

Have the survey data and methods been subject to independent review?

The monitoring methods have been reviewed by Dr Mick Brown.

Have other forms of monitoring been considered for these species?

Monitoring methods decided upon after extensive research.

Prepared by: Nick Fitzgerald

Project Officer – Vegetation Conservation

................................................................. (Signature)  .................... (Date)

Approved by: ................................................................. (Name)

................................................................. (Position)

................................................................. (Signature)  .................... (Date)
Montane Conifer Monitoring Scientific Program

Background

Tasmania’s Montane Conifers

Conifers have a long evolutionary history in Tasmania, with fossilised Gondwanan taxa closely related to extant species. A dramatic decline in the extent, diversity and dominance of Australian conifers during the Tertiary coincides with increasing aridity in this period, with many of the relictual species now restricted to Western Tasmania, which is a refugium for conifers (Jordan 1995). Eight of Tasmania’s ten native conifers are relictual species confined to rainforest and alpine habitats. Montane rainforests and coniferous heaths are the best exemplar of Tasmania’s unparalleled primitive southern hemisphere flora (Balmer et al. 2004).

Amongst the regional conifer assemblages in Australia, Tasmania’s cool temperate conifer flora is notable for its diversity and endemism, however it is lower in species richness than New Zealand and New Caledonia (Enright & Hill 1995). Amongst global conifer floras Tasmania has the equal highest level of endemism at the generic level, with four out of eight genera endemic (Contreras-Medina & Vega 2002 report an endemism rate of 37.5% however subsequent taxonomic work places Lagarostrobos as a Tasmanian endemic genus which makes the endemism rate 50%). On the basis of biogeographic criteria, Contreras-Medina et al. (2001) identified Tasmania as one of five global hotspots of conifer diversity.

Most Tasmanian conifers exhibit physiological drought intolerance (Brodribb & Hill 1998) and are extremely fire sensitive (Gibson et al. 1995). Life history traits including longevity, slow growth rates and poor dispersal ability provide limited capacity to respond to environmental change, especially rapid or widespread change as in the case of current and predicted climatic trends. These relictual conifers are therefore confined to cool, wet climates and within this climatic niche they are severely restricted due to inability to disperse to suitable sites, including areas where local extinction has been caused by fire in the past (Cullen & Kirkpatrick 1998a). Climate change is expected to result in range contractions for Athrotaxis as montane zones shrink and fires increase (Cullen & Kirkpatrick 1988a).

Fire is the greatest threat to montane conifer vegetation (Balmer et al. 2004; Kirkpatrick et al. 2010). Although coniferous taxa have survived millennia of environmental change they are likely to be particularly vulnerable to current trends due to their present limited geographic distribution, the high and likely increasing incidence of fire in the landscape and the particularly rapid rate of climatic change expected during this century and beyond (Grose et al. 2010; Kirkpatrick et al. 2010).

Species Descriptions

Characteristics of the targeted montane conifers are summarised in Table 2. Despite confusion about the status of Athrotaxis Xlaxifolia, having been considered a separate species in the past, it has been confirmed as a naturally occurring hybrid (Isoda et al. 2000).

The non-target conifers Podocarpus lawrencei (mountain plum pine) and Microcachrys tetragona (creeping pine or strawberry pine) are typically sub-dominant or understorey species with a prostrate growth habit in coniferous heath or subalpine forest. Podocarpus may grow as a large shrub in sheltered locations such as lowland riverbanks and is occasionally dominant in coniferous heath on
Table 2. Characteristics of montane conifer taxa.

<table>
<thead>
<tr>
<th>Name</th>
<th>Common Name¹</th>
<th>Family</th>
<th>Reproductive system</th>
<th>Seed production</th>
<th>Seed dispersal</th>
<th>Vegetative reproduction</th>
<th>Seedling requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Athrotaxis cupressoides</strong></td>
<td>Pencil pine</td>
<td>Cupressaceae</td>
<td>Monoecious</td>
<td>Mast, 5 or 6 yearly²</td>
<td>&lt;9m²</td>
<td>Common, suckers &gt;50m from parent²</td>
<td>Moist site, high light levels²</td>
</tr>
<tr>
<td><strong>Athrotaxis Xlaxifolia</strong></td>
<td>Hybrid pencil pine</td>
<td>Cupressaceae</td>
<td>Monoecious</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td><strong>Athrotaxis selaginoides</strong></td>
<td>King Billy pine</td>
<td>Cupressaceae</td>
<td>Monoecious</td>
<td>Mast, 5 or 6 yearly²</td>
<td>~100m by wind⁴</td>
<td>Yes⁷</td>
<td>Site (or period)without extreme frosts, moderate light levels⁵</td>
</tr>
<tr>
<td><strong>Diselma archeri</strong></td>
<td>Dwarf pine</td>
<td>Cupressaceae</td>
<td>Dioecious</td>
<td>Unknown. Germinates readily³</td>
<td></td>
<td>No?⁷ (but needs further study)</td>
<td></td>
</tr>
<tr>
<td><strong>Pherosphaera hookeriana</strong></td>
<td>Drooping pine</td>
<td>Podocarpaceae</td>
<td>Dioecious</td>
<td>Annual seed prod⁴, low to medium viability, apparent deep dormancy, limited germination in trials³⁶</td>
<td>Wind, water, possibly birds⁶</td>
<td>Layering, apparently main form of recruitment⁶</td>
<td>Moist, shady sites⁶</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Altitudinal range⁷</th>
<th>Pathology</th>
<th>Endemism</th>
<th>Height (metres)⁷</th>
<th>Max DBH (cm)⁷</th>
<th>Diameter increase (mm/yr)</th>
<th>Longevity (years)</th>
<th>Conservation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Athrotaxis cupressoides</strong></td>
<td>600-1360</td>
<td>Pine Lake dieback (agent?)</td>
<td>W Tas (at genus level)</td>
<td>30</td>
<td>150</td>
<td>0.02-2.87</td>
<td>1300</td>
<td>W Tas (at genus level)</td>
</tr>
<tr>
<td><strong>Athrotaxis Xlaxifolia</strong></td>
<td>900-1200</td>
<td>W Tas (at genus level)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td><strong>Athrotaxis selaginoides</strong></td>
<td>20-1300</td>
<td>W Tas (at genus level)</td>
<td>&gt;40</td>
<td>220</td>
<td>0.4-5.0</td>
<td>1300</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diselma archeri</strong></td>
<td>1000-1400</td>
<td>Cankers (<em>Pseudophacidium diselmae</em>)⁸</td>
<td>W Tas (at genus level)</td>
<td>4 (&gt; 10m at Mt Read⁹)</td>
<td>30 (&quot;60 at Mt Read⁹)</td>
<td>549</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pherosphaera hookeriana</strong></td>
<td>1000-1400</td>
<td>W Tas (at species level)</td>
<td>2-3⁷</td>
<td>?</td>
<td>unknown</td>
<td>Vulnerable (TSPA)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

boulderfields. Unlike the target species, they both have bird-dispersed seed. Both are in the Podocarpaceae. *Podocarpus* is the only montane conifer not endemic to Tasmania. *Lagarostrobus franklinii* (Huon pine) is another Tasmanian endemic in the Podocarpaceae, it is a lowland species only known from one montane site at Mount Read, where it is subject to a photo-point monitoring program described in a separate Establishment Report.

### Palaeobotany

*Athrotaxis* has a long evolutionary history with a Gondwanan distribution, as evidenced by the fossil record from Tasmania, New Zealand and South America. The oldest *Athrotaxis* fossils, *A. ungeri* from Argentina, date from the late Jurassic/early Cretaceous (around 150 Million years) and are similar in appearance to *A. cupressoides* (Hill & Brodribb 1999). DNA evidence of evolution in the Cupressaceae supports the ancient origins of *Athrotaxis*; indeed the genus is possibly a Pangaean relict (Balmer et al. 2004). In the past, the genus was more widespread and diverse (Hill 1995).

In Tasmania, macrofossils of extinct *Athrotaxis* and *Microstrobos (= Pherosphaera)* species date back at least 45 million years and *Athrotaxis* fossils are relatively common from 35 million years, when rainforests were extensive across Australia (Hill & Brodribb 1999). Macrofossils virtually identical to *Pherosphaera hookeriana* date from the Early Miocene (circa. 20 Mya) at Monpeelyata on the Central Plateau (Macphail 2007). Fossil pollen from this genus suggests it was a dominant of heath or scrub in a mild humid climate on the West Coast in the Late Pliocene (circa. 2 Mya) (Macphail et al. 1995). The fossil record indicates that this genus occupied a much wider climatic range in the past, including lowland rainforest habitats, with a relatively recent contraction to cooler sites (Hill 1990).

Palynological evidence shows that conifers were more diverse, widespread and common in Australia in the past (Macphail 2007). Diverse rainforests in which gymnosperms were prominent occurred in southeast mainland Australia 1.5 million years ago (Sniderman 2011). Contraction and fragmentation of the previously widespread and diverse Gondwanan rainforest flora coincides with increasing aridity and climatic variability since the Eocene (Byrne et al. 2011). This is reflected in a dramatic decline in the extent and diversity of conifers across Australia, including *Athrotaxis*, over the past c. 35 million years. Physiological drought intolerance in most extant southern hemisphere conifers suggests that moisture availability is a key factor controlling their distribution (Brodribb & Hill 1998). *Athrotaxis* species are well suited to colder glacial and interstadial climates (Cullen & Kirkpatrick 1988a).

The fossil record from western Tasmania shows a decline in conifer diversity from a peak in the Tertiary, although many taxa persisted until the Early Pleistocene, with a subsequent loss of several genera during the Pleistocene most likely caused by drought during glacial periods (Jordan 1995). Rainforests in Tasmania have declined since a warmer, more humid period 5000 to 8000 years before present (Macphail 1979).

### Distribution and Floristics

Rainforest and alpine vegetation communities dominated by conifers cover less than 1% of Tasmania’s land area (Figure 2). These communities are internationally significant due to their primitive flora and Gondwanan affinities (Balmer et al. 2004).

King Billy pine (*Athrotaxis selaginoides*) and pencil pine (*A. cupressoides*) are the dominant species of coniferous rainforest. The statewide vegetation mapping scheme, TASVEG, recognises six rainforest communities dominated by *Athrotaxis* species and one alpine treeless community characterised by the
dominance of conifers: highland coniferous heathland (Harris & Kitchener 2005). These mapping units are predominantly contained within formal reserves (94.2 %), with more than 75% of their extent within the Tasmanian Wilderness World Heritage Area (Table 3). The subalpine and alpine conifer communities are almost entirely contained within the TWWHA, with 97.5% of pencil pine forest and 92.5% of coniferous heath, compared to only 58.5% of living king billy pine forest, much of which occurs to the west of the TWWHA, particularly in the West Coast Range. Mining is permitted in some of the reserves outside of the TWWHA, including where major populations of A. selaginoides occur in the West Coast Range.

Another community, highland rainforest scrub with dead A. selaginoides, is characterised by dead stags of Athrotaxis, but since seedlings and surviving adults of Athrotaxis are rare or absent in this community it is not considered conifer-dominated. Vegetation mapping for the TWWHA (unpublished hard copy maps at DPIPWE) does identify dead and fire damaged stands of pencil pine however these mapping units were not incorporated into TASVEG. The other conifer-dominated TASVEG community in the TWWHA, Lagarostrobos franklinii rainforest and scrub, is primarily riparian at low elevations and is not considered here.

Table 3. Reservation of montane conifer communities (data from TASVEG 2.0 and CAPAD06).

<table>
<thead>
<tr>
<th>VEGCODE</th>
<th>TASVEG community</th>
<th>Total extent (Ha)</th>
<th>Extent in TWWHA (ha)</th>
<th>% in TWWHA</th>
<th>Other formal reserves (Ha)</th>
<th>% in other formal reserves</th>
<th>Unreserved (Ha)*</th>
<th>% unreserved</th>
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<td>6212</td>
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<td>849</td>
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<td>184</td>
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<td>53.2</td>
<td>5942</td>
<td>31.1</td>
<td>2233</td>
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<tr>
<td>RKS</td>
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<td>5757</td>
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<td>6.4</td>
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<td>4172</td>
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<td>9522</td>
<td>16.1</td>
<td>2542</td>
<td>4.3</td>
</tr>
</tbody>
</table>

* ‘unreserved’ is all land tenures outside of legislated formal reserves (i.e. IUCN categories I-VI) and therefore includes ‘informal’ reserves


Athrotaxis selaginoides occurs on a wide range of geological substrates including dolerite, sandstone, mudstone, limestone, quartzite, conglomerate, Mt Read volcanics and glacial till (Cullen & Kirkpatrick 1988c; Kirkpatrick & Harwood 1980). The distribution of A. selaginoides individuals and communities has been comprehensively mapped (e.g. Brown 1988; Felton et al. 1991; TWWHA vegetation mapping project; TASVEG). King billy pine has a broader elevation and latitude range than pencil pine (Figure 3).
Pencil pine forest reaches its best development in unburnt parts of the Walls of Jerusalem and Traveller Range in the western part of the Central Plateau where an open canopy of large *A. cupressoides* occurs over either an open understorey with groundcover of *Poa* or *Gleichenia*, or a dense shrubby understorey of *Nothofagus gunnii* (Corbett 1995). In the northern part of the Plateau, pencil pine forest is more localised and typically occurs on boulderfields with a distinctive heathy understorey (Corbett 1995). Both *A. cupressoides* and *A. selaginoides* occur as small stands and isolated individuals on the northern scarp of the Central Plateau, particularly along creeks.
Figure 3. Distribution of the four montane conifer species targeted for monitoring, with bioregion boundaries (IBRA 5) and TWWHA shaded. Records from Natural Values Atlas as at October 2010 (only records post-1950 and with better than 1 km spatial accuracy shown).
Hybrids generally occur as isolated individuals, and their rarity compared to parent species may be due to selective pressures or pollen swamping, however apparent hybrid swarms occur in at least two locations (Jordan et al. 2004).

Dwarf pine (*Diselma archeri*) is the major dominant of coniferous alpine heath. Drooping pine (*Pherosphaera hookeriana*) also occurs in coniferous heath but has a more limited distribution, being confined to around 20 populations and listed as vulnerable in Tasmania (*Threatened Species Protection Act 1995*) due to the risk of local extinction by fire and potential sensitivity to climate change (Threatened Species Section 2009). Both genera are endemic to Tasmania’s southwest and highlands (Figure 3). Other key species are mountain plum pine (*Podocarpus lawrencei*), which may be the dominant species of coniferous heath on block streams, and creeping pine (*Microcachrys tetragona*) (Harris & Kitchener 2005).

*Diselma* is a small dense shrub generally under 2 metres tall and occasionally to 3 to 4 metres in sheltered sites on the Central Plateau (Corbett 1995). There is a small atypical population of this species at Lake Johnston where it occurs as a tree reaching heights of over 10 metres with DBH up to 45.5 cm.

The majority of conifer vegetation and the best examples occur within the Tasmanian Wilderness World Heritage Area, except for *Pherosphaera hookeriana* which has major populations in Mount Field National Park.

Drought conditions in the past, with possibly more extreme cold arid conditions in the northeast than other highland areas, may be responsible for the paucity of montane conifers in the North East Highlands, with only highly localised populations of the bird-dispersed *Podocarpus lawrencei* being present (Davies 1996). However bioclimatic modelling suggests that the North East Highlands are presently climatically unsuitable for *A. selaginoides* (Read & Busby 1990).

**Biogeography and Ecology**

*Athrotaxis* species are well adapted to the prevailing cool climatic conditions during the Quaternary, however they are poorly adapted to recent environmental impacts such as logging, increased fires and grazing by exotic herbivores; indeed it would take thousands of years for *Athrotaxis* species to reoccupy areas from which they have become extinct in the past 200 years (Cullen 1987a).

The treeline in temperate regions is related to temperature in the growing season (Richardson & Friedland 2009). However in Tasmania it is poorly defined due to influences of factors such as soil and topography and relatively subtle environmental gradients, resulting in often gradual transitions from forest to shrubland (Kirkpatrick 1982). King billy pine short rainforest and scrub occur in this transition zone between subalpine forest and alpine treeless vegetation. *Athrotaxis* can survive well above the apparent treeline as evidenced by individuals growing as low shrubs in the alpine zone. Inverted treelines associated with cold air drainage are more distinct than the alpine treeline and these can be seen in the abrupt transition from pencil pine forest to treeless grassland or heathland.

Pencil pine is confined to montane environments and often occurs at sites where other tree species are excluded by cold temperatures or frosts. The lower distributional limits seem to be determined by inability to compete with other rainforest tree species including *A. selaginoides* (Cullen & Kirkpatrick 1988a).

Seed production is episodic in both species, with synchronous mast seeding every 5 or 6 years (Cullen & Kirkpatrick 1988b). Seed dispersal is generally very limited and is comparable to vegetative dispersal for
A. cupressoides, with suckers occurring more than 50 metres from the parent plant (Cullen & Kirkpatrick 1988b). Recruitment of A. cupressoides occurs preferentially in damp locations such as Sphagnum bogs and does not occur under closed rainforest canopy. Long-term recruitment failure (dating back at least until the first half of the 19th century) of A. cupressoides on the Central Plateau in open grassy montane rainforest is apparently due to grazing pressure from wallabies and rabbits, possibly due to the removal of top order predators (Cullen & Kirkpatrick 1988b).

A. selaginoides is less reliant on vegetative reproduction and appears to be more shade tolerant than A. cupressoides (Cullen & Kirkpatrick 1988c). Drought sensitivity and infrequent seed production in Athrotaxis selaginoides combined with relatively slow growth compared to other rainforest trees would limit its ability to colonise disturbed sites, requiring a combination of good seedfall and moist conditions (Read 1989).

In mature rainforest, Athrotaxis selaginoides relies on canopy disturbance for regeneration with seedling recruitment confined to gaps caused by treefalls or landslides, although stand structure can appear to be more-or-less even aged due to prolonged recruitment period and slow growth rates (Cullen 1991). Self thinning is evident with dead and severely suppressed individuals in the 20-50 cm DBH size class (Cullen 1987b). Tree size can be variable within an age class and growth rates appear to decline in response to intense competition as stands undergo self thinning (Kirkpatrick & Harwood 1980). Continuous recruitment of A. selaginoides occurs in implicate rainforest or subalpine scrub where the understory is typically dominated by Nothofagus gunnii (Cullen 1987b).

Growth rates for Athrotaxis are slow but variable, with diameter increment of A. selaginoides ranging from 0.4 mm/yr for krumholz shrubs at 1100 metres elevation (Ogden 1978) to over 5 mm/yr (Cullen 1987b). Ogden (1978) reports that the average age of one metre tall individuals at Mount Field is 42 years for A. selaginoides and 55 years for A. cupressoides, while krumholz A. selaginoides under two metres tall on Mount Read are around 500 years old. Growth rates of A. selaginoides are slower than or comparable to co-occurring angiosperm trees and light requirements are higher (i.e. larger canopy gap needed for establishment in closed forest) (Read 1995). However the greater height and longevity of A. selaginoides compared to other rainforest canopy trees appears to allow this species to maintain dominance even if recruitment opportunities are very infrequent.

Although A. selaginoides is capable of massive recruitment following a disturbance provided there is a seed source, fire can be devastating since this species “is poorly adapted to this form of disturbance and is at a selective disadvantage under frequent or widespread fire regimes because of its long seedling phase and poor seed dispersal” (Cullen 1987b). Of the approximately 50,000 ha of A. selaginoides forest mapped in the 1980s, nearly one-third had been killed by fire (particularly during the 1880s on the West Coast and the 1915 and 1934 fires in the south) plus localised destruction due to mining, logging and drought (Brown 1988). Using a different mapping scheme, TASVEG identifies 8,600 ha of burnt A. selaginoides compared to 28,627 ha of living forest (i.e. nearly one-quarter of the mapped extent is fire-killed). Extensive logging of A. selaginoides occurred in places, such as the Dundas region, and the species was still subject to logging in Western Tasmania in the early 1980s (McMurray 1982).

All of the montane conifer species are readily killed by fire as are their seeds; and Athrotaxis species, Pherosphaera and Diselma have poor seed dispersal (Kirkpatrick & Dickinson 1984). In some circumstances recovery of conifer species can begin within two decades of a fire, particularly for Microcachrys and Podocarpus which have bird-dispersed seed. Palynological profiles provide strong
evidence for local extinctions of conifer species due to fire and reoccupation has not occurred after thousands of years in some cases (Cullen & Kirkpatrick 1988a; Kirkpatrick & Dickinson 1984). Even on burnt sites with adjacent unburned conifer vegetation it appears to take centuries for conifers to return to their pre-fire cover by seedling establishment and lateral vegetative growth (Kirkpatrick et al. 2010). If a single fire can remove a species and seed dispersal is not sufficient for recolonisation it would be expected that fire-sensitive poorly-dispersed taxa would be absent from many suitable habitats even with extremely low incidence of fire. The present distribution of montane conifers supports these theories. For example, it is unlikely that coniferous heath has occupied the southeast part of the Central Plateau in the past 10,000 years (Corbett 1995). Podocarps with bird-dispersed seed have an advantage in rapidly changing environments such as migration to and from refugia during glacial cycles (Barker 1995).

Fires burnt around two-thirds of the Central Plateau in 1961 and there has been virtually no regeneration of conifers in areas of burnt coniferous heath or pencil pine forest, resulting in the distribution of coniferous heath contracting 2 to 3 km to the west and pencil pine forest up to 5 km west (Corbett 1995). Fires burnt one-third of the area of A. cupressoides on the Central Plateau between 1960 and the 1980s and there is little prospect of recolonization even in the extreme long term (Cullen & Kirkpatrick 1988a). Relatively small-scale landscape features such as Carex fens can protect remnant stands of pencil pine from fire (Corbett 1995).

Montane conifer communities contain a high proportion of endemic and primitive species (Balmer et al. 2004). One of Tasmania’s three endemic ferns, the skeleton filmy fern (Sphaerocionium applanatum syn. Apteroperis plananata), is largely confined to coniferous rainforest where it typically grows on Athrotaxis trunks (Garrett 1996). The lichen Roccellinastrum flavescens only grows on the leaves of A. cupressoides (Kantvilas 1990). The pencil pine moth (Dirce aesidora) relies on A. cupressoides as its only food plant (Edwards & McQuillan 1998).

Ecophysiology

Ecophysiological work shows that A. selaginoides is adapted to cool temperatures (Read & Busby 1990) and is poorly adapted to water stress (Brodrrib & Hill 1998; Jordan et al. 2004). Read and Busby (1990) suggest that low summer rainfall is the primary limitation for A. selaginoides based on bioclimatic modelling, while their physiological research suggests high summer temperatures are directly limiting, at least at lower elevations where rainfall is adequate. The difficulty of interpreting the climatic niche is compounded by the substantial influence of fire and slow dispersal on the realised niche and the possibility that present distributions of conifer vegetation may reflect past climatic events (Read & Busby 1990).

Athrotaxis cupressoides is more frost tolerant than A. selaginoides (Cullen & Kirkpatrick 1988c) and is physiologically better adapted to water stress (Jordan et al. 2004), suggesting it will have a competitive advantage in dry conditions, although Cullen and Kirkpatrick (1998c) report no significant difference between the species in experimental drought mortality. Unseasonal (summer) frosts may be a limiting factor for A. selaginoides (Cullen & Kirkpatrick 1988c, Read & Hill 1988). The bioclimatic limits of A. cupressoides have been less studied but are likely to be similar to A. selaginoides based on phylogeny, ecophysiological similarities and ecological observations. Athrotaxis cupressoides leaves display good capacity to adapt to elevated atmospheric CO₂ by producing fewer stomata, which may reflect the ancient history of this genus including periods of much higher CO₂ than has been experienced by more recently evolved species (Haworth et al. 2010).
Little ecophysiological and bioclimatic research has been published for *Diselma* and *Pherosphaera*. Shrubby alpine conifers including *D. archeri, M. tetragona*, and *P. lawrencei* have comparable freezing resistance to *A. cupressoides* (in the range -17 to -22°C) and are amongst the most cold-tolerant woody species in the Southern Hemisphere (Sakai et al. 1981). The leaf anatomy of *Diselma* and *Pherosphaera*, with epistomatic (stomata only on upper leaf surface) imbricate leaves and stomatal wax plugs, lowers stomatal conductance and consequently reduces water loss (Brodribb & Hill 1997). *Microcachrys* and *A. cupressoides* have similar leaf anatomy. Even in *A. selaginoides*, which has the least imbricate leaves and is hypostomatic (stomata only on lower surface), stomatal conductance is considerably reduced (Brodribb & Hill 1997). Stomatal wax plugs occur in all of the Tasmanian montane conifers and along with other leaf features such as imbricate foliage serves to restrict water loss (Brodribb & Hill 1997).

**Phenology**

*Athrotaxis* species exhibit mast-seeding, where large quantities of seed are produced every 5 or 6 years with only small quantities of seed produced in intervening years. Masting can be defined as the “synchronous highly variable seed production among years by a population of plants”, however few plants exhibit ‘strict masting’ in which there is no seed production in intervening years, rather there is a range of annual variability in seed production which confers some evolutionary advantage (Kelly 1994). Mast years in both species are synchronised. Cullen (1987a) reports that *A. cupressoides* produces no seed between mast years (‘strict masting’ sensu Kelly 1994) while *A. selaginoides* produces small amounts of seed in intervening years (‘normal masting’ sensu Kelly 1994).

![Figure 4. Athrotaxis phenology: reproduction in A. cupressoides (1-3); and wood growth in A. selaginoides, largely based on a site at 960 metres on Mt Field (4-5). From Ogden (1978).](image)

The reproductive cycle and growth pattern appears to be similar in both *Athrotaxis* species (Ogden 1978, see Figure 4). *Athrotaxis selaginoides* produces seed heavily every 5 to 6 years, seeds ripen in January to February, seed fall occurs over approximately one month and seeds remain viable for 3 to 4 months (McMurray 1982). For *A. selaginoides* at Mt Field, seed maturation and release occurred from mid-April to early June at 920 m elevation in 1982 (Read 1989). Anecdotal evidence suggests that
**Athrotaxis** phenology may have shifted from this pattern with more variable cone production in recent years.

Several theories are supported for the selective advantage of mast seeding in different species, including predator satiation (seed production greatly exceeds seed predation in a mast year), environmental prediction (seed is produced to coincide with favourable years for seedling establishment) and wind pollination (the scale of pollen and ovule production in a mast year confers better odds of fertilisation) (Kelly 1994). Cues may be environmental or based on an internal ‘clock’.

It is not known what the cue or evolutionary advantage for masting is in **Athrotaxis**. Masting occurs in many Tasmanian tree species, including the rainforest conifer *Phyllocladus aspleniifolius*, and the major rainforest dominant *Nothofagus cunninghamii*, and some *Eucalyptus* species.

Mast years for celery top pine (*Phyllocladus aspleniifolius*) in 1982 and 1989 had similar climatic patterns: both the mast year and the preceding year were warm and dry, suggesting there may be a climatic stimulus for seed and fruit production (Barker 1995). Mast seeding is not necessarily geographically coincident and perhaps local variations in climatic conditions introduce some spatial variability in seed production (Barker 1995).

Mast seeding in the New Zealand temperate dioecious conifer *Dacrydium cupressinum* follows a pattern of cool temperatures two years previous followed by a warm summer at the time of seedfall and is synchronised between male and female plants; it most likely evolved as a mechanism for improving success of wind pollination (Norton & Kelly 1998).

The periodicity of masting in **Athrotaxis** (5-6 yearly) and ENSO cycles (on average 5 years) are similar. Mast-fruiting in tropical dipterocarp trees appears to be triggered by ENSO events (Williamson & Ickes 2002). A large seed crop occurred in **Athrotaxis** in the summer of 1982-83 (Cullen & Kirkpatrick 1988b) which coincides with a strong El Niño event including drought across Tasmania. Heavy seeding in **Athrotaxis** occurred at Mt Field in 1981-82 and again in 1988-99 (Read 1989), the former apparently not related to any ENSO phenomena, the latter coinciding with a strong La Niña (April 1988-July 1989) and following a strong El Niño event from Winter 1987 through Summer 1988. The 2009-10 masting of *A. cupressoides* coincided with the start of a weak El Niño phase, although there was no decline in rainfall in Tasmania – indeed above average rainfall occurred in winter and spring prior to a dry period in the 2009-10 summer. The mast seeding, however, may have been triggered prior to this event or may be purely coincidental.

In contrast, *Pherosphaera hookeriana* appears to produce seed annually rather than masting, yet the proportion of viable seed is low and germination trials have historically been unsuccessful for this species (TSS 2009). Recently some germination was achieved following cold stratification treatment but the dormancy mechanism is not well understood (Wood 2011). The seeds appear to have deep physiological dormancy which may result in a semi-persistent soil seed bank with germination staggered over several years (J. Wood, pers. comm.). This concurs with field observations which suggest that seedlings are very rare and reproduction is largely vegetative in this species (TSS 2009). This lack of seedling recruitment may explain why *Pherosphaera* is less widely distributed than other alpine conifers and it presents a potential limitation to geographic dispersal and genetic adaptation in response to climate change.

The only other member of this genus, *P. fitzgeraldii*, has a very restricted distribution in the Blue Mountains of NSW and appears to be entirely reliant on vegetative reproduction (Jones *et al.* 1993). It
is likely that poor dispersal and recruitment along with sensitivity to fire and drought would have disadvantaged this genus as Australia has become drier, resulting in the present limited distributions. If indeed there is very limited sexual reproduction in *Pherosphaera* a potential consequence is lack of outcrossing and reduced adaptive capacity.

**Montane Conifers and Climate Change**

Climatic projections for Tasmania indicate little change for central and western Tasmania until after 2040, when there is likely to be a reduction in rainfall year-round for the Central Plateau and a change in seasonal patterns for western Tasmania with a distinct decrease in summer rainfall, particularly in the central west which coincides with the core range of *A. selaginoides* (Grose et al. 2010). The Central Highlands and western Tasmania are expected to experience increases (from the baseline period 1978-2007) in average and maximum temperatures of approximately 1-2°C during the period 2040-2069, increasing to 2.5-3°C after 2070; this magnitude of change is expected to be year-round on the Central Plateau, while the West Coast is likely to see more warming in summer than other seasons (Grose et al. 2010). Even if atmospheric greenhouse gas concentrations remain stable the Earth’s surface will continue to warm for decades (Pierce et al. 2011).

Climatic models predict a decline in rainfall for the Central Plateau (Grose et al. 2010); with likely impact on *A. cupressoides* whose stronghold is the western Central Plateau. An additional pressure on *A. cupressoides* on the Central Plateau is lack of recruitment due to grazing (Cullen & Kirkpatrick 1988b). Climate change has already affected vegetation in this region: dieback of cider gum (*Eucalyptus gunnii* ssp. *divaricata*) on the eastern Central Plateau appears to be largely driven by long term decline in rainfall, although additional factors including stock grazing and wildlife browsing are implicated (Calder & Kirkpatrick 2008).

Warmer temperatures are expected to increase the elevation of the treeline, allowing subalpine forest to migrate upslope. Treelines are unlikely to be in perfect equilibrium with climate since there is a time lag in the response of trees, and seedling establishment is the limiting factor for treeline expansion (Richardson & Friedland 2009). Given the longevity and slow growth of *Athrotaxis*, migration of *Athrotaxis* forest would be slow but the already established shrubby *Athrotaxis* at high elevations would provide a basis for forest development at sites previously marginal for tree species, dependent on other factors such as wind and snow. A reduction in the severity of frost would be expected to facilitate *A. cupressoides* migration downslope into frost hollows.

Apart from direct climatic influences on the distribution of species, climatic change will have indirect impacts such as changes in herbivory, pathogens and fire regimes. Rainforest and alpine vegetation is at risk of increased frequency and intensity of fire events if recent trends of increased incidence of dry lightning and higher Soil Dryness Index values in western Tasmania continue (DPIPWE 2010). In the past ten years there has been a threefold increase in lightning-ignited fires in Tasmania (David Taylor, pers. comm.) which poses a risk to the more remote and isolated patches of conifer vegetation which may have been less at risk due to their distance from more frequent anthropogenic ignition sources. Interestingly a sharp increase in the number of lightning-ignited fires has been noted in mesic temperate forests of northwest Patagonia since the mid-1970s associated with a trend toward warmer summer temperatures (Kitzberger & Veblen 2003). Extensive wildfires are in contrast to disturbance regimes such as avalanches and landslides which are particularly associated with colder glacial period climates and are likely to advantage *A. selaginoides* (Cullen 1991).
Changes in phenology are expected in response to environmental change, either through physiological responses to environmental cues or as a response to stress. Phenological changes can be variable and difficult to predict within a species, so long-term and geographically broad datasets are needed to determine trends (Primack et al. 2009). The observed phenological change in Athrotaxis in recent years may be related to environmental change and it is likely that future climatic change will influence phenological phenomena such as timing of cone development and seedfall.

Athrotaxis trees are internationally important for dendrochronology research into climatic patterns in the Southern Hemisphere (Balmer et al. 2004).

**Dieback**

Dieback symptoms such as chlorosis, foliage thinning and death have been observed in several conifer species at widespread locations in Tasmania’s highlands. Changes in vegetation condition may be related to various causes and can manifest at different scales ranging from health of individual trees, to forest condition at the stand scale to overall extent of the community. Observation and monitoring at different scales is therefore a strategic approach to detect and quantify change.

Browning and death of foliage is a part of the normal aging process for Pherosphaera fitzgeraldii which is the only congener of P. hookeriana (Jones 1993). This rare shrubby conifer from the Blue Mountains of mainland Australia also displays dieback symptoms with an unknown cause (Jones 1993).

Stands of pencil pine near Pine Lake on the Central Plateau affected by a unique localised case of severe dieback in the 1990s have since showed signs of recovery (PWS 2004). This dieback event was spatially localised and affected several woody angiosperm species in addition to pencil pine. Symptoms of chlorosis, anthocyanescence and crown dieback were followed by plant death in many cases (Whinam et al. 2001). No correlations between dieback and potential climatic and pathogenic causes were evident; rather it is likely that dieback resulted from a combination of factors (Whinam et al. 2001).

Localised dieback of Diselma archeri observed at sites on the Central Plateau and Cradle Mountain during the 1990s appears to be a natural disease event associated with a canker-forming fungus (Yuan et al. 2000; PWS 2004).

In these cases localised dieback seems to be a short-term, isolated phenomenon however such events may be the beginning of a widespread, ongoing decline and therefore it is important to monitor condition.

**Monitoring Outline**

This survey determines the current condition status across the range of the four conifer species, providing a baseline for monitoring of spatial and temporal trends. Long-term changes in the health of conifers at the stand level are likely to occur over decadal scales. If climate change is a driver of health decline, the conifers may not show significant effects until a climatic threshold is reached, possibly not before the middle to late 21st century.

Cunningham et al. (2007) recommend using the term ‘tree condition’ to describe the appearance of a tree while ‘tree health’ is restricted to physiological and pathological factors. Several methods have been considered for monitoring conifer condition. Given the life history traits of the conifer species such as slow growth and longevity, and the estimated rates of climatic change, it is expected that trends in conifer health would be evident over decadal scales, but may be sudden if a threshold is reached. Consequently, frequency of monitoring may need to be altered in response to observed changes.
Seasonal and inter-annual variations in condition and phenology are natural phenomena and therefore it is important that monitoring is robust enough to detect trends over multiple years without being confused by short-term fluctuations. Another complication is assessing tree condition in exposed environments where trees are deformed and defoliated by weather conditions but may be healthy despite having features such as dead branches (or trunks), a small crown or bark stripped by ice storms.

**Long-term Monitoring Plots**

The major research method to establish baseline data is field monitoring of conifer vegetation using qualitative measures of conifer condition at permanent plots. Data collected assesses overall condition of conifers based on an observational scale, along with site details which are indicative of environmental conditions such as moisture availability. Demographic information (stem diameter classes or height classes) is useful to examine whether condition is related to particular types of population, or particular size classes within a population. It also indicates where mortality and recruitment are occurring. While other researchers have used several indices of tree condition (e.g. crown extent, crown density, crown vigour, leaf condition) for trees with well defined architecture and dieback processes (e.g. Cunningham et al. 2007, Souter et al. 2010a, 2010b) this has proved impractical for the montane conifer species due to variability in tree form related to age and site factors.

**Repeat Photography**

Repeat photography is a useful tool for examining vegetation change over time and can be more efficient and less prone to observer bias than subjective tree condition measures. Permanent photo points have been established in order to provide a photographic time series in the future to complement the monitoring plots. Additionally, there is potential for relocating and rephotographing historical images of conifers to provide an historical time series to investigate past trends in conifer condition.

**Remote Sensing**

Large scale aerial photography will be used to map dieback and death of conifers where possible. Emerging satellite imaging technology provides sufficient resolution and data analysis tools to map health of vegetation at the tree and stand scale, so the field monitoring program is designed to provide data suitable for ground-truthing of multi-spectral imagery (see for e.g. Cunningham et al. 2007).

**Phenology**

While it is convenient to observe cone production in the course of the on-ground monitoring, a thorough investigation of conifer phenology requires monitoring at multiple times during each year. To this end, the ClimateWatch program (www.climatewatch.org.au) collates phenological observations for select Australian species, including *Athrotaxis cupressoides* and *A. selaginoides*. Provided sufficient observations are submitted this will generate useful data on *Athrotaxis* phenology and condition. Observations over a minimum period of 20 years are typically required to detect phenological changes (Sparks & Menzel 2002). Herbarium specimens have been used to investigate phenology (Gallagher et al. 2009) and could be useful for determining an historical record of mast years for *A. cupressoides* and possibly *A. selaginoides*. 
Further investigation of conifer phenology could be integrated with the conifer condition monitoring by conducting frequent phenological monitoring at a subset of monitoring sites, ideally with quantification of seed production and experimental analysis of seed viability.

**Monitoring Program and Data Analysis**

Monitoring is intended to be undertaken for at least 30 years, with an interval of 10 years for recording plots (timing may need to be reviewed in light of rates of change detected). Annual or biannual monitoring of a small subset of the monitoring sites, e.g. some of the photo-points, would provide some indication of change in between major monitoring events. Additionally, where fire occurs in conifer-dominated vegetation it would be desirable to set up monitoring plots using this method or a modified version to investigate damage and recovery.

Data collected will be analysed for long-term spatial and temporal trends in conifer condition. The range of monitoring sites combined with remote sensing techniques provides replication and allows analysis of spatial patterns in condition. The geographic variation between sites (e.g. elevation) also provides a surrogate for climate and will be useful for examining the potential influence of climatic factors on conifer health.

**Relationship to Other Monitoring**

Dendrochronology work undertaken on *Athrotaxis* species at various locations provides centuries-scale data on growth rates and responses to environmental change in these species (e.g. Allen *et al.* 2011).

Changes in the extent of mapped conifer communities will be assessed periodically by the TASVEG change project which uses satellite imagery, while observed changes can also be mapped and updated by TASVEG at other times (e.g. following loss by fire).

A system for monitoring vegetation condition has been developed based on TASVEG communities, with benchmarks for community characteristics such as diversity and coverage of different lifeforms and number and condition of dominant trees (Michaels 2006). This system has been applied mostly to lowland vegetation and benchmarks have not been defined for the conifer communities, except for *Lagarostrobos franklinii* rainforest (TASVEG: RHP) and *Athrotaxis cupressoides* open woodland: *Sphagnum* peatland variant (a distinct facies of RPW).

This project will have linkages with the Vegetation Monitoring Strategy for Tasmania which is in preparation.

A weather station will be installed by DPIPWE on the Cradle Plateau in late 2011. This will provide climatic data from the alpine environment which will be relevant to conifer monitoring at this location.

The monitoring protocols and techniques employed here could be adapted and applied to other flora species in the TWWHA considered to be at risk from climate change such as creeping pine (*Microcachrys tetragona*), Huon pine (*Lagarostrobos franklinii*) and deciduous beech (*Nothofagus gunnii*) (see Brown 2010). Outside of the TWWHA these methods might be applied to dominant species in east coast remnant rainforest, such as the endemic conifer celery-top pine (*Phyllocladus aspleniifolius*).
Site Selection and Establishment

Thirteen localities have been identified for conifer monitoring (Table 1). These localities cover the geographic extent of the conifer species, with an emphasis on the northern and eastern range limits. Locations have been chosen to take advantage of previous monitoring projects or historical photography where possible. Ten of the locations are in the TWWHA and the others are in reserves managed by the National Parks and Wildlife Service (Mt Read, Mt Field) or Forestry Tasmania (Winter Brook). Mount Read and Mount Field are recognised as areas of particular significance for preservation of Tasmanian alpine and subalpine flora outside of the TWWHA (Balmer et al. 2004). These locations also have existing relevant vegetation studies (Brown 2010). Other possible additional monitoring sites include: Skullbone Plains/upper Nive River (Private Reserve – Tasmanian Land Conservancy), Butlers Gorge (State Forest), Wentworth Hills (State Forest), Snowy Range (TWWHA), Smoko Creek (Meander Forest Reserve, part of TWWHA).

Plots are identified by an alphanumeric code with 2 letters indicating the locality, 2 letters indicating the vegetation type and 2 digits for the plot number, e.g. BB KB 01 refers to Black Bluff, King Billy pine dominant, plot number 1 (KB = *A. selaginoides*, PP = *A. cupressoides*, CH = coniferous heath).

Long-term Monitoring Plots

The sampling method depends on the lifeform of the species being monitored (i.e. tree or shrub). *Athrotaxis* monitoring uses a modified point-centred quarter method (PCQM) where each ‘plot’ consists of 12 *Athrotaxis* ‘individuals’ and sampling is based on a centre-point permanently marked with a light weight aluminium stake 50 to 80 cm high with a brass tag attached and a unique identifier number. Within each quarter (delineated by cardinal compass points) the nearest three *Athrotaxis* individuals greater than 2 m tall are sampled. PCQM is widely used for forest inventory surveys as it more efficient than plot-based sampling and although it is designed for single-trunked upright trees it can be adapted to situations where trees have multiple or leaning trunks (Dahdouh-Guebas & Koedam 2006; Mitchell 2007). Using this method there is theoretically no distance limit for inclusion of trees from the centre-point, however in practice with small discrete stands of Athrotaxis there may be a quarter in which there are fewer than three trees. In this case a correction factor can be applied to the PCQM data to adjust for vacant quarters, or for fewer than 12 individuals (Mitchell 2007).

Multi-trunked trees where the trunks clearly arise from a common base are considered to be an individual, as are distinct clusters of stems. Root suckers or trunks distant from the cluster (more than c. 1.5 m) are treated separately, even if it appears that they may be connected. Pencil pine can produce root suckers more than 50 metres from the parent tree (Cullen & Kirkpatrick 1998b) so it is not feasible or desirable for a field monitoring program to define individuals on a genetic basis.

*Athrotaxis* sampling involves recording the following details for each individual:

- distance and direction from marker post (to centre of stem or centre of cluster for multi-stemmed individuals; to base of trunk for leaning trees),
- DBH at 1.3 metres (for multi-stemmed individuals measure all stems that are more than ¼ the diameter of the largest stem),
- easting/northing (if DGPS is available),
- chlorosis or death of apical foliage (recent/old/absent),
- overall condition score:
  1. Dead
  2. >50% foliage brown
  3. <50% foliage brown
4. no dieback symptoms
   • cones (absent, present on <50% of branches, present on >50% of branches),
   • age and sex of cones (e.g. predominantly male or female, from previous season),
   • other observations (e.g. fungal infection, insect attack, browsing).

Diameter at breast height over bark (DBH) is measured to the nearest 0.5 cm using a diameter tape according to forest science conventions, viz. diameter is measured at 1.3 m vertically from the ground surface (below litter) on the upslope side of the tree trunk (for trees with prostrate or leaning trunks the DBH is measured at 1.3 metres along the trunk, not at 1.3 metres vertically). For individuals with multiple trunks, each trunk is measured except for very small trunks (less than ¼ of the diameter of the largest stem). The growth form of pencil pine sometimes involves branches close to the ground which begin more or less horizontally then curve upward taking on the form of a trunk; where these are comparable in size and form to the main trunk(s) they are considered to be a trunk and the diameter is measured at 1.3 metres, otherwise they are classed as a branch and not measured. Where multiple trunks or branches occur at 1.3 metres height and the DBH is therefore not amenable to measurement, trunk diameter is measured at a lower point.

Distances are measured using a tape measure or laser rangefinder. Alternatively, measuring distance and direction to individual trees can be semi-automated using a laser rangefinder and electronic compass connected to a field computer with appropriate software (Hédl et al. 2009).

For coniferous shrubbery (and *Athrotaxis* scrub under 2 m tall) sampling is based on 10 x 10 metre quadrats oriented to magnetic north. The northwest corner (NE at Mt Read and Mt Anne) of each quadrat is permanently marked with a light weight aluminium stake 50 to 80 cm high with a brass tag attached and a unique identifier number. Aluminium stakes 20 to 30 cm high mark the other three corners of the quadrat.

Coniferous shrubbery sampling records the following details for each species:
   • percentage cover and average height,
   • overall condition score:
     1. Dead
     2. >50% foliage brown
     3. <50% foliage brown
     4. no dieback symptoms
   • cones (absent, present on <50% of branches, present on >50% of branches),
   • other notes (e.g. signs of disease, physical damage from trampling, snow, browsing).

Site description for each plot (PCQM and quadrats) includes:
   • easting/northing of post (preferably DGPS),
   • elevation (from GIS),
   • slope and aspect,
   • geology,
   • landform,
   • drainage (waterlogged/well drained),
   • TASVEG community,
   • fire history,
   • recruitment for each conifer species (seedling, sucker, seedling & sucker, indeterminate, none),
   • vegetation structure (height, percentage cover and dominant species for each stratum),
   • cover estimates using a Braun-Blanquet scale for: rock, water, litter, moss, shrubs, grass/graminoids, bare ground.
Photos 2a to 2f. Examples of *Athrotaxis cupressoides* condition classes: top = 4, middle = 3, bottom = 2.
Photos 3a to 3f. Examples of *Athrotaxis selaginoides* condition classes: top = 4, middle = 3, bottom = 2.
Photos 4a to 4f. Examples of *Diselma archeri* condition classes: top = 4, middle = 3, bottom = 2. Note that foliage varies in colour from yellowish-brown to green seasonally.
Photos 5a to 5f. Examples of *Pherosphaera hookeriana* condition classes: top = 4, middle = 3, bottom = 2.

Reference photographs of conifers representing the different condition scores are used as a guideline for assigning condition scores (Photos 2-5).

For PCQM tree monitoring the ‘plot’ area is defined as an irregular shape delineated by the most distant sampled trees. Within this area, observations of recruitment are recorded as: seedling, sucker, seedling & sucker, indeterminate, none.

Details of all sites have been submitted to the Tasmanian Parks and Wildlife Service’s Information Management System: Project title, contact person, GPS coordinates and tag number for each marker post, including as a GIS layer.
Data Analysis

PCQM data is typically analysed to determine measures such as absolute density (number of trees per unit area) and basal area for the total population of trees and also total and relative values for different tree species within a stand (Mitchell 2007). Since this project is typically looking at single species stands and is interested in the demographics of these stands, these methods can be adapted by treating different size classes (based on DBH values, or maximum DBH for multi-stemmed individuals) as subpopulations (instead of species) and thus determining the relative density, frequency and basal area of each size class. For A. cupressoides, the criteria used to define an individual will affect the results of the modified PCMQ analysis. Furthermore the formula used to estimate density assumes a random distribution of trees which is rarely the case in nature (Mitchell 2007). A. cupressoides appears to have a distinctly clumped distribution in most cases, particularly in woodland communities. Consequently the results must be considered estimates of stand density rather than definitive measures. Nevertheless they are useful for comparison of sites within this study.

The PCMQ data allows analysis of total basal area/percentage live basal area for trees. The following formula (Pollard 1971, in Mitchell 2007) provides an unbiased estimate of population density \( \lambda \) for a traditional PCMQ survey where four trees are sampled at each of several sampling points:

\[
\lambda = \frac{4(4n - 1)}{\pi \sum_{j=1}^{n} \sum_{j=1}^{l} R_{ij}^2},
\]

where \( 4n \) is the number of trees where \( n \) is the number of sample points, \( i \) is a particular sample point, \( j \) is a quarter at a sample point and \( R_{ij} \) is the point-to-tree distance at point \( i \) in quarter \( j \).

To suit the modified PCMQ method used here where there is only one sample point and \( n \) is 12 instead of 4 (except at sites where less than 12 trees are sampled), the formula used is:

\[
\lambda = \frac{4(n - 1)}{\pi \sum_{i} R_{i}^2}
\]

Since the distance measurements are in metres, \( \lambda \) is multiplied by 10,000 to determine trees/ha.

Basal area in m\(^2\) for each stem is calculated by \( \pi \left( \frac{DBH}{200} \right)^2 \) and for multi-stemmed trees these are summed to give a total basal area for the individual tree. Stand basal area in m\(^2\)/ha is calculated by multiplying the population density \( \lambda \) by the average basal area for that stand.

Tree condition characters and recruitment can be examined in relation to environmental variables and stand structure. Since the condition scores are ordinal only specific types of statistical analysis are suitable (e.g. Kruskall-Wallis test, ordered probit regression models).

For purposes of ordination analysis, aspect values have been converted to indices by converting degrees to radians and then using trigonometric functions (Roberts 1986):

- northness index = \( \cos(\text{radians}) \);
- eastness index = \( \sin(\text{radians}) \).
### Historical Photography

Photographs of conifer vegetation will be collated from various sources, representing a variety of locations and times (e.g. Photo 6). Photographic monitoring undertaken by the parks and Wildlife Service for walking tracks (Dixon *et al*. 2004) may prove useful where conifer vegetation occurs. Original photographs will be scanned and copies printed for use in the field. Where possible, the sites will be relocated and rephotographed, preferably at the same time of day and season (methodological issues are reviewed in Pickard 2002). Site details (GPS location, direction of view, site description) are recorded along with the photographs so that they can be revisited in the future. Comparison of the time series pairs involves scoring change in condition and foliage density (e.g. increase, decrease, no change).

![Photo 6. Historical photograph including *Athrotaxis cupressoides*, Lake Balmoral by A. Lawrence Green (1908), from Haygarth (2008).](image)

### Photo-points

A photo-point consists of a camera post and sighting post which is used to position a photograph so that the same scene can be rephotographed at a later time (see Barker 2001, p. 14). Photo-points have been established at most conifer monitoring plots.

Each photo-point is marked with a pair of 10mm tubular aluminium stakes. For each photo-point, one stake designates the camera post location and the other the sighter post. Prior to photographing, a 1.5 metre length of plastic tubing is used as a temporary camera post, placed on the permanent aluminium camera post marker, and a 1.5 m plastic tube with sighting disc attached at top is positioned on top of the permanent sighter post marker.
In the case of coniferous shrubbery quadrats, each corner post is used as a camera post with the sighter post placed on the diagonally opposite corner, resulting in four photo-points for each quadrat. For the conifer tree sites the camera post is located at the ‘plot’ centre-post and a variable number of photo-points have been established. Aluminium stakes driven into the ground with around 20 cm visible mark the location of the sighter post for each photograph, with the distance and direction from the centre-post recorded to aid relocation.

For each photo-point, the camera is positioned on top of the sighter post and aligned so that the sighting disc is in the centre of the viewfinder, then 3 bracketed exposures are made (typically an auto-
exposure bracketed 2/3 stop either side, but the correct exposure and bracketing range will depend on lighting conditions as determined in the field). Additional photographs may be taken with the sighter disc positioned in the centre of the bottom or top edge of the frame, or with camera oriented vertically, to achieve a greater vertical range of coverage.

While it is not essential to use the same lens (Pickard 2002), it is preferable for consistency to use a lens with a field of view equivalent to 20 mm focal length on a typical digital SLR (Focal Length Modifier of 1.6, i.e. equivalent to a 32 mm lens on a 35mm film camera).

Photographs will be repeated when the monitoring plots are resurveyed every ten years. It is desirable to rephotograph a subset of these at a shorter interval, e.g. 5 years or opportunistically. Photographic time series will enable a simple visual assessment of change in tree condition (i.e. increase, decrease, no change) or a well-defined subjective ordinal classification for each individual or species in the photograph for each time interval. From this assessment overall trends can be determined and compared between sites.

Image analysis software (e.g. WinSCANOPY, WinCAM, WinFOLIA or SideLook) has been used to quantify vegetation features such as canopy gaps, plant height and leaf discoloration from canopy or profile photographs (e.g. Jonckheere et al. 2004, Zehm et al. 2003). With profile photographs, this is difficult in the field due to technical issues such as changing lighting and differentiating foliage from background. Alternatively, limited sections of each photograph which only contain conifer foliage are analysed for foliage density (as in Cunningham et al. 2007); this is simpler than delineating and analysing the entire tree and avoids distracting elements such as other vegetation.

Probably the best quantitative method for this project is to sample a number of points on the image by overlaying a grid and assigning values to each grid point (such as non-conifer, healthy conifer foliage, brown conifer foliage). This can be achieved using ‘Samplepoint’ software. A number of photograph series would be needed to generate statistically useful quantitative data.

**Aerial Photography**

High-resolution aerial photography is capable of detecting dieback and death of trees or shrubby vegetation. Aerial photography 1:5,000 is available for a number of locations where conifers occur in the TWWHA and other reserves. Individual *Athrotaxis* trees are readily discernable at this scale (Photo 9).

Key conifer sites that relate to on-ground monitoring for which 1:5,000 photography is available are shown in Table 4. Photographs are held by either Information and Land Services (DPIPWE) or the Track Monitoring Team (Parks & Wildlife Service). Selected photographs have been scanned at 450 DPI and saved as TIFF images on the RMC server: \RMC_Images\Vegetation\Aerial photography\Montane conifer sites 1-5000 photos.

In some cases 1:5,000 photography at different times overlaps in coverage, providing a time series, albeit probably too short an interval for changes in conifer condition or extent to be apparent. These sites include the Lonely Tarns – Mt Sarah Jane area at Mt Anne (1995 and 2000) and the Pigsty Ponds – Mt La Perouse area in the Southern Range (1996 and 2000). Limited areas around Cradle Mountain have been captured in both 1988 and 1991.
Some sites of conifer vegetation have been photographed at 1:5,000 scale in 2011 and are stored as high resolution TIFF images. These include Mount Rufus, Greystone Bluff and Mount Anne. The latter two have existing photography at the same scale from the 1990s. Change in conifer extent or condition could be determined by visual inspection of these photographs compared to the earlier photographs of the same sites. If dieback is visible the photograph can be scanned and orthorectified, then the dieback mapped using GIS. Alternatively living trees can be mapped using tracing paper to compare time series (Calder & Kirkpatrick 2008).

Another technique suggested by Brown (2010) is using an aircraft-based still or video camera linked to GPS to fly monitoring transects for conifers. These spotter flights could be employed opportunistically when other projects are using aircraft in relevant parts of the TWWHA. This imagery could be subject to categorical analysis of condition or quantification of mortality by a trained observer. Mast seed
production can also be observed during aerial transects. This technique was employed on the northern slopes of Mt Anne in March 2011 (see Photo 10) and the resulting digital images are archived on the RMC server.

Table 4. Large scale (1:5,000) aerial photography of selected conifer sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Photo series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Bluff/ Winter Brook</td>
<td>2000</td>
<td>1323-67 to 1323-79, 1327-21 to 1327-26</td>
</tr>
<tr>
<td>Cradle</td>
<td>1988</td>
<td>1107-190 to 1107-202</td>
</tr>
<tr>
<td></td>
<td>1991</td>
<td>1178-102 to 1178-190, 1179-1 to 1179-25</td>
</tr>
<tr>
<td>Walls of Jerusalem</td>
<td>2000</td>
<td>1328-228 to 1328-250</td>
</tr>
<tr>
<td>Pine Lake</td>
<td>1995</td>
<td>1237-130 to 1237-160</td>
</tr>
<tr>
<td>Mount Field</td>
<td>2000</td>
<td>1324-96 to 1324-106</td>
</tr>
<tr>
<td>Mount Anne</td>
<td>1995</td>
<td>1229-186 to 1229-205, 1230-8 to 1230-20</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>1326-210 to 1326-231</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>1456-105 to 1456-122, 1456-259 to 1456-272, 1457-1 to 1457-72</td>
</tr>
<tr>
<td>Greystone Bluff</td>
<td>2011</td>
<td>1456-228 to 1456-241</td>
</tr>
<tr>
<td>Southern Range</td>
<td>1996</td>
<td>1245-1 to 1245-16</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>1328-228 to 1328-250, 1330-78 to 1330-97</td>
</tr>
</tbody>
</table>

Photo 10. Oblique aerial photograph from handheld digital SLR, Mount Anne: *A. selaginoides* trees are the bright green crowns, some crown dieback is evident in the lower left.
Public Observations

Both *Athrotaxis* species have been selected as target species for the long-term citizen science project ClimateWatch. ClimateWatch is operated by the Earthwatch Institute and data will be collated and made available via the Australian Government’s Atlas of Living Australia.

ClimateWatch provides a system for interested members of the public (e.g. naturalists and bushwalkers) to record observations of the phenology of selected target species using the ClimateWatch website ([www.climatewatch.org.au](http://www.climatewatch.org.au)).

For *Athrotaxis* species, ClimateWatch will record observations of the following features:

- Healthy trees – little or no browning and death of foliage
- Unhealthy trees – recent widespread browning and death of foliage
- Presence of unopen fresh (fleshy) female cones
- Open female cones

In the future this will provide a long-term dataset to complement the infrequent, localized conifer monitoring plot data. It can potentially inform of dieback events and is particularly useful for monitoring phenology of ovulate cone production.
Baseline Monitoring Results 2011
Characteristics of conifer species at each site are summarised in Appendix 7.

Size class distributions of conifer trees based on DBH measurements (using the maximum DBH value for multi-stemmed individuals) indicate continuous or episodic regeneration for *A. cupressoides* (Figure 5) and more episodic recruitment for *A. selaginoides* (Figure 6).

Density and basal area varied widely between sites and plots and should be regarded as estimates on account of the large variances associated with these values using the Pollard (1971) formulae for PCMQ tree data. The highest values for basal area were mostly mature *A. selaginoides* forest, while the lowest values were typically *A. cupressoides* woodland where trees are small and sparse or *A. selaginoides* forest where the density of *Athrotaxis* is low (and angiosperms account for a relatively high proportion of the total basal area)(Table 5). Density and basal area were not calculated for *A. Xlaxifolia* because of the small sample size for this taxon (less than 3 trees per sampling site where it was recorded), however individuals of *A. Xlaxifolia* are included in the total *Athrotaxis* tree figures for these sites.

Recruitment was evident at 11 out of 34 sites for *A. cupressoides*, with most or possibly all juveniles being root suckers. Recruitment was most frequent at Mount Field, followed by Pine Lake with very little or no recruitment observed at the other study sites. Recruitment was more frequent for *A. selaginoides* with juveniles present at 20 out of 24 sites (see Appendix 7). *Athrotaxis selaginoides* recruitment was apparently all from seed except at Mount Read where there appear to be some root suckers, although further investigation would be required to determine their origin. Some sites had large numbers of small seedlings (less than c. 3 cm tall) but larger seedlings were infrequent.

For the shrubby conifers it was difficult to distinguish seedlings from root suckers, although some form of recruitment was observed for these species at most sites. Instances where no recruitment was observed were usually associated with a very low coverage of that particular species in the plot, e.g. only one mature plant present. Continuous vegetative reproduction appears to be commonplace in *Microcachrys* and *Pherosphaera*. Variation in timing of surveys precludes useful comparison of cone production between sites since unlike *Athrotaxis* the strobili are not retained on the plant for more than a few weeks.

Condition scores for *A. cupressoides* show a statistically significant difference between sites (Kruskall-Wallace test, P-Value = 2.986^{-9}) with Mount Field and Mount Ironstone having a median condition score of 3 while the other sites have a median of 4 (see Tables 6-8, Figure 9). There is no significant difference between sites for *A. selaginoides* with all sites having a median score of 4 (Kruskall-Wallace test, P-Value = 0.067421).
Figure 5. Size class distribution for sites with *A. cupressoides* only.
Figure 6. Size class distribution for sites with *A. selaginoides* only.

Figure 7. Size class distribution for sites with mixed species of conifer trees.
Table 5. Density and basal area estimates for conifer trees for each plot, with site averages in bold.

<table>
<thead>
<tr>
<th>Site</th>
<th>Conifer trees individuals/ha</th>
<th>Conifer basal area (m²/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVKB01</td>
<td>123.1</td>
<td>38.5</td>
</tr>
<tr>
<td>CVKB02</td>
<td>56.5</td>
<td>4.8</td>
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<tr>
<td>CVKB03</td>
<td>275.3</td>
<td>29.0</td>
</tr>
<tr>
<td>CVKB04</td>
<td>247.4</td>
<td>31.1</td>
</tr>
<tr>
<td>CVPP01</td>
<td>228.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Cradle Valley</td>
<td>186.3</td>
<td>21.6</td>
</tr>
<tr>
<td>DKPP01</td>
<td>170.4</td>
<td>24.8</td>
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<tr>
<td>DKPP02</td>
<td>318.7</td>
<td>21.4</td>
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<td>DKPP03</td>
<td>240.0</td>
<td>18.7</td>
</tr>
<tr>
<td>DKPP04</td>
<td>98.8</td>
<td>18.8</td>
</tr>
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<td>DKPP05</td>
<td>47.0</td>
<td>6.0</td>
</tr>
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<td>DKPP06</td>
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<td>DKPP07</td>
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<td>57.1</td>
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<td>DKPP08</td>
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<td>57.8</td>
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<td>DKPP09</td>
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<td>DKPP10</td>
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<tr>
<td>Dixons Kingdom</td>
<td>209.2</td>
<td>28.6</td>
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<td>LMPP01</td>
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<td>40.2</td>
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<td>LMPP03</td>
<td>334.5</td>
<td>15.5</td>
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<td>LMPP04</td>
<td>299.0</td>
<td>33.8</td>
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<td>Lake Mackenzie</td>
<td>185.2</td>
<td>18.1</td>
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<tr>
<td>MAKB01</td>
<td>166.5</td>
<td>80.6</td>
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<td>MAKB02</td>
<td>40.1</td>
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<td>MAKB05</td>
<td>53.4</td>
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<td>93.0</td>
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<td>Mickeys Creek</td>
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<td>45.3</td>
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<tr>
<td>Site</td>
<td>Conifer trees individuals/ha</td>
<td>Conifer basal area (m²/ha)</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>MFPP01</td>
<td>97.4</td>
<td>2.8</td>
</tr>
<tr>
<td>MFPP02</td>
<td>227.7</td>
<td>3.0</td>
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<tr>
<td>MFPP03</td>
<td>139.2</td>
<td>14.2</td>
</tr>
<tr>
<td>MFPP04</td>
<td>202.6</td>
<td>17.2</td>
</tr>
<tr>
<td>MFPP05</td>
<td>190.4</td>
<td>33.0</td>
</tr>
<tr>
<td>Mount Field</td>
<td>171.4</td>
<td>14.0</td>
</tr>
<tr>
<td>MIPP01</td>
<td>40.1</td>
<td>5.4</td>
</tr>
<tr>
<td>MIPP02</td>
<td>95.9</td>
<td>15.9</td>
</tr>
<tr>
<td>MIPP03</td>
<td>28.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Mt Ironstone</td>
<td>54.8</td>
<td>8.5</td>
</tr>
<tr>
<td>MRKB01</td>
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<td>16.2</td>
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<tr>
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<td>82.2</td>
</tr>
<tr>
<td>MRKB03</td>
<td>407.4</td>
<td>17.6</td>
</tr>
<tr>
<td>MRKB04</td>
<td>289.0</td>
<td>2.3</td>
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<tr>
<td>MRKB05</td>
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<td>MRKB06</td>
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<tr>
<td>MRKB08</td>
<td>529.9</td>
<td>40.7</td>
</tr>
<tr>
<td>Mount Read</td>
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<td>27.1</td>
</tr>
<tr>
<td>PLPP01</td>
<td>94.7</td>
<td>5.6</td>
</tr>
<tr>
<td>PLPP02</td>
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<td>9.1</td>
</tr>
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<td>PLPP03</td>
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<td>24.3</td>
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<tr>
<td>WBKB01</td>
<td>116.4</td>
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</tr>
<tr>
<td>WBKB02</td>
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<td>42.6</td>
</tr>
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<td>WBKB03</td>
<td>978.0</td>
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<td>WBKB04</td>
<td>245.1</td>
<td>82.7</td>
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<tr>
<td>WBKB05</td>
<td>10.1</td>
<td>5.6</td>
</tr>
<tr>
<td>WBKB06</td>
<td>66.6</td>
<td>5.0</td>
</tr>
<tr>
<td>Winter Brook</td>
<td>254.9</td>
<td>28.0</td>
</tr>
<tr>
<td>All sites</td>
<td>90.3</td>
<td>16.5</td>
</tr>
</tbody>
</table>
Table 6. Frequency of tree condition scores by species.

<table>
<thead>
<tr>
<th>Condition Score</th>
<th>Species and Location</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. cupressoides</td>
<td>Cradle Valley</td>
<td>13</td>
<td>144</td>
<td>237</td>
<td>382</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dixons Kingdom</td>
<td>3</td>
<td>24</td>
<td>93</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lake Mackenzie</td>
<td>16</td>
<td>32</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mickeys Creek</td>
<td>3</td>
<td>14</td>
<td>19</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mount Field</td>
<td>3</td>
<td>35</td>
<td>22</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mount Ironstone</td>
<td>23</td>
<td>13</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pine Lake</td>
<td>4</td>
<td>31</td>
<td>37</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

A. selaginoides | Cradle Valley        | 1 | 9 | 26 | 36 |       |
|                 | Mount Read           | 27| 53 | 80|     |       |
|                 | North East Ridge     | 1 | 7 | 50 | 59 |       |
|                 | Winter Brook         | 1 | 9 | 46 | 56 |       |

A. × laxifolia  | Cradle Valley        | 2 | 2 |     | 4  |
|                 | Mount Read           | 2 | 2 |     |   |

D. archeri     | Mount Read           | 14| 14|     |   |

Total          | 1 | 16 | 198| 428| 643|

Table 7. Frequency of tree condition scores by location for sites with multiple species.

<table>
<thead>
<tr>
<th>Condition Score</th>
<th>Location and Species</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cradle Valley</td>
<td>1</td>
<td>10</td>
<td>49</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. cupressoides</td>
<td>1</td>
<td>21</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. selaginoides</td>
<td>1</td>
<td>9</td>
<td>26</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. × laxifolia</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mount Read</td>
<td>29</td>
<td>67</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. selaginoides</td>
<td>27</td>
<td>53</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. × laxifolia</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D. archeri</td>
<td>14</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8. Frequency of A. cupressoides and A. selaginoides by condition class for all sites sampled.
Figure 9. Frequency of conifer trees in each condition category by site.
Pine Lake is the only location where condition scores appear to be related to tree size (as measured by DBH) at a statistically significant level \((p = 0.012)\), while Lake Mackenzie and Mount Ironstone display a significant relationship at the 10 % confidence level (Table 8). These sites are all located at the northern extent of the Central Plateau and are dominated by \textit{A. cupressoides}, although the nearby Mickeys Creek site does not show a similar relationship. Given that these are not strongly significant they indicate that these sites need further investigation to determine if there is a real relationship.

Condition scores vary between 3 and 4 in most size classes with only a weak trend of decreasing condition with age (e.g. Pine Lake, Figure 10). Natural processes such as intraspecific competition and aging can influence tree condition so caution is required when interpreting tree condition and dieback. For example, at Pine Lake none of the largest individuals were classified in the highest condition class, likely due to natural senescence, similarly the poorest condition individuals occur in the smaller size classes and probably reflect natural stand thinning (Figure 10).

**Table 8.** Results of statistical analysis of relationship between condition scores and DBH.

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>Kruskal-Wallis chi-squared statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cradle Valley</td>
<td>\textit{A. cupressoides}</td>
<td>0.7528</td>
<td>0.3856</td>
</tr>
<tr>
<td>Cradle Valley</td>
<td>\textit{A. selaginoides}</td>
<td>1.9308</td>
<td>0.3808</td>
</tr>
<tr>
<td>Cradle Valley</td>
<td>\text{All Athrotaxis spp.}</td>
<td>1.7311</td>
<td>0.4208</td>
</tr>
<tr>
<td>Dixons Kingdom</td>
<td>\textit{A. cupressoides}</td>
<td>1.3889</td>
<td>0.4993</td>
</tr>
<tr>
<td>Lake Mackenzie</td>
<td>\textit{A. cupressoides}</td>
<td>3.751</td>
<td>0.0528</td>
</tr>
<tr>
<td>Mickeys Creek</td>
<td>\textit{A. cupressoides}</td>
<td>1.6366</td>
<td>0.4412</td>
</tr>
<tr>
<td>Mount Ironstone</td>
<td>\textit{A. cupressoides}</td>
<td>2.881</td>
<td>0.0896</td>
</tr>
<tr>
<td>Mount Read</td>
<td>\textit{A. selaginoides}</td>
<td>0.3426</td>
<td>0.5583</td>
</tr>
<tr>
<td>Mount Read</td>
<td>\text{All conifers (Athrotaxis spp., Diselma)}</td>
<td>1.4721</td>
<td>0.225</td>
</tr>
<tr>
<td>North East Ridge</td>
<td>\textit{A. selaginoides}</td>
<td>0.2092</td>
<td>0.9761</td>
</tr>
<tr>
<td>Pine Lake</td>
<td>\textit{A. cupressoides}</td>
<td>8.8453</td>
<td>0.012</td>
</tr>
<tr>
<td>Tarn Shelf</td>
<td>\textit{A. cupressoides}</td>
<td>2.9411</td>
<td>0.2298</td>
</tr>
<tr>
<td>Winter Brook</td>
<td>\textit{A. selaginoides}</td>
<td>4.1958</td>
<td>0.1227</td>
</tr>
</tbody>
</table>

**Figure 10.** Condition scores for \textit{A. cupressoides}: all plots at Pine Lake, with second order polynomial regression line.
Figure 11. Box plots of most significant environmental variables associated with tree condition scores, ordered by decreasing Kruskall-Wallis statistic. Box represents quartiles, whiskers are the range, vertical line is median, diamond is mean. Group 1 is the plots with lowest mean condition score classified by PATN. (a) A. cupressoides (Group 1 are sites with mean condition > 3.5); (b) A. selaginoides (Group 1 is plots with mean condition 3.3–3.7, Group 2 is scores = 3, Group 3 is scores 3.8–4).

Classification and ordination analysis of plots based on condition scores for each of the two Athrotaxis species was performed using PATN software (Belbin 2004). When clustered into two groups, the pencil pine plots with lower mean condition (< 3.5) were associated with blockstream...
sites with high rock cover, low moss cover and a more southerly latitude, while healthier sites had more moss and a more southerly aspect (Figure 11a). King billy pine was clustered into three groups with the poorest condition stands occurring in the A. selaginoides – N. gunnii community on relatively flat, south-facing sites at Mt Read (Figure 11b). Better condition king billy pines generally occurred in A. selaginoides rainforest on steeper slopes. Elevation does not appear to have an influence on condition scores for either species. Conifer density and basal area showed little relationship to condition.

**Discussion**

Consensus on condition scores was readily achieved by two or three observers. Souter et al. (2010a) found significant correlation between observers using a five-class scale of crown extent and crown density scores.

There was generally little difference in conifer condition between sites and between species within sites. Overall, pencil pine displayed poorer condition than king billy pine, with two locations in particular having notably lower condition scores. However this may be related to the environmental influences of a more exposed habitat, or to other factors such as site history. Consequently repeat monitoring of individual trees and stands is needed to indicate trends in condition. This will help determine whether observed condition is within the normal range for this species or is representative of poor or declining health.

The weak trend in declining condition with age at Pine Lake may be due to prolonged senescence of older trees, reflected by a lack of the highest condition score in the largest size classes. In most cases where poor condition was observed (trees scored in class 2) this appears to be the result of natural stand thinning.

Lack of recruitment of A. cupressoides at grassy montane rainforest sites on the Central Plateau (e.g. Dixons Kingdom) compared to sites with boulder or heathy understoreys (e.g. Pine Lake) or in other regions (e.g. Mount Field) is consistent with the observations of Cullen and Kirkpatrick (1988b). However recruitment was also lacking at Mount Ironstone where the pencil pine woodland occupies a boulderfield with heathy understorey. On mainland Australia, many populations of the widespread conifer Callitris columellaris display a long term (past 100-200 years) lack of recruitment consistent with impacts of introduced herbivores (Prior et al. 2011).

**Further research possibilities**

**Identifying refugia**

Refugia are increasingly being recognised as important features for conservation planning and management (Mackey et al. 2007). Likely glacial refugia have been identified in Tasmania (Kirkpatrick & Fowler 1998), but these locations will not necessarily function as refugia in warmer climates. The identification of potential future refugia is fundamental for management of climate change impacts in the TWWHA (Styger et al. 2010). Rainforest in southwest Tasmania is largely confined to fire refugia such as valleys and steep south-facing slopes which are topographically protected from the prevailing northerly and northwesterly fire weather (Wood et al. 2011). Identification of drought- and fire-refugia will be particularly important for fire-sensitive and moisture-limited species such as montane conifers.
Bioclimatic modelling

There are a wide range of species distribution models (SDMs) available which utilise statistical methods to model the ecological niche or habitat suitability for a species in relation to environmental variables (Franklin 2009). GIS can be used to map the modelled fundamental or realised niche for a species and predictive mapping where the modelled niche is extrapolated to a future climate scenario.

Comparing change between present and predicted climatic envelopes for a species can indicate if the range is likely to expand or contract and how much it is likely to shift which has implications for conservation management, for example, identifying likely refugia or migration routes.

Although these models rely on a number of assumptions and on the accuracy of the input data (Hughes 2003), and the realised niche for a species is influenced by non-climatic factors such as competition, migration barriers and stochastic extinction of populations, the modelling of bioclimatic envelopes can be informative for predicting the impacts of climate change on biodiversity, providing these limitations are considered (Pearson & Dawson 2003).

The major factors controlling the distribution of alpine and rainforest conifers are climate and fire. Interspecific competition may be important in early successional stages and in marginal habitat such as near the lower altitudinal limits. Interactions between climate, soil and fire complicate attempts to interpret climatic niches for *A. selaginoides*. Moreover, the present distribution of long-lived conifers in high-altitude forests may reflect past climatic events (Read & Busby 1990). It is an assumption of bioclimatic modelling that the species is in equilibrium with present climate (Hughes 2003).

High elevation conifers in the Pacific Northwest of the USA appear to be limited by climatic factors at the upper altitudinal limits (treeline), whereas lower limits and the distribution of lowland conifer species showed little response to climate and may be controlled by biotic interactions (Ettinger et al. 2011). Cullen and Kirkpatrick (1988) note that the lower distributional limit of *A. cupressoides* appears to be determined by competition with other rainforest tree species. *Athrotaxis selaginoides* has a lower elevation distribution than the other conifer species and also differs in its typical closed forest habitat compared to an open montane habitat, and so may be influenced more by competition than by climate throughout most of its range. However, the upper altitudinal limit for *A. selaginoides* is in low open vegetation at or near the treeline so would be expected to be climatically controlled.

A 1:25,000 scale climatic dataset is available for Tasmania with 35 bioclimatic variables on a 25 m raster grid (Landscape Logic 2008). This provides a good basis for modelling the climatic envelope for conifer species based on known records (Natural Values Atlas) and vegetation mapping (TASVEG).

Previous climatic modelling for *A. selaginoides* (Read & Busby 1990) used a lower resolution climate surface (0.1° lat/long grid) and fewer bioclimatic variables than is available in the Landscape Logic dataset. That study used BIOCLIM which, although effective, does not perform as well as more modern statistical modelling methods (Elith et al. 2006, Franklin 2009).

The Climate Futures for Tasmania project has generated predicted future climate surfaces at a scale of 0.1° lat/long. The predicted changes in climatic parameters from this dataset can be used to adjust the current 25 m climatic surface and hence to map modelled climatic envelopes in relation to future climate scenarios.

Modelling future climates at regional scales relevant to species migrations and refugia is difficult. Climate models typically have coarse spatial resolution which means climatic variables are averaged
over the area of each cell so that local microclimates that might be important refugia are not detected (Pearson 2006). Refugia are likely to be located in locations where topoclimatic influences such as cold air drainage are important (Dobrowski 2011).

A wide variety of modelling methods are available, however most require absence records in addition to presence records for a species. Since absence data are often unavailable many methods use ‘pseudo-absence’ or random sampling of the background environment. Real absences can be determined from plot data where the species in question was not recorded, especially if it is a dominant that would have been recorded if present. In addition to variability between models, the accuracy of modelling varies greatly between species.

Statistical methods tend to perform better than expert rule models (Franklin 2009). Commonly used algorithms that can be employed with only presence data (but do require pseudo-absence or background) include Genetic Algorithm for Ruleset Prediction (GARP) and maximum entropy (maxent). Boosted Decision Trees and Maximum Entropy performed best in comparisons of several widely used modelling methods (Elith et al. 2006; Guisan et al. 2007). These methods cope well with complex and interacting factors and noise in the data (Elith et al. 2006). Free software tools are available such as HabMod toolboxes for ArcGIS, Maxent, openModeller and Spatial Data Modeler. Model outputs may benefit from expert training and verification, e.g. an expert workshop to look at model results.

**Remote sensing**

Various remote sensing technologies have proven useful for mapping forest health in conifer and hardwood trees, e.g. colour infrared aerial photography, multispectral satellite imagery. Processing usually involves pattern recognition to differentiate tree crowns from background and shadows followed by image classification based on spectral indices to detect defoliation or discolouration. Hyperspectral imagery has the advantage of providing information related to the physiological condition of the vegetation which can be modelled using software in comparison to the subjective visual assessment of structural and textural features from aerial photography (Stone et al. 2003).

Remote sensing of forest condition has mostly been applied at the scale of forest stands or large forest estates but can detect dieback in individual trees with sufficiently high resolution imagery (e.g. 1:5,000 aerial photography, QuickBird <3 m multispectral sensor). High resolution imagery (c. 5 m) would be needed to detect the relatively small scale dieback in Tasmanian conifer stands.

Regression analysis of ground-truthed data is typically used to determine the most suitable spectral index for detecting the phenomenon. An alternative is to develop a radiative transfer model by measuring leaf-level reflective properties and scaling up to the canopy level. The standard 4-band data (blue, green, red, near infrared) allows a number of vegetation indices to be generated which have proved useful in many applications for vegetation monitoring.

DPIPWE has RapidEye 5 m resolution 5-band coverage for Tasmania from summer 2009/10. The Department also has SPOT 4-band imagery from 2005 and early 2009 at 10 m resolution; this would provide a useful time series, but might not be sufficient resolution to be calibrated for detecting conifer condition.

Of the currently available satellite data, Quickbird is probably the best choice given its exceptional resolution, however RapidEye has almost as high resolution and has the advantage of a 5th band (‘red-edge’, in between red and near-infrared) which might provide more useful indices for discriminating foliage condition.