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A review of melting ice adaptation strategies in the glacier tourism context

Globally, tourism is being deeply impacted by glacial retreat caused by climate change. However, research on stakeholders' adaptation to climatic change and its threat to the industry on tourism niche is currently inadequate. Thus, through a literature review of 61 glacier peer-reviewed papers, this paper highlights the advancement in research on glacier tourism and provides some basis for understanding stakeholders' adaptation strategies to climate change. The review shows that glacier tourism research publications increased between 2015 and 2020. It also identifies some impacts of climate change on the glacier tourism industry as well as 27 adaptation strategies to climatic change, which are classified under seven main themes: changes to access, activities, tourism planning, educational activities, temporal substitutions, spatial substitutions, and glacier shrinkage attenuation. We discuss the relevance of the resilience concept in the tourism industry and recommend that tourists' experiences should be enhanced by applying the findings of research on tourists' motivations and landscape perception and developing more adaptation-oriented research. The findings suggest that the glacier tourism industry can reduce its vulnerability to climate change through increased collaboration between tourism operators and climate and tourism researchers.

Keywords: climate change; glacier tourism; adaptation; resilience; sustainability

Introduction

The glacier tourism context

Glaciers and ice caps outside of Greenland and Antarctica cover about 500,000 km² of the world's surface (Zemp et al., 2014). Although there are relatively few glaciers in the world, they provide water (Akhtar et al., 2008; Xu et al., 2010) and energy (Sternberg, 2010; Zimmermann, 2001) for many human societies. For instance, La Paz, a city in Bolivia with over one million people derives 85% of its water supply from glaciers. Glaciers are also attractive landscapes and have thus been a tourism resource for more than three centuries (Duffy, 2007). Presently, more than 1.5 million people visit the Bashui Glacier No. 1 in China every year (Shi-jin Wang et al., 2010) and about one million visit the Athabasca Glacier in Canada (Lemieux et al., 2018). Glacier tourism has emerged as a concept in the tourism literature. It refers to a form of nature-based tourism that emphasises visitors' awareness of nature and a site's attractive natural features (Fredman & Tyrväinen, 2010; Mehmetoglu, 2007a, 2007b). However, glacier shrinkage as a result of climate change is threatening this tourism niche. According to Bosson et al. (2019), 90% of the total ice mass located in designated World Heritage areas could disappear by the year 2100.

Several scholars have studied the relationship between nature-based tourism and climate change (e.g. Hambira et al., 2013; Han et al., 2016; Scott et al., 2012). Kaján and Saarinen's (2013) study showed that climate change is impacting nature-based tourism in several ways, including by creating a niche for a particular kind of nature-based tourism: last chance tourism (LCT). The term LCT first emerged in three different publications in 2010 (Eijgelaar et al., 2010; Hall & Saarinen, 2010; Lemelin et

al., 2010). Lemelin et al. (2010) describe LCT as a "niche tourism market where tourists explicitly seek vanishing landscapes or seascapes, and/or disappearing natural and/or social heritage" (p. 478). Because glacier tourism is a relatively new field of research (Welling et al., 2015), the impact of climate change on it is just beginning to gain attention in research (e.g. Wang et al., 2019). However, no study has investigated how stakeholders are adapting to climate change. Therefore, this paper hopes to contribute to the literature by reviewing and reflecting on the industry's implementation of adaptation strategies to counteract or mitigate the effects of climate change.

Such adaptation strategies will be important in the future for human societies (Simonet, 2015). Climate adaptation strategies are defined as a group or individual's adjustment to the sensitive consequences of climate-induced disturbances (Swart & Raes, 2007). Pelling (2011) proposes three categories of adaptation strategies: i) reactive, which consists of responding to an immediate risk; ii) transitional, which consists of marginal adjustment to foster flexibility; and iii) transformative, which consists of fundamental changes to the system. These adaptation strategies allow tourist operators to survive threats because they consist of re-organising and implementing new operating models (Adger, 2000) and therefore, can be considered as increasing the tourist operators' resilience. Resilience refers to a system's ability to absorb a disturbance without modifying its qualitative structure (Dauphiné & Provitolo, 2007). This state is reached by the system's elements taking action to ensure its continued existence (Aschan-Leygonie, 2000). Nevertheless, literature indicates that although operators can respond to immediate changes, this becomes difficult when faced with long-term incremental challenges that pose a threat to their sustainability (Espiner et al., 2017). This raises concerns about the resilience concept's capacity to implement transformative changes in the status quo that will lead to sustainability. Lew (2014)

suggests three major orientations for resilience planning: i) engineering approach that focuses on reaching the pre-disturbance state; ii) ecological approach that leads to a new equilibrium; and iii) synoptic approach that considers human and natural systems in a state of constant evolution. This paper uses both the concepts of adaptation and resilience to frame glacier tourism's reactive responses to climate change because climate adaptation strategies share this quality with the discussion of resilience in the physical sciences – they can be proactive or reactive, planned or spontaneous (IPCC, 2001) and thus cover or involve all three of Pelling's (2011) forms of adaptation.

Tourism operations are systems that are perpetually adapting (Scott et al., 2009). According to many summer tourism literatures, these adaptations have been studied to some extent (e.g. Cholat et al., 2019) but less than research on impacts of climate change (Kaján & Saarinen, 2013). Conversely, in the winter tourism context, several studies were published on the climate-related adaptations of winter tourism operations, such as ski operations (Steiger et al., 2019) showing that adaptation-related research on summer tourism are underdeveloped. Few summer tourisms studies have discussed adaptation to cryosphere changes (Rasul et al., 2019). Accordingly, this paper aims to fill this gap with an overview of adaptation strategies implemented in the glacier tourism context.

The glacier tourism literature reviews

Two significant reviews of glacier tourism have been conducted. Welling et al. (2015) described the state of the field with a review of 53 peer-reviewed papers and identified three central themes within them: perception and value of glaciers, social and ecological effects of glacier tourism, and impact of climate change on glacier tourism. They suggested that future researchers should design a conceptual framework for studying

glacier tourism, investigate motivations and behaviours of glacier tourists, and examine both the impact of climate change on glacier tourism and the development of climate change adaptation strategies.

More recently, Wang and Zhou's (2019) review examined the impact of climate change on glacier tourism, referencing 42 papers, and found that climate change has aesthetic, cultural, and experiential impacts on glacier tourism. They noted that glacier tourism research gained momentum since 2015, but research on climate change adaptation strategies in this context is still inadequate. This paper aims to address this issue by reviewing the climate change adaptation strategies developed in the context of glacier tourism. It also intends to describe the evolution of glacier tourism research since 2015. The two research questions that guide this study are as follows: Has climate change-related glacier tourism grown since Welling et al.'s (2015) review, in terms of volume but also in terms of insights? How much research on developing climate change adaptations exists in literature and what did research reveal about how the sector is adapting to climate change?

Methods

We applied the systematic quantitative literature review method described by Pickering and Byrne (2014). This technique allows for the methodical examination and selection of subject-related papers, using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process explained below (Moher et al., 2009; Figure 1).

First, we created a set of relevant keywords, including "glacier tourism," "glacier tourist," "glacier recreation," "tourism" AND "glacier," and "geotourism" AND "glacier." We then entered these keywords into six main scholarly databases: Google Scholar, BASE, ScienceDirect, Leisure Tourism, Taylor & Francis Online, and

the Directory of Open Access Journals (DOAJ). We searched for these keywords in the titles, abstracts, and texts of articles in these databases. Our July 2020 search excluded years of publication to demonstrate the evolving relationship between climate change and glacier tourism.

Next, we screened the titles and abstracts of all of our selected articles (n = 267), and manually excluded duplicates and those not relevant to our topic (n = 143). We determined their relevance by asking "Does the paper deal with a form of tourism related to a glacier or its heritage?" We included those that did.

Third, we assessed the 123 articles for eligibility as per Pickering et al. (2015) and extracted 95 valid articles. We then used peer-reviewed articles and conference papers in the synthesis and PhD dissertations, Master's theses, book chapters, and research reports as "grey literature" (n = 26) for the qualitative analysis. We also removed articles written in Chinese (n = 8), which we could not read. Thus, we used 61 peer-reviewed articles written in English, French, German, and Polish.

The first phase of quantitative analysis focussed on these questions: "Where and when was the study conducted?"; "What was the main glacier assessed in the study?"; "What kind of methods were used?"; "Does the paper deal with stakeholder management?"; "What was the main purpose of the research?"; "Does the paper deal with the impact of climate change?"; and "Does the paper deal with climate adaptation strategies?" To answer these questions, the set of 61 articles was entered into a database and subsequently analysed qualitatively by theme. All themes not related to glacier tourism were excluded.

Of the 61 papers included in this review, 21 were published before 2015. Welling et al.'s (2015) review up until 2015 included 53 papers. We presume this

disparity is due to our exclusion of scientific reports and book chapters. Conversely, Wang and Zhou included a maximum of 42 papers to their review.

Results

This section consists of two parts. The first part considers the evolution of glacier tourism research since 2015. The second part deals with climate change issues and the development of climate change adaptation strategies in the glacier tourism context.

Research on glacier tourism evolution

Eight papers included in our review (13%) were published between 1984 and 2009, and 53 (87%) between 2010 and 2019. Of those published after 2010, 38 were published since 2016 (62%), which clearly illuminates glacier tourism as an emergent and dynamic field of research since 2015.

Figure 2 shows that these papers' foci can be categorised into five different themes: i) risk and accessibility, ii) landscape degradation, iii) tourism planning, iv) glaciers as a resource for tourism, and v) LCT. Tourism planning (17 papers) and glaciers as tourism attractors (25 papers) have been studied since the emergence of the field (e.g. Cayla, 2009; Pearce, 1984; Reynard et al., 2009). Risk and accessibility, LCT (e.g. Purdie, 2013; Yuan et al., 2006), and the impact of summer skiing tourism (e.g. Demiroglu et al., 2018; Vujović, 2012) themes related to specific issues of climate change have appeared since 1994 (c.f. Abegg et al., 1994) and gained momentum since 2010.

Climate-related glacier tourism research corresponds to three major themes: the evolution of the risk and accessibility of glaciers due to climate change (21 papers), landscape degradation (six papers), and LCT (three papers). In essence, these articles show that access to glaciers is becoming more difficult and sometimes dangerous, that

the landscape is becoming dirty, and that LCT is becoming an important motivation for glacier tourism. Nine papers between 2010 and 2015 and 17 between 2016 and 2020 were published with these themes. This indicates that researchers are increasingly interested in the relationship between glacier tourism and climate change.

Glacier tourism and climate change

The first papers related to climate change and glacier tourism were published in the mid-1990s (Abegg et al., 1994). Interest in glacier tourism increased from 2000 to 2009, with one paper focussing on the relationship between glacier tourism and climate change (Yuan et al., 2006). Our review showed that 10 of the 14 related articles published between 2010 and 2015 dealt with climate change's impact on the industry, and 35 of the 41 articles published since 2015 have done so (Figure 3). The other six assessed the recreational value of glacier tourism (Yuan & Wang, 2018), the volatility of the demand for skiing in summertime (Mayer et al., 2018), and the various potentials of geotourism (Duraj et al., 2017; Gordon, 2018; Tavera Escobar et al., 2017).

The impact of climate change on glacier tourism

Wang and Zhou (2019) suggest that climate change directly impacts glacier tourism by decreasing access to glaciers and increasing the risk of ice-related activities. Moreover, they suggest that glacier landscapes are impacted and can lead to a decrease in the scenery and cultural value. Those impacts had already been suggested by Welling et al. (2015) and our literature review confirms that glacier tourism all over the world is impacted by geomorphic processes driven by climate change (Figure 4). For instance, moraine destabilisation and glacier shrinkage make glacier access difficult (Mourey & Ravanel, 2017; Mourey et al., 2019; Stewart et al., 2016; Watson & King, 2018). Glacial retreat and disappearance reduce the aesthetic value of these landscapes

(Diolaiuti & Smiraglia, 2010; Garavaglia et al., 2012; Groulx et al., 2016; Moreau, 2010) and increases the presence of debris on the glacier's surface (Purdie et al., 2015). Permafrost warming increases the frequency of rock falls and related hazards (Mourey et al., 2019; Ravanel et al., 2017) and changes in glacier morphology increase the size and occurrence of crevasses (Demiroglu et al., 2018). These processes make glacier-related activities and tourism more dangerous and are already impacting the glacier tourism industry (Figure 5). Furthermore, modulizations of the glacier's future dynamics (Bosson et al., 2019) show that those impacts will become more prevalent in the immediate future.

Glacier tourism's adaptations to climate change

Of the 47 papers in this study, which included topics related to climate change, 30 dealt with climate change adaptation strategies. Climate change adaptation-related studies first materialised in 2010, and only six such studies were included in Welling et al.'s (2015) review. However, 13 papers on glacier tourism and climate change adaptation were published since 2015, including 7 since 2019. This research question is thus attracting scholarly interest in pace with glacier tourism development.

Of the 30 papers that considered glacier tourism and climate change adaptation, 10 recommend that stakeholders and tourism planners adopt specific adaptations. These include developing artificial snow-making and weather manipulation capabilities to reduce glacier shrinkage (Wang et al., 2020), adapting trails and enhancing conservation of glacial sites (Diolaiuti & Smiraglia, 2010), covering glaciers with blankets (Naald, 2019), creating new paths or using helicopters to make glacier access more environmentally friendly (Weber et al., 2019), developing new touristic infrastructure (L. Wang et al., 2017), preparing people for living in a deglaciated world using

educational tools (Lemieux et al., 2018), and enhancing conservation measures (Wang et al., 2010; Wang et al., 2020).

Twenty papers presented current climate adaptation strategies. Adapting how tourists access glaciers (e.g. by developing new trails, adding security equipment, or closing off some viewpoints) is the main strategy recommended in 13 papers (e.g. Mourey & Ravanel, 2017; Purdie et al., 2015; Ritter et al., 2010). Others suggest changing activities to cope with the challenges presented by glacial retreat, including diversifying glacier tourism activities (e.g. Mourey et al., 2020; Stewart et al., 2016; Wang et al., 2010), developing new infrastructure (Demiroglu et al., 2018), or shifting activities completely (e.g. Demiroglu et al., 2018; Kaenzig et al., 2016). Ten papers deal with the development of educational activities (e.g. Rasmussen, 2018; Rasul et al., 2019; Welling et al., 2019) and tourism planning (e.g. Watson & King, 2018; Welling & Abegg, 2019) as adaptation strategies. A further eight papers studied temporal and spatial substitution (e.g. Furunes & Mykletun, 2012; Salim et al., 2019; Stewart et al., 2016) Finally, three articles (Rasul et al., 2019; Wang et al., 2010; Welling et al., 2015) discuss glacier shrinkage attenuation as adaptation strategies. The 27 different climate adaptation strategies identified in this literature review are listed in Table 1.

Discussion

Here, we discuss the implications and limits of existing climate change adaptation strategies and propose new avenues for future research.

Adaptation or business as usual?

This study's results show that there is still more research on climate change impacts on glacier tourism operators than of adaptation to it. This might be because many operators

are not really worried about the future even though they are already feeling the impacts of climate change (e.g. Espiner & Becken, 2014; Furunes & Mykletun, 2012). Some mountain guides in the French and Italian Alps argue that such adaptation is a part of their job (Salim et al., 2019), as do glacier tourism operators in Iceland (Welling & Abegg, 2019) and stakeholders in New Zealand (Stewart et al., 2016). However, whereas field operators such as guides can integrate daily evaluations and adaptations into their everyday work, tourism operators face high operating costs that require long-term investments, reducing their ability to respond quickly and effectively and plan for the long term.

According to the glacier tourism and climate change adaptation literature, most glacier tourism operations' adaptation strategies attempt to maintain the status quo (e.g. the view that glacier use is the only operable tourism resource at a site, glacier shrinkage attenuation) or initiate a slight transition while maintaining a strong dependence on the glacier as a primary tourism resource (e.g. by developing heli-hikes, new paths around the glacier, interpretative materials). These strategies are reactive and transitional (Pelling, 2011) and can lead glacier tourism operators to engage in investments that increase their vulnerability or liability – for example, New Zealand glacier tourism sites developing heli-hikes (Stewart et al., 2016). The dynamic is similar within the skiing industry, where artificial snowmaking is a popular adaptation strategy despite the resources, energy, and investments required to pull it off (Steiger & Scott, 2020).

As future glacier volumes are expected to decrease due to climate change, so will glacier tourism (Zekollari et al., 2019) and operators engage in transformative adaptations (Fedele et al., 2019) that do not seek to perpetuate the status quo but pursue new and balanced responses to a continuously changing environment. Only a few

transformational strategies have been implemented in the glacier tourism context, for example, decreasing tourism operations' dependence on glaciers instead of altitude as a primary tourism resource (Kaenzig et al., 2016). The implementation of these adaptions is challenging, as they require extensive planning (Fedele et al., 2020). The literature indicates that transformative adaptations are more often implemented in large, established, important glacier tourism sites than in self-employed glacier tourism operations (e.g. Kaenzig et al., 2016; Wang et al., 2010; Wang et al., 2020). Of the 12 papers on climate change adaptation strategies developed by self-employed glacier tourism operators, 9 show that their adaptation strategies are mainly reactive, 11 describe them as transitional, and only 3 describe transformational strategies. Conversely, 7 of the 11 papers dealing with larger tourism companies or decision-makers report the implementation of transformational strategies. This shows the need for planning and concertation between all stakeholders to effect successful transformative adaptations.

The foregoing discussions raise concerns about the resilience of the glacier tourism industry. Many of the adaptation strategies reviewed correspond to an engineering approach of resilience (Lee, 2014) that aimed to reach a steady state without considering the future of environmental evolution. According to Espiner et al. (2017), resilience is a necessary part of sustainability but is not sufficient to reach it. From this perspective, resilience in the glacier tourism context must be implemented in an ecological or synoptic approach (Lee, 2014), taking into account the future threats (glacier shrinkage and associate paraglacial activities) of climate change. For example, in the case of guided activities around the Mer de Glace, operators can show engineered resilience by reducing their vulnerability to external hazards (e.g. rock falls) and continuing operations without being dissuaded that glacier tongue may disappear in less

than 20 years (Vincent et al., 2019). As glacier tourism is naturally vulnerable to climate change, operators must be able to accurately forecast the effects of climate change on their industry and engage in sustainable and transformative adaptations (Fedele et al., 2020). Furthermore, to ensure the sustainability of tourism in glaciated areas, ecological or synoptic approaches of resilience (c.f. Lew, 2014, p. 15) must be applied, which involves views on both social and ecological system evolution. Lang et al. (2012) have suggested that scholars can alleviate glacier tourism operators' vulnerability by engaging in more interdisciplinary research including both social and environmental sciences.

Research perspectives

Even though glacier tourism literature has grown since 2015, there remain some gaps to fulfil. Here, we propose three different avenues for future researchers to enhance glacier tourism research and support tourism operators in a sustainable manner: i) filling the spatial gap in the European Alps, ii) researching how changes in the landscape affect tourism behaviour, and iii) adding empirical studies to validate glacier tourism's relationship with LCT.

Glacier tourism sites in the European Alps: a spatial gap in knowledge

Major glacier tourism, that is tourism at those sites which see more than 100,000 visitors per year – has been investigated in various national contexts, including New Zealand (Purdie, 2013; Stewart et al., 2016), China (Liu et al., 2006; Wang et al., 2010) and Canada (Groulx et al., 2016; Lemieux et al., 2018). However, few studies have been conducted on the European Alps. For example, *Mer de Glace* in France sees over 360,000 visitors per year and is experiencing rapid glacial shrinkage, but it has not been

studied until recently (Salim & Ravanel, 2020). Aletsch Glacier in Switzerland, a designated UNESCO World Heritage site and the largest glacier in the Alps, has over 1 million visitors a year (Jungfraubahn Data). However, the glacier is melting quickly (Bosson et al., 2019; Paul & Bolch, 2019). Paraglacial events, which is directly link to glacier retreat, have occurred and a large landslide has obstructed access to a scenic path (Kos et al., 2016). Thus, the glacier retreat can be challenging for stakeholders, for example, with respect to infrastructure destabilisations (e.g. Duvillard et al., 2018). Thus, more studies are required to associate environmental and social sciences on the evolution of glacier tourism in the European Alps in the context of climate change as it is preconised for Nordic tourism face to climate change (Hall & Saarinen, 2020).

Changes to the landscape and tourists' behaviour

People are drawn to scenic landscapes, which seem to motivate glacier tourism (Espiner et al., 2015; Kaenzig et al., 2016; Lemieux et al., 2018; Purdie, 2013; Salim & Ravanel, 2020); however, these landscapes are being increasingly jeopardised by climate change (Furunes & Mykletun, 2012; Moreau, 2010; Purdie et al., 2015; Wang et al., 2010). Therefore, understanding how climate changes' effects on the landscape will affect glacier tourists' behaviour is a priority for tourism operators. Research methods such as Climate Futurescape (e.g. Groulx et al., 2016), combining natural and social science methods and assessing the three dimensions of landscape issues – data, techniques, and public consultation – could make significant contributions to this field. In addition, future research could attempt to understand any mismatch between the landscape imagined by visitors before their visit and how they perceive it once there, and whether receding glaciers contribute to their satisfaction.

Last Chance Tourism and glacier tourism

Climate change has also seen the rise of LCT. Beyond the case of the Athabasca Glacier in Canada (Lemieux et al., 2018), tourists are exhibiting LCT motivations in many contexts, including polar bear viewing in the Arctic (Dawson et al., 2010; Groulx et al., 2016), the Great Barrier Reef (Piggott-McKellar & McNamara, 2017; Salvatierra & Walters, 2017), and endangered bird-watching (Hvenegaard, 2013).

There seems to be no doubt that LCT motivations will exert a huge influence on the glacier tourism industry. In this sense, the emergence of LCT can be seen as an opportunity for glacier tourism stakeholders (Furunes & Mykletun, 2012; Lemieux et al., 2018). However, Wang et al. (2010) caution that as LCT brings more people to glacier tourism sites, it places greater stress on glacial ecosystems and produces excess carbon emissions (Dawson et al., 2010). In addition, LCT is paradoxical: tourists driven by this motivation are generally environmentally aware but participate to destroy what they love (Dawson et al., 2011). This paradox seems to be related to cognitive dissonance (Aronson, 1969) – for example, even when last chance tourists are aware of the impact of their actions, they are unwilling to pay for carbon offset projects and continue to visit glacier tourism sites (Groulx et al., 2019). Future researchers could investigate LCT glacier tourism and develop frameworks to better understand this phenomenon and its ethical concerns. Furthermore, the learning dimension of LCT can be an opportunity to develop and implement environmental education initiatives as part of the glacier tourism industry and have these initiatives take meaningful effects.

Conclusion

This paper expands previous literature reviews (Wang & Zhou, 2019; Welling et al., 2015) with an overview of glacier tourism adaptation to climate change regarding the resilience concept. It indicates that this topic is attracting academic interest as an increasing number of papers on this topic have been published since 2015. It also indicates that climate change's impacts on glacier tourism are well-known and widespread and that stakeholders are adopting 27 kinds of climate adaptation strategies. We classified these strategies into seven categories: developing new activities, changing glacier access, enhancing educational actions, shifting the seasonality and spatiality of activities, attempting to attenuate glacier shrinkage, and increasing tourism planning. However, these strategies are mainly reactive and largely maintain the status quo without reducing the vulnerability of the sites. It also suggests that transformative adaptation strategies require long-term planning, and many self-employed glacier tourism operators do not implement them. Correspondingly, the results suggest that glacier tourism operators are mainly concerned with reaching a steady state without taking into account future environmental changes. We suggest that more interdisciplinary research on environmental and social science could facilitate sustainable climate change adaptation of glacier tourism stakeholders. Interdisciplinary research through the European Alps would be crucial despite the number and importance of glacier tourist sites. Glaciers visitors' response to landscape change and an understanding of the LCT phenomenon will help tourism operators and stakeholders design sustainable futures.

In the current climate-warming context, the sustainability of glacier tourism is uncertain as glaciers diminish. In a world of ever-shrinking glaciers, the future of glacial tourism should be debated. In territories where the economy is highly dependent on glacier tourism, new sustainability methods must be found. Glaciers and its landform as

a heritage element could be part of the answer. A solution can be to enhance and promote the scientific and pedagogic value of glaciers as an easily readable marker of the Anthropocene. Viewed through this lens, glaciers could become the ambassador of climate change and the natural feature that communities can fight for.

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Figure & Table list:

Figure 1: Overview of the article selection method for this study using the PRISMA approach (Moher et al., 2009).

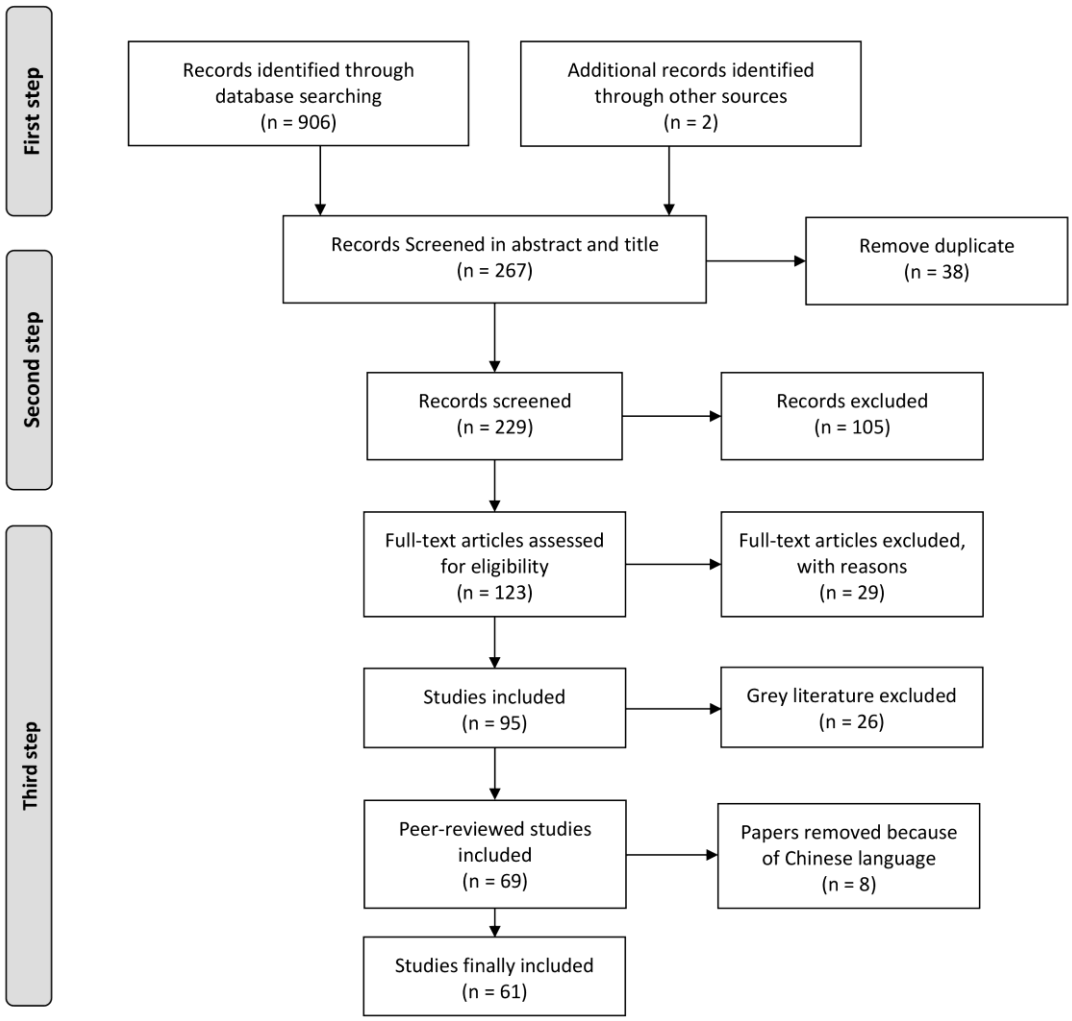

Figure 2: Topics of the published papers on glacier tourism per year.

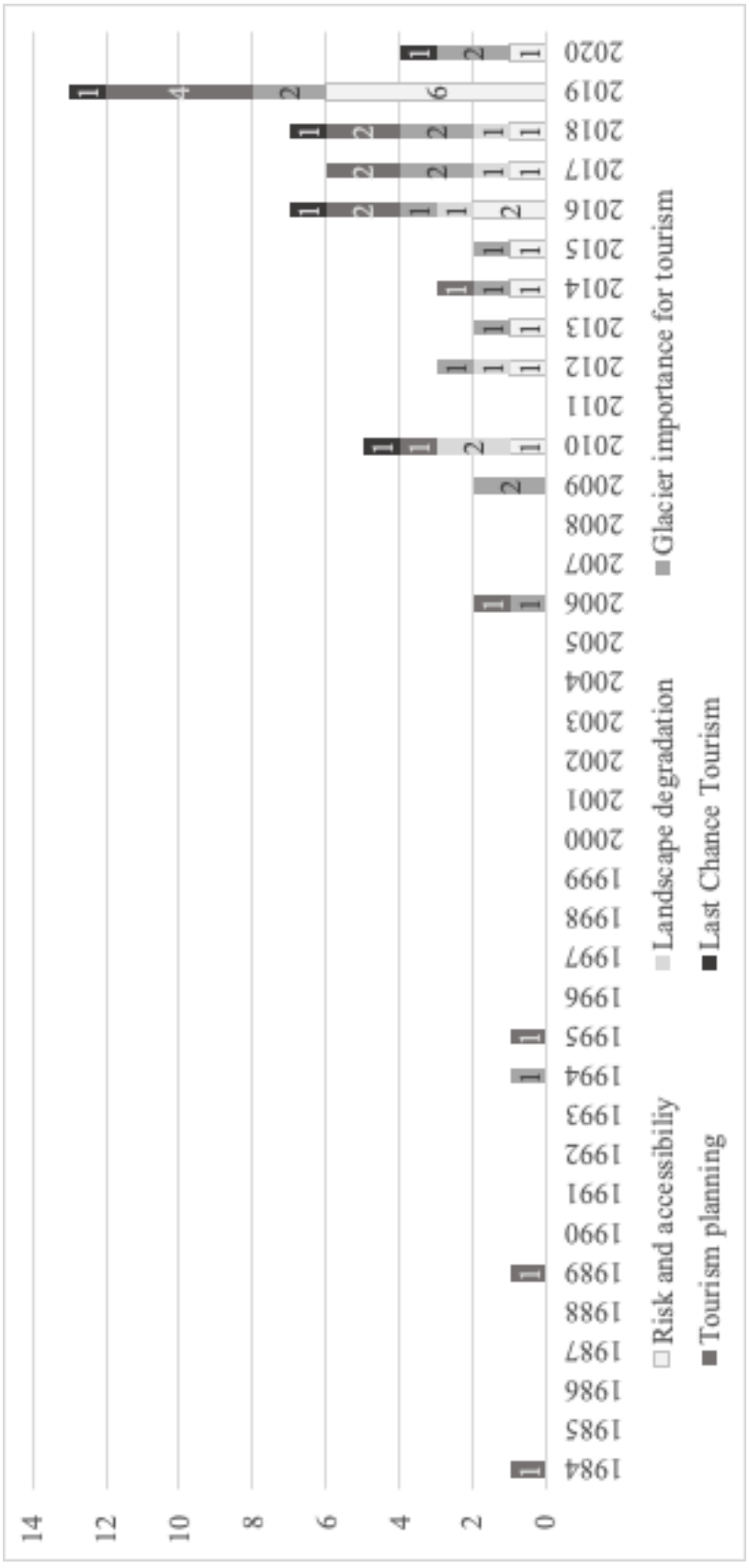

Figure 3: Number of articles dealing with the relation or absence of relation between climate change and glacier tourism

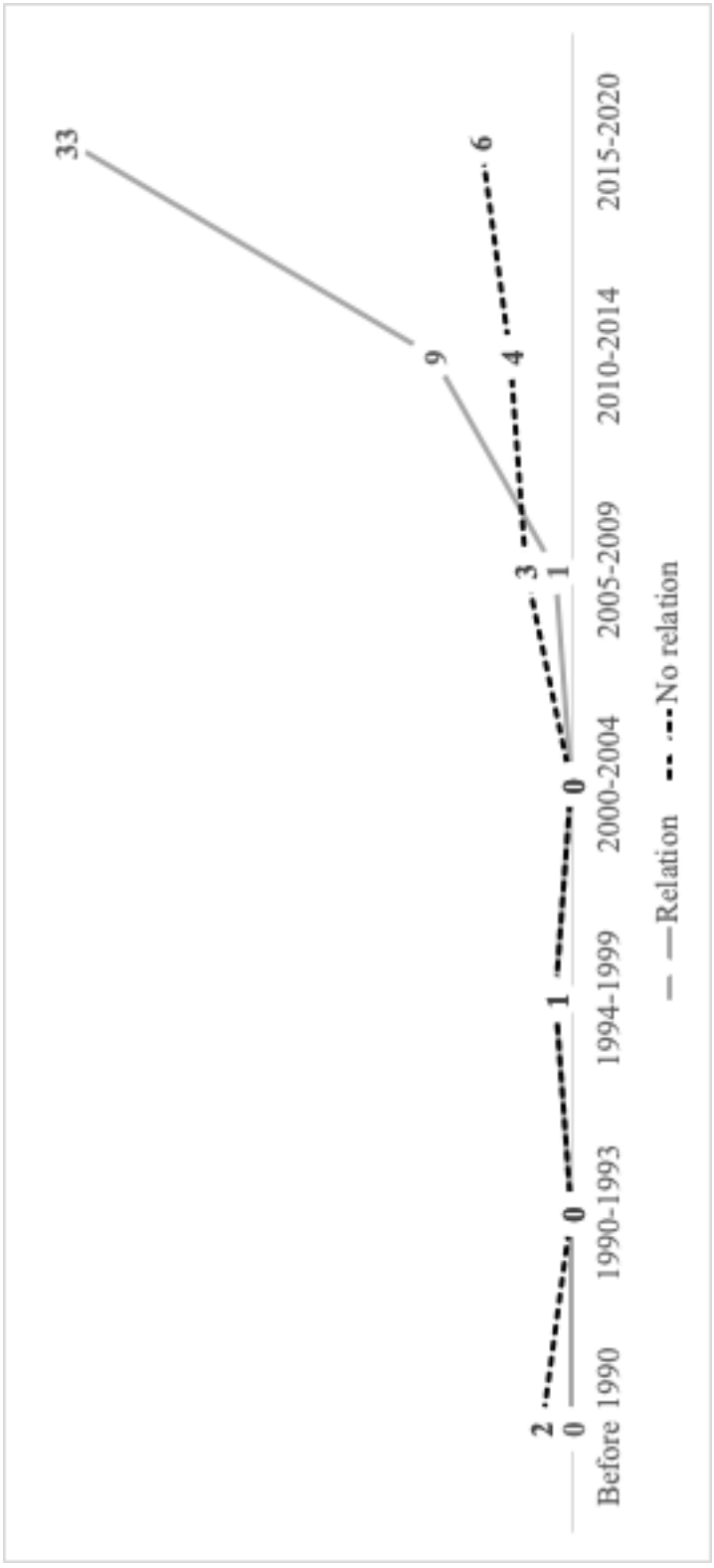

Figure 4: Glacier tourism and climate change, published papers by continent.

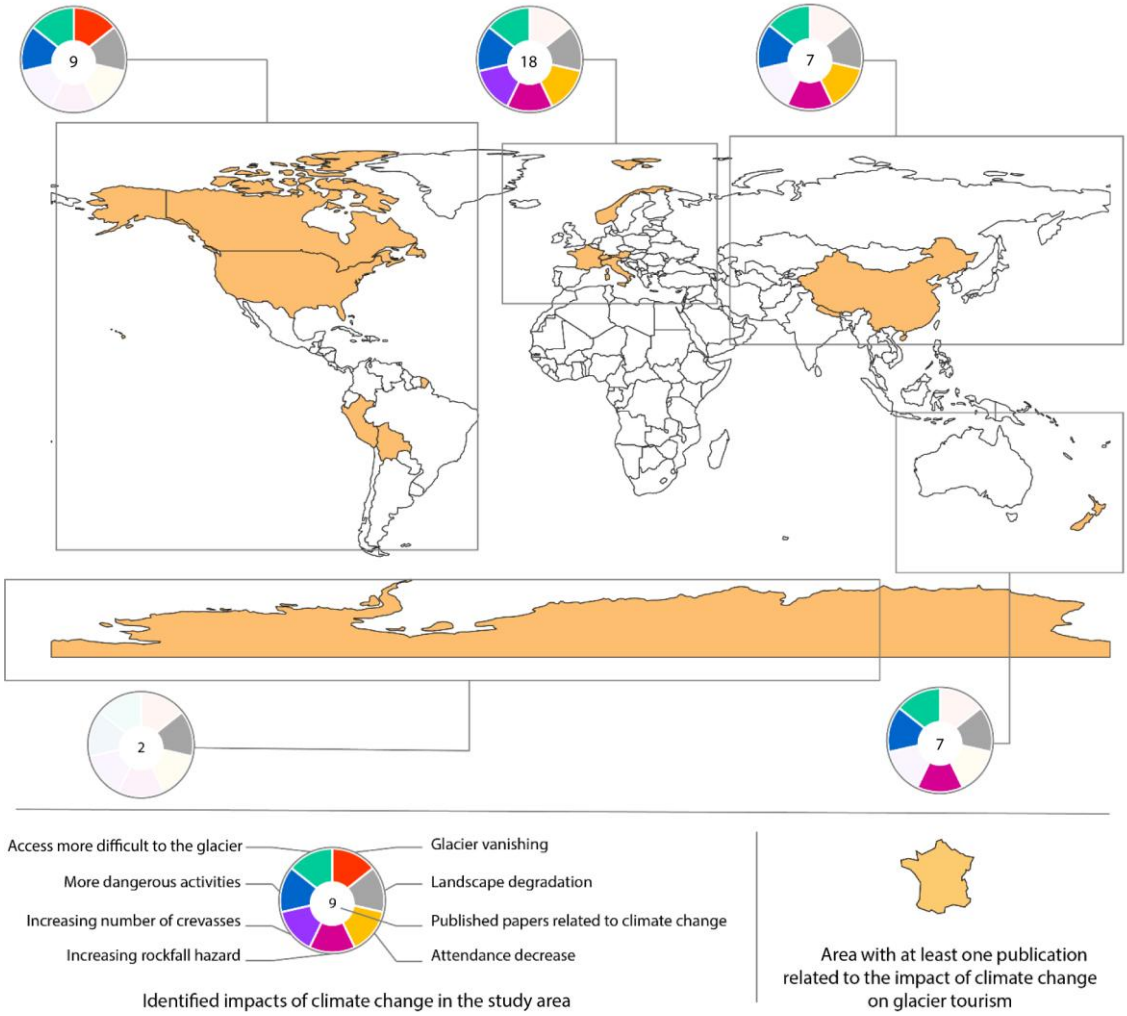

Figure 5: Synthesis of the climate change impacts on glacier tourism according to geomorphological processes.

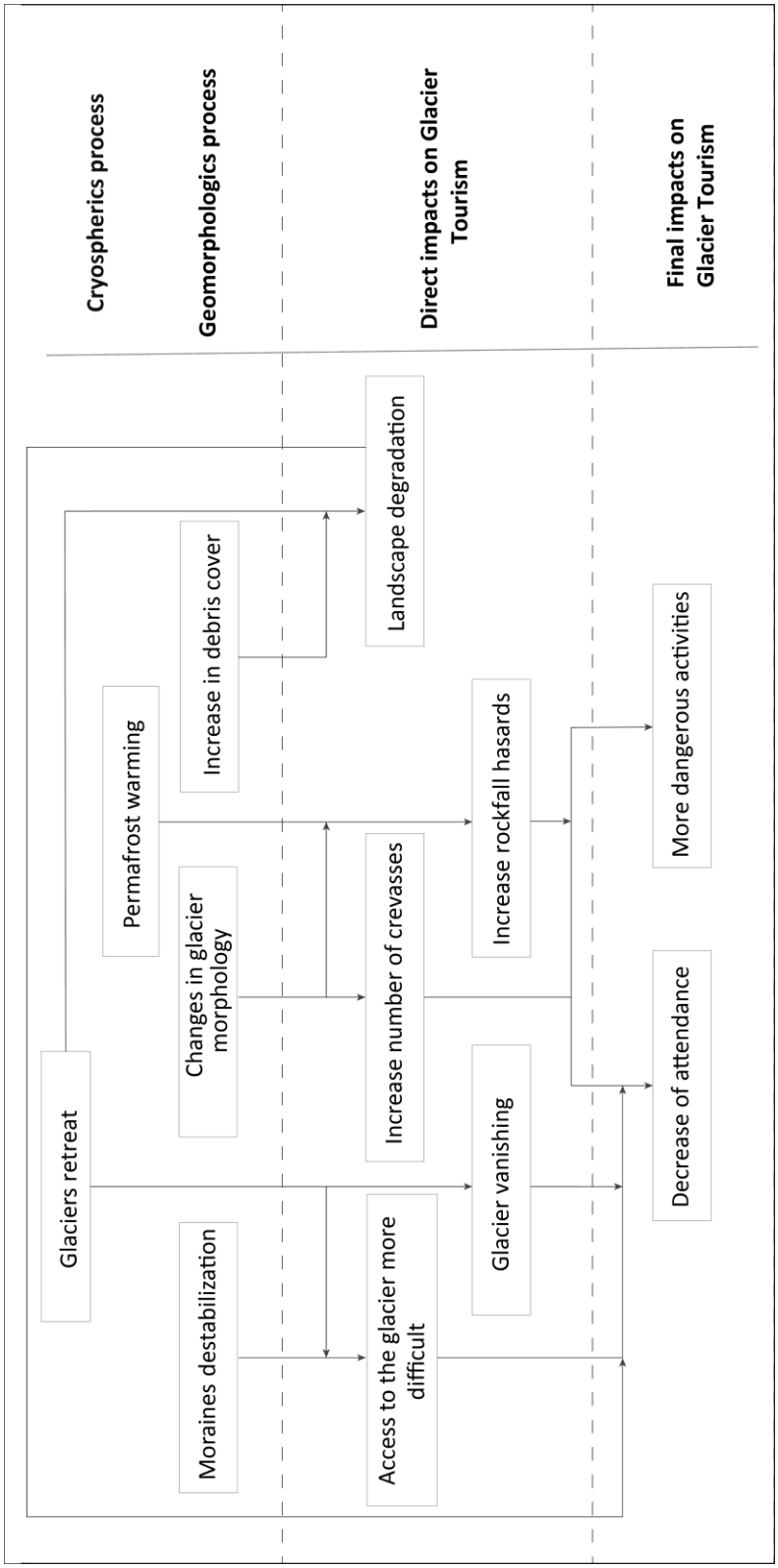

Table 1: Adaptation strategies implemented by glacier tourism stakeholders

Table 1. Adaptation strategies implemented by glacier tourism stakeholders

Changes to access (13)	Spatial substitutions (4)	Glacier shrinkage attenuation (3)	Temporal substitutions (4)	Educational activities (5)	Tourism planning (5)	Changes of activities (12)
New path for existing activites (Ritter et al., 2010); (Purdie et al., 2015); (Mourey et Ravanel, 2017); (Watson & King, 2018); (Mourey et al., 2019); (Welling et al., 2019)	Moving to another glacier (Furunes and Mykletun, 2012); (Demiroglu et al., 2018)	Artificial snowmaking (Wang et al., 2010); (Rasul et al., 2019)	Changing seasonality (Demiroglu et al., 2018); (Salim et al., 2019); (Mourey et al., 2020)	Intepretation tools (Rasul et al., 2019); (Welling et al., 2019)	Networking (Watson & King, 2018); (Welling & Abegg, 2019); (Welling et al., 2019)	Diversification (Wang et al., 2010); (Purdie, 2013); (Espiner & Becken, 2014); (Purdie et al., 2015); (Kaenzing et al., 2016); (Stewart et al., 2016); (Demiroglu et al., 2018); (Rasul et al., 2019); (Salim et al., 2019); (Welling & Abegg, 2019); (Mourey et al., 2020); (Purdie et al., 2020)
Path refection (Ritter et al., 2010); (Mourey et Ravanel, 2017); (Watson & King, 2018); (Mourey et al., 2019); (Welling & Abegg, 2019); (Welling et al., 2019)	Changing place of practice (Demiroglu et al., 2018); (Salim et al., 2019); (Mourey et al., 2020)	Artificial weather manipulation (Wang et al., 2010)	Reactivity (Stewart et al., 2016); (Salim et al., 2019); (Mourey et al., 2020)	Marketing (Welling et al., 2019)	Enhanced conservation (Wang et al., 2010); (Rasul et al., 2019); (Welling et al., 2019)	Redirecting (Kaenzing et al., 2016); (Demiroglu et al., 2018)
New road and new path for new activty (Wang et al., 2010); (Welling & Abegg, 2019); (Welling et al., 2019)	Enhanced individual mobility (Salim et al., 2019); (Mourey et al., 2020)	Blanket cover (Welling et al., 2015)		Glacier museum (Wang et al., 2010); (Kaenzing et al., 2016)	Scientific research (Wang et al., 2010); (Welling & Abegg, 2019)	New infrastructures (Demiroglu et al., 2018)
Safety equipment (Welling et al., 2015); (Mourey et Ravanel, 2017); (Mourey et al., 2019)				Educational element (Wang et al., 2010); (Rasmussen, 2018); (Rasul et al., 2019)	Protection law (Wang et al., 2010); (Welling et al., 2019)	
New types (heli-hike) (Purdie, 2013); (Espiner & Becken, 2014); (Purdie et al., 2015); (Stewart et al., 2016); (Purdie et al., 2020)					Cooperative plateform (Welling & Abegg, 2019); (Welling et al., 2019)	
Monitoring access route and path (Welling et al., 2015); (Watson & King, 2018); (Welling & Abegg, 2019)						
Closing path (Purdie, 2013); (Espiner & Becken, 2014); (Mourey et Ravanel, 2017); (Purdie et al., 2020)						