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Climate Change Impacts on Ecosystem Services in High Mountain Areas: A Literature Review

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High mountain areas are experiencing some of the earliest and greatest impacts of climate change. However, knowledge on how climate change impacts multiple ecosystem services that benefit different stakeholder groups remains scattered in the literature. This article presents a review of the literature on climate change impacts on ecosystem services benefiting local communities and tourists in high mountain areas. Results show a lack of studies focused on the global South, especially where there are tropical glaciers, which are likely to be the first to disappear. Climate change impacts can be classified as impacts on food and feed, water availability, natural hazards regulation, spirituality and cultural identity, aesthetics, and recreation. In turn, climate change impacts on infrastructure and accessibility also affect ecosystem services. Several of these impacts are a direct threat to the lives of mountain peoples, their livelihoods and their culture. Mountain tourism is experiencing abrupt changes too. The magnitude of impacts make it necessary to strengthen measures to adapt to climate change in high mountain areas.

Keywords: *Adaptation and mitigation; climate change; ecosystem services; glaciers; natural hazards; local communities; mountaineering; tourists.*

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Background

High mountain areas are arguably the region most affected by climate change (Beniston 2003; 2005). Assessments of climate change impacts in these regions have been mostly single-disciplined. Biophysical studies have focused on temperature changes, glacier retreat, hazards, and biodiversity (Dullinger et al 2012; Linsbauer et al 2012; MRI 2015). Social research has focused on impacts associated with water availability and livelihoods, and these impacts have been described more for downstream communities (Xu et al 2009; Immerzeel et al 2012) than upstream inhabitants (Beniston et al 1997; Kohler et al 2010). Integrative approaches that focus on climate change impacts on multiple ecosystem services in high mountain areas are still lacking.

Ecosystem services research allows overcoming the bias towards biophysical studies in mountain areas (Gurung et al 2012; Barrio et al 2013) by bridging their biophysical and social realms. It also allows connecting nature with the well-being of mountain peoples. Local communities in high mountain areas are especially vulnerable to climate change impacts because they have limited livelihood options and low adaptive capacity (Maraseni 2012). How ecosystem services delivered by high mountain areas (Grêt-Regamey et al 2012; Walz et al 2016) are affected by climate change and how these changes impact local communities are therefore research questions of pressing priority.

High mountain areas are increasingly visited by tourists, who are also affected by climate change impacts on ecosystem services (Welling et al 2015). In turn, climate change impacts on tourists also affect local communities. Mountain tourism has become a major source of livelihoods for mountain communities through economic benefits and direct and indirect employment (eg providing accommodations, renting animals, selling handicrafts, and serving as mountain guides, cooks, and drivers). In 2014, for example, Nepal received nearly 100,000 tourists, mostly for trekking and mountaineering, accounting for about 2% of its GDP, and the Huascarán National Park, a trekking destination in Peru, received 180,000 visits (MCTCA 2015). Glacier tourism is an important economic driver in many regions; in Norway alone it attracts up to 30,000 visitors per year (Furunes and Mykletun 2012; Espiner and Becken 2014).

In this work I synthesize existing knowledge about climate change impacts on ecosystem services that benefit local communities and tourists in high mountain areas through a systematic review of the literature. Then

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I provide a classification and description of the most common impacts found in these studies. Based on these results, I provide some reflections on future research needs regarding climate change in high mountain areas.

Methods

I searched the ISI Web of Science until the year 2016 for the terms "climate change," and "mountain*" (or "alpin*" or "Himalayas" or "Andes" or "Alps" or "Rockies" or "Carpathians"), and "stakeholder*" (or "local communit*" or "touris*") and excluding "ski*" occurring in article titles, abstracts, and keywords.

The search, carried out in December 2016, yielded 251 articles, from which I selected those referring to impacts on ecosystem services benefiting local communities and tourists in high mountain areas by reading the titles and abstracts and consulting the text when needed. I used Troll's (1973) definition of high mountains areas' altitudinal boundaries, based on the lower limit of periglacial dynamics or the upper timberline, usually presenting permafrost, snow cover, and glacier systems. Some villages are located in these areas, and many more use their resources directly for their livelihoods. I also included articles referring to high plateaus and highlands, such as those in Tibet, Scotland, and South America, because of the similarities of the impacts on these areas with those in high mountain areas. I defined mountain tourists as those undertaking backpacking, hiking, climbing, and mountaineering (see Pomfret 2006) and excluded articles referring to alpine (downhill) skiing, since this is performed in controlled environments with more specific impacts of climate change, mostly of an economic nature and affecting mainly tourists (Dawson and Scott 2013).

After discarding the articles not related to this review, such as those focused on low mountain environments or solely on biophysical aspects, and checking the reference lists of articles found for extra studies, I reviewed a total of 91 articles.

Results

Number and distribution of studies

Although the first scientific study on this topic was published in 1999, 77% of articles were published within the last 6 years. The geographical areas covered by the articles reviewed is biased to northern countries, with Switzerland (19 articles) coming first, followed by Nepal (15) and China (10) (see Figure 1 for a global map). Most articles focused on the mountain regions of the European Alps, the Himalaya, or the northern Rocky Mountains. Europe was the continent with the most articles (52), followed by Asia (43), North America (10), South America (8), Oceania (7), and Africa (1).

Impacts on ecosystem services

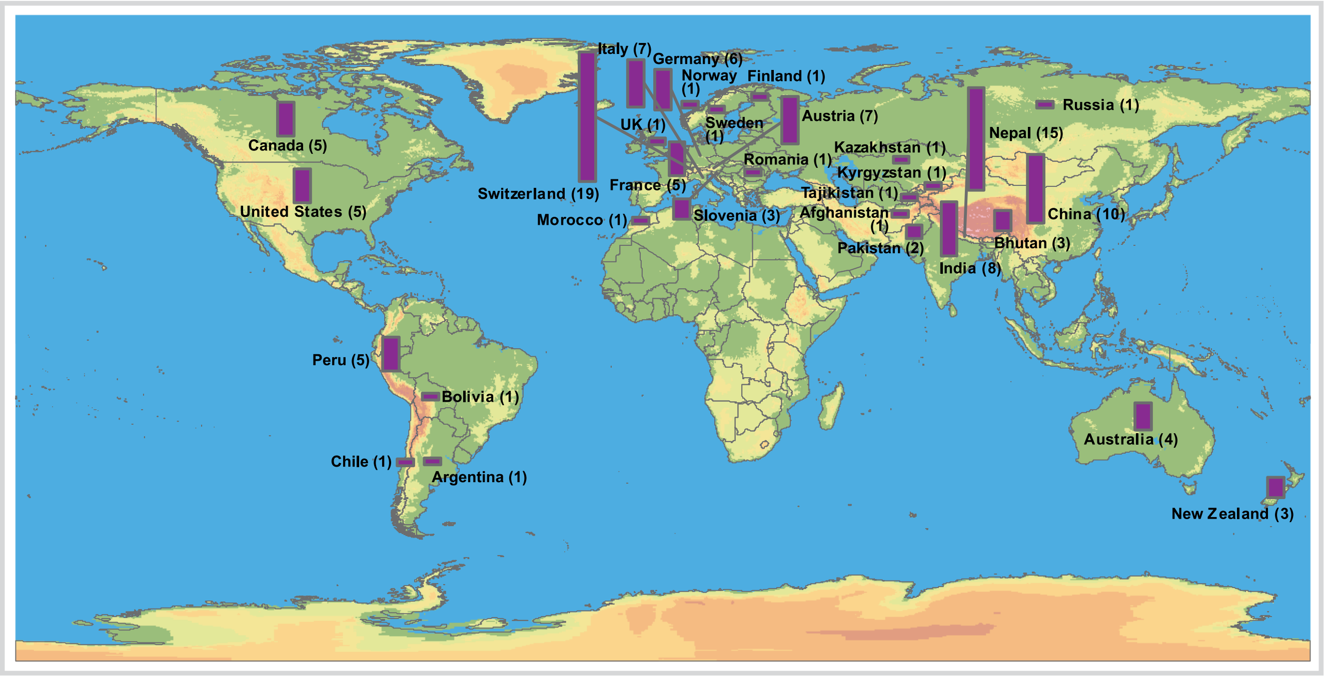
Climate change affects ecosystem services and the well-being of people in high mountain areas mainly through its impacts on food and feed, water availability, natural hazards regulation, spirituality and cultural identity, aesthetics, and recreation.

Impacts on food and feed: In the harsh environment of high mountain regions, climate change can profoundly affect food systems, as multiple studies show. Diminished snow cover and changing precipitation patterns affect subsistence agriculture in high-elevation villages in India and Nepal (Ogra and Badola 2015; Smadja et al 2015). In the meadows of Nagqu Prefecture in Tibet, climate change has contributed to a reduction of plant density, affecting yak and sheep herders (He and Richards 2015), and in the Tibetan steppe in Sunan Yugur Autonomous County, climate change seems to be contributing, together with increased grazing intensity, to the reduction of soil organic carbon (Yuan and Hou 2015). In dry high-mountain environments such as the Moroccan High Atlas, climate change could have negative consequences for livestock management (Parish and Funnell 1999). All these changes lead to continuing multidimensional poverty in rural mountain communities (Gentle and Maraseni 2012). On the other hand, increased temperature can also enable the cultivation of new crops that could not previously be grown in high mountain areas and that could diversify local diets (Singh et al 2010; Chaudhary 2011; Konchar et al 2015).

Impacts on water availability: Mountains have been called the world's water towers (Immerzeel et al 2010). The provision of water is one of the major ecosystem services affected by climate change in high mountain areas, with severe consequences for downstream populations (Barnett et al 2005; Beniston 2005) as well as high mountain areas. Local communities in Peru have experienced a decline in water resources in the dry season (Bury et al 2011). In the Khumbu region of Nepal, decreased stream flow due to climate change is affecting the availability of water to meet the high water demands of tourists (McDowell et al 2013). In Austrian mountains, exceptionally hot and dry summers have been shown to diminish the amount of water recharging the aquifers, decreasing water availability (Vanham et al 2009). In arid mountain regions, such as the Jabal Al Akhdar mountains in Oman, groundwater decline has led to water shortages for domestic supply and increased demand for bottled water (Al-Kalbani et al 2016).

Impacts on natural hazards regulation: As glaciers retreat, the decreased land-surface stability affects the frequency and location of natural hazards (Kääb et al 2005; Keiler et al 2010; Nepal 2013). Hazards are mainly caused by permafrost melting (producing landslides and rockfall), glacial lake outburst floods (GLOFs), and extreme weather

FIGURE 1 Countries that were the focus of articles of climate change impacts on local communities and tourists (excluding ski tourism) in high mountain areas until 2016. (Map by Ignacio Palomo)



events (virulent storms). Recent evidence seems to indicate that permafrost degradation increases the risks in high mountain areas due to a higher probability of rockfalls (Huggel et al 2012; Ritter et al 2012; Purdie et al 2015; Temme 2015). Climate change has increased the number and size of high-mountain lakes. This increases the likelihood of GLOFs (Byers et al 2014; Garrard et al 2016; Linsbauer et al 2016), which have been documented as a major threat to local communities and tourists (Purdie et al 2008; Nyaupane and Chhetri 2009; Ziegler et al 2016). Climate change–related extreme weather events might also make high mountain areas a riskier environment. Examples include the precipitation that peaked at 300 mm in a day on the Cévennes mountains in France and the virulent storm that trapped local mountain guides and mountain tourists on the Annapurna trail in the Himalaya in 2014 (Herring et al 2015). Certain ice-climbing routes, such as the northeast face of the Eiger in Switzerland or the Diamond Corridor on Mount Kenya, are now often bare of snow, making climbing more exposed. Other classic ice climbing routes in the Eastern Alps have also been affected by increased rockfall (Schwörer 1999).

Impacts on spirituality and cultural identity: Many glaciers are considered sacred or have strong symbolic meaning for local communities (Gagné et al 2014; Allison 2015). For example, African tribes living at the base of Mount Kilimanjaro consider the glacier on the mountain to be the house of God (Mölg et al 2008). Local communities close to Mount Khawa Karpo in China have an identity strongly linked to the Mingyong Glacier, which is decreasing rapidly; they also depend on its water (Allison 2015). On the sacred Mount Yulong Snow, also in China, local communities perceive that climate change has disturbed their spiritual world and worship practices (Shijin and Dahe 2015). This has also happened in Nepal, where the *ghats*, ie traditional places used for religious bathing and cremation, can be affected by changes in water runoff (Shrestha and Aryal 2011). The Quechua people in Peru living near the glacier on Mount Ausangate associate the decline of the glacier with God's departure and have lost traditional customs associated with the glacier (Kormann 2009; Allison 2015). Identities linked to glaciers and high mountains exist outside of high-elevation communities as well. In Bolivia, the Illimani Glacier is pictured on La Paz's official shield and on the labels for local beer, and its retreat or disappearance could have a strong impact on local identity (Orlove et al 2008).

Impacts on aesthetics: High mountain areas are highly appreciated for their aesthetic value and preferred visually over lower elevations in mountain areas (Schirpke et al 2013). Snow-covered areas seem to be visually preferred as well (Acar et al 2006). Although there has been little research on the effect of climate change on the aesthetics of high mountain areas, this effect is unquestionable, mainly associated with the retreat of glaciers, which is relatively well monitored worldwide (Diolaiuti et al 2011; Bolch et al 2012; Rabatel, Francou, et al 2013). The glacier on Mount Kilimanjaro has lost 85%

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of its area over the last 100 years, and it is unlikely that any ice will remain in the year 2060 (Cullen et al 2013). Also in the tropics, the Cordillera Blanca in Peru has lost more than 30% of its glacial area since 1930 (Schauwecker et al 2014). Climate change impacts reduced snow cover in June in the northern hemisphere by 11.7% every decade between 1967 and 2012, and the upward retreat of the glacier tongues of 43 glaciers in the western Alps between 1984 and 2010 has been 170 meters on average (Rabatel, Letréguilly, et al 2013). Snow cover in the Alps is predicted to drop significantly due to climate change (Bavay et al 2013).

Impacts on recreation: Climate change impacts have started to shift mountain tourism patterns, with several consequences for local communities (Scott et al 2008). More than 50 well-known glacier tourism destinations worldwide are or will be affected by climate change (Scott et al 2007; Wang et al 2010). For example, in Peru in 2007, the Pastoruri Glacier was closed to tourists because of its rapid recession, greatly diminishing the number of visits (from an estimation of about 100,000 in the 1990s to 34,000 in 2012 [Taj 2013]) and creating social conflicts until a new and better regulated trail was opened (Bury et al 2011). The establishment of the "climate change route" is an attempt to attract tourists to the area again. In Bolivia, the Chacaltaya Glacier, an important tourism destination, has completely disappeared (Chevallier et al 2011). In addition to the closure of specific attractions, perceptions of increased risks could also discourage visits by tourists (Purdie et al 2015).

On the other hand, new tourist opportunities might emerge. In the Swiss Alps, summer heat waves have increased the number of nights that tourists spend in alpine resorts (Serquet and Rebetez 2011), and in Germany, mountains could act as refuges from the heat in higher-temperature scenarios (Endler and Matzarakis 2011; Steiger et al 2016). A study in the Canadian Rocky Mountain region predicted an increase of up to 36% in tourism by 2050 because of warmer weather, but a decline in tourism by 2080 because of strong environmental impacts including glacier disappearance, changes in ecosystems, and occurrence of forest fires, among others (Scott et al 2007). Summer tourism in the Alps could be reduced by higher risks of thunderstorms or debris flows—but it could also be increased by the Alps' higher number of sunny days and cooler temperatures compared to the cities below (Pröbstl-Haider et al 2015). New tourist attractions might emerge due to glacier melting—like "Ötzi," a mummy dating to 3300 BCE that was found by hikers in 1991 and is now housed in a museum in Italy (Brida et al 2012).

Climate change might affect not only the number of tourists but also the time of year of their visits. High-elevation trekking in Bhutan, for example, might expand from spring and autumn to include winter due to higher temperatures, but greater precipitation might shorten the spring and autumn tourist seasons (Hoy et al 2016). In the United States, tourists have already shifted the time when they visit national parks due to climate change (Buckley and Foushee 2012).

Impacts on infrastructure and accessibility

Beyond the direct impacts described above, climate change affects ecosystem services through impacts on infrastructure that contribute to ecosystem services co-production. For example, GLOFs can affect hydropower dams, threatening the distribution of energy and water regulation, and several dams have been identified as at risk in Bhutan (Hoy et al 2015). In the European Alps, the stability of mountain huts is threatened by permafrost degradation, which loosens rocks beneath them, affecting the security of tourists (Ravanel et al 2013). An inventory of high mountain infrastructure in the French Alps has been undertaken to assess the social and economic costs of climate change impacts (Duvillard et al 2015).

Impacts on accessibility refer to the ability of local residents and tourists to reach certain areas or to follow certain routes, which in turn also affect ecosystem services. The lack of redundancy in the transportation network in high mountain areas makes accessibility highly vulnerable to climate change impacts (Strauch et al 2015)—for example, damage to transportation infrastructure by natural hazards such as rockfalls, landslides, GLOFs, and stream flooding. This can, in turn, have severe consequences for food security, for example if the only road to a village is blocked (Dame and Nüsser 2011). Damage to roads can also limit the connectivity among regions, affecting access to markets (Fort 2015). The accessibility of certain routes and mountain huts in the Austrian Alps has been negatively affected in this way (Ritter et al 2012). The Konkordia hut in the Swiss Alps, for example, which used to be located a few meters from the Aletsch Glacier, required a new access stair to bypass a rock wall more than 100 m high left by the retreating glacier. Glacier retreat in the New Zealand Alps has rendered access by foot difficult, making bridges and alternative transport necessary (Espiner and Becken 2014). On the other hand, as glaciers retreat, new ice-free routes can potentially be developed, which could facilitate accessibility in some contexts.

Discussion

There is robust and abundant evidence in the literature that climate change impacts local communities and tourists in high mountain areas. Analyzing these impacts through the ecosystem services framework shows that these impacts affect human well-being and ways of life in multiple and diverse ways. Although this is not an exhaustive study covering all ecosystem service categories, it shows the impacts most studied until now and makes it possible to identify research gaps. Infrastructure of high economic value is also at risk. Although some positive impacts might emerge as well (such as the possibility of growing more plant varieties at higher elevations), negative impacts on ecosystem services outweigh the positive ones.

Geographic gaps exist in the literature on this topic. In particular, there is an alarming lack of studies in Africa. With the exception of Nepal, China, and India, most of the research is originated in European countries, especially Switzerland, where more funds for research exist (R&D Magazine 2016). Given that the fastest changes in glacier cover seem to be happening in the tropics (Chevallier et al 2011), more studies about impacts in these areas are urgently needed.

Provisioning ecosystem services face multiple and diverse impacts. In terms of agropastoral livelihoods, positive and negative effects could occur in different regions, and more studies are needed to understand them. In any case, it seems obvious that changing agricultural practices will require several sociocultural changes (Konchar et al 2015). Climate change is likely to create water scarcity for local communities, according to the articles reviewed here. Given the rising numbers of tourists in mountain regions, this might lead to competition for water between local residents and tourists (Hoy et al 2016). The disappearance of tropical glaciers on which local communities depend for melting water might exacerbate water-scarcity issues. This could create water shortages in the long term and affect local subsistence agriculture. Other provisioning services might be affected as well. There is evidence that some medicinal plants that thrive only at very high elevations can be endangered by rising temperatures because they cannot shift their habitats (Grabherr 2009).

Regarding regulating services, most articles reviewed here focused on the hazards of GLOFs and landslides, because these directly threaten the lives of mountain people. In contrast to other complex processes in which climate change acts synergistically with other drivers, such as drought coupled with overgrazing, these hazards can undoubtedly be attributed mostly to climate change. It is not clear, though, how climate change could impact the frequency and intensity of avalanches, and it seems that forest expansion under climate change scenarios could enhance avalanche protection at some sites (Grêt-Regamey et al 2008). Other services such as climate regulation, which benefits society at broader scales (including high mountain areas), will be affected as well through snow/glacier-albedo feedbacks.

Little research exists on impacts on cultural ecosystem services on high mountain peoples. However, the identity of mountain communities is intertwined with their glacial environments. The rich and diverse conceptualization of glaciers across cultures highlights the need for place-based research on the impacts of glacier loss (Gagné et al 2014). Glacier loss can lead to the disappearance of cultural identity in local communities and to the loss of moral examples of the consequences of human behavior because glacier melting is perceived to be a negative consequence of human–nature interactions (Allison 2015). The dominance of biophysical research on climate change impacts is probably one of the reasons that social and cultural aspects such as these have been little studied to date. Mountaineering will be negatively affected as the glaciers retreat, and consequently, a significant element of human culture will be lost (Pomfret 2006). Glaciers are also data sources, for example as paleoclimatic archives for the study of past climate patterns, and their loss will have negative consequences for scientists and society as a whole (Thompson 2010).

Other negative impacts that have not yet reached high mountain areas might do so in the near future. Human migrations due to glacier retreat have not been documented yet, but are likely to occur as a result of the loss of livelihoods associated with changing water regimes (Raoul 2015). These migrations could exacerbate poverty in some areas and create humanitarian crises. An increase in vector-borne illnesses such as malaria and dengue due to climate change has already been reported in the mountains of Nepal (Dhimal, Ahrens, and Kuch 2015). Vector-borne transmitting species for dengue and chikunguya have already been found at 2100 m above sea level and might reach high mountain areas soon (Dhimal, Gautam, et al 2015).

Mountain tourism, apart from being impacted by climate change, is one of its causes through CO_2 emissions. Low carbon mountain tourism should increase for the sake of mountain communities and mountain tourists themselves. Other changes are needed as well. Tourism developments should avoid areas that are vulnerable to floods and debris flow hazards, something that is not happening yet (Ziegler et al 2016). Moreover, mountain tourism is characterized by high seasonality and spatial concentration, usually demanding elaborate infrastructure (such as roads, lifts, and cabins) and has multiple impacts on biodiversity and ecosystems (Nepal and Nepal 2004; Geneletti and Dawa 2009; Immitzer et al 2014; Wasowicz 2016). Hiking can cause soil erosion and impacts on vegetation and fauna close to hiking trails (Ballantyne et al 2014; Immitzer et al 2014; Tolvanen and Kangas 2016). Waste generation, such as in high-mountain base camps, has long been recognized as a major impact of tourism on high mountain regions (McConnell 1991; Nepal 2016). Climate change and tourism can also act synergistically, facilitating the spread of alien species (Tolvanen and Kangas 2016).

In addition to environmental impacts, economic impacts of tourism are of concern. As seen in this review, climate change might increase or decrease tourism in high mountain areas in different regions. In both cases, there is a risk that tourism revenues will benefit only state organizations, big tour operators, and high- and average-income households and not reach the poorest of the poor (Spiteri and Nepal 2008; Yang et al 2009; Steinicke and Neuburger 2012). Although successful examples of equitable access to tourism revenues exist, such as the equitable access model of homestays created in Ladakh that integrates community development needs with conservation goals, many challenges remain for the establishment of similar models in other regions (Anand et al 2012). There is a lack of research on mountain tourism's effect on multidimensional poverty (Zhao and Ritchie 2007).

All the impacts described in this review demand increased attention to high mountain areas. Not only the magnitude of impacts makes this an issue of research priority for mountains. High mountain areas are early-warning systems of climate change, and lessons learnt might be applied at lower altitudes. Beyond covering the geographical gaps identified in this review, those referring to the impacts on food systems, water availability, hazards regulation, and cultural ecosystem services, further research is needed in 4 areas:

1. A better characterization is needed of how many people live in high mountain areas and use them for their subsistence, and how they are being affected by climate change.
2. Better understanding of mitigation and adaptation options for high mountain areas and their peoples is a high priority given the diversity and magnitude of impacts (Ives et al 2010; Bouwer et al 2013; Konchar et al 2015).
3. The exposure to climate change of local residents and tourists in high mountain areas make them especially aware of climate change impacts (Wang and Cao 2015). Research on these population groups can provide a better understanding of how climate change awareness is triggered, and valuable lessons for climate change educational programs could be derived (Weber 2013; Clayton et al 2015).
4. The emerging citizen science on climate change impacts in high mountain regions (Criscuolo et al 2013), and science communication about glacier retreat, are also important topics for research (Paul et al 2007) that can help improve mitigation and adaptation.

Conclusions

High mountain areas are profoundly affected by climate change. Research on this issue has mainly focused on biophysical aspects, rather than social aspects such as impacts on stakeholders. Climate change affects ecosystem services benefiting local communities and tourists through impacts on food and feed, water availability, natural hazards regulation, spirituality and cultural identity, aesthetics, and recreation. Climate change impacts on infrastructure and accessibility also affect ecosystem services. This review has shown that, while most research focuses on northern countries, there is an urgent need to increase the number of studies in southern regions, especially in tropical countries. The diversity and magnitude of climate change impacts highlights the need to monitor ecosystem services in high mountain areas and to increase the adaptation options for local communities and tourists.

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