Alpine Resort Futures Literature Review

Final Report

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1 LITERATURE REVIEW

1.1 Introduction

Literature review in the study

This literature review provides background information on climate change adaptation. This review aims to provide insights for the Victorian alpine resorts sector from the key findings of climate change research across Victoria's, Australia's and the world's alpine regions. This review provides insights on questions like:

- What climate changes are currently impacting on the Victorian alpine regions?
- What further changes can we expect and over what sort of timeframe?
- What are the implications of these changes and what social and economic impacts do they have?
- How are other alpine regions responding and adapting to these changes?
- What are the best practice approaches to engage with communities and build capacity with a view to adaptation to climate change?

The literature review consolidates contemporary literature relevant to the Alpine Resort Futures Climate Change Vulnerability Assessment (Social and Economic). Sources are predominantly from peer-reviewed academic sources, however where it adds value, non-peer-reviewed, grey literature (typically government commissioned reports and organisational annual reports) have been included, sometimes in grey text boxes. This adds context to the literature review from the Victorian situation.

The content of the literature review is of great importance to the stakeholder and community engagement and ensures the project delivers informed and constructive conversations.

Summary

This report summarises the findings of the literature review, attempting to be easily accessible by a broad audience; technical and abstract language is kept to a minimum.

The structure enables easy dissemination of parts into community engagement and consultation. The Review follows an empowering narrative, as follows:

- The climate is changing, and in alpine regions the signs are already starting to show. What we already see in the Victorian Alps is that snow cover has diminished by about fifty percent since the 1960s. The impacts of climate change are expected to accelerate towards 2100 (IPCC, 2014; Timbal et al., 2016).
- Over the next 10 to 80 years the changing climate will impact on the length and quality of snow seasons, increased operating costs for resorts due to additional snowmaking, possible impacts on snow sport participation, social and cultural impacts of reduced snow cover and a reduction in snow sport activity, and limitations of green season tourism activities due to bushfires.
- However, humans are very adaptive, and experience elsewhere shows us, some of the things the resort sector can do are adaptation planning and capacity building, implement efficient snowmaking, diversify to other tourism offerings, diversify to other industries, and prepare for bushfire events. These and other adaptive responses are already occurring in Victoria's alpine resorts.

1.2 Climate change in alpine regions

The climate is changing and in alpine regions the signs are already starting to show. Temperatures are warming (especially minimum temperatures) and precipitation (rain and snow) is decreasing (Fiddes & Pezza, 2015). These results have been supported by observations and climate model estimates of both the past and future periods[1]. This has implications across the year for both the white and green seasons. Scientifically approved and validated climate models all project that the impacts of climate change will accelerate into the future (IPCC, 2014). To illustrate, globally the earth has experienced an increase in temperature of about 0.85°C over the period of 1880-2012 (IPCC, 2014). The models project this to increase to about 2°C in the next 40 years following a *business-as-usual* 'Zero Mitigation (RCP8.5)' scenario. This means the rate of warming will accelerate to about 3-times the rate of warming we have experienced to date.

This chapter describes the expected climate change impacts in the Victorian alpine region and its alpine resorts. It will then go on to describe what the implications may be in terms of extreme events. The content of this chapter is based on an extensive review of available literature. One important document on snowfall and snow depth is "The Potential Impacts of Climate Change on Victorian Alpine Resorts" by Harris et al. (2016), which builds on and supports the work of Whetton et al. (1996), Hennessy et al. (2003 and 2008), Bhend et al. (2012). The assessments with Timbal et al. (2016) also support these assessments.

A summary of the science

The alpine regions of Australia are unique because of the existence of snow. Almost every other aspect of the landscape and ecosystem is linked to the physical influence snow has on this environment. As the climate changes, the main drivers of snow creation (temperature and precipitation), are projected to change in such a way that snowfall will reduce, and melt rates will increase. As snow is strongly linked to the meeting of certain climatic thresholds, the transition to a snow-free region may be quite abrupt. These climatic conditions also give rise to a number of other changes in the landscape.

The impact of climate change across the Victorian Alpine Region has been investigated numerous times since the 1990s, with almost all studies giving special attention to the changes in snow due to its importance to the region. Throughout the last 20 years, the science has become more sophisticated and the projected changes have improved in quality, however the message has remained the same – a warming climate, lower precipitation, less snow and hotter summers. The differences between the studies are the rate of change, the certainty of the projections and the details of how precipitation will change.

The Coupled Model Intercomparison Project (CMIP) is an international scientific collaboration to standardised the way global atmosphere-ocean modelling experiments are designed and maintained. The main objective is to make it easier to compare the outputs from the various different modelling systems and approaches, thus improving the quality of the outputs from the entire modelling ecosystem. The most recent outputs are from the 5th Phase of this programme, known as the CMIP5 outputs. These are the first family of global climate model outputs to include emissions scenarios that include 'mitigation' pathways. These were included in the experimental scheme to allow us to understand what magnitude of climate change the earth is already committed to, regardless of any efforts to decrease the concentration of CO_2 in the atmosphere moving forward. This provides a level of confidence in the projected changes expected over the next 30 years. In Figure 1, all the emissions scenarios project an increase in global temperatures of ~1°C compared to the last century by about 2030 (although the exact timing may be earlier or later by 5-10 years). The projected impacts out to the end of the century are quite different depending on the emissions scenario that the world eventually follows. At present, we

[1] Climate models are used to estimate how the climate is changing in regions or time-periods where there is an absence of observations. For example, much of the Australian Alpine Region has no measurements, so models are used to estimate what conditions were probably like in the past. Similarly, for estimates of the future, sophisticated global, and regional climate models are used to get the best estimates of what the future climate will look like.

are tracking the *business-as-usual* ‘Zero Mitigation (RCP 8.5)’ scenario. All alternative scenarios reach warmer temperatures at later decades, but only the *best-case* ‘Aggressive Mitigation (RCP 2.6)’ scenario assesses the impact of decreasing the concentration of CO_2 in the atmosphere within a reasonable timeframe for decision making (i.e. within 50 years).

FIGURE 1. ASSESSMENT REPORT 5 PROJECTED CHANGES IN GLOBAL TEMPERATURE COMPARED TO THE PERIOD 1900-2000

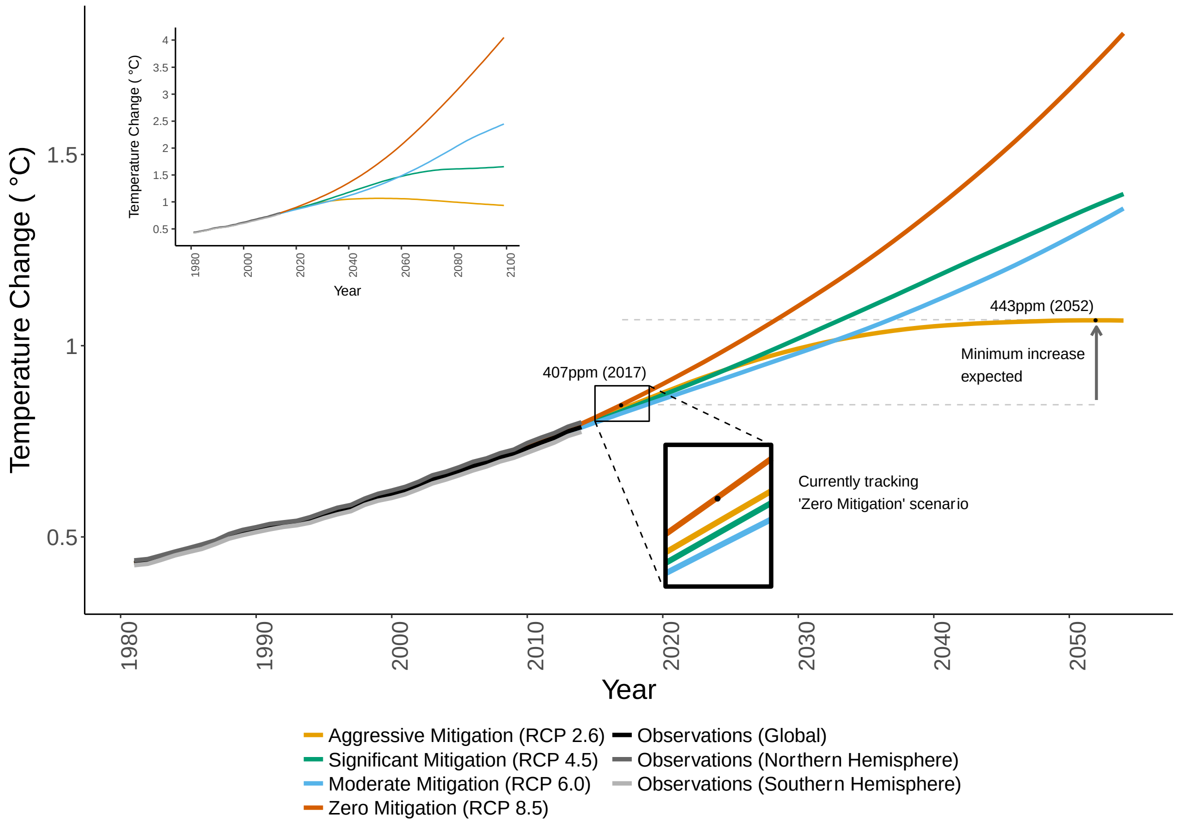


Figure 1: The increase in temperature projected for a given Coupled Model Intercomparison project – Phase 5 (CMIP5) global climate model emission scenarios, as reported in the IPCC Assessment Report 5 (AR5). These scenarios represent various levels of global CO_2 mitigation efforts. We are currently tracking the *business-as-usual* ‘Zero Mitigation (RCP 8.5)’ scenario. We may still transition towards the *best-case* ‘Aggressive Mitigation (RCP 2.6)’ scenario. In both cases, we are committed to at least 1°C of warming of the globe compared to the preindustrial period. The model projections expect the globe to have transitioned to that pathway earlier than we actually have, so we are likely to warm the globe by slightly more than this scenario projects. Data sources: IPCC AR5 CMIP5 model outputs and observational data from the Institute for Atmospheric and Climate Science (IAC) at Eidgenössische Technische Hochschule in Zürich, Switzerland.

Impact of climate change on temperature

Temperature in the high elevation regions of Australia has been observed to be increasing, about 0.2°C since the 1960s (Timbal et al., 2016; Davis, 2013). This has been faster than the global average, and this increased rate of change is projected to continue. The high elevation regions are expected to warm faster than the global average due to the reduction of snow cover. Snow reflects the sun’s energy away from the region, if not back out to space. As the snow cover is reduced, the energy is absorbed by the soil increasing the local temperature. Global climate models project an increase in mean annual temperatures over the Australian Alpine Region of about ~5°C by the end of the century compared to the period 1961-1990 following the *business-as-usual* ‘Zero Mitigation (RCP 8.5)’ scenario (Harris et al., 2016). This can be limited to an increase of ~2°C over the alpine region if we follow a *best case* ‘Aggressive Mitigation (RCP 2.6)’ scenario. Increased temperatures result in more rapid evaporation and increased transpiration rates of vegetation, decreasing the litter and soil moisture, increasing the risk of bushfire (discussed below).

Relative to the recent period (1986-2005), general trends in temperature over the Southern Slopes Cluster (which includes the Victorian Alpine Region) project a 1ºC to 1.5ºC increase by near future (~2030) and a 1.5ºC to 2.5ºC by mid-century (~2050) (Timbal et al., 2016). This is followed by a 2.8ºC to 5ºC by end of century (after 2070) depending on the emissions scenario that the world follows (Timbal et al., 2016; Harris et al. 2016). These increases can be presented in the change in monthly conditions, presented in Figure 2.

FIGURE 2. ASSESSMENT REPORT 5 PROJECTED CHANGES IN GLOBAL TEMPERATURE COMPARED TO THE PERIOD 1900-2000

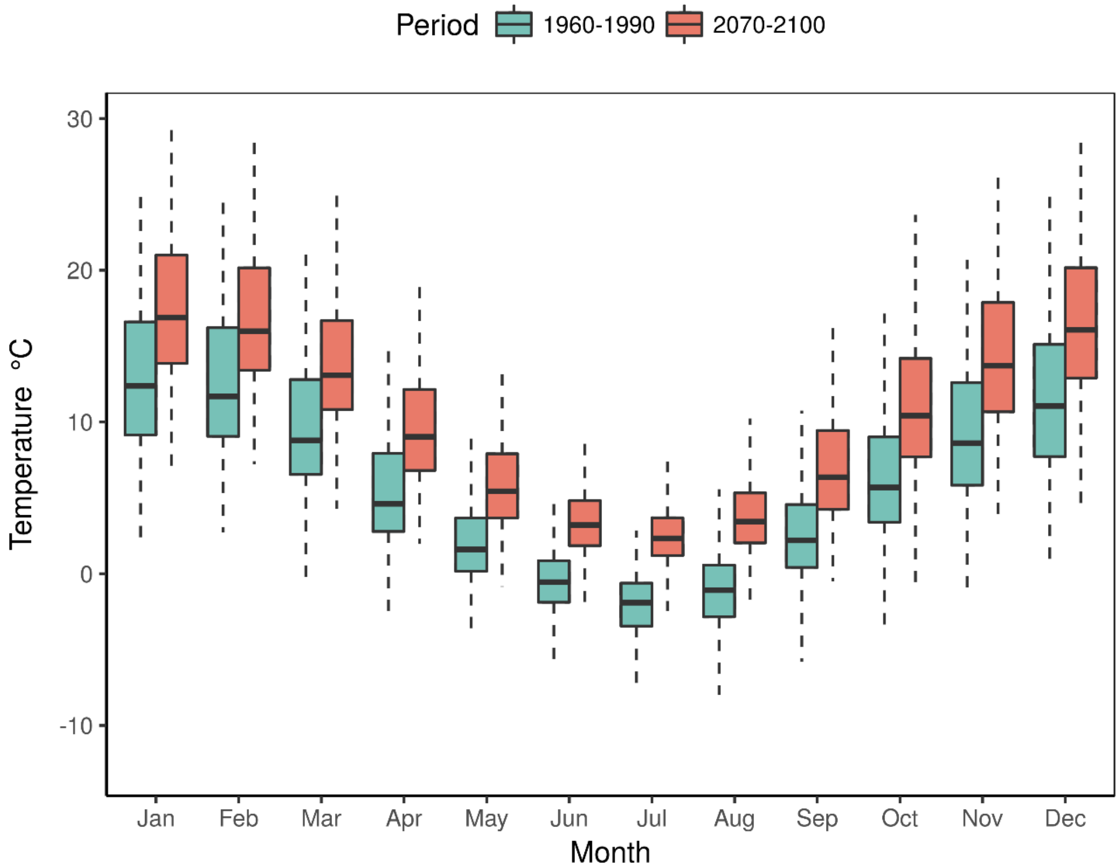


Figure 2: A demonstration of the projected change in the monthly temperature range (as estimated by multiple models). This is for the Falls Creek region. It shows how the future (red) time period will be warmer in every month compared to the current (blue) period, although the effect on seasonal aspects is most dramatic in peak summer and peak winter conditions. Future March temperatures will be more similar to those currently in February, where-as future July temperatures will be more similar to those currently in May. The bottom and top of the box are the 25th and 75th percentiles, the bar is the median, and the whiskers go to the most extreme data point which is no more than +/- 1.5 times the interquartile range from the box.

An increase in the mean annual temperature also results in a much larger increase in the frequency of extreme events such as hot days, warm nights or heatwaves. However, a specific analysis of how the frequency, duration and severity of heatwaves will change, due to climate change, has not been conducted for the Victorian Alpine region. Timbal et al. (2016) assessed the prevalence of heatwave over a region of Victoria they call the 'Southern Slopes' which includes (but is larger than) the Victorian alpine region. For the period 1986-2005, an extreme heat event that would occur about once every thirty years is projected to occur about 1-3 times each year by the end of the century, which is about 25-100 times more often. Due to the adaptive capacity of humans, and the relatively moderate absolute temperatures at elevation (Nairn & Fawcett, 2013; Langlois et al., 2013), heatwaves are unlikely to be life threatening to humans in the Victorian Alpine Region. However, it is very likely these extremes in the future will exceed the safe limits for some native species resulting in widespread loss of immobile species (such as plants), especially during dry periods. Such an event would have significant ecological impacts that may reduce the capacity of the environment to deliver essential eco-systems services, and therefore, may also have social and economic impacts (Jacobs & Anderson, 2016).

Impact of climate change on precipitation

The highest elevation areas of the Australian Alpine Region are drying faster than the lower slopes, especially during the winter months. There has been an observed decrease in precipitation of 5-15 percent at the mountain peaks compared to the 1960s (Bhend et al., 2012).

Precipitation over the Australian Alpine Region is highly variable, similar to the rest of Eastern Australia. Since about 1985 there has been a steady decreasing trend in rainfall (Fiddes & Pezza, 2015; Timbal et al., 2016), although this is still within the historical range of natural variability according to the historical records. That said, the observations have followed the expected pathway projected by climate models since 1990. Bhend et al. (2012) found that there has been an observed decrease in precipitation over the Australian Alpine Region between 1954 to 2011. The rate of drying has been significantly larger at higher elevations. This supports the model projections, which suggest a decrease over the high elevation areas[2] of the Victorian Alpine Region as the temporal pattern and distribution of precipitation is projected to change (Bhend et al., 2012; Timbal et al., 2016). Most climate modelling indicates an increase in precipitation on the lower eastern slopes, and a decrease in precipitation on the peaks and the western slopes, and these projections are generally supported by the evidence so far (Bhend et al., 2012; Fiddes & Pezza, 2015). The reduced precipitation is projected to result in long term drying of litter and soil throughout the region, increasing the risk of bushfire (discussed below). CSIRO (2008) has investigated how these changes will impact on the availability of water for human settlements, agriculture and ecological communities within the Murray-Darling Basin. However, this work was focused on the impact downstream of the resort locations, and cannot be translated into the impact expected at a resort level, as the resorts are at the head of the catchment, have a much smaller catchment to supply water to themselves and are thus far more vulnerable to variability in the specific location of rainfall. As such, there has been no specific research to determine if water supply (including ground-water sources) will continue to meet water demand for human and ecological communities living in the high elevation areas.

The underlying drying trend is clear, but it is much smaller than the projected range of natural variability, especially in the period from 2010 to 2050 (Timbal et al., 2016). As the atmosphere warms, it can hold more moisture, resulting in longer dry periods, and more intense precipitation events and this is also being observed in the observational record (Fiddes et al., 2015a). There will be longer periods between rainfall or snowfall events, but these events have the potential to be as large, or even larger, as previously observed. So, big dumps of snow at higher altitudes are still projected to occur, although they will be landing into a warmer environment.

Impact of climate change on snow

The production of natural snow is an amazing phenomenon which can only occur within a limited range of climatic conditions, too warm and it rains, too cold and the air is too dry to create heavy snowfalls. As such, snow is highly vulnerable to the influence of changes in climate. Evidence of glaciers forming in the Victorian Alpine Region in the geologically recent past indicate conditions were much colder than today, but more recently, historical stories and photos suggest the snow covered a greater area, was deeper and present for more of the year than is common today.

There are a few excellent historical snow depth records collected throughout the Australian Alpine Region (available from sites that are part of the Snowy River Hydro Scheme, currently managed by the company AGL) and these provide a regionally relevant dataset that can be used to assess the changes in snow since the 1950s. Observations clearly show that interannual variability is very high, dominating any influence of climate change for any given year. This has made it very difficult to identify any long-term trends until very recently. After a period of relative stability from when records began until 1985,

[2] In the academic literature ‘high elevation’ has been defined as each of >500m, >750m and >1000m. In all cases precipitation is expected to decrease.

conditions appear to have changed, with a reduction in the frequency of conditions that support the presence of snow on the ground.

Fiddes et al. (2015b) found the number of *light snow days* (0-10cm of snow fall) per year has declined by 30 percent since the 1980s, although the number of *heavy snow days* (>10cm) has not changed. This indicates that on borderline days, when it could either rain or snow, it is more likely to rain, which is highly detrimental to snow on the ground and although big dumps of snow are still just as common, the consistency is being lost as smaller top-up snowfalls are less frequent. Fiddes et al. (2015) also found snow depth was decreasing at a rate of about 20cm per decade. This supports the earlier findings of Davis (2013) and Bhend et al. (2012) who reported annual maximum snow depths at Rocky Valley Dam had decreased by about 30cm compared to the baseline period (1961-1990). Bhend et al. (2012) also found there is a trend towards an earlier finish to the snow season, with the season finishing about 30 to 40 days earlier than what occurred during the baseline period (1961-1990). Further evidence of a reduction in conditions that support the presence of snow has been found by Green & Pickering (2009), who have found a significant reduction in the number and size of persistent snow patches at a number of locations in the Australian Alpine Region. More recently, Bormann et al. (2012) used satellite observations to find that the annual maximum area covered by snow in the Victorian Alps diminished by about 40 percent between 2000 and 2010, mostly lost from the lower elevation regions. Each of these studies refers to a coincident drying and warming of the spring months being the key drivers, resulting in significant reductions in all attributes of snow throughout the region.

To summarise, observations since the 1980s have found a 30 percent reduction in the number of *light snow days*, a decrease in annual maximum snow depths of about 20cm per decade, a reduction in the duration of the season that the ground is covered in snow by about 30-40 days and a significant reduction in number and size of patches of persistent snow throughout the region.

These changes observed in the long-term observational record validate the early climate change impact assessments from the 1990s (Whetton et al., 1996) that projected at that time that the warming climate would result in significantly reduced snowfall, snow cover and snow depths by 2020. This has happened. These early models have accurately projected the evolution of the climate that has occurred over the last 20 years, as well as the associated impacts. Crucially, the general trajectory of these projections has remained consistent across the many coordinated Intergovernmental Panel on Climate Change (IPCC) modelling experiments conducted over the last 25 years (i.e. the FAR, SAR, CMIP3 and CMIP5 experiments and their data archives). The improvements in the algorithms, assumptions and model regimes that have occurred between model generations have dramatically improved the accuracy and confidence of our estimates, but have only confirmed the direction and magnitude of changes expected. The most recent round of experiments, the CMIP5 projections, was the first to include a *best-case* 'Aggressive Mitigation (RCP2.6)' scenario to assess the relative impact of the world transitioning to a low carbon economy. However, the comparison between the different scenarios suggests there is no divergence of different pathways until about 2030 (see Figure 1). This means that for the coming decade, the assessments from earlier research projects, such as Whetton et al. (1996), are still as relevant today as when they were first published, and this view has been supported by all subsequent climate impact assessments (Hennessy et al., 2003; Hennessy et al., 2008; Bhend et al., 2012; Harris et al., 2016). Each subsequent assessment has added value, providing more sophisticated methods to assess or present the future impacts.

The climate impact assessments relevant to the Australian Alpine Region conducted by various groups (Whetton et al., 1996; Hennessy et al., 2003; Hennessy et al., 2008; Bhend et al., 2012; Harris et al., 2016; Timbal et al., 2016) using a range of different models and approaches all concur on the general impacts projected for snow in this region.

Following a *business-as-usual* 'Zero Mitigation (RCP 8.5)' scenario:

- After 2030:
  - at elevations below 1400m throughout the Australian Alpine Region conditions that support the on-going presence of snow will be close to zero

– at elevations above 1700m throughout the Australian Alpine Region conditions that support the on-going presence of snow will be half the average area covered, as observed in the period 1960-1985
– After 2070:
  – at elevations below 1400m throughout the Australian Alpine Region conditions that support the on-going presence of snow will be zero
  – at elevations above 1700m throughout the Australian Alpine Region conditions that support the on-going presence of snow will be close to zero

Following a *best-case* 'Aggressive Mitigation (RCP 2.6)' scenario:
– After 2030:
  – at elevations below 1400m throughout the Australian Alpine Region conditions that support the on-going presence of snow will be close to zero
  – at elevations above 1700m throughout the Australian Alpine Region conditions that support the on-going presence of snow will be half the average area covered, as observed in the period 1960-1985
– Following a *best-case* 'Aggressive Mitigation (RCP 2.6)' scenario, with a global aim to return to pre-industrial conditions (eventually), it is expected to be possible to maintain the conditions of about 2030 indefinitely.

An example of the extent of snow reduction expected over the Australian Alpine region as projected by the CMIP5 model archive following the *business-as-usual* 'Zero Mitigation (RCP8.5)' scenario is presented in Figure 3. These projected changes have so far been supported by observations (comparing the 1960s to the 2000s).

FIGURE 3. MAXIMUM EXTENT OF SNOW COVER (NUMBER OF DAYS PER YEAR)

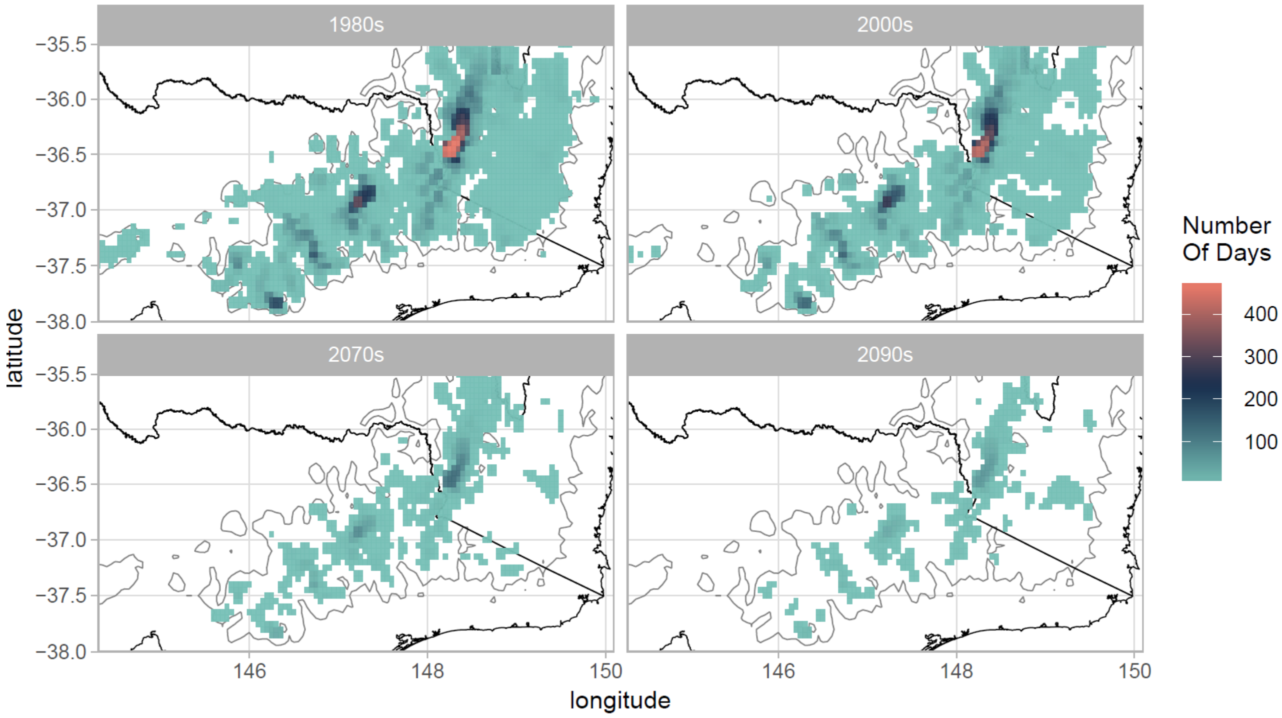


Figure 3: The maximum extent of snow cover as estimated using the number of days in any year that it snowed in a particular pixel of the model world. All images are representations of model output, due to the absence of adequate observations of snow extent prior to 1990 (after which appropriate satellite products became available). The models estimate a significant reduction in the extent of snow between the 1980s and the 2000s. This reduction of extent is projected to continue into the future to the 2070s and beyond following the *business-as-usual* 'Zero Mitigation (RCP 8.5)' scenario. Source: adapted from Harris et al. (2016).

Other expected impacts of climate change are the increase in inter-annual variability and less predictable progression throughout each year. The climate system is projected to become more dynamic as more energy (heat) is added to the climate system, resulting in more extreme events of most kinds (Pachauri & Meyer, 2014), and this includes snow producing storms. This may be a feature we are already experiencing, as described by Fiddes et al. (2015a), although the historical records are not long enough, or numerous enough to determine this empirically in the Australian Alpine Region. To create a robust climatology, researchers need at least 30 years of data to take into account natural variability. It is well known that large scale climate drivers such as El Nino, the Southern Annular Mode or the Indian Ocean Dipole have greater influence of the Australian climate at present than the slow background influences of a warming and drying climate. As such, very long time periods are needed to make accurate assessments of how the current climate has been influenced by climate change so far, and these are not available for this region.

Local knowledge of the changes in the Victorian Alpine region exist in a general sense, however, no scientific effort to document this *living memory* of change has yet been conducted but would be of significant value.

Impact of climate change on bushfire

Increasing temperatures coupled with a general drying of soil and ground fuels will increase the likelihood of bushfire into the future. No specific modelling or research into the current risk of bushfire on the alpine resort locations has been conducted.

Significant increases in mean fire danger and the occurrence of extreme fire danger days as measured by the McArthur Forest Fire Danger Index (FFDI) have been observed at selected weather stations across southeast Australia over the period 1973-2010 (Clarke et al., 2013). Under a high emissions scenario, Lucas et al. (2007) found a 10-30 percent increase in measures of annual fire danger and a 100-300 percent increase in the number of extreme fire danger days by 2050 over 1990 levels, however no stations in either study were located in the Australian alpine region. The Australia-wide gridded analysis by Pitman et al. (2007) is generally consistent with both of these studies, although their results are for January only. Timbal et al. (2016) also found that fire danger across Victoria is projected to increase under moderate to high emissions scenarios, however, these projections do not include the alpine area.

The NSW and ACT Regional Climate Modelling (NARCLiM) Project, conducted an analysis of FFDI at 50 km resolution across all of Australia (Clarke et al., 2016). However, the alpine region is not one of the broad climate zones for which projected changes in fuel loads and FFDI are summarised. The research most relevant to the Victorian alpine area has been conducted within the NARCLiM for the Murray Murrumbidgee region (Evans et al., 2014; Olson et al. 2016), where finer-scale projections (~10km) of FFDI have been calculated as part of their state-wide analysis. Modest increases are projected in summer and spring mean FFDI as well as minor increases in the number of days of extreme FFDI, however, the analysis was focused on *FFDI > 50*, which is less relevant for the high elevation regions.

> NARCliM projections are available from the AdaptNSW website: http://climatechange.environment.nsw.gov.au
>
> While the NARCLiM Project is well documented (Evans et al., 2014, Olson et al., 2016) the FFDI projections for the Murray Murrumbidgee region have not been published in peer-reviewed literature.

The delineation of sub-regions in the fine-scale NARCLiM analysis splits the alpine region among three of the sub-regions. The focus of these analyses is on metrics and threshold values applicable to broad lowland areas making up the majority of these regions and very likely masks the changes occurring in alpine areas. Recent analysis of fine-scale projections of fire danger in Tasmania has shown that analysing small regions characterised by unique climates and ecosystems using methods specific to the vegetation types can reveal dramatic projected changes in fire danger that are not evident in the broader analyses conducted previously (Fox-Hughes et al., 2014, 2015; Love et al., 2017). The southeast Australian alpine region is a highly localised unique environment which requires a similar approach.

While the FFDI describes fire danger associated with the combination of fuel amount, fuel dryness and fire behaviour due to weather, the other key factor is ignition for which the major natural source is lightning. No projections of lightning occurrence have been made for the Victorian alpine region. In Tasmania lightning occurrence is projected to decrease steadily throughout the current century (Love et al., 2017), although observed trends indicate that increasing dryness is outweighing decreased lightning in terms of fire occurrence and annual area burned. This is likely to be the case for much of southern Australia due to its likely attribution to the projected expansion of the tropics (Nguyen et al., 2015). The alpine region could be an exception to this due to the sensitivity of the analysis methods to altitude, hence analysis of trends in lightning occurrence and its relationship to increasing dryness would need to be part of future studies of fire danger in the alpine region.

The PHOENIX model, used by Victorian Department of Environment, Land, Water and Planning (DELWP) for fire behaviour modelling, is a tool that can be used to assess the level of risk bushfire poses to a specific resort, however this work has not explicitly been done, or investigated at a site level. The risks that bushfire poses to the natural environment are very high, as the projected frequency of fire exceeds the survivable tolerances of many native plants, such as the Alpine Ash (Bowmann et al., 2016). These ecological considerations are already components of fuel reduction operations and planning.

Impact of climate change on land slide and flash flooding

The current flood or landslide risk at the alpine resort locations are unlikely to be outside the existing engineering limits. However, the access roads to each of these locations often traverse areas that are at risk of damage or destruction from bushfire, flood or landslide. The destruction of a section of road can take considerable time to repair, particularly given some alpine resorts have only one road in and out. In addition to bushfire being a significant risk itself, it can change the landscape so dramatically that it also temporarily increases the risk of flash flooding and landslide.

The impact of climate change on the risk of damage to critical transport infrastructure within the alpine region has not been assessed in available literature and is identified as a critical gap. The 2015 VicRoads Climate Change Risk Assessment identifies sea level rise as the single biggest risk to VicRoads assets, followed by both flood and bushfire. However, the Victorian alpine region is not identified in the risk assessment. Flash-flooding and landslide are very complicated natural hazards, highly dependent on specific small-scale local conditions (e.g. slope, soil type, vegetation type and coverage). The specific impacts of climate change on each of these variables is required to assess the future risk. This work has not been conducted throughout the region. The effect of climate change on flash-flooding or landslide related hazards is identified as a key gap.

Impact of climate change on storm and wind

The impact of climate change on storm or wind risks over Victoria has been investigated by Timbal et al. (2016). There has been no observed trend in the nature of wind over Victoria, and only minimal changes expected in the future projections. Existing engineering standards are sufficient to account for the changes projected within the models. However, as with the other hazards, the Australian alpine region is a special case, and the conditions expected on a state-wide, or even regional basis may not reflect the conditions that would be expected at the top of the mountain. As such, the effect of climate change on wind and storm related hazards is identified as a key gap.

Impact of climate change on heatwave

The most recent research in the Victorian context is from Timbal et al (2016) who found that the Southern Slopes cluster (a climatic region in their study that includes the Victorian Alpine Region) has experienced only 1-2 events classified as a heatwave over the 30-year baseline period (1986–2005). They defined 'extended warm spells' as an event of 6 continuous days where the daily maximum temperature was above the 90th percentile of daily maximum temperatures of the baseline period.
Timbal et al., (2016) found that this region is projected to experience a 25-100 times increase in the frequency of these 'extended warm spells'. That is, instead of only 1-2 events every 30 years, it is projected there will be 3 events every year by the end of century. Although no near-future or

mid-century projections are available, the increase by the end of century is so substantial that change should be evident in the coming decades. The frequency, intensity and severity of a heatwave event is projected to increase nationally (Argüeso et al., 2016).

The effect of climate change on the frequency, severity and duration of heat waves in the Australian Alpine Region has been identified as a key gap.

Impact of climate change on frost

There has been an observed decrease in the number of days below 2°C in the historical record (as implied in the discussion about temperature above).

The NARCLiM project is the most in-depth investigation into the change in frost-events over the Australian alpine region. The assessment has only been done for the Murray Murrumbidgee region, which is adjacent to the Alpine Shire and incorporates some of the Snowy Mountains. This research found that there will be significant decreases in the number of frost events in both the near-future, with greater impacts in the distant future. By the 2030s, NARCLiM projects the number of frost days per year within the high elevation regions will decrease by 10-20 days (a 10 percent decrease) compared to the recent period 1990-2009), with the bulk of these days being lost in winter and spring. By the 2060s, this becomes more than 40 fewer frost days per year (a >20 percent decrease) compared to the recent period 1990-2009.

Frost is a very difficult variable to model due to the interaction of variables such as temperature, atmospheric pressure, humidity and cloud cover. Model projections around frost carry low certainty, however as temperatures rise, cooler conditions will become less frequent (Timbal et al., 2016).

The effect of climate change on frost throughout the Victorian Alpine region has not been specifically investigated and is identified as a key gap.

Impact of climate change by resort

While some conditions under a *business-as-usual* 'Zero Mitigation (RCP8.5)' scenario vary by resort, the following trends relative to recent decades (1961-2010) are seen across the region by the end of the century:

- An increase in the number of extreme hot temperatures and a decrease in the number of very cold days;
- No or minimal changes in wind speed or wind direction;
- An increase in mean annual temperature of 3-5°C (mean of 4°C) for all resorts except Falls Creek which shows 3.5-5.7°C (mean of 4.5°C);
- With warmer temperatures, there is a reduction in the proportion of precipitation falling as snow. More snow falling as sleet has implications for the retention of snow.

Not all changes are as uniform. While mean annual temperatures are generally expected to rise within a narrow range, the change in extreme temperatures is more varied across the region as shown in Figure 4.

FIGURE 4. PROJECTED INCREASES IN EXTREME TEMPERATURES BY THE END OF CENTURY COMPARED TO THE HISTORICAL PERIOD

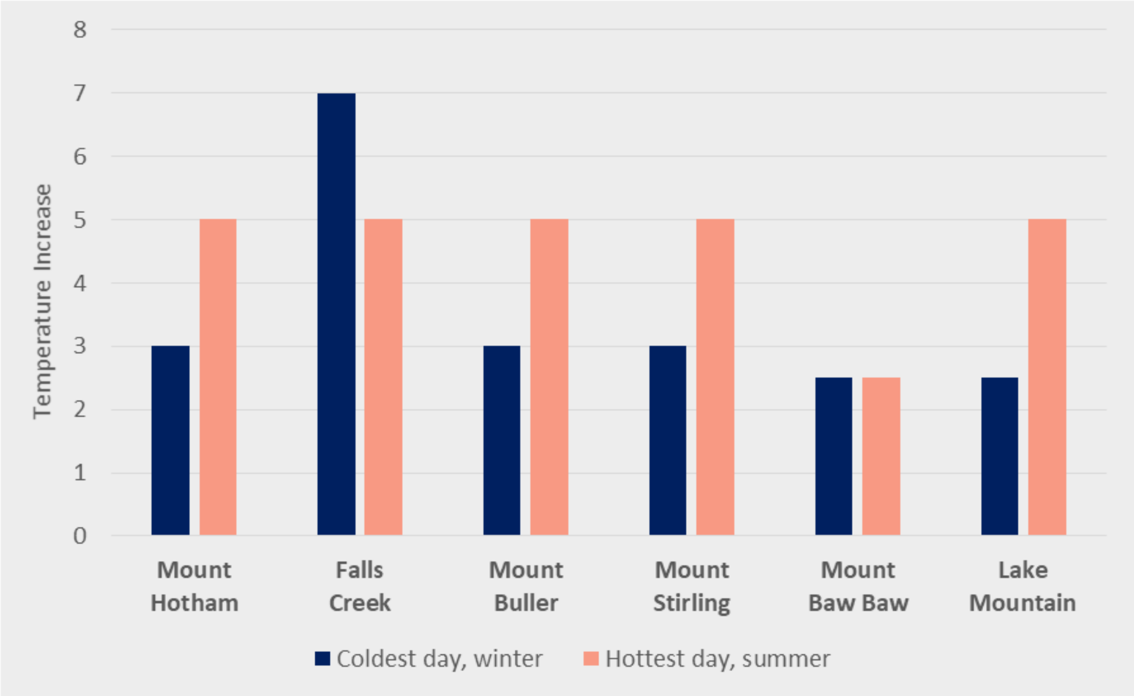


Figure 4: The changes expected at the hottest and coldest extremes of temperature throughout the year are different to those expected for the annual mean temperature. Typically, the hottest days will become much hotter and the coldest days will warm, but at a slower rate. This indicates that there will always be cold days, although they will be less frequent, and the hottest days are going to be more frequent and much hotter than currently experienced. These outcomes are projected for the 2070s and beyond following the *business-as-usual* 'Zero Mitigation (RCP 8.5)' scenario. Source: ACE CRC, 2016

While precipitation is generally expected to decline, the extent varies by resort, as does the uncertainty of the models. Figure 5 presents the change in annual precipitation for each resort.

FIGURE 5. PROJECTED CHANGES IN ANNUAL PRECIPITATION BY THE END OF CENTURY COMPARED TO THE HISTORICAL PERIOD

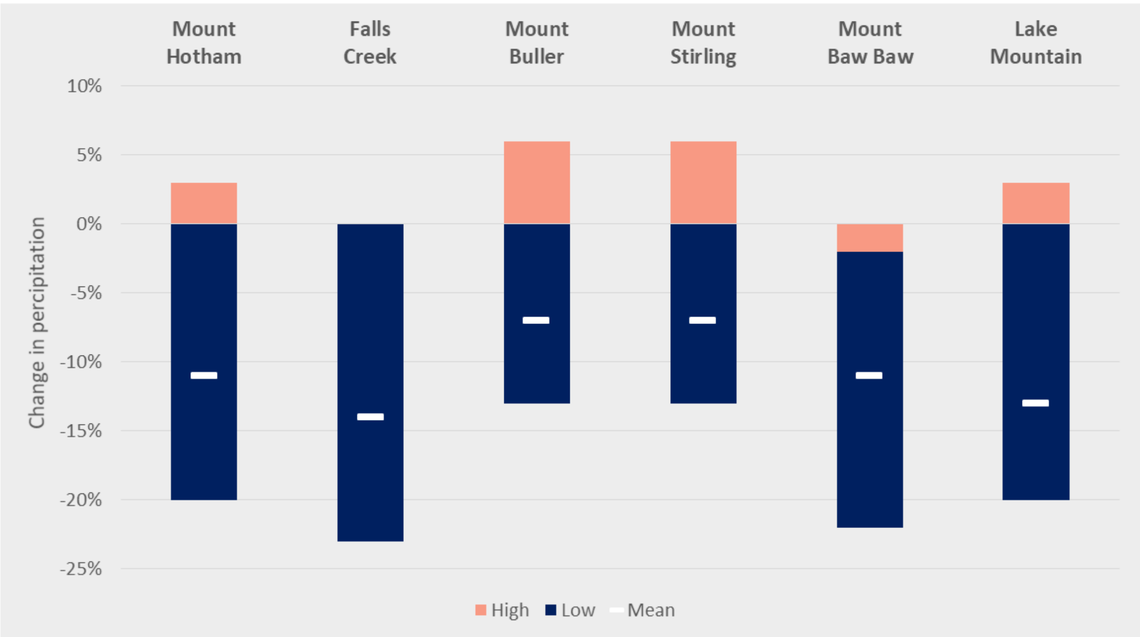


Figure 5: The change in annual precipitation by the end of century following the *business-as-usual* 'Zero Mitigation (RCP 8.5)' scenario. The range indicates the different model projections from multiple different studies. Sources: Hennessy 2008; Harris 2016; ARCC 2016.

The change in precipitation also varies by the months in which it occurs, with all models indicating a reduction in precipitation in the months show below in Figure 6.

FIGURE 6. PROJECTED MONTHS WHICH PRECIPITATION IS PROJECTED TO DECREASE BY THE END OF CENTURY COMPARED TO THE HISTORICAL PERIOD

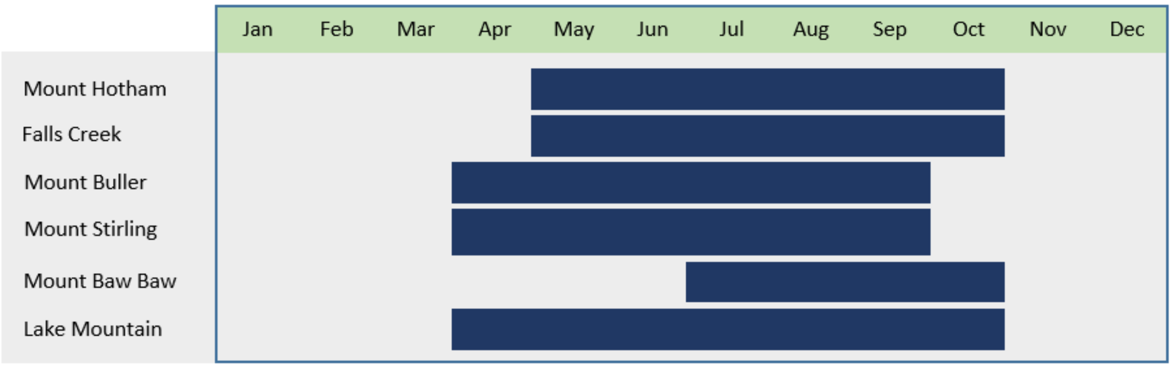


Figure 6: There is high confidence that the total precipitation is expected to decrease in the colder months across all resorts, following the *business-as-usual* 'Zero Mitigation (RCP 8.5)'. Although the months in which all models agree varies by resort. Sources: Hennessy 2008; Harris 2016; ARCC 2016.

Snowfall changes more than average annual precipitation, both because the precipitation decline is greatest in the winter months, and because warmer conditions mean more precipitation falls as rain or sleet, and less as snow. In comparison to total precipitation decline, the change is snowfall is more dramatic. The project changes in snowfall by the end of century are presented in Figure 7.

FIGURE 7. PROJECTED CHANGES IN SNOWFALL BY THE END OF CENTURY COMPARED TO THE HISTORICAL PERIOD

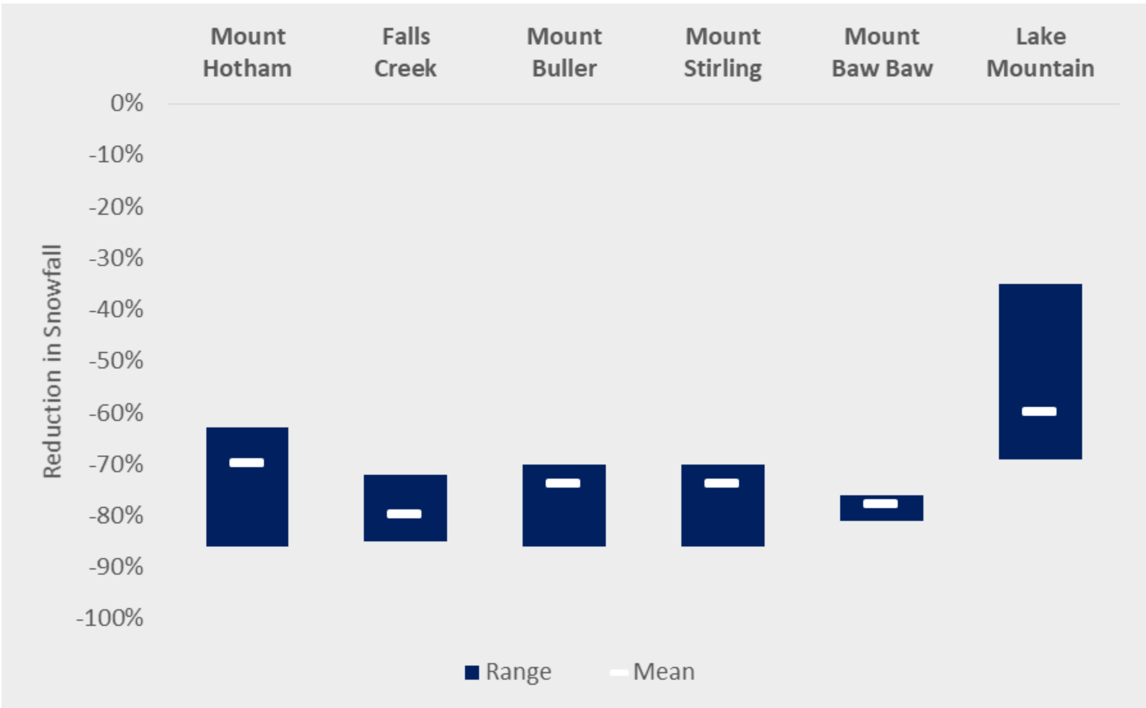


Figure 7 There is high confidence across the all model projections that snowfall will decline significantly by 2070, and possibly much sooner. At present, we are following the *business-as-usual* 'Zero Mitigation (RCP 8.5)' scenario. If the world fails to rapidly transition towards the *best-case* 'Aggressive Mitigation (RCP 2.6)' scenario over the next decade, it is highly likely snowfall will reduce by the maximum values presented. Sources: Hennessy et al. (2008); Harris et al. (2016); ARCC (2016).

The change in the total snowfall and rising temperature has a corresponding effect on both the number of days on which naturally falling snow is found on the ground (presented in Figure 8) and the maximum annual snow depth achieved in any given year (presented in Figure 9). Of course, in resort areas it is expected to be supplemented with snowmaking.

The modelling shown was generally for the *business-as-usual* 'Zero Mitigation (RCP 8.5)' scenario, or business as usual (BAU) case with very limited mitigation of GHG emissions. Regardless of the degree of emissions reductions achieved in the next decade, the 2020s result will be more or less unchanged. However, if the 'best case' efforts to reduce emissions should occur (i.e. the globe achieves the *best-case* 'Aggressive Mitigation (RCP 2.6)' scenario), then the long-term conditions may stabilise somewhere around those shown for the 2050s, or perhaps slightly better. This would result in the possibility of snow conditions on the higher resorts being comparable to those currently found at the lower resorts.

FIGURE 8. DAYS PER YEAR WITH AT LEAST 1 CM OF SNOW COVER

Figure 8: The number of days in a year when at least one centimetre of (natural) snow cover is expected to be present. The width of the columns corresponds to 365 days, the width of the navy blue areas indicating the number of days of snow cover. The numerical values shown on the diagram indicate the historical measured values for the 2000s at various altitudes. The pink area is fitted to match these values and extrapolated/interpolated elsewhere so is only indicative. However, the near straight line relationship and consistency of the trend by altitude even between resorts is striking. For the future periods, the range of models provide high and low estimates, the lowest snow days estimate shown by the navy blue and the highest shown by the pink. The range of the estimated values is shown at each altitude for which it was modelled. Note that the uncertainty of the number of days rises to the 2050s, but by the 2070s all models are showing little to no snow days remaining at any altitude.
BAU = *business-as-usual* 'Zero Mitigation (RCP8.5)' scenario. Sources: Hennessy et al. (2008); Harris et al. (2016); ARCC (2016).

FIGURE 9. ESTIMATED MAXIMUM SEASONAL SNOW DEPTH

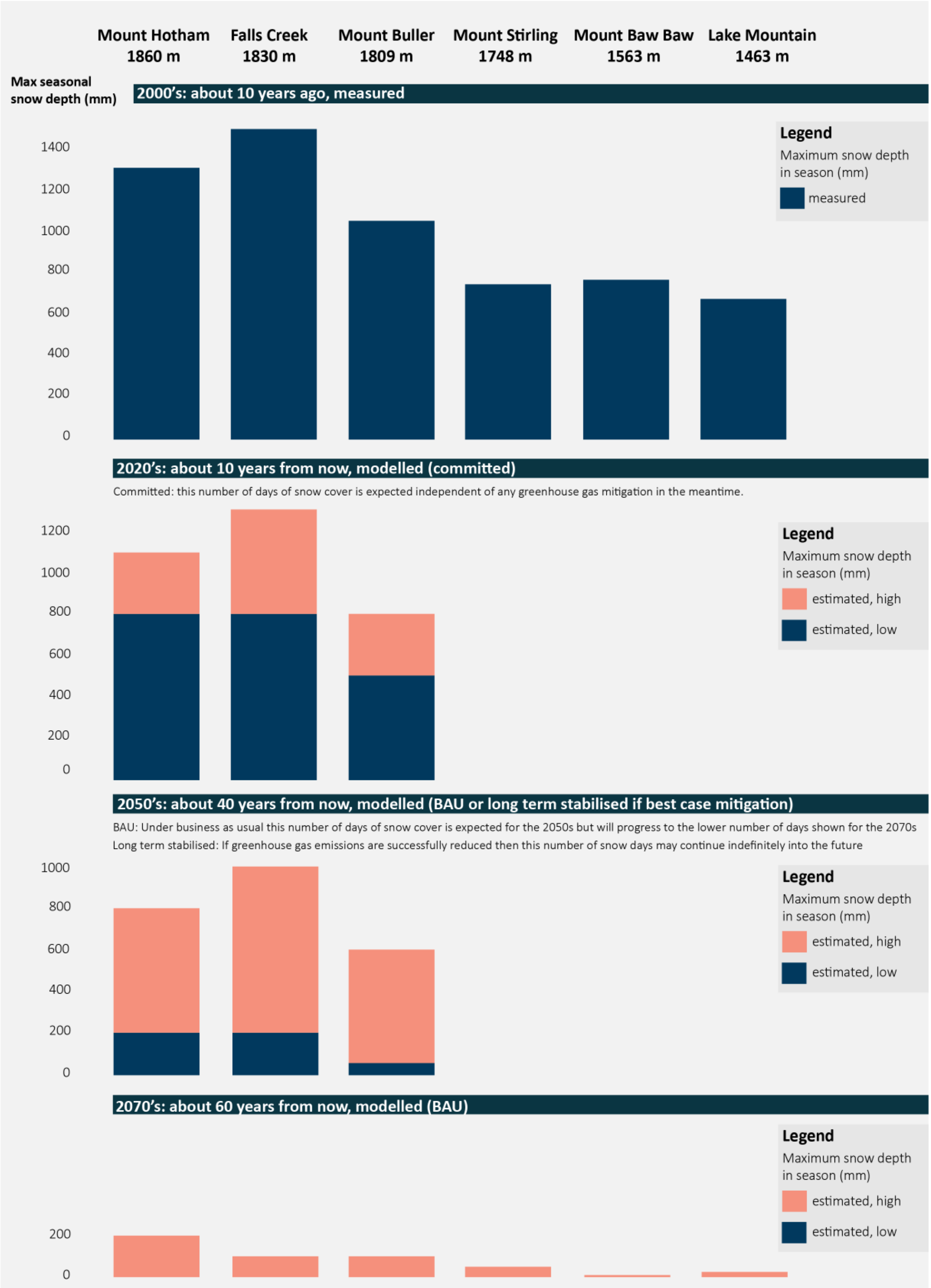


Figure 9: The maximum seasonal snow depth for the same circumstances as the previous figure shows number of days. Estimates are not available for three resorts for the 2020s and 2050s. As with the number of snow days, the best-case mitigation could lead to maximum depths at the higher resorts stabilising at conditions similar to those found today at lower resorts. Anything much less than that leads to essentially no snow by the 2070s. BAU = *business-as-usual* 'Zero Mitigation (RCP8.5)' scenario.
Sources: Hennessy et al. (2008); Harris et al. (2016); ARCC (2016).

Data limitations

Observational records of snow depth, snow cover and snow quality have significant limitations. Recording locations are very few, and have similar types of locations, biasing the measurements in possibly unknown ways. The historical record is relatively short. Quality data back to the 1950s is good, but in order to identify long-term climate trends much longer time-series are ideal (like those found throughout the European alpine regions).

To date, minimal assessment of the *best-case* 'Aggressive Mitigation (RCP 2.6)' scenario has occurred over the Australian Alpine Region. Therefore, future projections can only be described for a high atmospheric CO_2 world. Similarly, specific regional assessments of each resort location have not been conducted for the near-future (2030s) or mid-century (2040s-2060s) periods.

1.3 Alpine adaptation

Alpine regions around the world are starting to grapple with the consequences of climate change on the functioning and development of their alpine industries. This chapter will first briefly describe the economic, social and community impacts climate change has been observed to have on alpine resorts in Australia, New Zealand, Europe, Canada and the USA.

Then this chapter moves to a review of adaptation responses observed in alpine resorts elsewhere. The review describes what the options entail, their benefits, barriers, modes of failure and implications of implementation.

Climate change can have dramatic consequences for the economic viability of resorts, and the social and economic viability of the communities that rely on the economic activity generated in the alpine industry, in both the green and white seasons.

In the white season, reduced natural snowfalls can impact on the number of days there is sufficient snow cover for tourists to engage in activities like skiing and snowboarding. In the green season, increased bushfire risks may result in higher costs for bushfire management and reduced access and use of the alpine resort areas in order to meet evacuation protocols.

Alpine resorts use various responses and strategies to respond to climate change. This may include operational and institutional changes, increased snowmaking efforts, increased bushfire risk mitigation, diversification of the tourism offer and diversification away from tourism. In reality, resorts may deploy more than one option.

The results in this chapter are based on a review of selected available and known literature. Gaps in the literature, where further research would be needed to address these gaps, will also be identified.

Impacts on alpine region economies and communities

Climate change will continue to drive up average temperatures in the Victorian Alps, while precipitation will diminish. The consequences are reduced snow cover, increased bushfire risk and an increased incidence of heatwaves.

Reliable snow conditions are a crucial economic prerequisite for the snow sport industries and the lack of natural snow due to low precipitation and/or high temperatures is an immense challenge for alpine destinations (Rixen et al., 2011). It is increasingly evident that climate change in the coming decades will jeopardize the sustainability of alpine destinations and their white season tourism product (Walters & Ruhanen, 2015) in regions across the world, impacting the communities who depend on tourist and skier visitation for their livelihood.

Alpine tourism can be split into two yearly phases, the white season dominated by the snow sports, and the rest of the year – the green season. The snow sports industry is a significant generator of revenue and is distinct from alpine tourism in general because of its "seasonal, spatial and temporal concentration" (Bicknell & McManus, 2006, p. 389). Green season tourism largely focuses on the natural surroundings including activities such as bushwalking, touring car holidays, camping, and sightseeing. Other green season activities include mountain biking, road cycling, fishing, white water rafting, paragliding, horseback riding, and arts and cultural activities and events.

Snow sports in the white season include downhill skiing, tobogganing, cross country skiing, snowboarding and snow hiking. Snow tourism also includes accommodation provided in ski resorts and/or chalets, and the food and beverage establishments located at the resorts. In Australia, although small in global standards, the economic contribution of the alpine ski industry is significant; in Victoria, a report found that in 2016-17 the alpine resort industry contributed $790 million in value add and 7,892 jobs in the white season, and $168 million and 1,684 jobs in the green season (EY Sweeney, 2017). The value of the resorts identified by EY Sweeney (2017) demonstrate the importance of the alpine resorts to local economies and the state of Victoria; they argue that the presence of alpine resorts in Victoria means that many snow sports enthusiasts, who would otherwise have travelled overseas to the snow (if the Australian resorts had not been developed) have a high quality Australian snow sports option. This means interstate and international visitors along with local snow sports enthusiasts can spend on snow sports activity in the Australian economy rather than spending this money overseas (EY Sweeney, 2017).

There are 10 main snow sports resorts currently operating in the Australian Alps, with six located in Victoria. The Australian resorts range from 1,520 to 2,054 m in altitude. Mt Hotham is the highest resort in Victoria at 1,882 m. The majority of the Australian Alps lie within national parks, with the actual resorts all within or adjacent to these parks. The snow sports season extends nominally between two particular public holidays in June and October, a period of 113-120 days (Pickering & Buckley, 2010). In 2016 there were 762,981 visitors to the Victorian Alpine resorts during the white season, above the ten-year average of 679,523 (Alpine Resorts Coordinating Council, 2016).

Skier and snowboarder numbers in Australia, and therefore revenues for the snow sports industry, are highly sensitive to snow cover (Pickering & Buckley, 2010). Businesses associated with snow sports are particularly vulnerable to the projected impacts of climate change because snow sports are a climate dependent activity.

> Green season tourism can be interrupted by climate change induced events including an increased risk of bushfire. The risk of bushfires can limit number of visitors who can be safely accommodated in vulnerable areas and bushfires can interrupt tourist visitation during, and after, fire events. Even without an actual fire, the risk of bushfire itself can deter people from visiting.

This negative economic impact of climate change on snow sport participants is evident in ski fields around the world. For example, in Sweden changes in climate are mostly negative for the survival and continued development of alpine white season tourism and snow sport resorts, especially in the southern part of the mountain region (Moen & Fredman, 2007). In Canada and the United States, the most vulnerable tourism sectors are snow-dependent sports, such as alpine skiing, snowmobiling, and cross-country skiing (Bleau, Blangy, & Archambault, 2014).

According to a significant study on the European Alps for the Organisation for Economic Co-operation and Development (OECD), edited by Agrawala (2007), countries with a large proportion of low elevation ski areas will be at the highest risk of losing reliable snow conditions impacting the snow sports industry and ski resorts. Germany for example, could face a 60 percent decrease in naturally snow-reliable ski areas under a warming scenario of just +1 degree Celsius. In comparison Switzerland, with a high proportion of high elevation ski resorts, would suffer a decrease of only 10 percent of snow-reliable ski areas under the same scenario (Agrawala, 2007).

The white season is not the only time of the year when alpine areas will be impacted by climate change. Increasing temperatures coupled with a general drying of soil and ground fuels will increase the likelihood of bushfire into the future (ACE CRC, 2016).

Increased bushfire risk may generate a range of additional costs due to increased mitigation management, emergency response operations and adaptation. Bushfire adaptation may include measures that reduce the exposure of communities to risk for instance by reducing the number of visitors in the alps during high and extreme fire risk days. This has obvious consequences for green season tourist visitation and spending in the alpine sector. There is limited literature available that describes adaptation specifically in the alpine area.

> Climate change may also impact on alpine ecosystems, especially as a result of bushfire damage as happened recently in the Tasmanian alpine region during bushfires in January and February 2016. These fires resulted in permanent damage to cushion plants and pencil pines which do not regenerate after fires. In Victoria, the Alpine Ash is vulnerable if a changed fire regime leads to less recovery time between bushfire events. In socio-economic terms this may have flow-on effects on green season tourism and visitors attracted by certain landscape types.

Impact on snow sport participation

Snow-reliability is a key element of offers made by tourism in the alpine region. The relationship between snow levels and the economic viability of regional snow sport industries is clear, with the relationship between snow depth and ski industry performance identified by many authors over the past few decades (Cocolas, Walters, & Ruhanen, 2015; (Fukushima, Kureha, Ozaki, Fujimori, & Harasawa, 2002; Shih, Nicholls, & Holecek, 2009). The economic impacts of reduced snow depth reaches beyond the ski-fields to the wider service sector at a destination, including accommodation providers, cafes, shops and tourism operators (Hopkins, 2013).

In Australia, Pickering & Buckley (2010) have found that there is a close relationship between the cover of snow and the number of visitors at alpine resorts. The numbers of white season visitor days increased linearly with cumulative daily snow depth at the highest-altitude snow course between 2000 and 2008 with, on average, every additional metre of cumulative natural snow cover being associated with 3,000 additional white season visitor days (Pickering & Buckley, 2010, p. 432). In Canada highly unpredictable and variable conditions (i.e. heat waves) in the northeast has already led to the early closure of ski resorts and shorter seasons, with resorts experiencing an 8 percent decrease in attendance during a year with reduced snow cover (Bleau, Blangy, & Archambault, 2014).

Research by Cocolas, Walters & Ruhanen (2015) indicated that there is a general preference among the current Australian white season market for spatial substitution in the event of poor snow. This means that participants are likely to visit different resorts, instead of visiting resorts with poor snow cover. Given that low-elevation resorts are more vulnerable to climate change impacts, the low altitude of the Australian Alps makes the entire snow sports tourism industry particularly vulnerable to losing visitors to other destinations, for example New Zealand, if the snow coverage becomes poor. There may also be movement in the amount of visitors to Australian resorts from low altitude to high, for example Lake Mountain (altitude 1400m) to Mt Buller (altitude 1740m).

Particular attention should be paid to highly involved skiers and snowboarders who not only visit alpine areas most frequently but who are also the most susceptible to behavioural adaptations due to poor snow cover. Dawson, Havitz, & Scott (2011) argue that the loss of one highly involved person (who would visit alpine resorts regularly) from a particular ski area means that about three medium involved, or five less involved people, must be found to take their place if the same amount of revenue is to be achieved.

Saying this, the extent of the impact of reduced snow has been contested by some in the literature (Cocolas, Walters, & Ruhanen, 2015), with suggestions that other factors may influence tourists' decisions to visit, such as other leisure activities on offer or place loyalty and attachment

(Dawson, Havitz, & Scott, 2011) and that demand is not likely to decrease proportionally to snow cover. However, in general it can be assumed that resorts who specialise only in snow sports can only survive if snow-reliability is guaranteed.

Increased operational costs during white seasons

The development of high quality ski areas constitutes considerable costs and it is imperative that the resorts can generate income for a relatively long period to recover these costs (Moen & Fredman, 2007).

Snowmaking is a technique used to guarantee snow cover and is already an everyday occurrence in alpine ski resorts across the world. A consequence of climate change is that snowmaking systems will need to cover increasingly large areas of snow deficiency, requiring larger systems and consequently greater costs (Bicknell & McManus, 2006).

The costs of additional snowmaking and other slope management costs are likely to be passed on to the users of the slopes. Depending on the price elasticity of demand, this can have profound impacts, namely fewer visitors and snow days and less money to spend on accommodation, food and beverage, and on other mountain recreational activities. The profitability of alpine resorts will be impacted if higher prices (due to the cost of additional snowmaking) and lower snow quality lead to visitors travelling overseas to participate in snow sports, or simply participating less often (Pickering & Buckley, 2010).

Impact on financial viability of white season based tourism

The financial cost of a poor snow season is caused by the reduction in visitor numbers and the increase in operational costs due to snowmaking and other expenses. Ski areas can rebound easily from the impact of a single poor snow season among a series of good snow seasons; this is something ski managers have come to expect (Dawson & Scott, 2013). However, changing climatic conditions mean that limited natural snowfall and warmer temperatures are becoming the 'new normal' and the financial impact of single marginal seasons can no longer be buffered. This is because one bad season is likely to become a series of below average seasons, not just an irregular event.

Pickering & Buckley (2010) argue that the simplest explanation for predicted climate change impacts on ski resorts and the snow sport industry is that it simply represents a higher proportion of low-snow years. During the 2006 ski season in the Australian Alps, natural snowfall was at a 20-year low and the net incomes of ski resorts fell heavily as visitor numbers decreased and operating costs increased. A series of such years in succession, however, could have more serious financial consequences (Pickering & Buckley, 2010).

Dawson & Scott (2013) have approximated total revenue loss in the ski marketplace in the Northeast of the USA due to climate change. They found that with a high emissions scenario in the 2049-60 time period, ski areas in the US Northeast could see a total impact of US$322 million per season; this is due to resorts being closed during the currently very popular Christmas and new year period, the loss of snow sports in the shoulder seasons, and an increase in annual snowmaking costs.

Whilst there is concern around the impacts of climate change on snow sport tourism and alpine resorts financial sustainability, Bicknell & McManus (2006) have previously argued that whilst research has suggested that climate change would result in a physical 'meltdown' of the ski slopes, the "collapse of the ski industry is neither certain nor unavoidable" (Bicknell & McManus, 2006, p. 398). Adaptation techniques can be used to maintain a successful ski industry.

Wider economic and social impacts of changes in white season tourism

Not only are billions of industry dollars at risk, the communities and individuals that rely on ski tourism will also be significantly impacted under projected climate change conditions (Dawson & Scott, 2013).

Within the Victorian ski resorts private companies operate ski lifts and snow guns, as do some resort management boards, there are not for-profit ski club/lodges as well as commercial accommodation providers (hotels, commercial ski lodges, etc.), along with other commercial business such as restaurants, bars, ski hire facilities and shops. In effect, most of the Victorian ski resorts function as small towns (Morrison & Pickering, 2012), and the entire 'town' will be impacted by a climate induced loss of snow sport participants. At lower altitudes from the Australian Alps, there are also population centres that depend to a large extent on jobs and incomes generated from snow based tourism; tourism is an important industry in towns such as Mount Beauty, Marysville, Bright, Myrtleford, Beechworth, and others (Morrison & Pickering, 2012).

Therefore the impacts of climate change on snow sports will be felt both at the resort level and at a regional scale, depending on the level of reliance a particular region has on the white season economy (Dawson, Havitz, & Scott, 2011). If the reliance is high, the lost white season revenues and related jobs will heavily impact these communities, and, in Canada, it has been argued there is likely to be increased pressure on social services, unemployment, as well as a drop in real-estate values (Dawson & Scott, 2013). In Europe Tranos & Davoudi (2014) has found that the economies of the Alps region surrounding alpine resorts are likely to be affected more severely than the rest of Europe as a result of climate change, this is due to the Alps' economic dependency on visitor expenditure in white season and high stock of tourism infrastructure, in combination with the changes in average annual snow-covered days. In the U.S. Northeast, where many small communities rely heavily on the ski sector for local employment and ancillary tourism income (i.e., accommodation, food and beverage, après ski activities, etc.), many towns could be significantly impacted by visitors choosing to ski elsewhere (Dawson, Havitz, & Scott, 2011).

Behind the economic costs of climate change, there are impacts on people who are directly affected and will lose their livelihoods through climate change. These organisations may not be able to adapt as flexibly as the tourists, who will simply travel to a different ski resort with good snow conditions (Elsasser & Bürki, 2002). While Switzerland will be the least affected area within the European Alps due to the high altitudes, the consequences for local livelihoods at lower alpine resorts are potentially severe; "For local alpine communities, the current lack of economic diversification is a major impediment to their ability to accommodate changes in climate that would impact tourism" (Hill, Wallner, & Furtado, 2010, p. 74). Nevertheless, for the time being an economic development paradigm based on snow, whether natural or artificial, is still surviving in the tourism destinations of the Alpine region (Bonzanigo, Giupponi, & Balbi, 2016).

In Sweden suggested climate-driven changes will have implications for future sustainable development in mountain regions due to shorter seasons leading to diminishing employment opportunities for local residents (Moen & Fredman, 2007). In the Bavarian Alps in Germany and Austria, most stakeholders have become convinced that the number of snow-reliable ski areas will decrease in future (Soboll & Dingeldey, 2012).

What to do with financially unsustainable resorts is an important question for the community and governments to consider. In the European Alps this conversation has been underway for quite some time, with a number of stakeholders being in favour of dismantling non-profitable cable-way and ski-lift operations and regard a certain 'healthy shrinkage' of the sector as necessary. Others believe that there is an obligation to retain these ski fields for regional economic reasons (Elsasser & Bürki, 2002).

This economic pressure will also impact on governments. With climate change in the European Alps, requests for financial support and funding will likely increase (Agrawala, 2007). Ski areas will likely ask for additional help to secure their operations, insisting that they make a vital and needed contribution to the local and regional economy. Governments may have to share the costs, particularly for snowmaking, as a growing number of ski area operators (in Europe) consider snow-making a 'public service' and argue that all those who benefit from snow-making should contribute to the costs; this includes not only ski area operators, but also the accommodation industry, and the surrounding community (Agrawala, 2007). The use of snowmaking by ski area operators is intended to yield a profit for the own business, but it also has positive flow-on impacts on the whole regional economy (Damm, Köberl, & Prettenthaler,

2014). Pickering & Buckley (2010) mention that in Australia resorts may lobby for government assistance in terms of access to additional water; government subsidies for new infrastructure and cheap electricity; and for access to higher-altitude terrain inside protected areas
(Pickering & Buckley, 2010, p. 436)

Community and cultural impacts of changes to white season

Climate change in alpine regions will also impact cultural values and heritage. Snow recreation is an important part of the cultural identity of alpine communities (Scott, Dawson, & Jones, 2008) and creates a 'sense of place' for many. Modification of cultural practices and meanings evokes emotive responses as lifestyles, expectations and experiences are reoriented in line with changing climatic conditions; "Cultural adaption to changing climate comes at an emotional cost" (Gorman-Murray, 2010, p. 75).

Cultural identity and attachment to place also present an opportunity to expand and attract cultural and artistic endeavours and events to the alpine region. Falls Creek, for example, has developed a strong engagement with the arts community, and has an artist-in-residence program.

Shift of white season tourism to higher altitude resorts

The specific economic and financial impacts that changing climate conditions will have for individual ski resorts will also partially depend on the impacts experienced by its competitors, i.e. the closure or reduction in popularity of some resorts will lead to more visitors for others (Dawson, Havitz, & Scott, 2011).

Climate change will lead to a new pattern of favoured and disadvantaged ski tourism regions. If all other influencing factors remain the same, ski tourism will concentrate in the higher altitude areas that are snow-reliable in the future (Elsasser & Bürki, 2002). Ski resorts at lower altitudes will withdraw from the market sooner or later because of the lack of snow and the regions at higher altitudes may experience greater demand, actually prompting expansion (Elsasser & Bürki, 2002).

In Australia, Pickering & Buckley (2010) have argued that it seems highly likely that the higher-altitude resorts will anticipate that their lower altitude competitors will be unable to continue operating ski lifts, and therefore in the short term visitor numbers at the higher-altitude resorts may be boosted by a contraction of the industry.

Green season impacts

The green season alpine regions refers, not only, to the summer months, but the shoulder seasons between summer and the white season. The changes in precipitation and temperature will have consequences for green season tourism. Increased temperatures will extend the duration of the warm weather and potentially strengthen visitation in periods that are now considered shoulder seasons. Climate change can therefore generate some opportunities for alpine resorts. Across the world alpine areas are often seen as summer refuges from the heat in lower lying areas.

During the green season, higher temperatures, lower precipitation and a shorter period of snow cover (which keeps vegetation moist) will increase the risk of bushfires. "Ash"-type forests are found at higher altitudes in Victoria. These "Ash"-type forests contain trees have thin bark and build up high fuel loads, but they only dry out during prolonged droughts. When they do dry out they "burn with high intensity and the fires are difficult to suppress." (Morgan & Leonard, 2015)

Alpine resorts are located in vegetation rich areas and, in some cases, can often only be accessed by one road thereby reducing the evacuation capacity of resorts. The number of visitors that can be allowed to stay in resorts during green season may become increasingly constrained by evacuation requirements.

Increased bushfire risk has consequences for recreation opportunities in the green season when the risk occurs (mostly November to April). An example of the possible impacts a fire event can have on the tourism industry in the Australian Alps occurred in in the green season of 2003. A bushfire caused the closure of the alpine areas in the Kosciuszko National Park area, costing the local tourist industry up to 1,000 jobs and $121 million in lost income over the green season period (Worboys, 2003).

1.4 Adaptation options for alpine resorts

Humans are very adaptive, and experience elsewhere shows that adaptation techniques are already in place (whether by accident or design), or are being considered. This section explores the adaptation options identified in the literature. The results primarily focus on adaptation options for snow-based tourism. Very little evidence was found about adaptation options in relation to increased bushfire risks and/or changes in amenity due to changes in the landscape that are specific to alpine resorts. A wider analysis of Victorian and global adaptation responses to bushfire was initiated in response to this gap in the alpine literature.

> Alpine resorts in Victoria have already implemented adaptation techniques including snow making, snow farming, slope management and diversification.

The impact of climate change on alpine regions demonstrates that coping mechanisms and adaptation strategies that both exploit opportunities and mitigate risks are required for the weather-dependent snow sport and alpine tourism industry (Hopkins, 2013). Strategies for adapting to both long term climate changes and increased risk for extreme climate events should be developed (Moen & Fredman, 2007).

Adaptation responses are required including generating man-made snow, diversifying into other tourism products and/or diversifying into other industries. If current climate trends continue, a ski area will fall below the minimum financially viable threshold if they rely on natural snowfall and take no adaptive action (Pickering & Buckley, 2010). Table 1 provides a summary of the adaptation options found in literature, their benefits and possible barriers to the implementation. Thereafter the chapter explores the literature and these adaptation options in detail.

> The adaptation techniques explored are drawn from literature across the globe to gain a general overview and understanding of how adaptation to climate change is being considered, or implemented.

These options are not mutually exclusive. Resorts may deploy more than one option, for example snowmaking in tandem with slope management techniques to capture more snow, and an all-year tourism offering, could be an appropriate response for some resorts.

TABLE 1. SUMMARY OF ADAPTATION OPTIONS FROM LITERATURE REVIEW

Actions and benefits	Barriers
Adaptation planning and capacity building	
– Undertaking adaptation planning and exploring options allows those impacted to see that there are solutions that can be pursued. This reduces the risk of maladaptation (actions that increase vulnerability or actions that undermine adaptive capacity). – Knowledge of the benefits and costs of adaptation options allows stakeholders to make informed decisions and enables them to take action. Fear of the unknown can stall progress. – Crisis is an opportunity for change and improvement if planned for and managed properly. – Ski areas are not necessarily destined for closure. Good planning and capacity building can overcome many barriers. – Bushfire planning and adaptation reduces vulnerability and saves lives.	– Stakeholders need to act collectively, which can cause planning and adaptation to be difficult and sometimes fail. – Promotion of the issues faced draws attention to the vulnerabilities of the alpine resorts and this could impact on investment. – Uncertainty about when to act. While climate impacts are increasingly well understood, the pace of change is less certain. It is difficult to predict the exact timing of climate induced impacts across decades. – Long adaptation planning horizons. Depending on resort altitude, severe impacts on the industry may still be more than a decade away. Most businesses have planning horizons of up to three years. – Internal factors can impact capacity, including the managerial ability and existing culture, a resistance to change, lack of understanding of the problem, or lack of resources and technical knowledge to properly design and implement adaptation options. – External factors can impact capacity to respond including lack of new technologies, levels of government funding, and policies and governance processes, amongst others.
Snowmaking	
– Mitigates against low snowfall seasons and acts as insurance policy for overcoming the unreliability of seasons. – Extends the duration of ski seasons. – Maintains high quality skiing areas for users. – Already part of normal operations at ski resorts. – There is scope for new snowmaking technologies to assist in overcoming the barriers of snowmaking as an adaptation strategy, namely water and energy costs, and supply constraints.	– Uncertain financial viability. Snow making requires significant capital and operational costs. Snowmaking using snow guns is only possible with certain temperatures. The return on investment requires a minimum number of suitable days for snow making. This applies especially to low altitude resorts with higher temperatures. Also, with climate change induced higher temperatures a lesser proportion of the white season is suitable for snow making (if using snow guns), making the investment less likely to be financially viable. Even if snow factories are used, the snow produced will melt faster with higher temperatures. – Constrained access to water and electricity for snowmaking. Snowmaking requires large amounts of water, with the supply of water having limits. Water supply also faces competition with other sectors (e.g. agriculture) and supply for potable water. Barriers may be overcome though with the use of recycled water, the recapture of snowmelt, or by maintaining watershed flows to downstream users. – Perpetuates anthropogenic climate change due to increased energy use and resource extraction. – Conflicts with local community i.e. water extraction. – Cultural issues in regards to technological fixes like snowmaking not being in-line with nature-based recreational values due to ecological concerns. – Higher operational costs lead to more expensive lift passes, reducing visitor numbers and spending. – Alpine 'scarring' due to new infrastructure, water storage lakes, and service roads.
Expansion/shift to areas with a climatic advantage (higher terrain or south facing slopes	
– Concentrates ski operations in locations with a climatic advantage with greater snowfall. – Movements to south facing, shaded or sheltered slopes allows for the snowpack to melt slower and the ski season to be extended or maintained. – Reduces the need for snowmaking.	– Not always possible. Areas for expansion at higher altitude or south facing slopes may not exist. – Skiers prefer sunny skies which are less common at higher altitude and on south facing slopes. – High elevation ski areas are prone to strong winds and avalanches which can disrupt ski operations and cause danger to visitors. – Extending existing ski areas to higher elevations is expensive. – High-elevation environments are fragile and shifting ski areas to these new areas will have environmental impacts. – High altitude areas are often covered by environmental protections and any attempts to move snow sports to these

Actions and benefits	Barriers
	areas are likely to face opposition from the public and environmental groups. – Higher altitude areas are also more difficult to reach for visitors, impacting visitor numbers in comparison to existing ski areas.
Skiable area management techniques	
– Can reduce of the amount of snow required, both natural and from artificial snowmaking. – Snow retention and shading techniques allows for a greater number of skiable days to be achieved as snow melts slower. – Management can shift skiers on to ski slopes with better snow conditions via increasing lift capacity, allowing more people to use high-performing runs. – Management can limit the number of runs available concentrating snowmaking efforts. – Flexible ticket pricing can allow managers to attract more visitors in poor snowfall seasons, and reduce numbers in well performing seasons.	– Slope levelling has large environmental impacts especially due to removal of vegetation. – Loss of attractiveness (or naturalness) of the area caused by landscaping and levelling works can impact green season visitation. – Concentrating skiers onto well performing slopes, and limiting the number of slopes available to concentrate snow making efforts, will only be successful if visitors remain satisfied and are not driven away due to overcrowding. – Flexible ticket pricing may be seen as unjust if prices rise due to good snow cover and only the wealthy can participate.
Diversification of tourist offerings	
Diversification allows the loss in profitability due to climate change to be offset through other revenue streams. **White season tourism diversification** – White season offerings based on 'snow experiences' as opposed to specifically snow sports redirects the focus away from the quality of the snow cover to the overall mountain experience. – Provides alternative activities for skiers and non-skiers alike. – Generates additional revenue which can compensate for lower visitor numbers, or help pay for snowmaking. – Can enable ski resorts to remain profitable during poor snow seasons. **Shift to all-year tourism** – All-year tourism offerings reduce dependence on the short white season susceptible to poor snowfall. – The shift from operating as a seasonal ski resort to year-round 'mountain resort' allows revenues to be increased. – There are positive social impacts due the availability of year-round employment instead of seasonal work. – May be that the only option for low altitude resorts is with diversification to other tourism offerings which provided an opportunity to maintain the tourist industry in the area.	**White season tourism diversification** – Visitors usually do not visit an alpine resort because of the non-snow sport offers alone in the white season (spas, bars and restaurants, festivals etc.), they do so for the snow sport activities. These other offers are considered complementary. The non-skiing offers alone might not be enough to attract a sufficient number of visitors to the resort if there is poor snow cover. – Diversification may not be beneficial for all stakeholders e.g. lift operators who rely on transporting skiers and snowboarders up and down the slopes. – Many alternatives for white season activities also rely on snowfalls. – If climate change results in less snow but more rainfall other white season activates (snow hiking, ice skating, tobogganing etc.) become undesirable due to the inclement conditions. **Shift to all-year tourism** – Diversification to popular green season activities may exceed the carrying capacity of the area causing environmental damage. – The development of a green season requires long term planning and significant effort by alpine resorts in order for them to develop recognition in this market. – Diversification to green season activities entails competing with other alpine resorts and other summer locations, for example coastal towns and beach resorts. – Increased risks due to having large numbers of tourists in bushland areas during the fire season. – Losing the seasonality of alpine resorts could be detrimental to the local community and businesses who use the off season as down time, for renovations, and to enjoy the area without a large number of tourists.
Diversification away from tourism	
– Regional advantages can be harnessed to diversify away from tourism completely, some examples found in the literature include renewable energy, organic vegetables and small-scale products such as woodwork. – Can provide alternate incomes if snow sports driven tourism needs to be abandoned.	– Loss of social and cultural identity and lifestyles due to shift to new industries. – Planning restrictions on different types of developments outside of tourism, particularly in protected alpine areas.
Planned retreat and dismantling of unneeded snow season infrastructure	
– Attention and effort can be refocussed to more suitable and viable industries.	– Large cultural and economic impacts as organised snow sports are lost to the Victorian community.

Actions and benefits	Barriers
– Avoids environmental damage caused by infrastructure left in place degrading. – Materials can be recycled.	
Bushfire adaptation	
– An acceptance that bushfire is now an inevitable part of the landscape will enable communities to be designed better and be more prepared. – Improving building codes makes houses and other buildings safer in extreme conditions. – Opening up new areas that are less vulnerable to fire for tourism, or consolidating green season infrastructure in less vulnerable areas in the Resorts, can improve visitor safety. – Developing awareness campaigns for tourists raises awareness of how to act and respond appropriately to the hazard. – Early warning systems allow people to leave safely before it's too late. – Risk minimisation strategies and 'no-grow' zones around properties reduce the risk to people and property.	– Accepting that bushfires are an inevitable part of the landscape will be controversial with the community who may prefer expensive technical fixes. – Back burning and fuel reduction activities is expensive and requires considerable resources. – Mountain Ash, the prevalent species in Victoria's alpine region, is not suitable for regular fuel reduction burns.

Adaptation planning and capacity building

Already, the impact of climate change on Australian snow fall is resulting in poorer seasons and higher dependency on snow making. Thus the adaptive capacity of ski resorts is crucial to enabling them to respond to the challenges (Walters & Ruhanen, 2015). In the tourism sector, adaptation can be characterized as the combined actions (or non-actions) of various stakeholders, including individuals, businesses, governments, communities, and nongovernmental organizations (Jacobs, 2015). Adaptation involves taking action to manage the impacts of climate change so that current goals can continue to be met, or working out which goals we are prepared to trade off against each other as climate change alters opportunities and imposes constraints (Jacobs, 2015).

Beyond identifying the biophysical, social and economic impacts of climate change there is a need to plan for adaptation, and make decisions on how to respond. There has been a significant investment in adaptation research, risk assessment and planning in Australia, however a major challenge has been moving from risk and vulnerability assessment to decision making and action (Webb & Beh, 2013). There is a need to focus on "enabling decision makers to make the difficult and urgent choices between a range of alternative policy and management options in interconnected social and natural systems."
(Wise et al., 2014, p.326)

Fünfgeld (2012) argues making policy decisions in the face of uncertainties (such as emissions scenarios, timing, geographical differences, modelling and forecasting uncertainty, and interdependent economic and social factors) requires a careful balancing of the need for quantifiable evidence, courage and political will. There also, crucially, needs to be a degree of flexibility in the decision-making process allowing for decisions to be updated.

Webb, R & Beh (2013) performed a review of adaptation support products currently available or planned in Australia and overseas; more than 300 international and Australian products were recorded. In the 'complex decision making' space, a number of process support products were identified overseas including:

– The UKCIP Risk Framework developed in the United Kingdom, which is decision-making framework using a step-by-step process to help assess what adaptation measures are most appropriate for organisations or businesses.
– The Local Government led ICLEI Canada guidance product. ICLEI's methodology provides a straightforward approach to adaptation planning using a five-milestone framework (initiate, research, plan, implement, and monitor/review)

– The United Nations Environment Program sponsored PROVIA Guide. The Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) is a global initiative which aims to provide direction and coherence at the international level for research on vulnerability, impacts and adaptation.

In Australia, Webb found that there were no products of this type (complex decision making tools) available for use in the public arena; however tools were identified in the private consultancy sector, including Climate Adaptation Decisions Pathways.

As part of the Australian Department of Climate Change and Energy Efficiency funded Climate Adaptation Decisions Pathways program several projects have developed procedural guidance to support decision making and have focused on a comprehensive guidance document as a primary deliverable. Webb argues that the Climate Adaptation Decisions Pathways tool could, with some slight modifications and enhancements, provide the basis for a more generally useful product in Australia as its' approaches are consistent with the main international products identified, it is up to date with latest thinking, and has already been tested in the Australian context.

Internationally, Walker, Haasnoot & Kwakkel (2013) performed a Review of adaptive planning approaches for adaptation under uncertainty. They included the Robust Decision Making (RDM) approach, Adaptive Policy Making (APM) Approach, Adaptation Tipping Points and Adaptation Pathways approaches, and the Dynamic Adaptive Policy Pathways (DAPP) approach. Looking at the family of adaptive planning approaches, Walker, Haasnoot & Kwakkel (2013) found a range "principles" for planned adaptation that the approaches all share. The essential idea of planned adaptation is that planners facing uncertainty create a "shared strategic vision of the future, explore possible adaptation strategies and pathways, commit to short-term actions, while keeping long-term actions open, and prepare a framework (including in some cases a monitoring system, triggers, and contingency actions) that guides future actions".

A key strength of a pathways approach for adaptation is that it explicitly considers the interdependencies between uncertain timing and the magnitude of climate-change impacts and the characteristics of responses in terms of costs, lead and lag times, and reversibility. In this regard, the tool emphasises the need for flexibility and iterative management of immediate decisions, informed by a strategic vision of the future and a framework to inform future actions based on decision triggers and monitoring (Haasnoot et al., 2013).

Communication is critical to adaptation, making adaptation planning and communication initiatives important as an adaptation technique and starting point. Those likely to be impacted need to get information about the likely impacts of climate change and how to respond. "If only the risks are communicated without communicating adaptation options, people will probably react by avoidant maladaptive responses like denial of the risk". (Grothmann & Patt, 2005, p. 209). Trawöger (2014) argues that only an increased knowledge of branch- and region-specific consequences of climate change related to snowmaking costs, water demand and the like will trigger a profound discussion of the issue and cause action to be taken.

> Victorian alpine resorts are already planning for climate change and increasing their capacity to respond. The process is already underway.

Similarly Wyss (2013) argues that in order for cooperative initiatives for climate adaptations to be successful, "individual actors within a tourism region must first of all find a motivation to engage in activities which lead to climate change adaptation" (Wyss, 2013, p. 4). For this to be possible, information must be provided in order to lay open the possible (future) vulnerability of the individual actors as well as the vulnerability of the system as a whole (Wyss, 2013).

Dawson & Scott (2013) stress that "importantly, it is not the entire ski market that is necessarily at risk to climate change, but rather at risk are individual ski areas and regions that are not able to adapt or afford the increased costs of adapting to projected change" (Dawson & Scott, 2013, p. 244). It is also important for destinations to recognize crisis as a chance for improvement if planned for and managed properly

(Paunović & Jovanović, 2017). In the European Alps, before decisions are taken regarding further snow based development, planners must evaluate the proposals' sustainability and take action accordingly (Bonzanigo, Giupponi, & Balbi, 2016), because "how tourism responds to climate change is absolutely critical to the sustainability of tourism" (Scott D. , 2011, p. 28)

Deciding a course of action for adaptation is a task being undertaken by alpine resorts and regions across the world. In the USA it is being argued whether vulnerable ski areas should invest heavily in adaptations that will aid in continuation of a snow-based business at least in the short to medium term (i.e., high efficiency snowmaking) or whether they should invest in adapting and evolving into a multi-season destination (i.e. a four-season resort, spa, or conference centre), or if they ultimately need to terminate their business altogether (Dawson, Havitz, & Scott, 2011).

> The literature review has not captured any information on how a termination of snow sport industries would be carried out and planned for. However the closure of the ski resort at Mt Buffalo in Victoria does provide a practical example of a ski resort terminating their business and could act as a case study for further research. Mt Buffalo was Victoria's first ski resort and had Australia's first tow and ski lifts. The resort closed in 2007 due to financial reasons. The resort infrastructure has been left in place and needs repair, including the five ski lifts and the original heritage chalet.
>
> Although the closure of the resort wasn't directly linked to climate change, it does provide an example of what retreat looks like.

In the European context, Bonzanigo, Giupponi, & Balbi (2016) have outlined the following as possible strategies for the future of the alpine areas:

- A Ski-Intensive (SKINT) strategy which entails construction of high-tech downhill skiing centres, with new lifts, hotels, and restaurants to frame the skiing offer, and includes artificial snow-making facilities.
- An Alternative- Skiing (ALTSKI) strategy which comprises a new typology of skiing resort focused on free-ride skiing, nordic skiing, and snowshoe trails. These activities require less infrastructure and snow than the ski intensive strategy.
- The Beyond-Snow (BYDSNW) strategy promotes the abandonment of investments in downhill skiing (and artificial snow), in favour of turning the area into a resort specialised on wellness and family tourism, with an increase in non-snow-related offers (spas, restaurants, shopping).

Adaptation pathways are sets of complementary and mutually reinforcing adaptation options, that are implemented as required over time. Pathways explore how an area may adapt over time and what the impacts of adaptation are. Different pathways are equally valid and possible ways to respond to the changing levels of risk, but their implications in terms of implementation costs, community values, natural values, economic impacts and infrastructure and services provision vary significantly (SGS, 2014). Adaptation pathways are a powerful metaphor and analytical approach that can help decision makers identify, explore and sequence possible adaptation decisions and actions over time (CSIRO, 2017[3]).

Barriers to adaptation planning and capacity building

Barriers to adaptation planning require implementing adaptation measures, various stakeholders from both private and public organisations are forced to pool their resources and act collectively; "While this sounds like a rather straightforward thing to do, many initiatives in this direction have failed in the past due to a broad variety of factors." (Wyss, 2013, p. 1).

Planning for climate change is not easy. Not only is it difficult to predict the exact environmental changes that will occur at any particular place and time, it is also challenging to ensure that the diverse needs of the community continue to be met (Jacobs, 2015).

The potential to adapt is also determined by economic and technical resources available, as well as the managerial ability or access to information resources (Trawöger, 2014). Some factors that contribute to adaptive capacity are mostly external; these can include the development of new technologies, levels of government funding, linking forms of social capital that facilitate access to ideas and opportunities, cultural values, policies and governance processes, economic wealth, information and skills, infrastructure, institutions, and equity (Jacobs, 2015).

Another barrier for resorts in the Australian ski industry in adaptation planning, and being vocal about meeting the challenges, is that it draws attention to their vulnerabilities. This could subsequently impact on investment, in the Australian Alps "the prospect of climate change as a threat was more damaging than the impact of climate change itself. As such many tourism participants needed to demonstrate that they have a viable future." (Morrison & Pickering, 2012, p. 32).

Snowmaking

Snowmaking is a technology that is already widespread at Australian and international ski resorts and is used to supplement natural snow falls.

Snowmaking using snowguns entails the automated production of man-made snow by forcing pressurised air and water through a snowgun into the cold air, where it forms into small ice particles, and falls on the ski slope. Snowmaking requires a significant level of infrastructure, including the snowguns, water storages, pump stations, compressors, electricity supply, hydrants and weather stations. In Australia, snowmaking is used principally to provide snow cover at the start of the season, to maintain cover on high use areas at lower altitudes, and to extend the season at the end (Pickering & Buckley, 2010). Artificial snowmaking also helps to improve skiing conditions and increase the number of runs available for snow sports (Bicknell & McManus, 2006).

Snowmaking is particularly important in years with poor natural snow cover and is viewed as an insurance policy for overcoming the unreliability of seasons (Bicknell & McManus, 2006). Tourists demand good snow conditions and snow making allows ski resorts to secure their tourism offerings and provide a higher guarantee to visitors of good snow cover. Snowmaking is therefore an important business strategy for ski resorts regardless of climate change.

Analysis of data from 109 French ski resorts covering eight white seasons (2006/2007 to 2013/2014) has found that a 10 percent higher capital stock of snowmaking infrastructure leads to an increase in the number of snow sports participant visits by 8 percent (Falk & Vanat, 2016). In Austria, Steiger (2011) has found due to snowmaking the impact of climate change on snow sport participation and demand is quite modest, at least in the short and medium term. Instead the biggest issue facing snow sport participation at Austrian ski resorts is actually demographic changes, such as the stagnating and ageing population.

Snowmaking technology can be harnessed to mitigate against less snowfall by supplementing the lack of natural snowfall with man-made snow. In the early 2000s, in response to the deteriorating snow conditions in the European Alps, snowmaking was one of the most familiar measures of adaptation (Elsasser & Bürki, 2002). In Switzerland Rixen, et al (2011) reported that artificial snow production was the key adaptation strategy to rising temperatures, enhanced economic competition, and increasing requirements of snow sports enthusiasts. This has resulted in a dramatic increase in snowmaking facilities in the Alps. In France it has been found that ensuring the economic success of a season encouraged ski resorts to mitigate their dependency on

> Snowmaking technology is evolving and improving. This section focuses on snowmaking using snowguns, as this is the technique explored in published peer-reviewed literature. Other types of snowmaking exist that are independent of climate, such as snow factories, however this literature review has not found any academic literature specific to climate independent snowmaking, and how the evolution of snowmaking technology will be able to assist with adaptation. For example in the Damm, Köberl, & Prettenthaler (2014) study 'Does artificial snow production pay under future climate conditions?' an assumption was made that snowmaking infrastructure (including type of snowgun technology) remains static into the future. This is unlikely to be the case in practice. The Damm, Köberl, & Prettenthaler (2014) study concluded that further research has to be done to analyse other ski management options such as new and more efficient snowmaking technologies.
>
> A consideration of snowmaking as an evolving adaptation technology, a technology that can be made more efficient and climate independent, is a noticeable gap in the literature.

natural snowfall through snowmaking facilities (Rutty, et al., 2015). Given the expected change in climate in Europe, “the trend toward extensive snow production will continue and increase” (Rixen, et al., 2011, p. 229).

Similarly in North America, the widespread uptake of snowmaking has been one of the most important investments ski areas have made in ensuring their economic viability (Dawson & Scott, 2013) and the adaptive capacity offered by advanced snowmaking has substantially reduced the climate change risk of the Northeast ski industry in the USA (Scott, Dawson, & Jones, 2008).

In New Zealand, snowmaking is reported as central to the ski industry, with ski-fields utilising snowmaking technologies not only to maintain, but also to extend the skiable season (Hopkins, 2013). A study in the Australian Alps by Morrison & Pickering (2012) found that most of the climate change adaptation strategies identified by the tourism industry involved snowmaking and water recycling for snowmaking.

Expanding snowmaking and water infrastructure is noted by the Victorian alpine resorts as a key technique to provide reliable snow cover for visitors. This ability to create snow artificially and guarantee snow cover demonstrates the adaptive capacity of the Resorts. Examples include:

- Buller Ski Lifts, with support from Mt Buller Mt Stirling Resort Management, has invested in Snowfactory capabilities for the 2017 snow season. The new Snowfactory can continuously produce snow 24 hours a day, 7 days a week at temperatures well above freezing.
- During the 2015 white season at Lake Mountain the ARMB reported that the season was enhanced by the use of snowmaking equipment to supplement small natural snow falls. Snow-making enabled the resort to provide a snow-based experience for more than 120,000 visitors, without which it would have been less than 60,000.
- At Mt Hotham in the summer of 2016/17 the last component of the Snowmaking Masterplan was completed with the installation of 12 new snowguns, bringing the total number of guns to 104. With expanded snowmaking increasing the chance of reliable snow conditions, Mt Hotham now offers a snow guarantee to visitors.

Barriers to snowmaking as an adaptation strategy

The literature review has revealed that snowmaking using snowguns may mitigate against the negative impacts of climate change, namely reduced natural snowfall, however there are likely to be a wide range of barriers to relying solely on snowmaking as an adaptation strategy.

For example, the literature reveals that while snowmaking has the potential to offset the impact of climate change on the natural snow-reliability of ski areas, a report for the OECD found that in the European Alps there are clearly both physical and economic limits to the extent to which this can be done (Agrawala, 2007). Similarly Pickering & Buckley (2010) argue that snowmaking using snowguns is subject to significant physical, economic and environmental constraints. Morrison & Pickering (2012) argue that even though snowmaking using snowguns is the primary climate change adaptation response by the tourism industry, it will not be economically, physically or socially acceptable in the future (assuming no significant leaps in technology).

Most investigations of the climate change impact concluded that snowmaking using snowguns may not be a relevant adaptation method beyond the short-term period (Rutty, et al., 2015). Walters & Ruhanen (2015) argue that in the longer term and under potentially worsening climate change scenarios, snowmaking strategies relying on snowguns may be less effective. In a warmer climate, snowmaking would still be possible, but the snowmaking potential using snowguns would be considerably reduced (particularly at low altitudes) and only be possible under high operation costs (Rixen, et al., 2011). Snowmaking using snowguns is only possible when the air temperature in under a certain temperature, and with climate change the amount of time low temperatures are experienced will reduce.

Another factor is that energy requirements are high for snowmaking and inversely related to temperature, i.e. the warmer it becomes the more snowguns that will be required and the longer they will need to operate. Therefore resorts will incur higher costs the warmer the temperatures get due to climate change (Moen & Fredman, 2007). From an economic perspective the cost of snowmaking using snowguns will increase disproportionately under warmer temperatures as not only would more quantities of snow be required, but it will need to be produced under higher ambient temperatures and with the snow melting quicker. However there are developing snowmaking technologies that can produce snow independent of the air temperature, such as snow factories.

To counter the impacts of climate change on snowfall, snowmaking systems will need to cover increasingly large areas of snow deficiency, requiring larger systems and consequently greater costs. In Australia it has been argued (Pickering & Buckley, 2010) that ski resorts in the Australian Alps would need to increase both the number of snow guns and how often they are used. This means they would need more water and more electricity to keep runs open.

Walters & Ruhanen (2015) argue that a snowmaking adaptation strategy depends on resorts having the necessary capital to develop the extensive snowmaking systems required, as well as access to the necessary water supply for increased snowmaking. These requirements are both challenging for Australia's resorts given their relatively smaller scales and lower altitudes as compared with North American and European resorts (Walters & Ruhanen, 2015); ski runs at lower altitudes need considerably more guns and water than those at higher altitude.

In Victoria some alpine resorts have more than sufficient water storage capabilities in place, whilst others are in need of further storage capacity or to introduce water recycling to increase water supply.

The increased production of artificial snow will also require increased water usage. Communities and environmental organisations in Europe have already expressed their concern about water consumption associated with snowmaking (Agrawala, 2007). Pickering & Buckley (2010) have estimated that with the necessary increase in snowmaking under a +1C warming scenario by 2020, the six ski resorts examined[4] in their study in Australia would consume 2,500–3,300 ML per month in the white season. For comparison, the average monthly water consumption in Canberra is about 2,800 ML per month. In order to secure the water supply for snowmaking, many mountain reservoirs and artificial lakes would likely need to be built. However, not only does the construction of such reservoirs involve high costs, but it can also be very destructive on the environment and lead to 'scars' on the alpine landscape (Agrawala, 2007).

Furthermore there is strong competition from various industry sectors for water from the Australian Alps including irrigated agriculture, urban residential use, power generation and a variety of other industrial uses (Pickering & Buckley, 2010). Water demand and costs for ski resorts will be reduced, however, if the resorts can capture and re-use snowmelt runoff, and use recycled water from accommodation and other facilities. Resorts are indeed starting to use these approaches, but they are unlikely to substitute completely for the consumption of raw water from natural river flow (Pickering & Buckley, 2010).

New developments in snowmaking technology could possibly assist in overcoming the water and energy barriers of snowmaking as an adaptation strategy. Modern and more efficient snowmaking technology can be applied to reduce energy and water consumption (Rixen, et al., 2011).

Other barriers to snowmaking as adaptation strategy to climate change include that:

- Snowmaking perpetuates anthropogenic climate change via increasing CO2 emissions due to snowmaking's high energy use and resource consumption (Hopkins, 2013).
- Hopkins (2013) also argues that social perceptions of the resource consumption of snowmaking will also act as a constraint. While "snowmaking has many positive outputs for the ski industry, there are also perceptions of negative externalities which impact upon perceptions of sustainability and (mal)adaptation in the longer term" (Hopkins, 2013, p. 121)
- A technology heavy strategy could undermine traditional white season tourism rather than building on it (Bonzanigo, Giupponi, & Balbi, 2016). Technology is seen by some as not compatible with the nature based experience of snow sports.

[4] Mt Perisher, Mt Thredbo, Mt Selwyn, Mt Buller, Falls Creek and Lake Mountain.

– Alpine resorts' financial situation could be worsened if higher prices (caused by higher operating costs due to snowmaking being passed on to visitors) and lower snow quality lead many of their current visitors instead choosing to travel overseas to ski, or simply ski less often (Pickering & Buckley, 2010).

Expansion/shift to areas with a climatic advantage

This strategy involves shifting, or expanding, ski runs, or even entire resorts, to higher altitudes or to areas with more snow. This was an adaptation option identified by several authors in the literature (Agrawala, 2007), (Bicknell & McManus, 2006), (Dawson & Scott, 2013), (Moen & Fredman, 2007).

A strategy identified in a study for the OECD by Agrawala (2007) for the European Alps was going higher and facing north (strategy would entail south facing slopes in Australia). The aim of this strategy is to concentrate ski operations in locations with a climatic advantage. The different options for this strategy include:

– Developing north (south) facing slopes, where the snow pack remains longer;
– Moving operations to the upper part of an existing ski area in order to make the best of a given altitudinal range;
– Extending an existing ski area to higher elevations.

Barriers to expansion/shift to areas with a climatic advantage

Barriers to this strategy exist; the most obvious being that the areas required might not actually exist and expansion/shifting ski areas is therefore not even possible (Moen & Fredman, 2007). Other barriers to moving to higher elevations and south facing slopes can include the loss of recreational values as it is more enjoyable to participate in snow sports in safe, sunny, clear conditions. In particular Agrawala (2007) identified that:

– Skiers ask for snow-reliability, but they prefer sunny ski runs to shaded south facing slopes or cloudy high elevations
– High elevation ski areas are prone to strong winds and avalanches which can disrupt ski operations and cause danger to visitors.
– Extending existing ski areas to higher elevations is expensive

> In Victoria ski resorts may not be able to shifter to higher altitudes as the Resorts are already operating at the limit of their altitudinal range.
>
> Similarly development of south facing slopes may not be feasible as these slopes can only be used by advanced skiers who are experienced with the icier conditions.

High-elevation environments are also fragile and their development will have environmental impacts. High elevation areas are likely to be covered by environmental protections and any attempts to move ski areas to these areas are likely to face opposition from the public and environmental groups.

Slope management techniques

There are other slope development techniques that can be used to adapt to climate change other than simply moving the skiable area. These techniques can include the levelling of ski runs, removing bumps, rocks and vegetation (for example with a grader or heavy machinery), the creation of shaded areas, the erection of snow fences to capture moving snow, the movement of snow from other areas and the draining of wetlands to avoid delayed snow accumulation and premature melt (Agrawala, 2007; Bicknell & McManus, 2006). The aim is to reduce the snow depth required for ski operation, which also enables the reduction of the amount of snow required from artificial snowmaking. These strategies can also act as snow preservation techniques and aim to prevent melting, for example it has been found that the use of sheltered ski slopes instead of wind-exposed slopes can help gain 15 days in terms of ski-use, the creation of shaded areas can help gain 30 days (Agrawala, 2007).

> Many of these slope management techniques have been in place for a considerable amount of time at the Victorian alpine resorts including high-tech snow groomers and flexible ticket pricing.

Other slope management techniques can include management responses. Intensifying the use of viable ski areas by raising the lift capacity is an example, as is limiting the number of slopes available for use to concentrate snow-making resources in particular areas. Another option is flexible ticket pricing, which entails reducing lift ticket prices in poor seasons to attract visitors (Bicknell & McManus, 2006); conversely prices can be raised in well performing seasons to manage visitor numbers and preserve the skiable area.

All Victorian resorts have demonstrated the capacity to develop green season tourism. For example, resorts have:

- Constructed significant mountain bike and bushwalking infrastructure
- Invested in adventure activity facilities
- Held cultural and arts events
- Staged sporting events such as road cycle races

Specific examples include (but are certainly not limited to):

- Mt Baw Baw aims to achieve sustainable year-round market growth. Mt Baw Baw's lower altitude makes it vulnerable to the effects of climate change and its potential impact on snow tourism.
- Falls Creek plans to continue building on their reputation as an altitude training ground for athletes of all calibres. They argue this will have significant local and regional impact and will support the continued diversification of the resort's activities (Falls Creek Annual Report 2015).
- At Mt Buller the Epic Mountain Bike trail has been built, the southern hemispheres only International Mountain Bike Association's accredited 'Epic Trail'. The head of the trail is the resort village, attracting visitation to the village in the green season.

EY Sweeney (2017) estimated there were 485,722 visitor days spent at the Victorian alpine resorts in the 2016/17 green season, which led to a $121 million contribution to gross state product, up from $104 million in 2011/12 (EY Sweeney, 2017). This is, primarily a result of increased visitation and

Barriers to slope management techniques

Levelling techniques, in particular, bulldozing, have large environmental impacts including removal of vegetation, which could then lead to erosion problems. Snow fencing and drainage of wetlands also carry environmental impacts, as well as impacting the naturalness of the area. This is likely to impact upon the green season, with the loss of attractiveness (or naturalness) of the area impacting visitation, especially those visiting for nature, e.g. bushwalkers.

Changes in management techniques including concentrating skiers on well performing slopes, and limiting the number of slopes available to concentrate snow making efforts will only be successful if revenue levels can be maintained, with visitors remaining satisfied and not being driven away by overcrowding on the slopes (Agrawala, 2007).

Diversification of tourism offerings

Tranos & Davoudi (2014) articulate that with alpine adaptation it is possible to distinguish between two main categories of adaptation options; options such as snowmaking and slope management aim to tackle the problem of exposure to climatic stimuli (i.e. the problems of reduced snowfall and snow cover); whilst other adaptation options tackle the problem of economic dependency (i.e. the problem of over-dependency on alpine snow sports as the major source of revenue). Diversification of tourism offerings is an adaptation option that addresses the economic dependency of alpine resorts and alpine regions on snow sports.

Diversification of tourism revenues (both to other white season activities and to all-year operations) was identified in the literature as an important component of adaptation to climate change for ski resorts across the world (Agrawala, 2007; Barnett, et al., 2015; Bicknell & McManus, 2006; Bonzanigo, Giupponi, & Balbi, 2016; Dawson & Scott, 2013; Hopkins, 2013; Morrison & Pickering, 2012; Pickering & Buckley, 2010; Scott, McBoyle, & Mills, 2003; Walters & Ruhanen, 2015).

Many resorts in the European Alps, North America, New Zealand and Australia rely heavily on one single season, the white season. However, this business model is increasingly perilous because of present climate variability (snow-deficient white seasons) and the potential impacts of projected climate change (Agrawala, 2007). One adaptation strategy, and an increasingly viable one in the Australian context, is to diversify product offerings through the development of alternative activities, both in the white and green seasons, that can sustain both the economic viability of ski resort facilities and the surrounding communities that are largely dependent on ski tourism for their own economic and social sustainability (Walters & Ruhanen, 2015).

Climate change will likely lead to revenue reductions (e.g. less skiers and snowboarders) and increased operating costs (e.g. greater use of snowmaking) for alpine resorts. The loss in profitability will need to be offset through other revenue streams and innovative business decisions (Dawson & Scott, 2013).

Creating additional white season offers, not directly related to the quality of the snow cover, will play an important role. Additional white season offers add variety, and support operations to reduce their snow reliance by offering snow sport enthusiasts alternative activities if there is insufficient snow (Bicknell & McManus, 2006). Climate independent white season offerings can include education and conference facilities, health and wellness spas, fitness retreats, restaurants, retail centres, indoor sports, concerts, festivals, and exhibitions. Diversified outdoor activities can also be considered, including skiing lessons, snowmobiling, skating, dog sled rides and non-snow activities including white water rafting, mountain biking, paragliding, and horseback riding (Walters & Ruhanen, 2015).

Scott & McBoyle (2007) discuss the diversification trend in North America, where many ski areas have diversified operations beyond traditional ski activities; they describe the process as the 'Disneyfication' of resorts into winter theme parks where non-skiers represent an important market of 20-30 percent. In Europe non-skiers also represent an important and growing market, with many resorts having made substantial investments to diversify their offerings (Agrawala, 2007). Many resorts, especially larger ones, in Europe now offer a diversified tourism product including spas, health clubs, and a variety of bars, restaurants and retail stores. In Switzerland alpine environments have long provided spiritual and health refuges for urban and lowland populations, with many resorts capitalising on this advantage to extend their operations into these areas (Hill, Wallner, & Furtado, 2010). These offers beyond traditional snow sport activities provide alternative activities for skiers and non-skiers alike.

Importantly such approaches would not require local stakeholders to move far beyond their current livelihood options, but could enable them to profit more broadly from local assets (Hill, Wallner, & Furtado, 2010). The development and marketing of non-ski related offers has enabled ski areas to remain profitable during poor snow seasons due to increased skier spending on food and beverage and general retail when snow cover is poor (Scott & McBoyle, 2007). Due to these and other factors Cocolas, Walters, & Ruhanen (2015) have argued that in Australia future marketing strategies should focus more on experiential driven tourists, as opposed to traditional snow sport enthusiasts. This shifts the focus away from the quality of snow towards the overall alpine experience.

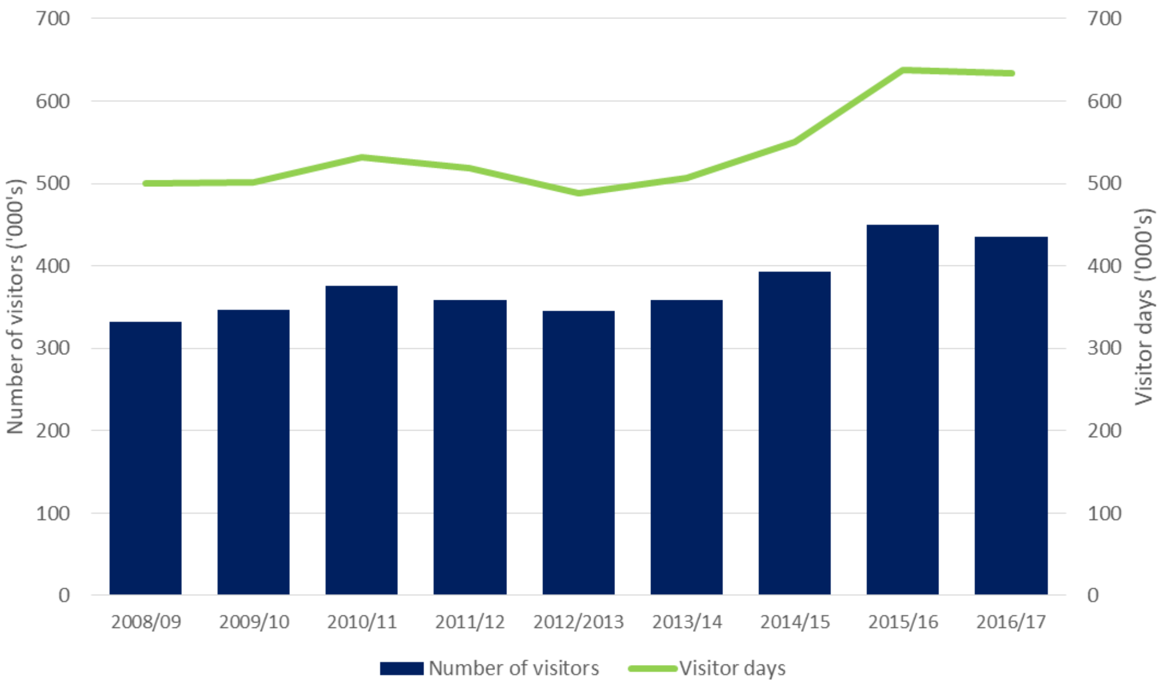
In terms of all-year and the green season there is clear evidence of a significant shift toward all-season operations with the incorporation of a wide range of different types of outdoor recreation and adventure recreation programs in many traditional ski regions (Pegg, Patterson, & Gariddo, 2012). In order to reduce the dependence on snow conditions, diversification to year-round tourism is often explored. Internationally, ski areas often use downhill mountain biking, and hiking, to attract green season tourists.

Historically a significant number of alpine resorts in Australia have closed their doors during the summer months and in so doing have foregone the opportunity to achieve higher revenue from increased operations beyond the traditional snow based period. Bicknell & McManus (2006) reported that the move to all-season tourism by ski resorts in Australia was already a noticeable trend. This is a shift from operating as ski resorts to year-round 'mountain resorts'. In NSW the establishment of festivals, sports, conferences, and cultural events, and other diverse open-air activities have become key considerations in attracting visitors to the alpine area (Pegg, Patterson, & Gariddo, 2012).

In Australia, diversification strategies have been somewhat successful. There have been proportionally larger increases in the number of non-white season visitors with as many as 50 percent of visits to ski destinations are now outside the white season (Walters & Ruhanen, 2015). Figure 10 below from

EY Sweeney[a] (2017) demonstrates the increasing visitation at the Victorian alpine resorts in the green season; visitation has increased by 29 percent between the green seasons of 2011/12 and 2016/17. This has resulted in an increase in economic impact generated by the resorts; between 2011/12 and 2016/17 there has been as estimated 16 percent increase in gross state product (GSP) generated by Resorts in the green season, from $104 million to $121 million; this GSP equates to 956 direct (on-mountain) and 1,205 indirect jobs off the mountains (EY Sweeney[a], 2017).

FIGURE 10. GREEN SEASON VISATATION OVER TIME - ALL VICTORIAN RESORTS



Source: EY Sweeney[a] (2017)

Given the climate change predictions for those Australian operations located in the lower alpine areas over the next decade, there is a need for the alpine tourism sector to positively reposition their businesses in the market place (Pegg, Patterson, & Gariddo, 2012). Rixen et al., (2011) argue that each alpine tourist destination should determine its regional strength because, given increasing economic competition and the changing climate, it will be crucial to use specific regional strengths to provide high-quality white and green season activities. Pegg, Patterson, & Gariddo (2012) have argued that in Australia tourism and hospitality operations that do not diversify their operations, will soon have to face the harsh reality that they may not remain viable as profitable businesses in the future.

Bicknell and McManus' (2006) research with Australian ski resort managers has found that diversification was not solely because of awareness and acceptance of climate change, but there were also financial imperatives driven largely by the need to meet the expense of white season related infrastructure by extending the operating/income period beyond the white season. In the Australian Alps it is likely that, in a future with reduced natural snow, the two strategies of snowmaking and all season tourism will need to be addressed together, since "the cost of increasingly required snowmaking infrastructure will have to be met by an extension of the resort's annual operations."
(Bicknell & McManus, 2006, p. 397)

Another positive impact of diversification is that such a strategy will also have positive social effects on traditional white season destinations as seasonal variations in job opportunities are bridged over (Moen & Fredman, 2007).

Another element to consider is that diversification is more likely to be needed at low altitude resorts where snowmaking will not be feasible with Pickering & Buckley (2010) concluding that whilst Australian ski resorts are likely to promote increased snowmaking as a short-term solution to climate change, this is in fact financially realistic only for the higher-altitude resorts. The situation is similar in parts of the German and Austrian Alps with some ski areas, particularly the smaller ones at lower altitudes, might be forced into ceasing ski operations and switch to snow-independent forms of white season tourism or to green season tourism instead (Soboll & Dingeldey, 2012). In Australia if alpine resorts at lower altitude were to cease operation, they are likely to lobby strongly to increase access to land for residential subdivision and for diversification to high-cost green season tourist activities such as golf and watersports (Pickering & Buckley, 2010). This shift to green season tourism can enable the tourism industry to be maintained in these areas.

Barriers to diversification

The first barrier to diversification identified in the literature is that snow sports are not easily substitutable. Visitors usually do not visit alpine resorts because of the 'complementary' offers such as restaurants, bars and spas, but because of the snow-related activities. Agrawala (2007) argues that it seems unlikely that the snow-related activities can be replaced entirely by non-snow related offers that can carry the white season industry; "For the time being, there is no activity available that could substitute the revenue-generating power of traditional winter sports, in particular skiing" (Agrawala, 2007, p. 55).

Another diversification barrier is that it may not be good for all stakeholders on the mountain. Hoteliers, restaurant owners, bars, and so on, who cater for all tourists are more likely to benefit from diversification than ski lift operators or equipment hire businesses who depend heavily on the number of snow sport participants (Agrawala, 2007). Developing alternatives to skiing and snowboarding during the white season is also problematic since many alternatives, such as snowmobiling, dog sleighing and ice fishing, are also dependent on snow cover or ice-covered lakes (Moen & Fredman, 2007).

The development of green season tourism requires long term planning by alpine resorts to develop recognition in this market. Alpine resorts will have to compete with each other and with summer destinations such as coastal locations to gain a market share (Bicknell & McManus, 2006).

Another barrier to all-year increasing visitation in the green season is the carrying capacity of the area. Activities that resorts may want to promote, such as bike riding and horse riding, could inadvertently spill over into areas of conservation, and cause environmental problems. If these forms of tourism increase in popularity, the carrying capacity of alpine destinations must be re-evaluated to encompass the potential impacts (Bicknell & McManus, 2006). Morrison & Pickering also argue that the diversification to year-round tourism causes fairly significant additional environmental impacts and issues dealing with fire safety and management for the conservation managers (Morrison & Pickering, 2012).

Losing the seasonality of the alpine tourism sector could also be detrimental to the local community and environment. An off-season is often vital for renovations, and is needed for permanent residents to recover from the feelings of being overwhelmed by the large volume of visitors at peak times (Pegg, Patterson, & Gariddo, 2012).

Diversification away from tourism

There are likely to be other opportunities that alpine communities can capitalise on and diversify away from tourism completely to other industries. In the Swiss Alps for example, production advantages have been found to exist in terms of renewable energy sources, organic and air-dried products, off-season vegetables, medicinal plants and other high-quality, small-scale products (Hill, Wallner, & Furtado, 2010).

Another diversification strategy could be the shift to a focus on residential property sales and associated retail activities. Residential developments close to ski areas, such as Dinner Plains near Mount Hotham (but not managed by the Resort Management Board) in Victoria, seem to have been highly successful in economic terms (Buckley, Sander, Ollenburg, & Warnken, 2006). However with the impacts of climate change on tourism there would need to be consideration as to whether these developments would be popular without snow sport tourism.

Barriers to diversification away from tourism

A reluctance from the local community to leave snow sports tourism behind, and the unique identity and lifestyle that brings, could be a barrier.

Planning restrictions on further residential developments limit Australian alpine resorts transition to mountain resort-residential towns (Pickering & Buckley, 2010).

Planned retreat and dismantling of unneeded snow season infrastructure

What to do with financially unsustainable resorts is an important question for the community and governments to consider. If it is found that alpine resorts are not feasible as the climate changes, planned retreat is an option that optimises the use of assets and tourism infrastructure for their remaining economic asset lifetimes, whilst dismantling unneeded snow season infrastructure.

In the European Alps this conversation has been underway for quite some time, with Elsassa & Burki (2002) revealing that a number of people had already identified the challenges of climate change and were in favour of dismantling non-profitable cable-way and ski-lift operations as part of 'healthy shrinkage' of the sector. Snow sport infrastructure including lifts and snowguns would be removed, and large hotels, visitor centres, car parking facilities and other significant infrastructure will also be dismantled as they no longer serve a purpose.

The planned retreat allows for the management of economic impacts and can include diversification to industries other than tourism, and re-use of any appropriate buildings and infrastructure. The dismantling of unrequired infrastructure will allow for the limitation of environmental damage which would be caused due to infrastructure degrading in-place.

Barriers to planned retreat and dismantling of unneeded snow season infrastructure

There are likely to be large cultural and economic impacts as organised snow sports are lost to the Victorian community. There are those who will likely argue that governments and resorts have an obligation to retain ski fields (with technological fixes) for regional economic reasons (Elsasser & Bürki, 2002).

Bushfire adaptation

Fire danger across Victoria, as measured by the McArthur Forest Fire Danger Index (FFDI), is projected to increase (Timbal et al., 2016). There is, therefore, a need for communities to adapt to increased fire danger.

> Literature on bushfire adaptation specific to Alpine regions is a gap in the literature. More general bushfire adaptation literature for Victoria and overseas has been reviewed instead.

In Australia, bushfires threaten, and sometimes consume, life and property on a broad scale; debates about how humans can manage and adapt to bushfires are increasingly prominent (Edwards & Gill, 2016). Australia has been considering how to respond to bushfire in changing environmental, economic and social circumstances (Howitt, 2013). In the past 15 years there have been official inquiries into the NSW/ACT fires that devastated parts of Canberra in 2003, Victoria's 2009 fires and Tasmania's 2013 bushfires; these inquiries all raised the need for learning to live with fire risk more effectively.

After the Black Saturday Bushfires in Victoria, Morgan & Leonard (2015) found that adaptation responses to the occurrence and impact of devastating mega-fires, with their increasing cost to humans and the environment, can include:

– Sound end-user-inspired independent research

- Strong land-use planning provisions that are cognisant of the wildfire risk and operational practicalities, enabling the reduction of wildfire risk
- Year-round landscape management strategies for forested areas
- Improved land- and fire-management agency resourcing; and
- An associated, unwavering all-party political will.

Adaptation options that have been suggested for Victoria's Surf Coast, a region dependant on tourism and vulnerable to bushfires (Jopp et al., 2013), include:
- The use of controlled burning (reducing fuel load in low risk fire season) and fire breaks
- Opening up new or different tourism areas that are less vulnerable to fire
- Increasing fire-fighting capacity
- Developing awareness campaigns for tourists
- Early warning systems,
- Risk minimisation strategies
- 'no-grow' zones around properties.

Wildfires, or bushfires, are a growing concern across North America; Schoennagel et al. (2017) report that wildfires have increased in number and size over the past three decades, and this trend will continue in response to further warming. The traditional response to wildfires in the US has been to reduce the risk by spending billions of dollars annually to manage fuels by removing some trees and underbrush from dense forests and intentionally setting some forests ablaze in controlled burns. In the dry season firefighters are brought in to fight nearly all blazes to prevent them from spreading. However Schoennagel, et al. (2017) argue that these strategies are inadequate to address a new era of wildfires and a shift from unsustainable defence of the buildings to developing fire-adapted communities is needed. This involves an acceptance that wildfire is now an inevitable part of the landscape.

Barriers to Bushfire adaptation

In south-eastern Australia forests are quite fire-tolerant at low altitudes and can be exposed to fire in the form of burn offs or back burning to reduce of prescribed fire as a form of management; at higher altitudes however, "ash"-type forests are often found; These forests are not generally conducive to the use of prescribed fire, making controlled burns unsuitable (Morgan & Leonard, 2015).

As Schoennagel, et al, (2017) has argued for North America, controlled burns and removing undergrowth is expensive. This cost could be a barrier to successfully adapting to climate change.

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