

# Limits to Climate Change Adaptation: Case Study of the Australian Alps

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Received • • • •; Revised • • • •; Accepted • • • •

## Abstract

Climate change is occurring and not being mitigated, motivating adaptation but adaptation strategies can have biophysical, economic, technological, and social limits. We review publicly available documents to assess how successful current and proposed adaptation strategies may be for the Australian Alps, including likely limits and potential collaborations and conflicts among stakeholders. Conservation managers, the tourism industry, and local communities have implemented or are proposing a range of adaptation strategies in the region. Some stakeholder strategies complement each other (e.g. invasive species control, fire management), while others are potential sources of conflict (water and electricity for snowmaking, year-round tourism). Economic costs and biophysical constraints are the most important limits to these adaptation strategies. These types of limits and conflicts between different stakeholders on adaptation strategies are likely to occur in other regions and demonstrate that adaptation may only provide partial and short term solutions to the challenges of climate change.

KEY WORDS *conservation; tourism; thresholds; society; economics*

## Introduction

There is general acceptance that anthropogenic climatic change is occurring, and will continue to occur, with limited success in current mitigation strategies (Intergovernmental Panel on Climate Change [IPCC], 2007; Garnaut, 2008). Some increase in global temperatures appears to be unavoidable (Schellnhuber *et al.*, 2006), and as a result, there is increased interest in adaptation strategies (Scott and McBoyle, 2007; Adger *et al.*, 2009). Adaptation, however, can not avoid all climate change impacts, with vulnerability to climate change not diminished, and in some cases even increased, with the implementation of climate adaptation strategies (Hill *et al.*, 2010).

Limits to climate change adaptation can be categorised into four major groups: (i) biophysical limits, (ii) economic limits, (iii) technological

limits, and (iv) social limits (Adger *et al.*, 2009). Ecological and physical limits exist where planned or unplanned climate change adaptation strategies fail to avoid climate change impacts (O'Neill and Oppenheimer, 2002; Fischlin and Midgeley, 2007). An obvious example of a biophysical limit is predicted rises in sea water temperatures where it is unlikely that any adaptation will avoid repeated and severe coral bleaching when water temperatures exceed critical thresholds (Parmesan and Yohe, 2003). Economic thresholds exist where the cost of adaptation exceeds the costs of the impacts avoided i.e. it is more expensive to adapt than it is to experience climate impacts, or stakeholders simply can not afford to pay for the adaptation strategies (Agrawala and Fankhauser, 2008). Technological thresholds exist where current or available

technology can not avoid future climate change impacts (Adger *et al.*, 2009). For example, current snowmaking technology may be able to cope with existing conditions but will not be efficient enough to cope with future projected changes in snowmaking conditions (Adger *et al.*, 2005). Lastly, social values play an important role in climate change adaptation. Ecological, economic, and technological limits are not strictly objective issues and at some point in the decision-making process, all entail subjective judgments based on social values (Ostrom, 2005; Adger *et al.*, 2009; O'Brien, 2009).

Understanding the limits to climate change adaptation is important for decision-making about adaptation strategies for a number of reasons: (i) it helps determine which climate change adaptation strategies are feasible, (ii) it determines the time scales over which adaptation may be effective based on climate change predictions, (iii) it helps to understand social values, and (iv) it helps prioritise adaptation strategies.

Australia is considered one of the most vulnerable developed countries to climate change (Pittock, 2009) with the Australian Alps, the Great Barrier Reef, and the Kakadu wetlands the most at risk ecosystem/regions (PMSEIC Independent Working Group, 2007; Green, 2009; Steffen *et al.*, 2009). The snow-covered mountains in southeastern Australia that form the Australian Alps are internationally and nationally important because of their conservation values, ecosystem services, economic values, and cultural importance (Kirkpatrick, 1994; Independent Scientific Committee [ISC], 2004; Worboys *et al.*, 2010). Predicted increases in temperature and decreasing precipitation will result in dramatic changes in the region with snow cover already declining (Nicholls, 2005; Hennessy *et al.*, 2008). These changes will adversely affect the natural ecosystems, the ski industry, and the capacity of the mountains to produce water and hydroelectricity for surrounding regions (Hennessy *et al.*, 2008; Pickering and Buckley, 2010; Worboys *et al.*, 2010).

The overall aim of this review was to identify limits to climate change adaptation strategies used by different stakeholder groups in the Australian Alps and compare these to alpine regions overseas. More specifically, we looked to (i) summarise predicted/actual impacts of climate change in the Australian Alps, (ii) identify current and planned climate change adaptation strategies used by different groups, (iii) identify actual or potential limits to these adaptation

strategies, (iv) identify collaborations between different stakeholder groups in relation to climate change adaptation, and (v) identify areas where climate change adaptation by one group of stakeholders exacerbates climate change impacts on another group or on the environment.

## Methods

### Study area

The Australian Alps are located in the southeastern corner of mainland Australia and extend over 500 km between the Victorian and New South Wales (NSW) capital cities of Melbourne and Sydney (Figure 1). They occupy a total area of about 25 000 km<sup>2</sup> or 0.3% of Australia (Crabb, 2003). The highest peak, Mount Kosciuszko stands at 2228 m. Within the Australian Alps are 11 national parks/reserves that occupy 1.644 million hectares and extend across the majority of the Alps Bioregion (Crabb, 2003).

The Australian Alps National Parks and Reserves have been recognised in Australia's prestigious National Heritage List as a National Landscape (Department of the Environment, Water, Heritage and the Arts, 2010). They include a United Nations Biosphere Reserve and International RAMSAR wetlands (ISC 2004) and are one of the 234 worldwide biodiversity 'Centres of Plant Diversity and Endemism' (Boden and Given, 1995).

The plant communities of the Australian Alps and their habitats are diverse. To date, 852 species of vascular plants and 221 species of nonvascular plants have been recorded in the largest and highest of the parks; Kosciuszko National Park, with at least 380 of these species found in the alpine and subalpine areas (Department of Environment and Conservation, New South Wales, 2006). The subalpine and alpine areas also contain rare plant assemblages including those dependent on late lying snow such as snow bank fieldmark and short alpine herbfield with limited distributions and many endemic species (Costin *et al.*, 2000).

Rare and threatened animals are dependent on specific plant communities. Examples include the plum pine communities associated with the periglacial boulder fields that are favoured by the endangered and emblematic Mountain Pygmy Possum (*Burramys parvus*) (Green and Osborne, 1994; Mansergh *et al.*, 2004) and alpine wetlands that are critical habitats for many species including the Alpine Water Skink (*Eulamprus kosciuskoi*), Alpine Tree Frog (*Litoria verreauxii*

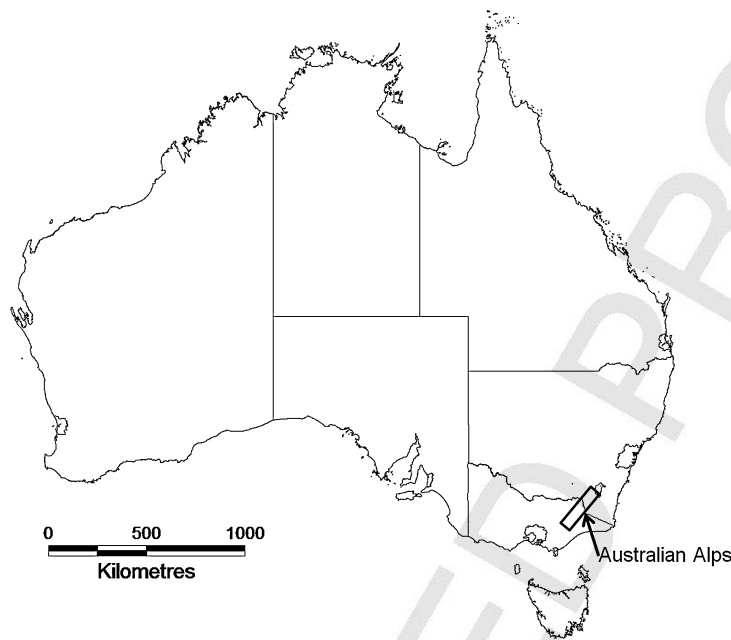


Figure 1 Location of the Australian Alps in southeastern Australia.

*alpina*), and Corroboree Frogs (*Psuedophryne corroboree* and *P. pengilleyi*) (Mansergh *et al.*, 2004). A total of 293 vertebrate species have been being recorded in Kosciuszko National Park, which includes 61 species (or 21%) that are considered rare, vulnerable, or threatened (Mansergh *et al.*, 2004). Many common species are also found that are of critical importance for the health and resilience of the Australian Alps ecosystems (Green and Osborne, 1994; Mansergh *et al.*, 2004).

As well as being highly biodiverse, the Australian Alps have a rich cultural and social heritage. Aboriginal people have continuously lived and visited the Alps area from at least 21 000 years ago as evidenced by archaeological sites (Flood, 1980). Their strong cultural links and continuing associations continue today (Worboys *et al.*, 2010).

While the Australian Alps are of high conservation value with most subalpine and alpine areas conserved in a series of protected areas, they are used/managed by different stakeholders. In or adjacent to the protected areas, there are currently 11 ski resorts, with winter visitation to the resorts worth AU\$906 million in 2005 (0.1% of gross domestic product in 2005, National Institute of Economic and Industry Research [NIEIR], 2006; Pickering and Buckley, 2010). At

lower altitude, there are population centres that depend to a large extent on jobs and incomes generated from snow-based and summer tourism (NIEIR 2006). Agricultural and other productive industries that occur in the lower lands surrounding the Australian Alps are dependent on water from the mountains, while much of southeastern Australia utilises hydroelectric power generated within the Australian Alps (Worboys *et al.*, 2010).

*Climate change predictions for the Australian Alps*

Climate change predictions for the Australian Alps have been discussed in detail in a number of publications and reports. Consequently, we will only summarise the predictions here (see Table 1). The changes in climate predicted for the Australian Alps involve increased temperature and decreased precipitation resulting in less snow (Whetton, 1998; Hennessy *et al.*, 2008). In addition to these direct changes, there are associated secondary factors including more cloud-free days, lower humidity, and increased total solar radiation (ultraviolet radiation) (Howden *et al.*, 2003). More variable and extreme climatic regimes and weather events such as high intensity rainfall area are also predicted (Hennessy *et al.*, 2008). Average summer temperatures are

Table 1 Summary of climate change predictions for Australian Alps under different climate change scenarios (Hennessy *et al.*, 2008).

Changes in:	Best Case 2020	Worst Case 2020	Best Case 2050	Worst Case 2050
Temperature	+0.2°C	+1.0°C	+0.6°C	+2.9°C
Rainfall	+0.9%	−8.3%	+2.3%	−24.0%
Reduction in area with snow cover				
At least 1 day	9.9%	39.3%	22.0%	84.7%
At least 30 days	14.4%	54.4%	29.6%	93.2%
At least 60 days	17.5%	60.3%	38.1%	96.3%
Average snow season length (ct 1990)	−5 days	−30–40 days	−15–20 days	−100 days

expected to rise resulting in increased frequency and/or intensity of bushfires (Lucas *et al.*, 2007). By 2020, the number of extreme fire danger days in southeastern Australia (where fire suppression is virtually impossible on any part of the fire line due to the potential for extreme and sudden changes in fire behaviour) is predicted to increase by 65% under the worst-case scenario, and by 300% by 2050 (Lucas *et al.*, 2007). There will also be an increase in climatic events such as storms and other related events including land-slides (Garnaut, 2008).

Data collection

Peer-reviewed journal articles, books and book chapters, and published and unpublished reports were examined for information relating to: (i) impacts of climate change in the Australian Alps, (ii) climate change adaptation strategies currently used or proposed in the region, (iii) limits to the climate change adaptation strategies, and (iv) potential stakeholder collaboration and conflict in regard to climate change. Source material included information obtained by searching electronic databases of academic journals including: Web of Science, Google Scholar, and Science Direct, personal communication with other researchers and stakeholders and existing research libraries of the authors. We divided the stakeholders involved with climate change impacts and adaptation in the region into three groups: (i) conservation managers (e.g. National Parks and Wildlife Service), (ii) tourism industry (primarily the snow-based ski industry), and (iii) local council (representing the local communities).

When assessing ecological and/or physical impacts, adaptation strategies, and limits, we used peer-reviewed papers based on data and modelling. For social limits and some of the economic limits, there were some peer-reviewed

papers. Because of the nature of the field, however, information on some impacts, adaptation strategies, and limits could only be sourced from reports and management plans. As these were often documents produced by, or on behalf of stakeholders such as Parks Agencies and the winter-tourism industry, they often reflect the perceptions, opinions, values, and decisions of those organisations. This does not invalidate the information; rather it demonstrates how stakeholders may be planning to respond to climate change. In addition to Australian literature, we have also included selected references that have examined climate change impacts, adaptation strategies, and limits in other mountain regions where the impacts of climate change are likely to be the same in Australia. Our final database composed of 71 peer-reviewed papers, 10 books, 15 book chapters, 6 published reports, 26 unpublished reports, and 9 management plans (137 in total).

Results

Impacts of climate change in the Australian Alpine region

The actual and predicted impacts of climate change in the Australian Alps are extensive and can be loosely grouped into four main categories: ecological, physical, economic, and social (19 impacts identified from 51 references, Table 2). The majority of current observed impacts are of an ecological or physical nature (14 out of 19 impacts) with several having a subsequent direct or indirect economic impact (3 out of 19 impacts). Predicted impacts focus more on ecosystem level issues (41 out of 51 references) and the economic impacts of decreased winter tourism (22 out of 51 references). Similar impacts have been observed and/or are predicted in mountain regions overseas with a ski tourism

Table 2 Observed and predicted impacts of climate change in the Australian Alps and overseas mountain regions.

Impact	Type	Australia	Overseas	References
Loss of snow cover	Ecol/Phys	Obs	Obs	<b>2, 6, 7, 12, 16, 19, 20, 21, 22, 24, 25, 27, 28, 31, 32, 42, 43, 45, 46</b>
Loss endemic species	Ecol/Phys	Pred	Obs	17, 18, 21, <b>29, 33, 35, 36, 42, 51</b>
Loss endemic communities	Ecol/Phys	Pred	Pred	12, 13, 17, 18, 21, 34, 35, <b>42</b>
Increased diversity of invasive species	Ecol/Phys	Obs	Obs	12, <b>29, 30, 35, 36, 42, 51</b>
Decreased connectivity	Ecol/Phys	Pred	Pred	<b>3, 39</b>
Decreased resilience	Ecol/Phys	Pred	Pred	1, <b>39, 51</b>
Changes to species phenology	Ecol/Phys	Obs	Obs	<b>14, 16, 24, 35</b>
Increased extreme fires/frequency	Ecol/Phys	Obs	Obs	12, 20, 38, 40, <b>42, 47, 48, 49</b>
Decreased soil moisture	Ecol/Phys	Pred	?	12
Increased soil erosion	Ecol/Phys	Obs	Obs	12, 35, 41, 51
Increased landslides/avalanches	Ecol/Phys	Pred	Obs	<b>6, 12</b>
Increase intensive storms	Ecol/Phys	Pred	?	<b>5, 6, 12</b>
Drier summers	Ecol/Phys	Obs	Obs	<b>19, 20, 21, 42, 51</b>
Decreased water availability	Ecol/Phys/Social	Obs	Obs	<b>4, 6, 20, 21, 32</b>
Increased loss of infrastructure (fire)	Ecol/Phys	Obs	Obs	12, 40, <b>42, 49, 50</b>
Loss of snow-based tourism industries	Economic	Pred	Obs	<b>3, 4, 7, 9, 10, 11, 12, 20, 21, 26, 27, 32, 45, 46</b>
Increased cost of skiing	Economic	Obs	Obs	<b>25, 27, 32, 36</b>
Decreased visitors (winter)	Economic	Obs	Obs	<b>8, 9, 10, 11, 19, 25, 27, 37, 43, 44, 46, 51</b>
Increased closure of Protected Areas	Social/Economic	Obs	Obs	<b>42, 50</b>

References in bold text represent non-Australian studies.  
<sup>1</sup>Anderson and Atkins, 2010; <sup>2</sup>Bark *et al.*, 2010; <sup>3</sup>Behringer *et al.*, 2000; <sup>4</sup>Beniston, 2003; <sup>5</sup>Beniston *et al.*, 2007; <sup>6</sup>Beniston *et al.*, 2011; <sup>7</sup>Breiling and Charamza, 1999; <sup>8</sup>Dawson *et al.*, 2009; <sup>9</sup>Elsasser and Bürki, 2002; <sup>10</sup>Elsasser and Messerli, 2001; <sup>11</sup>Fukushima *et al.*, 2002; <sup>12</sup>Garnaut, 2008; <sup>13</sup>Grabherr *et al.*, 1994; <sup>14</sup>Green, 2002; <sup>15</sup>Green, 2010; <sup>16</sup>Green and Pickering, 2002; <sup>17</sup>Green and Pickering, 2009a; <sup>18</sup>Green and Pickering, 2009b; <sup>19</sup>Harrison *et al.*, 1999; <sup>20</sup>Hennessey *et al.*, 2007; <sup>21</sup>Hennessey *et al.*, 2008; <sup>22</sup>Heo and Lee, 2008; <sup>23</sup>IPCC, 2007; <sup>24</sup>Inouye *et al.*, 2000; <sup>25</sup>König and Abegg, 1997; <sup>26</sup>McBoyle *et al.*, 2007; <sup>27</sup>Moen and Fredman, 2007; <sup>28</sup>Nicholls, 2005; <sup>29</sup>Pauli *et al.*, 2007; <sup>30</sup>Pauchard *et al.*, 2009; <sup>31</sup>Pickering, 2007; <sup>32</sup>Pickering and Buckley, 2010; <sup>33</sup>Pickering and Green, 2009; <sup>34</sup>Pickering and Green, 2010; <sup>35</sup>Pickering *et al.*, 2004; <sup>36</sup>Pickering *et al.*, 2008; <sup>37</sup>Pickering, 2011; <sup>38</sup>Pitman *et al.*, 2007; <sup>39</sup>Pulsford *et al.*, 2010; <sup>40</sup>Sanders *et al.*, 2008; <sup>41</sup>Scherrer and Pickering, 2010; <sup>42</sup>Scott *et al.*, 2007a, <sup>43</sup>Scott *et al.*, 2008; <sup>44</sup>Shih *et al.*, 2009; <sup>45</sup>Shijin *et al.*, 2010; <sup>46</sup>Unbehaun *et al.*, 2008; <sup>47</sup>Walsh and McDougall, 2004; <sup>48</sup>Williams *et al.*, 2001; <sup>49</sup>Worboys, 2003; <sup>50</sup>Wolfsegger *et al.*, 2008; <sup>51</sup>Worboys *et al.*, 2010.  
Ecol, ecological; Phys, physical; Obs, observed impact; Pred, predicted impact; ?, not mentioned in Literature.

industry (Table 2). The most common specific impacts highlighted in the literature are the loss of snow cover and/or duration (19 references), loss of snow-based tourism (14 references), decreased winter visitation (12 references), drier summers and the associated increases in fire danger (eight references), and the loss of endemic species and communities (eight references each). Less common are references to changes in soil conditions and the increased closure of protected areas during fire events (two references each).

Adaptations to climate change

There are a number of climate change adaptations that can be made by different stakeholder groups in the Australian Alps (20 strategies identified from 44 references, Table 3). The majority of publications examining climate change adap-

tation strategies involve the winter-tourism industry (32 out of 44 references). Actual and potential climate change adaptation strategies by the tourism industry highlighted in the literature include: snowmaking and associated snow-preservation activities (21 references), the development of non-snow-related activities in winter (eight references), and diversifying to year-round tourism (17 references) to maximise the benefits of extended warmer weather.

There were few references on climate change adaptation strategies relating to conservation of natural resources (eight references). Conservation managers favour strategies that promote ecosystem resilience and connectivity including: control of invasive species (three references), restoring disturbed habitats (four references), establishing better fire management plans (two references), and the establishment of *ex situ*

Table 3 Current or planned climate change adaptation strategies in the Australian Alps and overseas alpine regions.

Adaptation	Type	Australia	Overseas	References
Control/limit invasive species	Ecol/Phys	Current	Current	25, 28, 44
Rehabilitate disturbed sites	Ecol/Phys	Current	Current	4, 44
Restore endemic communities	Ecol/Phys	Current	Proposed	33, 44
Restore connectivity	Ecol/Phys	Current	Current	1, 4, 28, 44
Assurance populations of key native animals	Ecol/Phys	Current	Proposed	44
Seed banks for alpine plants	Ecol/Phys	Current	Current	13, 44
Reduce soil erosion	Ecol/Phys	Current	Current	4, 44
Fire suppression/control	Ecol/Phys	Current	Current	39, 44
Post-fire control of weeds	Ecol/Phys	Current	Current	41, 44
Tourism change to other industries e.g. agriculture, forestry	Ecol/Phys/Econ	Proposed	Proposed	11, 20, 21, 44
Increase capacity to deal with fire	Ecol/Phys/Tech	Proposed	Proposed	43, 44
Increase real estate sales	Economic	Proposed	Current	11, 12, 23, 31
Change to year-round tourism	Economic/Social	Current	Current	3, 5, 11, 14, 16, 17, 18, 20, 21, 22, 23, 25, 30, 31, 37, 38, 39
Non-snow-related tourism in winter	Economic/Social	Current	Current	5, 9, 11, 16, 17, 18, 20, 31
Snowmaking	Tech/Physical	Current	Current	2, 5, 6, 7, 8, 9, 10, 15, 23, 24, 29, 32, 34, 35, 36, 37, 40, 42
Supergrooming	Tech/Physical	Current	Current	2, 5, 6, 7, 8, 9, 15, 16, 17, 24, 31
Snow farming/harvesting	Tech/Physical	Current	Current	5, 6, 10, 16, 17, 24, 31, 40
Development of higher terrain	Tech/Physical	Proposed	Current	2, 5, 11, 16, 17, 20, 31, 34, 42
Cloud seeding	Tech/Physical	Current	Current	35
Water conservation-recycling	Tech/Physical	Current	Current	20, 23, 38, 40

References in bold text represent non-Australian studies.

<sup>1</sup>Anderson and Atkins, 2010; <sup>2</sup>Bark *et al.*, 2010; <sup>3</sup>Behringer *et al.*, 2000; <sup>4</sup>Beniston, 2003; <sup>5</sup>Bicknell and McManus, 2006; <sup>6</sup>Dawson and Scott, 2007; <sup>7</sup>Dawson *et al.*, 2009; <sup>8</sup>Del Matto and Scott, 2009; <sup>9</sup>Elsasser and Bärki, 2002; <sup>10</sup>Elsasser and Messerli, 2001; <sup>11</sup>Fukushima *et al.*, 2002; <sup>12</sup>Glorioso and Moss, 2007; <sup>13</sup>Good *et al.*, 2009; <sup>14</sup>Harrison *et al.*, 1999; <sup>15</sup>Heo and Lee, 2008; <sup>16</sup>Keage, 1990; <sup>17</sup>König, 1998; <sup>18</sup>König and Abegg, 1997; <sup>19</sup>Matasci and Altamirano-Cabrera, 2010; <sup>20</sup>Moen and Fredman, 2007; <sup>21</sup>Needhman *et al.*, 2004; <sup>22</sup>Pickering, 2007; <sup>23</sup>Pickering and Buckley, 2010; <sup>24</sup>Pickering and Hill, 2003; <sup>25</sup>Pickering and Hill, 2007; <sup>26</sup>Pickering *et al.*, 2003; <sup>27</sup>Pickering *et al.*, 2010; <sup>28</sup>Pulsford *et al.*, 2010; <sup>29</sup>Rixen *et al.*, 2003; <sup>30</sup>Scherrer and Pickering, 2010; <sup>31</sup>Scott and McBoyle, 2007; <sup>32</sup>Scott *et al.*, 2003; <sup>33</sup>Scott *et al.*, 2006; <sup>34</sup>Scott *et al.*, 2007a; <sup>35</sup>Scott *et al.*, 2007b; <sup>36</sup>Scott *et al.*, 2008; <sup>37</sup>Shijin *et al.*, 2010; <sup>38</sup>Sievanen *et al.*, 2005; <sup>39</sup>Unbehaun *et al.*, 2008; <sup>40</sup>Vanham *et al.*, 2009; <sup>41</sup>Walsh and McDougall, 2004; <sup>42</sup>Wolfsegger *et al.*, 2008; <sup>43</sup>Worboys, 2003; <sup>44</sup>Worboys *et al.*, 2010.

Ecol, ecological; Phys, physical; Econ, economic; Tech, technical.

seed banks and assurance populations of animal species (two references). These ecological and physical strategies essentially reflect those being conducted in some other protected areas in mountain regions (Table 3).

Limits to climate change adaptation

Despite a wide range of planned and current climate change adaptation strategies available for use by the different stakeholder groups, only a few have actually been implemented or seriously recommended for implementation. The remainder are usually considered as unsuitable or inappropriate due to the biophysical, economic, ecological, or social limits associated with them (28 limits identified from 32 references; Table 4). To date, the most obvious or important published limits to adaptation strategies are associated with

economic costs (13 out of 32 references) and ecological constraints (15 references). Potential limits to climate change adaptation are primarily associated with large-scale conservation management issues including increased environmental impacts from summer tourism (six references), the control of invasive species (two references), habitat restoration and rehabilitation (four references), improvement of connectivity and resilience (three references), and *ex situ* populations of endangered alpine flora and fauna species (three references). The most commonly reported limits to climate change adaptation in the tourism industry are related to technological and economic thresholds involved with snowmaking and/or manipulation (18 references) and the social and economic costs associated with diversifying to year-round tourism (six references).

Table 4 Limits to climate change adaptation in the Australian Alps and overseas mountain regions.

Adaptation	Limit	Type	Australia	Overseas	References
Snowmaking	Cost exceeds guest willingness to pay	Econ/Social	Potential	Potential	1, 2, 3, 4, 5, 6, 10, 11, 15, 18, 23, 24
	Low natural snow	Ecol/Phys	Actual	Actual	5, 7, 8, 15
	Fewer cold nights	Phys/Tech	Actual	Actual	1, 5, 7, 8, 11, 15
	Excessive consumption of water	Phys/Econ/Social	Actual	Actual	1, 9, 11, 15, 18, 19, 24, 26, 28
	Excessive consumption of electricity	Econ/Social	Actual	Actual	15, 18, 26
Snow manipulation	Costs	Econ/Social	Actual	Actual	11, 15, 18
	Inefficient	Econ/Social	Actual	Actual	1, 15, 18, 26
Resorts move into higher areas	Not physically/socially possible	Phys/Social	Actual	Actual	11, 15
Change to year-round tourism	Closure of resorts in summer due to fires	Ecol/Phys	Actual	Actual	31
	Additional impacts on environment	Ecol/Phys	Actual	Actual	5, 14, 17, 19, 20, 21
	Insufficient to meet economic demands	Econ	Potential	Actual	10
Control/limit invasive species	Cost becomes prohibitive	Econ	Actual	Actual	16, 32
	Fire frequency/intensity limit control capacity	Ecol/Phys	Potential	?	32
	Loss of specialist snow-communities	Ecol/Phys	Actual	Actual	16
Restore endemic communities	Cost becomes prohibitive	Econ	Potential	Potential	29, 32
	Fire frequency/intensity limit recovery capacity	Ecol/Phys	Potential	Potential	12, 29, 32
Reduce soil erosion	Cost becomes prohibitive	Econ	Potential	Potential	32
	Fire frequency/intensity limit recovery capacity	Ecol/Phys	Potential	Potential	29
Restore connectivity	Cost becomes prohibitive	Econ	Potential	Potential	32
	Fire frequency/intensity limit recovery capacity	Ecol/Phys	Potential	Potential	31
Rehabilitation of disturbed sites	Cost becomes prohibitive	Econ	Potential	Potential	32
	Fire frequency/intensity limit recovery capacity	Ecol/Phys	Potential	Potential	29
Seed banks for plants	In situ conservation impossible if habitat lost	Ecol/Phys	Potential	?	32
	Cost	Econ	Potential	?	12
Fire suppression/control	Insufficient knowledge about species ecology	Ecol/Phys	Actual	Actual	12
Increase capacity to deal with fire	Fire frequency/intensity limit control capacity	Ecol/Phys	Potential	Potential	29, 32
Post-fire control of weeds	Fire frequency/intensity limit control capacity	Tech/Econ	Potential	?	31
	Fire frequency/intensity limit recovery capacity	Ecol/Phys	Potential	?	29

References in bold text represent non-Australian studies.

<sup>1</sup>Bark *et al.*, 2010; <sup>2</sup>Bicknell and McManus, 2006; <sup>3</sup>Dawson and Scott, 2007; <sup>4</sup>Dawson *et al.*, 2009; <sup>5</sup>Elsasser and Messerli, 2001; <sup>6</sup>Hamilton *et al.*, 2007; <sup>7</sup>Hennessey *et al.*, 2007, Hennessey *et al.*, 2008; <sup>8</sup>Konig and Abegg, 1997; <sup>9</sup>Matasci and Altamirano-Cabrera, 2010; <sup>10</sup>Moen and Fredman, 2007; <sup>11</sup>Mondoni *et al.*, 2011; <sup>12</sup>Pickering, 2007; <sup>13</sup>Pickering, 2007; <sup>14</sup>Pickering and Buckley, 2003, <sup>15</sup>Pickering and Buckley, 2010; <sup>16</sup>Pickering and Green, 2009; <sup>17</sup>Pickering *et al.*, 2010; <sup>18</sup>Pickering *et al.*, 2010; <sup>19</sup>Rixen *et al.*, 2003; <sup>20</sup>Rolando *et al.*, 2007; <sup>21</sup>Scherer and Pickering, 2010; <sup>22</sup>Scott and McBoyle, 2007; <sup>23</sup>Scott *et al.*, 2003; <sup>24</sup>Scott *et al.*, 2006; <sup>25</sup>Scott *et al.*, 2007a, <sup>26</sup>Scott *et al.*, 2007b, <sup>27</sup>Scott *et al.*, 2008; <sup>28</sup>Vanham *et al.*, 2009; <sup>29</sup>Walsh and McDougall, 2004; <sup>30</sup>Wolfsegger *et al.*, 2008; <sup>31</sup>Worboys, 2003; <sup>32</sup>Worboys *et al.*, 2010. Ecol, ecological; Phys, physical; Econ, economic; Tech, technical.

*Potential collaboration and conflict between stakeholder groups in relation to climate change adaptation*

A number of actual and/or potential collaborations were identified among stakeholder groups, primarily between the conservation managers and the tourism industry. Examples include invasive species removal programs conducted in protected areas by conservation managers in conjunction with those done on ski resort land by the resorts. The conservation managers achieve their goal of minimising the spread or eradication of invasive species, while the tourism industry increases their aesthetic appeal, green credentials, and visitor satisfaction as well as fulfilling their obligations as land managers (Department of Sustainability and Environment [DSE], 2004; Mount Baw Baw, 2007). Similar collaborative projects are run for endangered species protection in the protected areas and on resort land, particularly for the mountain pygmy possum (DSE 2004; Mount Buller, 2005). Water management results in overall water conservation, which is important to the conservation managers, while decreasing costs and increasing green credentials benefit the tourism industry (DSE 2004; Mount Baw Baw, 2007). Fire management is critical for both groups; species and habitat conservation and human safety in particular for the conservation managers and human safety, infrastructure protection, and maintaining aesthetic appeal for the tourism industry (DSE 2004; Sanders *et al.*, 2008).

More commonly published are reports of conflicts between the climate change strategies favoured by the different groups (20 conflicts identified from 17 references; Table 5). Most of the issues arise between the conservation managers and the tourism industry (18 out of 20 conflicts). The two most reported conflicts involved snowmaking (10 references) and the increased diversification to year-round tourism (five references). While the use of snowmaking primarily benefits the tourism industry, it has a range of negative environmental impacts (important to conservation managers) and involves water and electricity consumption (important to local governments and communities). Similarly, the diversification to year-round or two-season tourism benefits the tourism industry and the local surrounding communities supporting the industry but, at the same time, causes significant additional environmental impacts and fire safety issues for the conservation managers. Conversely, habitat restoration and rehabilitation

strategies used by conservation managers can restrict visitor access and activities in some areas and therefore potentially have a negative impact on tourism through decreased visitor satisfaction.

**Discussion and conclusions**

While this study looks specifically at the Australian Alps, it highlights issues that will apply to other regions. Climate change imposes new challenges on groups that are dealing with a raft of existing challenges with stakeholder capacity to deal with climate change affected by the context in which they operate. Factors that limit park agencies capacity to deal with current challenges include: (i) inadequate funding, staffing, and facilities, (ii) social and political sensitivity around many management decisions including those dealing with fires, cattle grazing, and feral animals, (e.g. brumbies), and (iii) coordinating management among multiple park agencies that are under the oversight of governments that are often of very different political persuasions.

For resorts, existing adaption occurs in a context of (i) competition from overseas ski resorts including fluctuations in the value of the Australian dollar, (ii) competition with other types of tourism destinations (snow vs. beach), (iii) changes in the economic climate (global financial crises), and (iv) changes in visitor sensitivity to local conditions including snow cover. Local geography is also important as it affects how much individual resorts need to rely on snowmaking, if water will be available for snowmaking, and how successful they might be in diversifying into summer tourism. Governance issues for resorts include differences in who owns them and therefore how they operate: commercial operators for NSW resorts or government appointed management boards for Victoria resorts. As a result of the governance issues, resorts also vary in their capacity to access funds from the private sector, government, and other sources such as leases and property sales.

Factors that affect the capacity of local government to deal with current and future challenges include: (i) local community dependence on different industries such as tourism, agriculture, and forestry, (ii) politics including at all three levels of government (local, state, and federal), (iii) income including that from state government to local rate payers, and (iv) existing financial commitments including for infrastructure such as roads, etc.

Despite the factors that limit stakeholder capacity to deal with current challenges, stake-

Table 5 Potential and actual conflicts in relation to different climate change adaptation strategies in the Australian Alps and other mountain regions.

Adaptation Strategy	Benefits of Strategy	Negative Impacts of Strategy	References
Diversify to year-round tourism	Increase revenue for tourism industry	Greater impact on physical environment, e.g. soil erosion, trampling effects, invasive species dispersal, vegetation clearing for walking tracks, etc.	<b>6, 8, 11, 12</b>
	Economic and social benefits for local communities	Increased pressure on National Parks resources, e.g. fire response, new tourism facilities	<b>6, 11, 15, 17</b>
Development of higher terrain	Higher snow levels	Greater impact physical environment, e.g. soil erosion, trampling effects, infrastructure construction, invasive species dispersal, native vegetation clearing for ski infrastructure maintenance	<b>2, 3, 8</b>
	Increased visitor satisfaction		
Snowmaking	Higher snow levels	Negative impacts on vegetation	<b>2, 13, 14, 16</b>
	Increased visitor satisfaction	Negative impacts on soil hydrology and erosion	<b>2, 4, 12, 14, 16</b>
	Increase revenue for tourism industry	Competition for water – drive up costs	<b>1, 5, 9, 17</b>
	Economic and social benefits for local communities	Competition for electricity – drive up costs	<b>9, 17</b>
Snow manipulation	Higher snow levels	Negative impacts on vegetation	<b>2, 10, 13, 16</b>
	Increased visitor satisfaction	Negative impacts on soil hydrology and erosion	<b>2, 4, 10, 13, 16</b>
	Increase revenue for tourism industry	Negative impacts on native/endemic fauna	<b>14</b>
	Economic and social benefits for local communities	Increased invasive species dispersal	<b>10</b>
Control/limit invasive species	Restrict spread of invasive species	Limit visitor numbers/access to areas of National Parks	<b>6, 12, 17</b>
	Protect endemic species and communities	Restrict visitor activities in areas of National Parks	<b>6, 12, 17</b>
	Increased visitor satisfaction		
	Maintain condition of ecosystem	Limit visitor numbers/access to areas of National Parks	<b>6</b>
Reduce erosion	Protect endemic species and communities	Restrict visitor activities in areas of National Parks	<b>6</b>
	Maintain condition of ecosystem	Limit visitor numbers/access to areas of National Parks	<b>17</b>
Restore connectivity	Protect endemic species and communities	Restrict visitor activities in areas of National Parks	<b>17</b>
	Maintain condition of ecosystem	Limit visitor numbers/access to areas of National Parks	<b>6</b>
Rehabilitate disturbed sites	Increased visitor satisfaction	Restrict visitor activities in areas of National Parks	<b>6</b>
Increased real estate sales	Economic and social benefits for local communities	Drive up prices for locals	<b>4</b>
	Increase revenue for tourism industry		

References in bold text represent non-Australian studies.  
<sup>1</sup>Bark *et al.*, 2010; <sup>2</sup>Elsasser and Messerli, 2001; <sup>3</sup>Fukushima *et al.*, 2002; <sup>4</sup>Glorioso and Moss, 2007; <sup>5</sup>Konig and Abegg, 1997; <sup>6</sup>Needhman *et al.*, 2004; <sup>7</sup>Pickering, 2007; <sup>8</sup>Pickering and Buckley, 2003; <sup>9</sup>Pickering and Buckley, 2010; <sup>10</sup>Pickering and Hill, 2003; <sup>11</sup>Pickering *et al.*, 2003; <sup>12</sup>Pickering *et al.*, 2008; <sup>13</sup>Rixen *et al.*, 2003; <sup>14</sup>Rolando *et al.*, 2007; <sup>15</sup>Sanders *et al.*, 2008; <sup>16</sup>Wipf *et al.*, 2005; <sup>17</sup>Worboys *et al.*, 2010.

holders in the Australian Alps have started implementing climate change adaptation strategies in response to the impacts that they are familiar with and which directly impact on their group. These strategies however will not ameliorate all the currently known or predicted impacts of climate change. This is primarily for four reasons.

Firstly, some impacts do not have very good solutions. For example, being prepared for increased fires in summer does not deal with the issue that they will be uncontrollable in some cases (extreme fire days). In this case, they will be able to plan to save lives and possibly infrastructure in some areas but will not be able to stop large areas from burning. This was highlighted in 2003 where the Australian Alps experienced their largest bushfires in 60 years with an estimated 1.73 million hectares burned (Worboys, 2003). The fires started during electrical storms with 140 small, individual lightning strike fires reported in one evening. Despite consistent attempts at containment and control by up to 4000 personnel, the fires burned for 60 days resulting in considerable property being burnt; loss of human life; normal services such as power, gas reticulation, sewage treatment, and water supplies disrupted in places; livestock lost; and rural properties suffering damage (Worboys, 2003; Walsh and McDougall, 2004; Sanders *et al.*, 2008). Three years later, the 2006/2007 fires were also extensive lasting for 69 days and burning over 1.1 million hectares or almost 5% of Victoria and 15% of the state's total area of public land (Cioccio and Michael, 2007; DSE and Parks Victoria, 2008).

Secondly, some adaptations will only work for the short term or for limited changes in climate. For example, snowmaking in Australia is the primary climate change adaptation response of the ski tourism industry to low and unpredictable levels of natural snow (Pickering and Buckley, 2010). This adaptation strategy is likely to run into problems in the short-medium term as (i) the Australian Alps are relatively low (compared with mountains in Europe and North America) resulting in poor snowmaking conditions namely, fewer cold nights (Hennessy *et al.*, 2008), (ii) it will become more difficult to obtain (physically and economically) water for snowmaking (Pickering and Buckley, 2010), (iii) the excessive consumption of electricity becomes a significant economic and social issue (Pickering and Buckley, 2010), and (iv) skiers may alter their behaviour, avoiding low altitude ski resorts

and/or skiing less often including in Australia (Pickering *et al.*, 2010; Pickering, 2011).

Thirdly, there is the issue of conflict where one stakeholder's solution is another stakeholder's problem. For example, the diversification to year-round or two-season tourism by the tourism industry generates increased revenue for the industry as well as providing economic and social benefits for the surrounding local communities. Negative impacts include: (i) greater impacts on the physical environment, e.g. soil erosion, loss of vegetation including critical habitat for animals, and increased weeds and feral animal, etc. (Pickering *et al.*, 2003; Needhman *et al.*, 2004; Bicknell and McManus, 2006; Scherrer and Pickering, 2010), and (ii) increased pressure on protected area resources including fire response strategies for the protection of more people as well as new tourism facilities and infrastructure (Sanders *et al.*, 2008; Worboys *et al.*, 2010).

Lastly, there is the issue of different and/or changing social values. The impacts and consequences of climate change are valued according to different measures which can include monetary loss, loss of life, biodiversity loss, quality of life, and equity (Schnieder *et al.*, 2000; Adger *et al.*, 2009). Adaptation strategies favoured by different individuals, communities, or stakeholder groups usually reflect one or more of these measures over the others and are influenced by prioritised values unique to that group or individual. When it comes to decisions about what strategies to adopt in relation to climate change adaptation, questions arise over whose values count and whether these values will change over time as more evidence becomes available or climate change impacts become more detrimental. For example, the spread of wild horses in the Australian Alps poses a significant risk to fragile habitats, and while conservation managers have considered culling the horses to minimise damage, they are constrained by public attitudes (NSW National Parks and Wildlife Service, 2008). On the other hand, the culling of foxes or other invasive fauna does not provoke the same public reaction (Green and Osborne, 1994). A second example can be seen with the excessive water use by ski resorts for snowmaking. At the moment, the public does not seem to consider the impacts of the high water consumption on them. However, in the future when water shortages are predicted to occur in the region due to climate change and water prices subsequently increase, public opinion of snowmaking practices may also change (Pickering and Buckley, 2010).

Information as a limit

A major limit on the capacity to successfully adapt to climate change for any stakeholders is information. For many regions, including the Australian Alps and other mountain regions elsewhere, research needs include:

1. More certainty in climate change predictions for the region, particularly in relation to spatial scale and variability. However, it is recognised that this will simply not be possible in many areas within the Australian Alps and other vulnerable regions because of the lack of long-term climatic data among other issues (Hennessy *et al.*, 2007; 2008).
2. More information on indirect impacts of climate change, particularly ecological impacts (Williams *et al.*, 2008; Penuelas *et al.*, 2009; Steffen *et al.*, 2009; Traill *et al.*, 2010). An example of this is seen in the changing phenology of the arrival of the bogong moths to the Australian Alps and the timing of the emergence from hibernation of pygmy possums who consume the moths (Green, 2010). More information for conservation programs, particularly those involving *ex situ* conservation of plants and animals (Hunter, 2007; Harris *et al.*, 2009; Steffen *et al.*, 2009).
3. Skier's intentions and the economic potential of summer tourism from the tourism industry point of view (Bicknell and McManus, 2006; Scott and McBoyle, 2007; Pickering *et al.*, 2010). Some work has been done on visitor attitudes and responses to low or unreliable snow in Australia (Pickering *et al.*, 2010; Pickering, 2011), which suggest that visitors are sensitive to low levels of natural snow resulting in reduced revenue during the more lucrative winter months. To compensate, the diversification to year-round or two-season tourism will become much more important for many in the tourism stakeholder group (Bicknell and McManus, 2006; Moen and Fredman, 2007; Scott and McBoyle, 2007; Wolfsegger *et al.*, 2008). Importance of social values in climate change adaptation. While limits are traditionally analysed as fixed thresholds in economic, technological, and ecological/physical fields, these limits are also dependent on changing social values including ethics, knowledge, culture, and attitudes to risk. As such, these societal values need to be considered when examining and determining acceptable and feasible climate

change adaptation strategies (Adger *et al.*, 2005; 2009; Wolfsegger *et al.*, 2008).

4. More information on the current and proposed climate change adaptation strategies for the different stakeholder groups (Behringer *et al.*, 2000; Hill *et al.*, 2010; Matasci and Altamirano-Cabrera, 2010). Whether the different groups have considered the limits of their particular adaptation strategies and how they will address these limits is also critical. The identification of potential collaborations and conflicts can help the stakeholders within the region work together in better adapting to climate change.
5. More information on the limits of different adaptation strategies. This review highlighted a threefold discrepancy between the number of publications on (i) climate change impacts and adaptation strategies, and (ii) limits to adaptation. This information is needed to evaluate the feasibility of different climate change strategies and prioritise actions for adapting to climate change.

In conclusion, while this review represents and summarises publicly available information on climate change impacts, adaptation strategies, and limits to adaptation in the Australian Alps and other mountain regions, we are not attempting to evaluate success, appropriateness, or durability/sustainability of these adaptations and their limits nor do we attempt to evaluate their impacts on governance issues in the region. Instead, we find that the published data on climate change adaptation in the Australian Alps illustrates general issues that need to be addressed when dealing with limits to climate change adaptation and how we can more successfully adapt to climate change. While primarily dealing with the loss of snow cover and the numerous ecological, economic, technological, and societal flow on impacts for different stakeholders, this approach and its results can be applied to other obvious climate change issues including fires, cyclones, coastal flooding, and coral bleaching among others.

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