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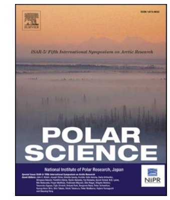

Polar tourism and environment change: opportunity, impact and adaptation

Wang Shijin [a,b,*], Mu Yaqiong [a,b], Zhang Xueyan [c], Xie Jia [a,b]

[a] State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou, 730000, China
[b] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, 100049, China
[c] Beijing Tripolers. Co., Ltd, Beijing, 100000, China

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ABSTRACT

The Polar Regions (PRs) are characterized by ice sheets, sea ice, glaciers, tundra, and other cryospheric landscapes and associated aboriginal cultural features. This primitive polar landscape is a huge contrast to the current human living environment and is a strong tourist attraction. Rapid environmental changes and the emergence of conflicts between tourism development and ecological protection, have affected sustainable development of polar tourism (PT). Polar high-latitude characteristics determine the vulnerability of their environment and the higher sensitivity of PT to climate change. This study comprehensively analyzed the status quo of PT development, systematically revealed mutual influence between environmental changes and tourism development, and proposed some adaptive measures to coordinate environment protection and tourism development.

1. Introduction

In general, 'polar' refers to the regions surrounding both the North and the South Pole, thus, polar tourism (PT) can correspond to almost any kind of tourism activities taking place around the North and South Poles (Grenier and Müller, 2011; Hall and Saarinen, 2010). The Polar regions (PRs), Antarctica and Arctic, play a vital role in scientific research and tourism development because of their special geographic location and relatively primitive environment (Müller and Viken, 2017). The PR is an important key area driving global environmental change. Even small climate fluctuation causes rapid polar environment changes (i.e., the cryosphere) and results in an increase in extreme weather events in low- and mid-latitude countries (Overland and Wang, 2016; Shepherd et al., 2018).

The PRs are characterized by their severe cold climate, special landforms, extensive cryosphere, strong cultural authenticity, and fragile ecosystems. The unique polar landscapes feature ocean, sea ice, coastal zone, ice shelf, ice sheet, snow field, polar day (night), aurora, tundra resource, and indigenous culture. Compared with the low- and the mid-low latitudes, the PRs have great spatial heterogeneity in terms of cryosphere, ecological landscape, cultural structure, and political system, which have established the PRs as areas with significant tourist potential globally and with enormous tourism value (Lück et al., 2010).

Polar tourism (PT) refers to the related activities to visit the Antarctic and Arctic (excluding scientific research). PT activities mainly include snowmobiling, visiting reindeer farms and reindeer sledding, viewing polar lights, husky safaris, fishing/ice fishing, boat tours and whale-watching. The PT relies mainly on cruise ships or airplane to transport tourists. Tourism development and management of the Arctic are relatively easy because there are no sovereignty disputes. In the Antarctic, tourism management is relatively difficult, and the time during which tourism activities can take place is extremely short as they occur throughout the relatively short summers.

The PRs have fragile and sensitive environmental conditions and are the most sensitive regions directly affected by global climate change. Unreasonable tourism development is bound to have irreparable effects on the PRs environments. Future tourism development has to take into account the environmental, social, cultural and economic aspects in a balanced approach to ensure that tourism will benefit the local people and the environment in the long term (Vaarala, 2006). In light of this need, the study systematically expounded on the current situation of environmental change and tourism development in the PRs, revealed the opportunities and risks of interaction between tourism development and environmental changes, and then proposed an adaptation mechanism or alternative approach for healthy and sustainable tourism development.

* Corresponding author. Donggang West Road 320, Lanzhou, Gansu, 730000, China.
E-mail address: xiaohanjin@126.com (W. Shijin).

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2. Overview of the polar regions

The Antarctic region is a massive frozen landmass around the South Pole and composed of the ocean, islands, and land on the south of the Antarctic Convergence Zone stipulated by the Antarctic Treaty, as well as some islands on the north. Antarctica is a vast ice-covered landmass surrounded by sea, whereas the Arctic is an ice-covered ocean surrounded by land. Sea ice extended over 19.44 million square kilometers (7.51 million square miles) in 2012, according to the National Snow and Ice Data Center (NSIDC). Antarctica includes east Antarctica and west Antarctica. The area of East Antarctica is 1, 018 × 10^4 km^2, whereas the area of west Antarctica in only 190 × 10^4 km^2. Vinson Massif with an altitude of 4, 897 m is the highest peak in Antarctica. The Antarctic Peninsula is a narrow mountain barrier with an average width of 70 km and an average altitude of 1, 500 m. The highest point is Jackson Peak (3, 184 m above sea level) (Larsen et al., 2014; Shepherd et al., 2018). The closest continent to the Antarctic continent is South America, between which is Drake Strait, which is 970 km wide. The Antarctic is one of the world's least-disturbed places, but it has become increasingly vulnerable, especially to global warming and climate change.

The Arctic region refers to the northern parts of the Arctic Circle (north of 60°33′N), including most of the Arctic Ocean and its islands and archipelagos, the North American continent and the northern margin of Eurasia, with a total area of about 2073 × 10^4 km^2. Compared with Antarctica, the Arctic is not far from other continents, and many countries surround its sea area (Larsen et al., 2014; Graham et al., 2017). Arctic land sovereignty is tied to eight Arctic countries: Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the United States. According to the nature, geography, political characteristics, and administrative characteristics, the Arctic borders are different. At

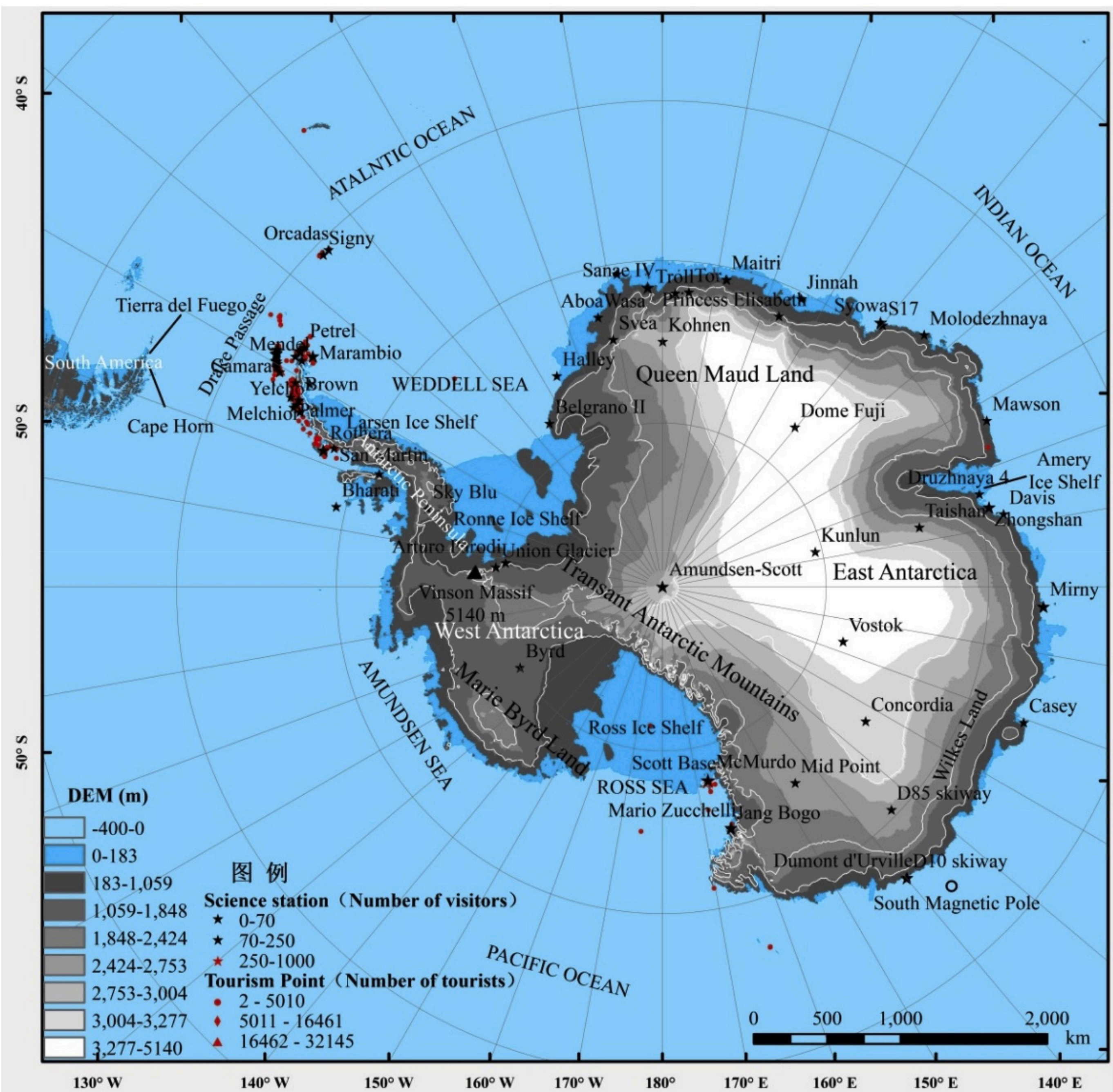

Fig. 1. Antarctica destinations.

present, the Arctic border defined by the Arctic Monitoring and Assessment Program (AMAP) has the greatest acceptance. In theory, the Arctic region should cover all areas of activity by indigenous people.

3. Tourism development

The huge spatial heterogeneity of the PRs has attracted the unprecedented interest and attention of global tourists, and the region has developed into the world's newest tourist destination. Tourism is also considered one of the region's few economic opportunities.

3.1. Antarctic region

Antarctica climate is characterized by extreme cold, extreme dryness, and frequent blizzards. Antarctica has unique landscapes and animal life, including ice sheet, icebergs ice shelf, aurora, penguin, walrus, seal, and whale. Antarctic Peninsula has the most abundant landscape resources, and this area is also the most visited areas for Antarctic tourists. Antarctic tourism is characterized by cruise and ship-based tourism from South America to the Antarctic Peninsula from about October to March (Jabour, 2014) and the suitable travel period is about 6–30 days. Other operations include some continental activities, yacht cruising, over flights, and fly–cruise as well as limited visitation to East Antarctic destinations. Antarctic tourism activities include cruise, kayaking, photography, videography, camping, skiing, helicopter aerial view, ice climbing, snowmobiling, diving, swimming, and visiting the scientific research stations. Since 1989, tourists have visited more than 200 tourist spots in the Antarctic Peninsula, including 20 scientific research stations (Fig. 1).

Antarctic tourism began in the 1950s. With improvements in transportation and communication technologies, Antarctic tourism has continued to develop, the number of tourists increased significantly, and the tour route became relatively mature. During the period from 1992 to 2018, 1930 new tourists were added each year, and the annual average number of visitors increased by 27% (IAATO, 1992–2019). In 2008–2011, because of the impact of global financial crisis, the number of visitors dropped slightly. During the tourism season of 2018–2019, a total of 55, 489 people arrived in Antarctica, an increase of 7% year on year (Fig. 2). The largest number of tourists (17, 679) still come from the United States, accounting for 31.86%; Chinese tourists total 8,149, accounting for 14.69%, making it the second largest source of tourists (IAATO, 1992–2019) (Fig. 3).

3.2. Arctic region

Arctic business travel began in the early 1950s. During this period, the industrial revolution in North America and Europe created a significant amount of property, increased leisure time, improved educational programs, and spurred inventions and technologies to changed social development (in particular railway and ship-building technologies) (Stonehouse and Snyder, 2010). Among these developments, global tourism expanded rapidly. The fierce competition between railways and ships has gradually reduced the cost of travel to the Arctic and has enabled more tourists to visit destinations. Major destinations and attractions in the Arctic include the Greenland Ice Sheet, Icelandic Ice Cap, Aurora, Alaska Mountain Glacier, Norwegian Fjord, Arctic Tundra, Taiga, polar bear, Arctic fox, reindeer, and Eskimo and other aboriginal cultural features (Fig. 4). The best cruise season around the Arctic is from June to September, while the long-distances travel is achieved mainly by airline in other seasons.

In recent years, the Arctic channel has been opened earlier and traffic conditions have greatly improved as a result of global warming (Dawson et al., 2017; Zhang et al., 2019). The number of tourists in the Arctic region (Canada, Russia, Iceland, Norway, Sweden, Finland, Alaska, and the United States) is growing rapidly, and tourism is devolving rapidly. At 2017, the number of inbound visitors in the noted regions reached 66.37 million, an average annual increase of 3.71 million since 1995. In 2017, Russia and Canada accounted for a large share of tourists, accounting for 68% of the total number of tourists visiting the Arctic. The Nordic Arctic countries have accounted for 18.71 million visitors, an increase of 2.6 times compared with in 1995. Greenland and Alaska have relatively small numbers, with only 2.51 million visitors, about twice as many as in 1995. In the five Nordic countries, for example, the number of inbound tourists in 1995 was about 7.34 million, whereas the number of inbound tourists in 2017 reached 18.98 million, 2.59 times higher than in 1995 (Table 1).

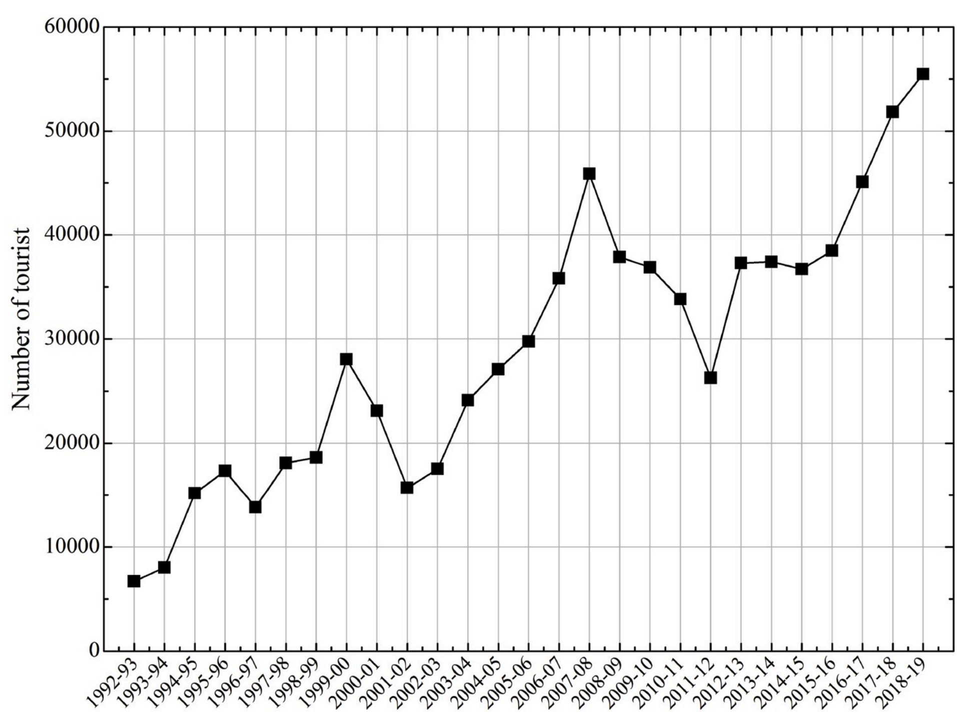

Fig. 2. Changes in the number of Antarctic tourists (Reich, 1980; IAATO, 1992–2019).

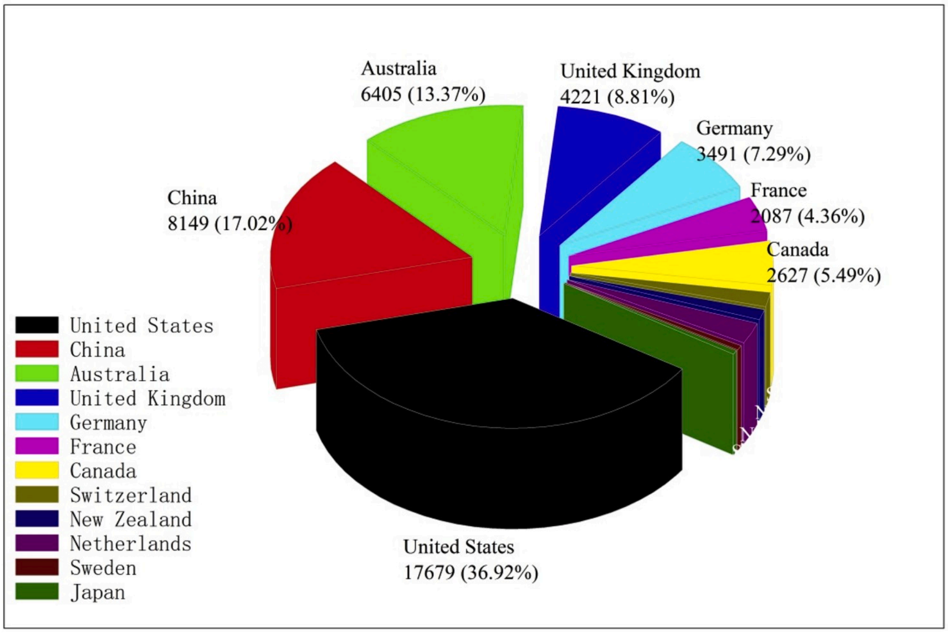

Fig. 3. Proportion of tourists from different countries to Antarctica during the tourism season of 2018–2019.

Table 1 Changes in international tourist numbers in the Arctic in 1995–2017 (10^4 people) (World Tourism Organization, 1995–2017; Fay et al., 2010; McDowell Group, 1994–2018).

Tourism has brought billions of dollars in economic benefits to the Arctic, and tourism development has become a major target for the indigenous economies of Greenland, Iceland, Nunavut, Yukon, the Russian Federation and Alaska. Of these, Alaska reached 2.25 million visitors in 2017, with direct tourism revenues of US$ 125.6 million. Its tourism–related jobs and labor income supported 43,400 people and reached US$ 1.5 billion, accounting for 10% and 5% of the state's total, respectively. Between 2011 and 2017, the number of state tourists and revenue increased by 23.28% and 38%, respectively (ADCCED, 2018). Data from the Association of Arctic Expedition Cruise Operators showed that in 2018, 27.2 million passengers planned to take a cruise in the Arctic, which demonstrated a 4.9% increase from 2017. Demand for cruises has increased by 20.5% over the past 5 years. The United States by far has the largest cruise market, with 11.5 million cruise passengers, followed by China (2.1 million), Germany (2 million), United Kingdom (1.9 million), and Australia (1.3 million) (AECO, 2017).

4. Environmental changes

4.1. Antarctic change

As the world's first and second largest "cold source," the Antarctic and Arctic have regulated global climate change, in which the most characteristic feature of the Antarctic climate is the low temperature environment. The average temperature of most areas is below 0 °C. With global warming and continued cryosphere melting, the Antarctic environment has undergone significant changes. Studies have shown that surface temperature of the southeastern Antarctic has not changed much since 1950, but the southwestern Antarctic has increased by about 0.7 °C/10a (Hodgson et al., 2010; Orsi et al., 2012; Turner et al., 2013). Between 1992 and 2017, the Antarctic ice sheet lost a total of 2,720 ± 139 billion tons of ice, which is equivalent to a global sea-level rise (SLR) of 7.6 ± 3.9 mm, of which 2/5 of the SLR (3.0 ± 0.6 mm) occurred in the past 5 years (Imbie team, 2018). Antarctica has the potential to contribute more than 1 m of sea-level rise by 2100 and more than 15 m by 2500, if emissions continue unabated (DeConto and Pollard, 2016). In recent decades, a number of these ice shelves have disintegrated in part or entirely (Cook and Vaughan, 2010; Shepherd et al., 2018). Antarctic sea ice has seen a small increase (the growth rate was only 1.6% ± 0.4% per decade during the period from 1979 to 2016), but regional differences are significant. Trends in the extent of sea ice have not changed much since 1979 in Weddell, Indian Ocean, and the Western Pacific (1.7% ± 0.8%, 1.7% ± 0.99% and 1.8% ± 1.2%, respectively), but the Bellingshausen–Amundsen seas sector showed a decrease of its sea ice loss from −5.1 ± 1.6%/10a to −2.9 ± 1.4%/10a, due to the cooling of the air temperature in the Peninsula and the increase of winds (De Santis et al., 2017). In particular, in recent years (2014–2017), the sea-ice extent in the Southern Hemisphere has experienced an unprecedented annual decline, and the sea-ice coverage area has reached its lowest point in the past 40 years. This significant decrease exceeded the rates seen in the Arctic during the same period (Parkinson, 2019). The Antarctic permafrost is about 4.98×10^4 km, accounting for 0.36% of the Antarctic continent. Although it is small, it is the primary controlling factor for the Antarctic terrestrial ecosystem (Vieira et al., 2010). The permafrost temperature is higher in the Antarctic Peninsula, especially in the north, and permafrost is more sensitive to climate change. This sensitivity has led to an active layer thickening and acceleration of permafrost degradation erosional phenomena (Bockheim et al., 2013; Mauro and Gonçalo, 2014).

4.2. Arctic change

The annual average Arctic surface air temperature increased by 2.7 °C from 1971 to 2017 (with a 3.1 °C increase during the cold season) and rose 2.4 times faster than average for the Northern Hemisphere (AMAP, 2019). Observed and projected annual average warming in the Arctic continues to be more than twice the global mean level and the frequency and duration of Arctic winter warming events have been increasing (Serreze and Barry, 2011; Graham et al., 2017). Annual precipitation appears to be increasing in the Arctic, by an estimated 1.5%–2.0%/decade, with the strongest increase occurring during the October–May cold season. Some regions, such as Scandinavia and the Baltic Sea basin, are seeing less precipitation falling as snow and more as rain (AMAP, 2019). The most direct impact of Arctic warming is reflected in the reduction in the extent of see ice, snow cover, permafrost and river/lake ice. Arctic winter sea ice maximums in 2015, 2016, 2017, and 2018 were at record low levels, and the 12 lowest minimum extents

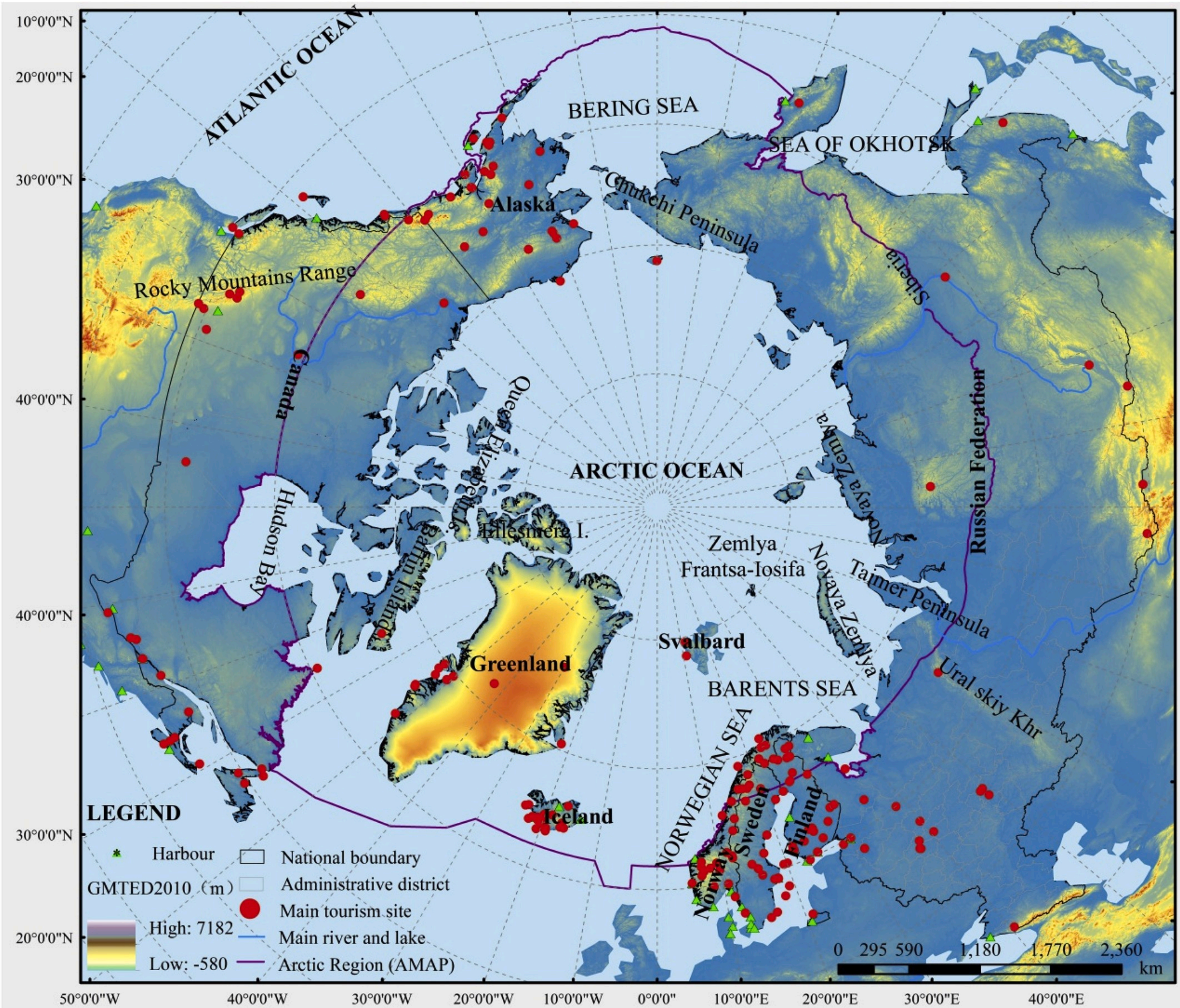

Fig. 4. Arctic region and its main tourist destinations.

(sea-ice volume with 5003 km^3 in 2018) in the satellite record have all occurred in the past 12 years (AMAP, 2019). Recent studies have shown that the Arctic accounts for 48% (10 cm) of the total global sea-level rise that occurred from 1850 to 2000 and 30% of the total sea-level rise that occurred from 1992 to 2017 (AMAP, 2019). Since 2005, the range of spring snow in the Arctic land has decreased significantly. Among these areas, the snow cover in Eurasia in 2017 was higher than the average (Mudryk et al., 2017). Recent observations have shown that the average temperature of the permafrost active layer in the Arctic has reached a record high, with the largest temperature rise occurring in the cold permafrost regions of the northern Arctic. Arctic warming is causing widespread river and lake ice subsides and thawing of permafrost areas (Vladimier et al., 2018; Hori et al., 2018; AMAP, 2019). Some results showed one-third of pan-Arctic infrastructure (e.g., roads, buildings, municipal facilities, industrial facilities, etc.) and 45% of the hydrocarbon extraction fields in the Russian Arctic are in regions where thaw-related ground instability can cause severe damage to the built environment (Hjort et al., 2018).

5. Opportunities and impacts

The PT is highly dependent on polar environment, and the opportunities and risks coexist.

5.1. Opportunities

Polar warming on the PR is significantly higher than the global average level. This warming amplification effect played an important role in the appearance of new landscapes, tourism climate comfort, outdoor leisure environment, accessibility, and tourist economy.

5.1.1. Appearance of new landscape features

Climate change can create a myriad of new tourist landscape features that range from the continental to microscopic scale. Northern Hemisphere greening is associated with warming permafrost, The 1982–2015 time-series of the area averaged seasonal NDVI in the permafrost regions across the Northern Hemisphere illustrate that there are statistically significant increasing trends in all seasons (Peng et al., 2020). The improvement of ecological vegetation will greatly improve the quality of

Table 1
Changes in the number of international tourists in the Arctic in 1995–2017 (10^4 people).

Year	Russia	Canada	Iceland	Norway	Sweden	Finland	Alaska	Greenland	Total
1995	1029.00	1693.20	19.00	288.00	231.00	177.90	117.52	17.82	3573.44
1996	1620.80	1728.60	20.10	274.60	237.60	172.40	129.48	17.07	4200.65
1997	1746.30	1766.90	20.20	270.20	238.80	183.20	133.02	18.11	4376.73
1998	1618.80	1887.00	23.20	325.60	257.30	186.70	138.00	20.06	4456.66
1999	1882.00	1941.10	26.30	322.30	259.50	183.10	143.42	20.51	4778.23
2000	2116.90	1962.70	30.30	310.40	382.80	197.10	145.54	24.38	5170.12
2001	2159.50	1967.90	30.10	307.30	410.80	199.90	145.35	22.35	5243.20
2002	2330.90	2005.70	28.50	311.10	427.60	204.30	152.88	20.87	5481.85
2003	2252.10	1753.40	31.70	326.90	426.80	204.70	156.72	23.21	5175.53
2004	2206.40	1914.50	36.00	362.80	467.60	208.30	169.39	23.73	5388.72
2005	2220.10	1877.10	37.40	382.40	488.30	208.00	187.52	26.55	5427.37
2006	2248.60	1826.50	42.20	407.00	472.90	231.70	188.10	24.77	5441.77
2007	2290.90	1793.50	48.50	437.70	522.40	247.20	196.15	23.46	5559.81
2008	2367.60	1714.20	50.20	434.70	455.50	249.40	195.48	23.67	5490.75
2009	2133.90	1573.70	49.40	434.60	489.90	222.00	189.71	22.48	5115.69
2010	2228.10	1621.90	48.90	476.70	518.30	231.90	180.41	21.62	5327.82
2011	2493.20	1601.40	56.60	496.30	522.20	262.30	178.87	21.37	5632.24
2012	2817.70	1634.40	67.30	453.80	514.60	277.80	183.85	20.99	5970.44
2013	3079.20	1605.90	80.73	477.80	522.90	279.70	190.33	21.40	6257.96
2014	3242.10	1653.70	99.76	485.50	566.00	273.10	194.97	20.96	6536.08
2015	3372.90	1797.10	128.90	536.10	648.20	262.20	200.66	21.85	6967.91
2016	2457.10	1997.10	179.20	596.00	678.20	278.90	213.43	24.06	6423.99
2017	2439.00	2079.80	222.50	625.20	705.40	318.00	224.83	26.28	6637.03

Data source: World Tourism Organization, 1995–2017; Fay et al. (2010); McDowell Group, 1994–2018.

polar ecotourism.

In the short term, glacial ablation will form small features (Wang et al., 2012), creating a new landscapes, such as ice tables, ice lakes, ice rivers, ice caves, and ice mushrooms. These miniature landscape forms will increase the geomorphic diversity of the glacier on a local scale (Diolaiuti and Smiraglia, 2010), which adds an attractive element of glacier landscapes and partially compensates for losses resulting from glacier retraction (Garavaglia et al., 2012). The new landform created by glacier retreat is quite obvious in the front area of the glacier, in which moraine ridge, canyon, fjord, and Moraine Lake have all become important landscape features for many glacier tourist destinations (Kessler et al., 2008; Evans et al., 2013). As another example, the rapid retreat of tidewater glaciers, as observed for the Columbia Glacier, occurs over relatively short scales of decades and opens up new landscapes and fjords that previously were covered completely by ice (Pfeffer, 2007) and that now have provided opportunities for flora and fauna.

With climate warming, some snow-covered mountains have become bare rock mountains, especially in large valleys. The lower mountain bodies and valleys are no longer covered by snow and ice, and new vegetation has begun to occupy newly bare rocks and hillsides and changes in the mountain landscapes (Cannone et al., 2008). In the high latitudes, the freezing and thawing causes some new landscapes to appears, such as patterned ground, thermokarst lakes, thermokarst terrains, large solifluction lobes, pingos and lithalsas, mineral palsas, and seasonal ground ice mounds (B Frey et al., 2010; Bowden, 2010).

5.1.2. Extension of travel season and activities area

Polar climate warming has caused sea ice to melt rapidly, which has increased the accessibility to the Arctic and Arctic areas, which have been difficult to reach in the past (Stewart et al., 2010; Hall and Saarinen, 2010; Lück et al., 2010). Improved accessibility has reduced restrictions from the extreme climate in the PRs and has extended the travel season and activity areas, which not only reduces the cost of tourism and enhances the tourism revenue, but also improves the restrictions on small-scale tourism and promotes the progress of the Antarctic and Arctic regions to important international tourist destinations (Larsen et al., 2014; Rintoul et al., 2018).

Arctic sea ice extent (the total area of the Arctic with at least 15% sea ice concentration) has declined since 1979 in each month of the year (very high confidence). Changes are largest in summer and smallest in winter, with the strongest trends in September (1979–2018; summer month with the lowest sea ice cover) of −83,000 km^2/a (−12.8%/decade ± 2.3% relative to 1981–2010 mean), and −41,000 km^2/a (−2.7%/decade ± 0.5% relative to 1981–2010 mean) for March (1979–2019; winter month with the greatest sea ice cover) (Onarheim et al., 2018). In the next 30 years, it is likely that the Arctic will have ice-free summers (AMAP, 2019).

The longer warm season in the Arctic and the increased navigation time and range of the Arctic Ocean have an important impact on Arctic tourism, which will create more opportunities for Arctic tourism development. Recent Arctic sea-ice retreat indicates that the Russian coastal seas encompassing the Northern Sea Route will be among the first marine environments to transition to an ice-free summer state. Forty-six voyages carrying 1.26 million tons of cargo in 2012 suggested the increasing economic viability of the Northern Sea Route for eastward transport of natural resources from northern Norway and Russia (Stephenson et al., 2014). During the period from 1968 to 2011, the total sea-ice extent on the northwestern channel of the Canadian Arctic route decreased by 11%/10a, and the southern route decreased by 16%/decade (Stewart et al., 2013). In 2006–2011, the Northwest Passage became the most popular cruise destination in the Canadian Arctic, and the number of trips to these destinations has increased by 70% (Stewart et al., 2013).

5.1.3. Activated local economy

With an increase in PT activities, more investments in tourism have been made, which has enhanced the development level of the regional socioeconomic system. In particular, Arctic tourism has provided more opportunities for economic development. Several countries have increased their investment in terms of arctic tourism and have started a number of infrastructure projects involving tourism service facilities.

Recent years have seen considerable increases in tourism activities in the PRs (Fig. 2; Table 1). A large number of tourists have stimulated tourism development of Arctic indigenous people, bringing significant economic benefit to them, such as Eskimos, Inuit, Sami, Chukoqi, and Nenet. According to Tzekina (2014), tourist arrivals to the northern regions of Russia can be estimated at roughly 500,000 visitors annually. In the Canadian Arctic, tourism is considered both a stimuli and an agent of change for the region (Stewart et al., 2011). The promotional budgets for tourism in the region are lower than for the Canadian provinces with the Yukon ($5.2 million), Northwest Territories ($2.6 million), and Nunavut ($1.9 million) spending $9.7 million in total on marketing activities in 2011 (Belik, 2014). During the 12-month period of October 2012 through September 2013, visitor spending within the state was estimated at $1.82 billion US, tourism is a significant source of income for many Alaskans (McDowell Group, 2014; AKDOG, 2014). During 2015–2016, among the most tourist destinations in Iceland, 25% of all tourists visited the Vatnajor Glacier National Park. The number of glacier tourists accounted for half of the total number of Icelandic tourists (Icelandic Tourist Board, 2014, 2017). Tourism is relatively new to Greenland, with approximately 90, 000 tourist arrivals registered in 2017 (Tourismstat.gl, 2018). In 2017, Norwegian tourism revenue reached NOK 176.6 billion (www.ssb.no/en), with tourism in northern Norway reaching NOK 600 million and 10% of the population engaged in tourism-related occupations. Over the past decade, the expedition cruise and yacht tourism in the Nunavut region of Canada have increased by 70% and 400%, respectively (Johnston et al., 2018).

5.2. Impacts

Tourism and climate change are interrelated. Tourism itself contributes significantly to global greenhouse gas emissions, summing up to 12.5% of total global emissions (Scott et al., 2010). Climate change contributed by tourism in turn affects tourism development (Kelman et al., 2012; Craig et al., 2018). The rapid environmental changes affect not only the fragile natural cultural landscapes, but also the sustainable development (Hall and Saarinen, 2010; Maher et al., 2011; Monahan et al., 2016). Especially, Antarctic tourism could trigger international disputes that might pose a threat to the stability of the Antarctic Treaty System and might re-animate questions of sovereignty and territorial claims (Enzenbacher, 2007). Of course, the PR is disturbed only by small tourism activities, and for most regions, the direct impact of tourism activities on the PR is relatively limited (Lemelin et al., 2010).

5.2.1. Impacts of environmental changes on tourism resources

Changes in the climate and environment affect PT resources, especially the landscape resources associated with the cryosphere and their indigenous culture. With polar warming, the glaciers and sea/lake ices obviously retreat and shrink, which directly affects their beauty and quality (Purdie, 2013a,b; Purdie et al., 2015) and experience activities on glacier and ice surface (Wang et al., 2012; H. Frey et al., 2010; Garavaglia et al., 2012; Scott et al., 2012; Stewart et al., 2016; Wang and Zhou, 2019). In coastal areas, sea ice means freedom for travel, hunting and fishing, so changes in sea ice affect the experience of and connection with place (Gearheard et al., 2006). Unsafe ice conditions have resulted in greater risks of travel on rivers and the ocean in the frozen months (Rosales and Chapman, 2015). In particular, with longer open water seasons and poorer ice conditions, indigenous hunting on sea ice or lake ice has become dangerous (Laidler, 2012; Goldhar et al., 2014).

The ski industry is highly sensitive to weather and climate change, and rapid warming directly affects snowfall, snow depth, artificial snowmaking, and length of the ski season (Brouder and Lundmark, 2011; Schrot et al., 2019). For example, in mid-21st century, the length of the ski season in central Canada is expected to decline by 5%–37%, increasing snowmaking requirements by 37%–145% and causing operating costs to rise by US$1–4 million (Hewer and Gough, 2017). The number of Norway's ski resorts (currently 110 alpine ski resorts) with only natural snow and those with advanced snowmaking will be cut by almost half in the 2030s, and the ski season is expected to be significantly reduced. A substantial shortening of the ski season (up to 40 days) will begin in the 2050s under a high-emission scenario. In this context, the need to invest in snowmaking will continue to increase, with attendant financial and sustainability implications in the future (Scott et al., 2019). Relative to the historical period (1991–2010), in two time slices (2031–2050 and 2081–2100), in the high-emission situation, the annual average temperature in the western part of Greenland will increase by 1.1 °C–4.6 °C, and the snowfall and snow cover will be reduced by 34–42% and 21–49%, respectively. Resort skiing and cross-country skiing is affected by snow marginality and wet snow conditions, and ski-touring and heli-skiing have a higher adaptive capacity (i.e., translocation to snow-safe destinations). A reduced snow-cover thickness poses a particular threat to dog sledding (Schrot et al., 2019).

In Shishmaref (Alaska, USA) and Tuktoyaktuk (NWT, Canada), the combined effects of reduced sea ice, thawing permafrost, storm surges and wave erosion have led to significant loss of property, with subsequent relocation or abandonment of homes, facilities and other infrastructure (Instanes et al., 2005).

5.2.2. Impacts of climate change on tourism environment

Extreme weather and climate events will affect the sustainability of PT tourism. The clouds, gale, thunderstorm, and snowstorm affect the viewing of Arctic aurora, the willingness of tourists to travel, the safe operation of ski lifts, the blockage of ski slopes, and damage to tourism-related infrastructures. An increase in floating ices and icebergs caused by rising temperatures also makes it more difficult for cruise ships to enter the port. Increased temperature, reduced snow and sea ice, and warm winters and springs will contribute to the disappearance of this unique ice and snow landscapes and habitats, will shorten the winter and spring tourist seasons in many places, and will limit all winter and spring tourism projects that are highly depended on snow and sea-ice resources (e.g., polar bears, seals, and reindeer viewing) (Saarinen and Tervo, 2006; Hamilton et al., 2018). These climate change factors will force some tourists to cancel their trips, causing huge economic losses to the PRs winter and spring tourism industry (e.g., skiing and Christmas tourism). Some tourist destinations will be forced to move to higher latitudes and high altitudes.

Especially, polar disaster also directly influenced tourism activities and personal safety. As a result, the incidence of tourism accidents has increased (Bird et al., 2010; Purdie et al., 2015). For example, icebergs movement, ice shelves collapse, and glacier terminal ice calving will form huge waves in some waters, often affecting marine tourism activities, causing instability of cruise ships, and threatening the safety of tourists in sea and lake waters (Smiraglia et al., 2008; Purdie, 2013a,b; Purdie et al., 2015). In Alaska and Greenland, huge waves caused by ice calving have destroyed glacier cruise ships (Pedersen et al., 2002; Downey and Klint, 2011; Peddie, 2012). In the Arctic and Arctic waters, the collapse of ice shelves has led to the emergence of an increasing number of icebergs, and tens of thousands of icebergs and their ice floes have created great difficulties and dangers for maritime navigation safety (Johansson et al., 2013; Zhang et al., 2019; Afenyo et al., 2017).

As a result of rising temperature, the near-temperature rise in permafrost and the thickening of the active layer have led to a decline in infrastructure capacity in some regions of Siberia, Russia (Streletskiy et al., 2012). Especially, permafrost warming, increased active layer thickness and landscape instability, and changes to water levels impact overland navigability in summer (Brinkman et al., 2016; Dodd et al., 2018).

5.2.3. Impacts of tourism development on local environment

Impacts of the PT on environment mainly come from a lack of reasonable tourism activities and uncontrollable emergencies. Nevertheless, there are a number of ways in which tourism either via infrastructure, transport or human visitation affects the environment of the PRs. These impacts include the more obvious point sources of impact and pollution such as tourism infrastructure (e.g. resorts, roads, attractions), the demands of tourism on local resources such as water and energy, trampling or even picking of vegetation, disturbance of breeding sites, changes in animal behavior, and the subsequent effects of tourism on habitats, and living environment of the indigenous people (Gössling and Hall, 2006; Williams and Crosbie, 2007; Tejedo et al., 2009; Tin et al., 2009; Hall and Saarinen, 2010; Pearce et al., 2010; Goodwin et al., 2012; Welling et al., 2015).

In the PRs, tourists take numerous cruises, caused plenty of marine pollution, such as sewage and wastewater and solid waste and created potential threats that damage the polar ocean's ecological balance (Stewart et al., 2011; Maher, 2012). One example is the significant oil spill that followed the grounding and sinking of the Bahia Paraiso Vessel, Argentina (not a tourist vessel, but it carried a number of paying passengers), leaving 600,000 L of fuel in 1989 (Liggett, 2015).

At the same time, some tourist activities have directly interfered with the flora and fauna and the associated PR ecosystem and has disturbed the bird habitat (Tejedo et al., 2009; Liggett, 2015; Stephen, 2018). Because of these environmental issues, PT has become one of the most important topics discussed in the recent Antarctic Treaty Consultative and Arctic Council meetings. Therefore, in the process of the PT, the problem of disposing of a large amount of this tourism waste must be considered and the problems of interference of dense populations on fragile ecosystems and special populations (e.g., penguins, polar bears) must be solved (Stonehouse and Snyder, 2010). Along with an increase in the PT activities, the number of tourists increased continuously, which has introduced pressures and risks to ecological and tourism environment.

5.2.4. Impacts of tourism development on traditional lifestyle and culture

Traditional culture is the core driving force for PT development. The development of tourism has accelerated the cultural exchanges between tourist destinations and source markets. The indigenous people are currently in the process of transitioning from a nomadic lifestyle to a modern global lifestyle, and its cultural structure is fragile. Tourism development has promoted the all-around development of the economy and society in the Arctic region, but it also has dissolved traditional lifestyle and cultures in a certain sense. Of course, the indigenous people need a modern lifestyle and a diverse spiritual culture. When the traditional culture was replaced by a modern lifestyle, however, the Arctic region also lost the core driving force of its tourism development. In the Antarctic region, the social and cultural impact of tourism mainly includes: the disruption of scientific research activities, damage of historical artefacts, and transportation of material on boots (snow/ice/rocks) into historic huts and adverse effects of human activity on Antarctic wilderness values (Liggett, 2015).

In fact, different groups in the Arctic region have been implicated and affected by global economic and cultural processes. It can be said that tourism development and traditional culture protection are full of contradictions and paradoxes. On the one hand, the indigenous people have made great efforts to protect their unique traditional culture, and on the other hand, the demand for economic benefits brought about by tourism development has become increasingly vigorous (Davies, 2007; Klein, 2010).

In the Chukchi National Autonomous Region of Russia, improvement of modern industry and lifestyle has eliminated geographical characteristics between nomadic Chukchi people and the Chukchi people living along the coast and has broken the isolation between settlements and residences. Today, the lifestyles of these different ethnic groups are not much different (Kolga, 2001; Nordic Council of Ministers, 2018).

In Swedish Lapland, natured based tourism has greatly changed the hunting traditions of the indigenous people (Müller, 2011). In the Canadian Arctic, the growth of expedition cruising from increased access due to climate change is also resulting in negative cultural and environmental impacts in the form of people pollution, the sale of marine mammal parts for souvenirs, and increased garbage in local communities (Maher, 2012; Stewart et al., 2011). In the Arctic region, young indigenous people are sent to the south or to larger cities to be educated. Thus, the youth of the Arctic are expected to move from their homes for education and employment (Petrov, 2017; Huhmarniemi and Jokela, 2020).

In addition, with the rapid development of industrialization and tourism, the users and inheritors of traditional indigenous history and culture, such as indigenous languages, hunting techniques, national costumes, and living habits, are gradually decreasing. The inheritance of indigenous history and culture now faces enormous challenges. For example, the Arctic region once had more than 40 indigenous languages that existed for hundreds of thousands of years. With the colonial expansion of Europe and the United States and the immigration of large numbers of immigrants, many indigenous languages are on the verge of disappearing. The Arctic Biodiversity Assessment report shows that 21 Arctic languages have disappeared since the 1890s, with 10 languages disappearing completely since the 1990s and 28 endangered languages (CAFF, 2013).

6. Mechanisms for sustainable polar tourism development

Future PT needs to consider environment, society, culture, and economy development as a whole. This development must promote ecological protection and economic development through the sustainable tourism. Considering both the current situation of the PT and the comprehensive impacts of environmental change, the following adaptation mechanisms are proposed.

6.1. Stringently implement environmental protection regulations

The PRs have rich resources that have not been over-exploited, while the ecological environment is often fragile (Stephen, 2018). To achieve sustainable tourism development, it is necessary to formulate the most stringent environmental capacity control standards to avoid further deterioration of the ecological environment. The number of tourists in the PRs continues to grow, but the ecological environment and cultural capacity is limited. The PT must be scientifically planned and moderately and rationally developed. The production of tourism services must be done by exercising extreme caution. Tourism planning needs to consider two aspects: environment protection, and the attitude and views of local residents on tourism development. Local residents' participation can reduce the conflict between tourism development, social livelihood and ecological environment. Tourism planning must emphasize the principle of protection first and development second and tourism should be developed under the premise of protection and should emphasize regional differences.

Generally, tourism resources must be used in a sustainable way to protect the ecological and human social systems. In the process of tourism development, energy waste, tourism waste, and oil spills should be minimized, and the most stringent environmental protection system should be implemented.

6.2. Improve the accessibility of the polar tourism areas

Accessibility is the most critical factor of travel motivation of tourists in the PRs. Antarctic and Arctic travel range, reachable area, and travel season are subject to weather, climatic conditions (e.g., low temperature, cold wave, storm, strong ultraviolet light, and high pressure) and sea-ice extent, duration, and thickness. Solutions to these problems are urgently needed to improve ground, aviation, and marine transportation technologies or infrastructures.

In Arctic region, most tourist spots can be reached by land and air transportation, an increase in the number of travel routes and distances and the opening of a travel train and air route will overcome discomfort and harsh weather and climate conditions, and also enhance the comfort of the visitor experience. In the Antarctica, the accessibility of tourist attractions is mainly limited by cruise ships with or without ice-breaking capabilities. The development and operation of cruise ships with ice-breaking capabilities can address the obstacle of sea ice. Improvements in ice-resistant capacity, icebreaking capacity, navigation technology, frozen soil engineering technology, sea ice and weather information acquisition technologies, new energy and clean energy utilization technologies, and telecommunication technologies are all conducive to the rapid PT development. Driven by the economic benefits brought by the tourism industry, the expansion, building, and reconstruction of ports, railways, highways, and airports already are underway or are being planned. The accessibility and convenience of the PT in the future will be further enhanced.

6.3. Consider the development of high-end PT products

Tourism has become a way of life, and the diverse and personalized travel service needs of travelers are bound to require diverse tourism products to adapt to them. At the same time, tourism product diversification has been identified as an effective industry adaptation to climate change impacts, especially in winter resorts threatened by rising temperatures and unreliable snow cover (Dubois and Ceron, 2006). In the future, Antarctic tourism needs to be based on the principle of diversification of tourism products, refinement of tourism management, and facilitation of tourism services to enhance the types and content of Antarctic tourism products. The Arctic region should integrate the traditional culture of indigenous people into the tourism industry and ensure that these people are the core driving force behind high-end tourism in the Arctic region. At the same time, tourism products should highlight the distinct polar characteristics and diverse landscapes of the region. On the basis of the existing tourism, the Circum-Arctic Ocean tourism belt and other internationally renowned tourist destinations should be developed to adapt to the upcoming boom in Arctic tourism.

6.4. Innovate national tourism cooperation and exchange modes

Mutual cooperation is the basis for the PT development. Antarctic tourism is bound by the framework convention of the Antarctic Treaty, and tourism development is relatively normal. However, many cruise ships and airlines with IAATO certified operating qualifications have mastered the core resources of Antarctic tourism, and it is difficult for other countries to intervene. Countries should actively master the international rules and industry practices of Antarctic tourism, and accelerate resource sharing, coordinated cooperation and common development among tourism enterprises, and support cruise and aviation enterprises to join IAATO as soon as possible to promote the diversified development of Antarctic tourism industry.

In the Arctic region, tourism sites are scattered and the responsibilities, powers, and interests of different tourism stakeholders are unclear, lacking a common development framework and shared protection ideas. In addition, the Arctic lacks framework conventions and operational institutions, making interregional coordination and communication more difficult. Land-use competition is also quite strong. These factors have introduced many obstacles to Arctic tourism development (Dubois et al., 2013). Therefore, it is urgent to establish an Arctic Tourism Framework Convention to regulate interregional cooperation and create a win−win opportunity for Arctic tourism. It is necessary to build a community of tourism in the Arctic region, realize multidimensional coordination and development of the tourism−cultural−political system, strengthen the protection of the ecological environment and indigenous culture, and build a platform for exchange between Arctic and non-Arctic countries (Sun, 2014).

7. Conclusion

With the advent of the PT era, tourism development has received significant attention. The polar landscapes such as ice and snow, primitive environment, tundra landforms, and cultural authenticity are undoubtedly the most important motives for tourists to visit the PRs. At present, PT is in a developmental stage, and residents' perception of environmental changes has been offset by tourism revenue. Local residents still have a positive attitude toward tourism (Besculides et al., 2002).

However, with the rapid development change, the impacts and risks associated with the environmental changes as a result of tourism will appear and gradually expand. In fact, the rapid rate at which the climate is changing in the PRs already has affected the natural and social systems (high confidence) (Meredith et al., 2019), especially the tourism industry. Of course, any discussion of potential impacts has to take into account the positive effects of Antarctic tourism (Snyder, 2007). In the next phase of tourism development, the polar countries should consider the model of innovative cooperation as the entry point, actively integrate tourism into science research and environmental protection, and highlight the intentions of the countries participating in the PT. The PRs should also improve entry barriers for tourism projects by the development of high-end tourism products and should increase the responsibility of environmental protection through cooperation and shared goals (Lück et al., 2010; Hemmings et al., 2012).

In the face of the ever-expanding demand for international PT consumption, consumer countries should, while striving for economic benefits, pay more attention to the social benefits they bring to the polar indigenous people and appropriately direct the values of these tourists. Especially, the PRs should expand scientific research and tourism exchanges between Antarctic and nonparties, Arctic and non-Arctic countries, and should promote the scientific, rational, and orderly progress of the PT under certain regulations.

Antarctic tourism is strictly restricted by the International Association of Antarctica Tour Operators (IAATO) (Bauer and Dowling, 2003). IAATO concerned about Antarctic heritage and conservation and subscribed to what has been referred to as 'environmental stewardship' with the intention of "advocate[ing], promot[ing] and practice[ing] safe and environmentally responsible private-sector travel to the Antarctic" (IAATO, 1992). The Arctic has no body equivalent to the IAATO, certainly not one that spans the national boundaries, so the Arctic also should imitate IAATO and establish a sound environmental protection scheme in the future.

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References

ADCCED (Alaska Department of Commerce, Community, and Economic Development), 2018. The Economic Impacts of Alaska's Visitor Industry. McDowell Group.
AECO, 2017. Seasonal statistics and outlook. Association of Arctic Expedition Cruise Operators.
Afenyo, M., Khan, F., Veitch, B., 2017. Arctic shipping accident scenario analysis using Bayesian Network approach. Ocean Eng. 133, 224–230.
AKDOG (Alaska Division of Oil and Gas), 2014. Distribution of funds received from oil and gas leases (2002-present). Retrieved from. http://dog.dnr.alaska.gov/. Accessed on June 5, 2014. Arion banki. (2013). Fereatjónustan: Atvinnugrein á unglingsaldri [Tourism: sector in its youth]. Reykjavík: Arion banki.
AMAP, 2019. Arctic Climate Change Update 2019-An Update to Key Findings of Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. An Assessment by the Arctic Monitoring and Assessment Program (AMAP).
Bauer, T., Dowling, R., 2003. Ecotourism policies and issues in Antarctica. In: Fennell, D., Dowling, R. (Eds.), Ecotourism Policy and Planning. Centre for Agriculture and Biosciences International, London, pp. 309–329.
Belik, V., 2014. Our Annual Tourism Report Card. Up Here Business, 118. Retrieved from www.upherebusiness.ca. (Accessed 17 May 2014).
Besculides, A., Lee, M.E., McCormick, P.J., 2002. Residents' perceptions of the cultural benefits of tourism. Ann. Tourism Res. 29 (2), 303–319.
Bird, D.K., Gisladottir, G., Dominey-Howes, D., 2010. Volcanic risk and tourism in southern Iceland: implications for hazard, risk and emergency response education. J. Volcanol. Geoth. Res. 189, 33–48.
Bockheim, J., Vieira, G., Ramos, M., et al., 2013. Climate warming and permafrost dynamics in the Antarctic Peninsula region. Global Planet. Change 100, 215–223.
Bowden, W.B., 2010. Climate change in the Arctic – permafrost, thermokarst, and why theymatter to the non-Arctic world. Geogr. Compass 4, 1553–1566.
Brinkman, T.J., et al., 2016. Arctic communities perceive climate impacts on access as a critical challenge to availability of subsistence resources. Climatic Change 139 (3), 413–427. https://doi.org/10.1007/s10584-016-1819-6.

Brouder, P., Lundmark, L., 2011. Climate change in Northern Sweden: intra-regional perceptions of vulnerability among winter-oriented tourism businesses. J. Sustain. Tourism 19 (8), 919–933.
CAFF, 2013. Arctic biodiversity assessment report. Status and trends in Arctic biodiversity. Akureyri: Conservation of Arctic Flora and Fauna.
Cannone, N., Diolaiuti, G., Guglielmin, M., et al., 2008. Accelerating climate change impacts on alpine glacier forefield ecosystems in the European Alps. Ecological Applications, Permafrost and Periglacial Processes, 18 (3), 637–648.
Cook, A.J., Vaughan, D.G., 2010. Overview of areal changes of the ice shelves on the Antarctic Peninsula over the past 50 years. Cryosphere 4, 77–98.
Craig, C.A., Petrun-Sayers, E., Feng, S., 2018. A case study of climate change and extreme weather events in a coastal community: enhancing risk communication. In: Kar, B., Cochran, D. (Eds.), Role of Risk Communication in Community Resilience Building. Rutledge, London (forthcoming).
Davies, H., 2007. Inuit Observations of Environmental Change and Effects of Change in Anaktalak Bay, Labrador. Queen's University (Canada).
Dawson, J., Hoke, W., Lamers, M.A.J., et al., 2017. Navigating Weather, Water, Ice and Climate Information for Safe Polar Mobilities. World Meteorological Organization, Geneva.
De Santis, A., Maier, E., Gómez, R., et al., 2017. Antarctica, 1979–2016 sea ice extent: total versus regional trends, anomalies, and correlation with climatological variables. Int. J. Rem. Sens. 38 (24), 7566–7584.
DeConto, R.M., Pollard, D., 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531 (7596), 591–597.
Diolaiuti, G., Smiraglia, C., 2010. Changing glaciers in a changing climate: how vanishing geomorphosites have been driving deep changes in mountain landscapes and environments. Morphologie 16 (2), 131–152.
Dodd, W., et al., 2018. Lived experience of a record wildfire season in the Northwest Territories, Canada. Can. J. Public Health 109 (3), 327–337. https://doi.org/10.17269/s41997-018-0070-5.
Downey, M., Klint, C., 2011. Woman injured after wave from calving glacier hits boat. Channel 2 News, 8 August 2011. https://www.ktuu.com/news/ktuu-womaninjured-after-wave-from-calving-glacier-hits-boat-20110808,0,3882373.htmlstory. (Accessed 13 July 2012).
Dubois, G., Ceron, J.P., 2006. Tourism/leisure greenhouse gas emissions forecasts for 2050: factors for change in France. J. Sustain. Tourism 14 (2), 172–191.
Dubois, G., Ceron, J., Peeters, P., 2013. Tourism Sensitivity to Climate Change Mitigation Policies: Lessons from Recent Surveys. Taylor & Francis Group.
Enzenbacher, D.J., 2007. Antarctic tourism policy-making: current challenges and future prospects. In: Triggs, G., Riddell, A. (Eds.), Antarctica: Legal and Environmental Challenges for the Future. The British Institute of International and Comparative Law, London, pp. 155–189.
Evans, D.J.A., Rother, H., Hyatt, O.M., et al., 2013. The glacial sedimentology and geomorphological evolution of an outwash head/moraine-dammed lake, South Island, New Zealand. Sediment. Geol. 284–285, 45–75.
Fay, G., Colt, S., White, E.M., 2010. Data Survey and Sampling Procedures to Quantify Recreation Use of National Forests in Alaska. Gen. Tech. Rep. PNW-GTR-808. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.
Frey, H., Haeberli, W., Linsbauer, A., et al., 2010. A multi-level strategy for anticipating future glacier lake formation and associated hazard potentials. Nat. Hazards Earth Syst. Sci. 10 (2), 339–352.
Frey, B., Rieder, S.R., Brunner, I., et al., 2010. Weathering-associated bacteria from the Damma glacier forefield: physiological capabilities and impact on granite dissolution. Appl. Environ. Microbiol. 76 (14), 4788–4796.
Garavaglia, V., Diolaiuti, G., Smiraglia, C., et al., 2012. Evaluating tourist perception of environmental changes as a contribution to managing natural resources in glacierized areas: a case study of the forni glacier (stelvio national park, Italian alps). Environ. Manag. 50 (6), 1125–1138.
Gearheard, S., et al., 2006. "It's not that simple": a collaborative comparison of sea ice environments, their uses, observed changes, and adaptations in barrow, Alaska, USA, and clyde river, Nunavut, Canada. AMBIO A J. Hum. Environ. 35 (4), 203–211.
Goldhar, C., Bell, T., Wolf, J., 2014. Vulnerability to freshwater changes in the Inuit settlement region of nunatsiavut, labrador: a case study from rigolet. Arctic 67 (1), 71–83. https://doi.org/10.14430/arctic4365.
Goodwin, K., Loso, M.G., Braun, M., 2012. Glacial transport of human waste and survival of fecal bacteria on Mt. McKinley's kahiltna glacier, denali national park, Alaska. Arctic Antarct. Alpine Res. 44 (4), 432–445.
Gössling, S., Hall, C.M., 2006. Tourism and Global Environmental Change: Ecological, Economic, Social and Political Interrelationships. Routledge, London.
Graham, R.M., Cohen, L., Petty, A.A., et al., 2017. Increasing frequency and duration of Arctic winter warming events. Geophys. Res. Lett. 44, 6974–6983.
Grenier, A.A., Müller, D.K., 2011. Polar Tourism: A Tool for Regional Development. Québec, QC. Presses de l'Université du Québec.
Hall, C.M., Saarinen, J., 2010. Tourism and Change in Polar Regions: Climate, Environment and Experience. Taylor & Francis Group, Routledge, London, pp. 89–103.
Hamilton, C.D., Kovacs, K.M., Ims, R.A., et al., 2018. Haul-out behaviour of Arctic ringed seals (Pusahispida): inter-annual patterns and impacts of current environmental change. Polar Biol. 41 (6), 1063–1082.
Hemmings, A.D., Rothwell, D.R., Scott, K.N., et al., 2012. Antarctic Security. Routledge, Abingdon, Oxon, pp. 238–256.
Hewer, M.J., Gough, W.A., 2017. Thirty Years of Assessing the Impacts of Climate Change on Outdoor Recreation and Tourism in Canada. Tourism Management Perspectives. https://doi.org/10.1016/j.tmp.2017.07.003.
Hjort, J., Karjalainen, O., Aalto, J., et al., 2018. Degrading permafrost puts Arctic infrastructure at risk by mid-century. Nat. Commun. 9, 5147. https://doi.org/10.1038/s41467-018-07557-4.
Hodgson, D.A., Convey, P., Verleyen, E., et al., 2010. The limnology and biology of the dufek massif, transantarctic mountains 82°south. Polar Sci. 4, 197–214.
Hori, Y., Cheng, V.Y.S., Gough, W.A., Jien, J.Y., Tsuji, L.J.S., 2018. Implications of projected climate change on winter road systems in Ontario's Far North. Canada. Clim. Change 148, 109–122.
Huhmarniemi, M., Jokela, T., 2020. Arctic arts with pride: discourses on arctic arts, culture and sustainability. Sustainability 12, 604. https://doi.org/10.3390/su12020604.
IAATO, 1992–2019. Antarctic Tourism Statistics. http://www.iaato.org/.
IAATO, 1992-2018. Antarctic Tourism Statistics. http://www.iaato.org/.
Icelandic Tourist Board, 2014. Research and Statistics. https://www.ferdamalastofa.is/en.
Icelandic Tourist Board, 2017. Research and Statistics. https://www.ferdamalastofa.is/en/.
Imbie team, 2018. Mass balance of the antarctic ice sheet from 1992 to 2017. Nature 558 (7709), 219–222.
Instanes, A., Anisimov, O., Brigham, L., Goering, D., Ladanyi, B., Larsen, J.O., Khrustalev, L.N., 2005. Infrastructure: buildings, support systems, and industrial facilities. In: Symon, C., Arris, L., Heal, B. (Eds.), Arctic Climate Impact Assessment. Cambridge University Press, Cambridge.
Jabour, J., 2014. Strategic management and regulation of antarctic tourism. In: Tin, T., Liggett, D., Maher, P., Lamers, M. (Eds.), Antarctic Futures. Springer, Dordrecht.
Johansson, M., Eriksson, L.E.B., Hassellov, I.M., et al., 2013. Remote sensing for risk analysis of oil spills in the Arctic Ocean. In: ESA Living Planet Symposium, p. 145. Edinburgh, ESA SP-722. 2–13.
Johnston, M., Dawson, J., Stewart, E., 2018. Marine Tourism in Nunavut: Issues and Opportunities for Economic Development in Arctic Canada. American Jewish Year Book.
Kelman, I., Rauken, T., Hovelsrud, G., 2012. Local business perceptions of weather impacts on tourism in svalbard, Norway. N. Rev. 35, 96–124.
Kessler, M.A., Anderson, R.S., Briner, J.P., 2008. Fjord insertion into continental margins driven by topographic steering of ice. Nat. Geosci. 1, 365–369.
Klein, R.A., 2010. The cruise sector and its environmental impact. In: Schott, C. (Ed.), Tourism and the Implications of Climate Change: Issues and Actions (Bridging Tourism Theory and Practice, 3. Emerald Group Publishing Limited, pp. 113–130.
Kolga, M., 2001. The Red Book of the Peoples of the Russian Empire. NGO Red Book, Tallinn.
Laidler, G., 2012. Societal aspects of changing cold environments. In: French, H., Slaymaker, O. (Eds.), Changing Cold Environments: A Canadian Perspective. Wiley-Blackwell, Oxford, pp. 267–300.
Larsen, J.N., Anisimo, O.A., Constable, A., et al., 2014. Polar regions. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1567–1612.
Lemelin, R.H., McIntyre, N., Koster, R., et al., 2010. Climate disruption and the changing dynamics of polar bear – human interaction in Northern Ontario: a case study of polar bear management in Polar Bear Provincial Park, Ontario, Canada. In: Hall, C. M., Saarinen, J. (Eds.), Tourism and Change in Polar Regions: Climate, Environment and Experience. Routledge, London, pp. 104–118.
Liggett, D., 2015. Destination icy wilderness. In: Liggett, D., Storey, B., Cook, Y., Meduna, V. (Eds.), Exploring the Last Continent. Springer, Cham.
Lück, M., Maher, P.T., Stewart, E.J., et al., 2010. Cruise Tourism in Polar Regions: Promoting Environmental and Social Sustainability. Earthscan, London.
Maher, P., 2012. Expedition cruise visits to protected areas in the Canadian Arctic: issues of sustainability and change for an emerging market. Tourism 60 (1), 55–70.
Maher, P.T., Stewart, E.J., Lück, M., 2011. Polar Tourism: Human, Environmental and Governance Dimensions. Cognizant Communications Corporation, New York, pp. 221–235.
Mauro, G., Gonçalo, V., 2014. Permafrost and periglacial research in Antarctica: new results and perspectives. Geomorphology 225, 1–3.
McDowell Group, 2018. Alaska Visitor Statistics Program Interim Volume Report Fall/Winter 1994-2018. Research-Based Consulting. Juneau Anchorage, 1994.
McDowell Group, 2014. Economic impact of Alaska's visitor industry: 2012-13 update. Prepared for State of Alaska Department of Commerce, Community, and Economic Development, Division of Economic Development. Available at: http://commerce.alaska.gov/dnn/ded/DEV/TourismDevelopment/TourismResearch.aspx. .
Meredith, M., Sommerkorn, M., Cassotta, S., Derksen, C., Ekaykin, A., Hollowed, A., Kofinas, G., Mackintosh, A., Melbourne-Thomas, J., Muelbert, M.M.C., Ottersen, G., Pritchard, H., Schuur, E.A.G., 2019. Polar regions. In: Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., Weyer, N.M. (Eds.), IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (in press).
Monahan, W.B., Rosemartin, A., Gerst, K.L., et al., 2016. Climate change is advancing spring onset across the US national park system. Ecosphere 7 (10). https://doi.org/10.1002/ecs2.1465.
Mudryk, L.R., Kushner, P.J., Derksen, C., Thackeray, C., 2017. Snow cover response to temperature in observational and climate model ensembles. Geophys. Res. Lett. 44, 919–926.

Müller, D.K., 2011. Tourism development in Europe's "last wilderness": an assessment of nature based tourism in Swedish Lapland. In: Grenier, A.A., Müller, D.K. (Eds.), Polar Tourism: A Tool for Regional Development. Presses de l'Université du Québec, Montréal, QC, pp. 129–153.
Müller, D.K., Viken, A., 2017. Toward a de-essentializing of indigenous tourism? In: Viken, A., Müller, D.K. (Eds.), Tourism and Indigeneity in the Arctic, Channel View, pp. 281–289. Bristol, UK.
Nordic Council of Ministers, 2018. Arctic Business Analysis: Creative and Cultural Industries. Nordisk Ministerråd, Copenhagen, Denmark. https://doi.org/10.6027/ANP2018-708.
Onarheim, I.H., Eldevik, T., Smedsrud, L.H., Stroeve, J.C., 2018. Seasonal and regional manifestation of Arctic sea ice loss. J. Clim. 31 (12), 4917–4932. https://doi.org/10.1175/jcli-d-17-0427.1.
Orsi, A.J., Cornuelle, B.D., Severinghaus, J.P., 2012. Little ice age cold interval in west Antarctica: evidence from borehole temperature at the west antarctic ice sheet (WAIS) divide. Geophys. Res. Lett. 39, L09710.
Overland, J.E., Wang, M., 2016. Recent extreme Arctic temperatures are due to a split polar vortex. J. Clim. 29 (15), 5609–5616.
Parkinson, C.L., 2019. A 40-y record reveals gradual Antarctic sea ice increases followed by decreases at rates far exceeding the rates seen in the Arctic. Proc. Natl. Acad. Sci. Unit. States Am. 116 (29), 14414–14423.
Pearce, T., Smit, B., Duerden, F., Ford, J.D., Goose, A., Kataoyak, F., 2010. Inuit vulnerability and adaptive capacity to climate change in Ulukhaktok, Northwest Territories, Canada. Polar Rec. 46, 157–177.
Peddie, C., 2012. Adelaide Woman Sarah Williams Survives Greenland Iceberg 'tsunami'. News.com.au. 26 July. 2012. www.news.com.au/travel/news/. (Accessed 1 August 2012).
Pedersen, A., von Platen-Hallermund, F., Weng, W., 2002. Tsunami-generating rock fall and landslide on the south coast of Nuussuaq, central West Greenland. Geol. Greenl. Surv. Bull. 191, 73–83.
Peng, X.Q., Zhang, T.J., Frauenfeld, O.W., Wang, S.J., 2020. Northern Hemisphere 1 greening in association with warming permafrost. J. Geophys. Res.: Biogeosciences 25 (1). https://doi.org/10.1029/2019JG005086.
Petrov, A.N., 2017. Human capital and sustainable development in the Arctic: towards intellectual and empirical framing. In: Fondahl, G., Wilson, G.N. (Eds.), Northern Sustainabilities: Understanding and Addressing Change in the Circumpolar World, Springer Polar Sciences. Springer Nature, Cham, Switzerland, pp. 203–220.
Pfeffer, W.T., 2007. The Opening of a New Landscape: Columbia Glacier at Mid Retreat. American Geophysical Union, New York. ISBN: 978-0-8-8790-729-1.
Purdie, H., 2013a. glacier retreat and tourism: insights from New Zealand. Mt. Res. Dev. 33 (4), 463–472.
Purdie, H., 2013b. Glacier retreat and tourism: insights from New Zealand. Mt. Res. Dev. 33 (4), 463–473.
Purdie, H., Gomez, C., Espiner, S., 2015. Glacier recession and the changing rock fall hazard: implications for glacier tourism. N. Z. Geogr. 71 (3), 189–202.
Reich, R.J., 1980. The development of antarctic tourism. Polar Rec. 20 (126), 203–214.
Rintoul, S.R., Chown, S.L., De Conto, R.M., Englamd, M.H., Fricker, H.A., Masson-Delmotte, V., et al., 2018. Choosing the future of Antarctica. Perspective 558, 233–241.
Rosales, J., Chapman, L.J., 2015. Perceptions of obvious and disruptive climate change: community-based risk assessment for two native villages in Alaska. Climate 3 (4), 812–832. https://doi.org/10.3390/cli3040812.
Saarinen, J., Tervo, K., 2006. Perceptions and adaptation strategies of the tourism industry to climate change: the case of Finnish nature-based tourism entrepreeurs. Int. J. Innovat. Sustain. Dev. 1 (3), 214–228.
Schrot, Q.G., Christensen, J.H., Formayer, H., 2019. Greenland winter tourism in a changing climate. J. Outdoor. Recreat. Tourism. 27, 100224.
Scott, D., Hall, M.C., Gössling, S., 2012. Tourism and Climate Change: Impacts, Adaptation and Mitigation. Routledge, New York, NY.
Scott, D., Peeters, P., G€ossling, S., Stefan, G., G€ossling, S., 2010. Can tourism deliver its "aspirational"greenhouse gas emission reduction targets? J. Sustain. Tourism 18, 393–408.
Scott, D., Steiger, R., Dannevig, H., et al., 2019. Climate change and the future of the Norwegian alpine ski industry Climate change and the future of the Norwegian alpine ski industry. Curr. Issues Tourism. https://doi.org/10.1080/13683500.2019.1608919.
Serreze, M.C., Barry, R.G., 2011. Processes and impacts of Arctic amplification: a research synthesis, Global Planet. Change 77 (1–2), 85–96.
Shepherd, A., Fricker, H.A., Farrell, S.L., 2018. Trends and connections across the Antarctic cryosphere. Nature 558 (7709), 223. https://doi.org/10.1038/s41586-018-0171-6.
Smiraglia, C., Diolaiuti, G., Pelfini, M., et al., 2008. Glacier Changes and Their Impacts on Mountain Tourism//Darkening Peaks, Glacier Retreat, Science and Society. University of California Press, Berkeley, CA, pp. 206–215.
Snyder, J., 2007. Tourism in the Polar Regions: the Sustainability Challenge. UNEP, Paris.
Stephen, K., 2018. Societal impacts of a rapidly changing Arctic. Currnt. Clim. Chng. Rep. 4, 223–237. https://doi.org/10.1007/s40641-018-0106-1.
Stephenson, S.R., Brigham, L.W., Smith, L.C., 2014. Marine accessibility along Russia's Northern Sea route. Polar Geogr. 37 (2), 111–133.
Stewart, E., Dawson, J., Draper, D., 2011. Cruise tourism and residents in Arctic Canada: development of a resident attitude typology. J. Hospit. Tourism Manag. 18, 95–106.
Stewart, E., Dawson, J., Howell, S., et al., 2013. Local level responses to sea ice change and cruise tourism in Arctic Canada's Northwest Passage. Polar Geogr. 36 (1/2), 142–162.
Stewart, E.J., Tivy, A., Howell, S.E.L., et al., 2010. Cruise tourism and sea ice in Canada's Hudson Bay region. Arctic 63 (1), 57–66.
Stewart, E.J., Wilson, J., Espiner, S., et al., 2016. Implications of climate change for glacier tourism. Tourism Geogr. 18 (4), 1–22.
Stonehouse, B., Snyder, J.M., 2010. Polar Tourism-An Environmental Perspective. Channel View Publications, Bristol Buffalo Toronto.
Streletskiy, D.A., Shiklomanov, N.I., Hatleberg, E., 2012. Infrastructure and a changing climate in the Russian Arctic: a geographic impact assessment. In: Proceedings of the 10 Th International Conference on Permafrost. Salekhard, Russia, pp. 407–412.
Sun, K., 2014. Practice of engagement, discourse interaction and identity recognition: understanding China's participation in Arctic affairs. World Econ. Polit. 7, 42–46 (in Chinese).
Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P., Quesada, A., 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. Antarct. Sci. 21 (3), 229–236.
Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J., Snape, I., 2009. Impacts of local human activities on the Antarctic environment'. Antarct. Sci. 21 (1), 3–33.
Tourismstatgl, 2018. Greenland Tourism statistics. available at: http://tourismstat.gl/. (Accessed 15 July 2018).
Turner, J., Barrand, N.E., Bracegirdle, T.J., et al., 2013. Polar Record. Cambridge University Press, pp. pp1–25.
Tzekina, M., 2014. Estimation of Tourism Potential of Russian Far North. PhD, Economic, Social, Political and Recreational Geography. Moscow State University, Moscow, Russia.
Vaarala, M., 2006. Final Report: Sustainable Model for Arctic Regional Tourism (SMART). State Provincial Office of Lapland and Kemi Tornio University of Applied Sciences, Finland.
Vieira, G., Bockheim, J., Guglielmin, M., et al., 2010. Thermal state of permafrost and active-layer monitoring in the Antarctic: advances during the international polar year 2007-2009. Permafr. Periglac. Process. 21 (2), 182–197.
Vladimir, R., Sharon, L.S., KetilI, et al., 2018. Terrestrial permafrost [in "state of the climate in 2017. Bull. Am. Meteorol. Soc. 99, S161–S165.
Wang, S.J., Qin, D.H., Ren, J.W., 2012. Spatial development and distribution of glacier tourism in China. Sci. Geogr. Sin. 32 (4), 464–470 (in Chinese).
Wang, S.J., Zhou, L.Y., 2019. Integrated impacts of climate change on glacier tourism. Adv. Clim. Change Res. 10, 71–79. https://doi.org/10.1016/j.accre.2019.06.006.
Welling, J.T., Árnason, P., Richins, H., et al., 2015. Glacier Tourism in Iceland: Development and Challenges. CABI, Cambridge.
Williams, R., Crosbie, K., 2007. Whales and antarctic tourism. Tourism Mar. Environ. 4 (2/3), 195–202.
World Tourism Organization, 2017. Yearbook of Tourism Statistics, 1995.
Zhang, Z.H., Hui, D., Song, M., 2019. Exploitation of trans-Arctic maritime transportation. J. Clean. Prod. 212, 960–973.