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Climate change impacts on immovable cultural heritage in polar regions: A systematic bibliometric review

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Abstract

Over the past decade, research on the impacts of climate change on immovable cultural heritage (ICH) in the polar regions (Arctic and Antarctica) has slowly increased. This article offers a systematic review and synthesis of the publications about climate change impacts on the diverse ICH and climate change adaptation in the polar regions. Gray literature was not included in the study. Arctic countries like Sweden, Finland, Iceland, and Russia, and their associated research organizations, are under-represented in this literature when compared with the USA, Canada, Denmark, and Norway. More than half of the analyzed literature is published in the last 3 years (2019, 2020, and 2021) with a focus on coastal erosion and ICH degradation (cryospheric hazards). ICH is at risk from biological degradation, coastal erosion, debris flow, and thaw slumping. Nearly half of the studies report on the need for climate change adaptation planning and implementation for ICH. This study shows that advances in research on climate change impacts and adaptation responses are needed to improve decision- and policy-maker capacity to support effective adaptation policies and to contribute to the achievement of SDGs in polar regions. The polar regions' vulnerable landscapes and ICH sites can be used to communicate a larger message about the climate change challenges and adaptation measures.

This article is categorized under:

- Assessing Impacts of Climate Change > Observed Impacts of Climate Change
- Vulnerability and Adaptation to Climate Change > Learning from Cases and Analogies
- Climate and Development > Sustainability and Human Well-Being

KEYWORDS

Antarctica, Arctic, climate change, climate change adaptation, cryospheric hazards, cultural heritage

1 | INTRODUCTION

Climate change has already impacted various economic sectors and human behavior (Andrews & Smirnov, 2020), including the world's immovable cultural heritage (ICH) (Ljungqvist et al., 2021). Cultural heritage represents an expression of the way in which a community or a group of people developed and lived, passed on to future generations, including objects, places, practices, customs, and values; it is the foundation upon which global and historical values are based and represents the synergy between people, society, history, and landscape (UNESCO, 2017). A distinction is commonly made between tangible and intangible cultural heritage. Tangible cultural heritage includes movable heritage such as historic objects (sculptures, paintings, coins, and manuscripts), and immovable heritage that encompasses historic buildings, structures, landscapes, and archeological sites (including underwater archeological sites such as shipwrecks, underwater ruins) (UNESCO, 2017). Intangible cultural heritage includes oral traditions, performing arts, craftsmanship, social practices, skills, and knowledge (UNESCO, 2003).

Cultural heritage can strengthen a community's sense of belonging and cultural identity (Lombardo et al., 2020; Sesana et al., 2018), which in turn can enhance community resilience to disasters (Ghahramani et al., 2020). For instance, in the case of Indigenous Māori people, New Zealand, their attachment to cultural heritage assisted them in building community resilience against assimilation pressure including natural hazards (Pomeroy & Tapuke, 2016). Cultural heritage can also support various economic sectors and contribute to climate change mitigation (e.g., retrofitting and reusing existing historic buildings and structures to support greenhouse gas emission reduction; Foster, 2020). Furthermore, it is a source of knowledge about past climatic changes that informs and inspires current and future climate change adaptation planning (Cacciotti et al., 2021; Fatorić & Egberts, 2020; Sesana et al., 2021). Identifying and studying threatened cultural heritage is an effective way of communicating the urgency of the immediate and future impacts of climate change to the public (Dawson et al., 2020).

Over the recent decades, rapid changes in climate have been observed in the polar regions (Arctic and Antarctica). The most recent IPCC assessment reported with high confidence that the Arctic warmed at more than twice the global rate over the past 50 years with the greatest warming during the cold season. It is also likely that west Antarctica has warmed by 0.2–0.3°C per decade during 1957–2016, while no consistent change was observed over east Antarctica (Constable et al., 2022; Gutiérrez et al., 2021). The cryosphere (including seasonal snow, sea ice, glaciers, continental ice sheets, lake and river ice, permafrost, and seasonally frozen ground) covers roughly 14% of the earth's surface. The recorded atmospheric cryosphere hazards (frost, hail, freezing rain) decreased or exhibited great spatial heterogeneities, while their future development is difficult to predict. Sea ice extent is shrinking rapidly, leading to an increase in iceberg numbers and the accelerated erosion of permafrost-dominated coastlines. Paraglacial (non-glacial earth-surface processes, sediment accumulations, landforms, land systems and landscapes that are directly conditioned by glaciation and deglaciation) transformations will increase in the future, along with associated morphological processes, like rock and debris flow, thaw slumping, and thermo-erosion gullying, attributed to permafrost degradation (Ballantyne, 2002; Ding et al., 2021). Anthropogenic risks to the environment such as tourism impact have also increased (Holmgaard et al., 2019).

Furthermore, with the sea ice melting, accessibility to the Arctic through new shorter maritime trade routes has increased and triggered a race for the natural resources (minerals, oil, natural gas, fishing) (Ng et al., 2018). As such, geopolitical and economic consequences of new trade routes along with the changing climate present serious challenges in the polar regions for protecting cultural (and natural) cultural heritage, which is recognized in the Sustainable Development Goals, SDGs (UN, 2021). The SDGs represent an urgent call to action to end poverty, minimize climate change, biodiversity loss and socio-economic inequalities. Scholars highlighted that through their social, economic, environmental, and informational benefits, ICH can support the achievement of SDGs (Guzman, 2020; Henderson, 2019), thus, their preservation and climate change adaptation is of the utmost importance.

Despite growing evidence of climate change impacts on ICH globally (Dawson et al., 2020; Fatorić & Seekamp, 2017; Sesana et al., 2021), limited research has been conducted to explore climate change impacts and climate change adaptation measures for ICH in the polar regions.

1.1 | Types of immovable cultural heritage found in the Arctic

About 180,000 archeological sites are registered in the *Arctic* (Hollesen et al., 2018). Out of these, around 4000 cultural heritage sites are located in Svalbard and are automatically protected and included in Riksantikvaren – Norwegian

Directorate for Cultural Heritage Management database (Riksantikvaren, 2021); Svalbard has some of the most clearly defined legislation when it comes to the protection of immovable cultural heritage; according to the Svalbard Environmental Protection Act, all anthropogenic remains from before 1946 are automatically protected and considered cultural heritage sites, along with a 100 m buffer area around them; this includes remains from different activities such as hunting, trapping, whaling, mining, scientific exploration, plane wrecks from World War II, human graves, including crosses and other grave markers, bones and bone fragments found on or below the ground (Arlov, 1989). Some examples of diverse types of ICH in Svalbard (Norway) are illustrated in Figure 1.

In Greenland (Denmark), around 6000 sites are registered in Nunniffiit (National Database of Cultural Heritage Monuments and Properties) (Fenger-Nielsen et al., 2019). The remaining sites belong to mainland Norway and the other six "Arctic States," Sweden, Finland, Russia, USA (Alaska), Canada, and Iceland, which are State Parties to the 1972 World Heritage Convention. Currently, there are five World Heritage Sites (WHS) within the Arctic Circle; of which two are natural WHS: Natural System of Wrangel Island Reserve (Russia) and Ilulissat Icefjord (Greenland/Denmark); two are cultural WHS such as Rock Art of Alta (Norway) and cultural landscape of Vegaøyan—the Vega Archipelago (Norway), and one is mixed: the Laponian Area (Sweden) (UNESCO, 2007).

One of the first initiatives for the protection of Arctic cultural heritage was taken through the initiation of the Nordic Action Plan to Protect the Natural and Cultural Heritage of Arctic—Greenland, Iceland, and Svalbard; the plan

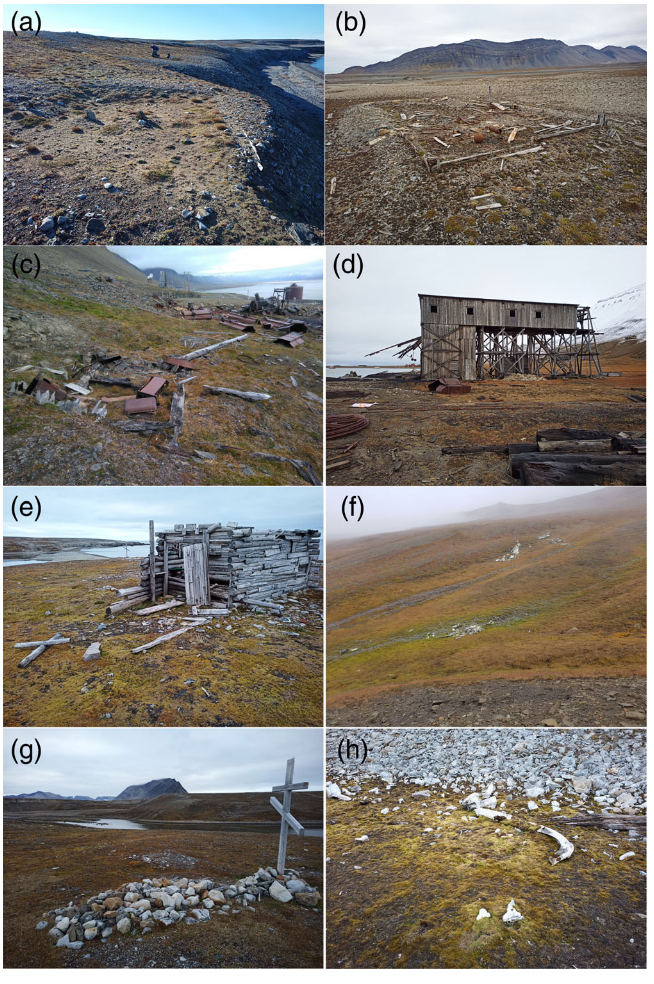

FIGURE 1 Different immovable cultural heritage sites in Svalbard, Norway (Arctic); (a). Remains of hunting, trapping and whaling hut (historic structure) at Russekeila affected by coastal erosion; (b). Remains of hunting, trapping and whaling huts in the proximity of Isfjord Radio (Linnéfjella mountain in the background); (c). Remains (historic structures) of mining activity in the proximity of Svea; (d). Remains of the Central Cable-car at Hiorthhamn used for coal loading; (e). Remains of a Polish research cabin at Russekeila; (f). Plane wrecks from World War II visible on the slopes of Hiorthhamn; (g). Restored grave and new Russian cross at Russekeila (Linnéfjella mountain in the background); and (h). Bone remains from whaling activities on the shores between Isfjord Radio and Russekeila. *Source*: Ionut Cristi Nicu, NIKU

was aimed at contributing to the realization of the goals in the Nordic Environmental Strategy and the Arctic Programme for Co-operation. It was approved on August 23, 1999, by the Nordic Environmental Ministers in Iceland (Nielsen, 2006). Following this, in 2009, UNESCO organized an international expert meeting on climate change and sustainable development in the Arctic titled "Climate change and Arctic Sustainable Development: scientific, social, cultural and educational challenges," where climate change was recognized as accelerating the transformation of environmental, social and cultural landscapes across the Arctic and Subarctic (UNESCO, 2009). This was followed by another meeting in 2017 when there was no focus on cultural heritage.

1.2 | Types of immovable cultural heritage found in Antarctica

Antarctic cultural heritage consists of the early resource exploitation (sealing) from the early 19th century and exploration from the beginning of the 20th century (Pearson & Stehberg, 2006). The current immovable cultural heritage consists of the temporary settlements created by sealers, as well as industrial archaeology, most of which comprises whale oil production plants. There are many huts built by explorers, for example, the hut from the Carsten Borchgrevink Southern Cross expedition, 1898–1890, located at Cape Adare, the R.F. Scott's Discovery Hut constructed in 1902, Ernest Shackleton's Hut, built in 1908 by the Nimrod expedition and R.F. Scott's Terra Nova expedition hut built in 1911. Nowadays, these huts are considered international heritage sites that are protected for their cultural materials from the "Heroic Era" of exploration. Ernest Shackleton is one of the most celebrated explorers in history, taking part in four expeditions to Antarctica, namely Discovery, Nimrod, Endurance, and Quest (Blanchette et al., 2004). Also, there are a few abandoned military bases that were turned into museums, and monuments created in memory of important events that are related to scientific discoveries and explorations. There are also many tombs and memorials of people who lost their lives while exploring Antarctica. For example, in close proximity to the hut from the Southern Cross expedition, is the first grave in Antarctica, of Nicolai Hanson (J. Hughes, 1994). The Historic Sites and Monuments (HSM) List, which has been developed within the Antarctic Treaty signed in 1959, counts around 90 sites and monuments, located in different parts of the continent (McKenzie et al., 2013).

1.3 | This review

Given that many of these types of ICH are exposed to rapidly changing climate, there is an urgent need to identify and understand the key climate change impacts on ICH in the polar regions, and to determine whether climate change adaptation has taken place. To respond to this need, a systematic bibliometric review is used to explore existing studies on the impacts of climate change on various ICH, along with climate change adaptation in the polar regions. A systematic bibliometric review is considered an important method for evaluating progress on scientific research, identifying knowledge gaps and research needs, and providing recommendations for current and future policy developments (Berrang-Ford et al., 2011; Haddaway & Pullin, 2014; Petticrew & Roberts, 2006).

2 | METHODOLOGICAL FRAMEWORK

The process of systematic literature review involved systematically selecting and analyzing publications found in the scientific database Web of Science (WOS) based on clearly defined questions (Berrang-Ford et al., 2011; Petticrew & Roberts, 2006). This analysis method allows the authors to develop a network based on the relationship between items like authors, organizations, keywords, and journals. WOS was chosen because it encompasses the world's largest scientific database which covers most scientific disciplines and contains publications extending over the longest period (from 1900 to the present). To the best of our knowledge, in the academic literature on the Arctic, there are only three literature reviews on the topic: Bancheva, 2019, who focused on environmental issues, Biresselioglu et al., 2020, showed the role of social sciences and humanities, and Ford et al. 2021 documented the societal aspects of climate change and their projected changes. There were no literature reviews related to the Antarctic.

The main research questions guiding this systematic analysis are: (1) What are the principal climate change impacts to ICH in the polar regions; and (2) Is climate change adaptation of ICH taking place? To answer these questions, the WOS Core Collection was explored between 1900 and 15 December 2021, using the following keyword searches in the topic field (asterisk wildcard was used to include permutations of each phrase) without applying a language restriction: (i) cultural heritag* AND

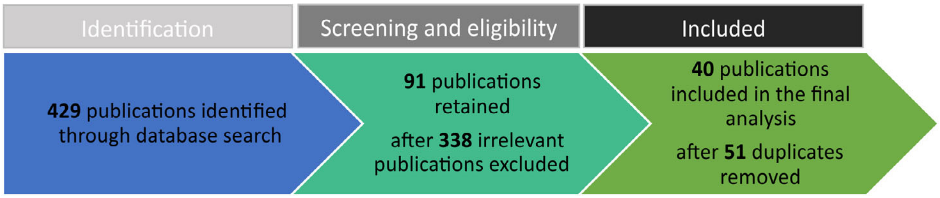

FIGURE 2 Methodological flowchart of the present study

climat* AND Arctic/Antarctic; (ii) heritag* site AND climat* AND Arctic/Antarctic; (iii) archaeol* site AND climat* AND Arctic/Antarctic; (iv) cultural feat* AND climat* AND Arctic/Antarctic; (v) historic* site AND climat* AND Arctic/Antarctic; (vi) historic* hut AND climat* AND Arctic/Antarctic; (vii) historic* wood AND climat* AND Arctic/Antarctic; (viii) historic* artifact AND climat* AND Arctic/Antarctic. The main limitation of this study is the lack of "gray literature," which is commonly unpublished or informally published materials that are often non-peer-reviewed (reports, conference proceedings, notes, manuals). Gray literature can be important at a local and regional level in research attributed to the effects of climate change on the polar ICH but it can be biased according to the author's background and field of research (Conn et al., 2003).

A total of 429 publications were identified and exported to a Microsoft Office Excel spreadsheet and their title, abstracts, keywords, and keywords plus were reviewed for inclusion in the final analysis (Figure 2). Following this step, 91 papers were retained, after 338 papers were excluded. This step ensured that only peer-reviewed publications that focus on climate change impacts on ICH together with climate change adaptation measures in the polar regions were retained.

For the final analysis, 40 publications were selected (Supplementary Material S1) after 51 duplicate publications (identified twice or more in the search process) were removed (a common ratio for systematic literature reviews; Petticrew & McCartney, 2011). Each publication was then coded using an inductive or explanatory approach, where codes were developed and modified throughout the coding process (Saldaña, 2013). The first author of this paper completed the coding and then together with the co-author reviewed and validated the codes (including a discussion of differences in coding). This process enhanced the accuracy and validity of the coding process. First, the information about the study itself such as publishing journals, research areas, publishing frequency, keywords of the publication, and the geographic location of the study was coded. Then, principal climate change impacts and status of climate change adaptation were coded. A thematic analysis together with descriptive statistics were used to analyze qualitative and quantitative trends, respectively. Furthermore, keywords from each publication were analyzed and visualized using VOSviewer (version 1.6.16), which is freely available software that can provide a graphical representation of bibliometric maps. Its main advantages are an automatic processing and semantic clustering, including determination of relationship and relevance among different items (van Eck & Waltman, 2010).

From the 40 papers analyzed in this study, 13 papers did not list keywords; this is mitigated by VOSviewer by considering the KeyWords Plus® feature of Web of Science, which represent index terms automatically generated from the papers' titles and they proved to be reliable for bibliometric analysis (Zhang et al., 2016). Specifically, Figure 4 was made using VOSviewer to reveal the trending topics and their relationship between climate change and ICH in the polar regions. It was developed by analyzing the keywords co-occurrence which are often used to analyze the strength of links between different keywords in publications. A total of 214 keywords were identified by VOSviewer, and the minimum occurrence of a keyword was set to three in order to maximize clarity in clustering and visualizing trending topics; following the selection of this threshold, 17 keywords meet the criteria.

3 | BIBLIOMETRIC ANALYSIS

In this section, a concise bibliometric analysis is presented, referring to the main publishing journals, research areas, publishing frequency, and the analysis of the publications' keywords.

3.1 | Publishing journals and research areas

The 40 articles analyzed in this review on climate change impacts on ICH and adaptation in the polar regions were published in 27 different journals. The highest number of articles ($n = 3$) were found in the journals *Scientific Reports*

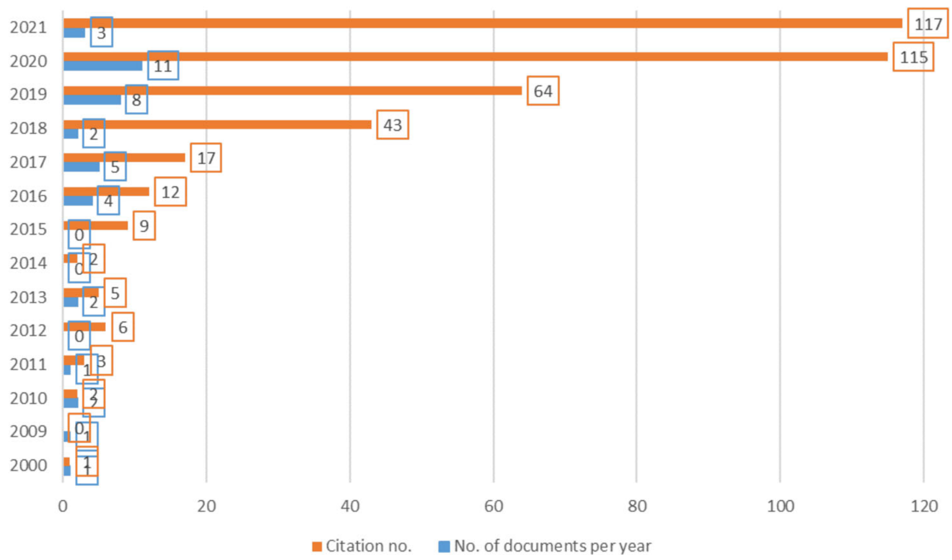

FIGURE 3 Frequency of published studies from 2000 to 2021 and their citation count (last access December 15, 2021)

and *Arctic*. While *Scientific Reports* is categorized as a Multidisciplinary Sciences journal, *Arctic* is categorized as a Physical Geography and Environmental Sciences journal. The journals *Archaeometry*, *Arctic Anthropology*, *Etudes Inuit Studies*, *Antiquity*, and *Open Archaeology* each published two papers (see full list of journals in Supporting Information S1). The analysis displays a multidisciplinary nature of ICH and climate change research in the polar regions, where many research areas overlap and complement each other.

3.2 | Publishing frequency

While the publication period for the search was 1900–2021, there was no publication found prior to year 2000 in WOS. The highest number of publications was in 2020, with 11 publications, which point to an emerging research field (Figure 3). More than half of the analyzed publications (22 papers) are concentrated over the last 3 years (2019, 2020, and 2021). The number of citations has been gradually increasing every year. Arctic countries such as Finland, Iceland, and Russia are underrepresented in climate change-ICH research, based on the affiliations of paper co-authors, which are dominated by locations in Canada, USA, Denmark, Greenland, and Norway.

3.3 | Publications keywords analysis

Keywords analysis identifies topics that are trending, which offer some hints to developments in the field of climate change impacts on ICH and adaptation in the polar regions. The research comprises three clusters with significant correlation between the keywords in each cluster (see Figure 4). Each node represents a keyword, the size of the node shows the frequency of the keyword, and the link connecting the two nodes indicates the relationship between the two keywords.

Cluster 1 (red) comprises of the following keywords "climate change" "Arctic" "permafrost" "impact" "remote sensing" "Alaska" each with a total link strength of 42, 31, 24, 21, 19, and 12, respectively. Being in the center of the image "climate change" relates to each keyword from the three clusters (i.e., red green and blue) thus being the topic trending most across the whole sample. The second most representative keyword in the cluster is "Arctic" which is also a study area of this paper; followed by "permafrost" and "impact" which point to a strong connection between climate change impacts such as permafrost thawing and ICH. Another keyword is "remote sensing" which represents a common method employed to survey polar ICH. Remote sensing techniques are particularly useful in polar regions due to their limited geographic and seasonal accessibility. Keyword "Alaska" relates to one of the most commonly studied areas of climate change impacts in polar regions (Jensen, 2020; Knecht & Jones, 2019; Tran et al., 2021).

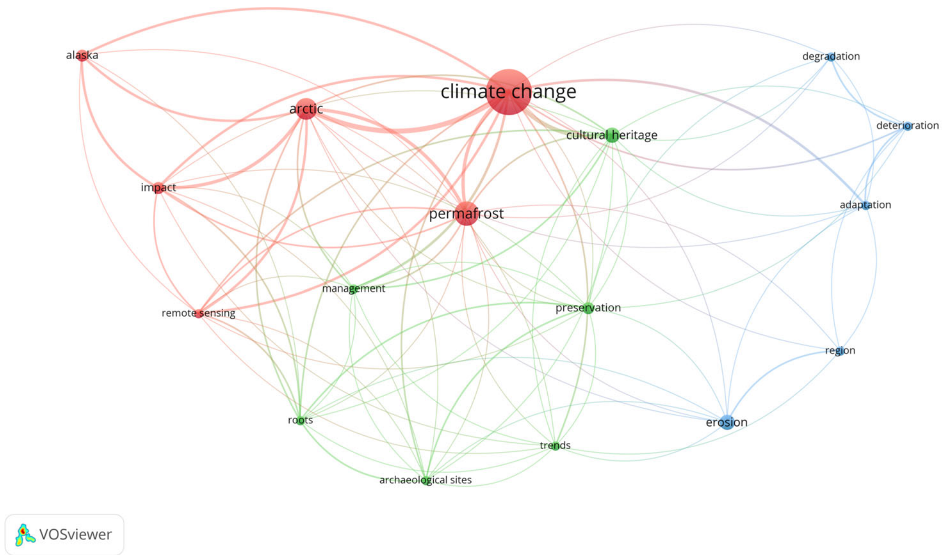

FIGURE 4 Map of the trending topics according to the keywords in analyzed publications

Cluster 2 (green) is dominated by the keywords "cultural heritage," "roots," "management," "preservation," "archeological sites," and "trends," each with a total link strength of 21, 18, 15, 15, 14, and 13, respectively. "Cultural heritage" is the most common term used to denote archeological features or remains; another term is "archeological sites." "Roots," "management," "preservation," and "trends" refer to studies from Greenland, where the impacts of vegetation on archeological sites was intensely studied (Fenger-Nielsen et al., 2019, 2020; Hollesen et al., 2019).

Cluster 3 (blue) comprises five keywords "erosion," "adaptation," "deterioration," "degradation," and "region," each with a total link strength of 10, 10, 9, 7, and 7, respectively. "Erosion" is related to coastal erosion. The earliest papers reviewed (Radosavljevic et al., 2016) documented the impacts of coastal erosion, and associated "deterioration" and "degradation" of a former whaling station along the NE coast of Herschel Island, Yukon, Canada.

4 | IMPACTS OF CLIMATE CHANGE ON IMMOVABLE CULTURAL HERITAGE IN THE POLAR REGIONS

This section reports on the impacts of hazards that endanger ICH related to atmospheric cryosphere effects (leading to biological degradation by fungi), sea ice decline (causing coastal erosion), and permafrost degradation (e.g., thaw slumps). Lastly, the question of the status of climate change adaptation planning is addressed.

4.1 | Atmospheric cryosphere hazards with emphasis on biological degradation

Research on biological degradation of ICH due to climate change started in the early 2000 s (J. D. Hughes, 2000) from the assumption that the dry cold in the polar regions will preserve historical buildings/huts, and archeological deposits. However, further research proved this to be incorrect. This issue was explored in 11 papers. Farrell et al. (2011) studied fungal degradation of the historic artifacts and huts on Ross Island, Antarctica, finding that climate change (warming) may not affect the local fungal species unless they are outcompeted by new arrivals or affected by unfavorable changes in ecosystem domination. Bertulli et al. (2013) examined the thinning of the wooden structures of the Peary huts, Fort Conger, Arctic due to wind ablation, salt, and chemical damage, including *Cadophora* fungi, which in moist conditions and above-freezing temperatures causes rot. Hollesen et al. (2016, 2017) studied the degradation of several types of organic archeological deposits in Greenland. It was found that degradation rates of the deposits are more sensitive to increasing temperatures than natural soils and the process is exacerbated by a high microbial heat production. Having a better understanding of organic preservation will lead to a better understanding and baseline monitoring of Arctic archeological deposits in the changing climate (Harmsen et al., 2018). Fenger-Nielsen et al., 2019 found that the archeological sites in south-west Greenland are "hotspots" of vegetation and plant nutrients, human activities are obvious in the vegetation after centuries of abandonment, and the distinct mark of vegetation makes archeological sites easier to detect through satellite imagery. This is advanced further by Hollesen et al., 2019, who made predictions on the loss of organic archeological deposits at a regional scale in Greenland. Their model is based on future climate scenarios (RCP 4.5 and RCP 8.5) and shows that 30%–70% of the archeological fraction of organic carbon could disappear over the next 80 years. As such, the organic remains from the Norse Viking Age settlers face serious threat of loss in the coming years. Another study from Western Greenland (Pedersen et al., 2020) highlighted that fungi cause extensive soft rot decay at all sites, regardless of climate and local environment. Wooden artifacts may also become further endangered if climate change leads to more favorable growth conditions. Flyen et al., 2020 argued that the extent of fungal decay is expected to increase in Svalbard's ICH due to climate change. In this context, another study at the Fort Conger and Peary Huts revealed that the soft rot is observed over many samples and the historic structures have been deteriorating (Blanchette et al., 2021).

There is limited research focused on Antarctica, with only six studies identified on the impacts of climate change on ICH. J. D. Hughes (2000) focused on the conservation issues associated with high humidity, fungi, salt damage, surface erosion by windborne particles and corrosion of metals; this was followed by Pearson et al. (2010), who showed that the major risk factors for sealing sites is related to climate change and accelerated coastal erosion, as well as growth of damaging fungi and algae that favor increased corrosion of metal items. Farrell et al. (2011) analyzed Antarctic fungi from historic huts, finding that there is significant overlap of the yeasts and filamentous fungi isolated from the historic sites, soil and historically-introduced materials and those isolated from environmental samples in pristine locations; they concluded that cultured fungi were cold active, and that climate change may not adversely affect these fungal species unless they were out-competed by new arrivals or unfavorable changes in ecosystem domination. Roura (2010) conducted photo documentation to assess transformations in some historic features, such as a memorial cross, a group of assorted artifacts inside a standing building, a group of mortuary artifacts, temporary camp remains and a standing wood frame building. It was found that deterioration due to wind action was the most natural process observed, while further changes were due to cultural processes (conservation and active management), archeological research and organized tourism. Powell et al. (2016), investigated how tourists' perspectives on climate change are influenced through the interplay between natural and cultural heritage resources. Tourists may be aware of climate change if a better narrative were to be used by guides. Garbe et al. (2020) emphasized the danger to coastal cities and their cultural heritage with the eventuality of the Antarctic Ice Sheet melting. Note that several studies were conducted in the Antarctic focusing on fungal activity and other conservation challenges of the historic huts (Arenz et al., 2006; Blanchette et al., 2004; Duncan et al., 2006; Held & Blanchette, 2017), including the use of laser scanner to record the historic huts (Gibb et al., 2011); however, these studies did not focus on climate change-related challenges.

4.2 | Sea ice decline related hazards (coastal erosion)

Coastal erosion rates in the Arctic are among the highest on earth (Walsh, Ballinger, et al., 2020; Walsh, Tejsner, et al., 2020). The average rate was calculated at −0.5 m/yr for the entire Arctic coast. Coasts of the western Canadian Arctic and north and north-west Alaska are characterized as one of the largest areas of high-sensitivity shorelines within the circumpolar Arctic (Lantuit et al., 2012). The study on shoreline projections and flood hazard by Radosavljevic et al. (2016) found that coastal erosion along the Herschel Island, a UNESCO World Heritage candidate site, decreased from −0.6 to −0.5 m/yr between 1952–1970 and 1970–2000, but increased to −1.3 m/yr in the period 2000–2011. O'Rourke (2017) in a study that focused on erosion rates in the Mackenzie Delta, Canada, showed a high risk of erosion on Inuvialuit archeological record; with erosion rates up to −4.27 m/yr. Irrgang et al., 2019 focused on predicting coastal erosion on a 210 km length of Yukon's Beaufort Sea coast, Canada, using different working scenarios. The results showed that by 2100, 45%–61% of all cultural features may be lost on the background of increasing coastal erosion and sedimentation processes. Darwent et al. (2019) and Walsh, Ballinger, et al. (2020); Walsh, Tejsner, et al. (2020) demonstrated, through basic research such as repeated photography, that the Arctic coastlines at the site of Iita and five sites from Nuussuaq Peninsula (Northwestern Greenland) were eroding. Studies from Svalbard over the period 1927–2020 showed an erosion rate of −0.14 m/yr. Shoreline forecast analysis highlighted that half of the protected cultural heritage will disappear over the next decades (Nicu et al., 2020; Nicu, Rubensdotter, et al., 2021).

4.3 | Debris flows and thaw slumps

Some climate-induced geomorphological processes can have devastating effects on ICH, especially in periglacial environments. Research from Walls et al. (2020) highlighted the devastating effects of debris flow and thaw slumps at a small settlement in Northwest Greenland (Siorapaluk). The intensity and suddenness of the two processes has global implications for archeologists working in periglacial landscapes worldwide. Nicu, Lombardo, et al., 2021 presented a preliminary view on thaw slumps affecting cultural heritage in Nordenskiöld Land, Svalbard, concluding (based on data from 2009 to 2011) that thaw slumps are affecting eight sites (represented by a trapping cabin, restored grave, and new Russian cross—they are taken as one, remains of posts, Russian hut, a house foundation, a boat house, a cabin, and a Russian cottage). Making predictive models of climate-induced processes (especially thaw slump), will lead to a better understanding of the environmental factors contributing to their occurrence and development (Nicu et al., 2022). Models made for certain areas could be adapted for other circum-Arctic areas (Rudy et al., 2016), as is a frequent practice for landslides in non-Arctic and non-Antarctic areas. A pan-Arctic susceptibility model for thaw slumps could shed light on future locations of these processes and could be used in both cultural heritage and infrastructure management.

4.4 | Adaptation

Out of the 40 analyzed papers, 17 papers reported on climate change adaptation or preservation responses for ICH in polar regions. Most of the studies reported on proactive adaptation planning which is focusing on a decision-making process that can reduce climate change impacts before the impacts are further observed (in the future). Specifically, the studies emphasized the need for increased research on climate change risks and impacts to ICH (Blanchette et al., 2021; Britton & Hillerdal, 2019; Flyen et al., 2020; Hollesen et al., 2018), monitoring of climate stressors on ICH (Holmgaard et al., 2019; Pearson et al., 2010), integration of community perceptions and knowledge in development of proactive adaptation actions (Bertulli et al., 2013; Britton & Hillerdal, 2019; Jensen, 2020; Tran et al., 2021), and the need for the development of approaches and methods to deal with irreversible loss of Arctic heritage (Jensen, 2020). Other studies called for designing and implementing targeted policy mechanisms, laws and regulations for climate change adaptation and protection of polar heritage (B. W. Barr, 2017; S. Barr, 2019; Pearson et al., 2010; Viikari, 2009), including transparent prioritization decision-making processes for diverse ICH (B. W. Barr, 2017; Jensen, 2020).

A small number of publications focused on monitoring and evaluation of implemented climate change adaptation or preservation actions (Dawson et al., 2013; Dawson & Levy, 2016; Farrell et al., 2011; Hillerdal et al., 2019; Roura, 2010). Examples include a ground based repeat photography for observing and evaluating past preservation (adaptation) actions in the Arctic and Antarctica (Roura, 2010), 3D laser scanning in the Arctic (Dawson et al., 2013) and virtual reality (VR) for preservation or adaptation of archeological sites in Arctic Canada (Dawson & Levy, 2016). Hillerdal et al. (2019) showed the benefits of using a community-based archaeology approach in south-western Alaska to preserve or adapt threatened archeological sites based on scientific and local community priorities. Research on engaging with decision-makers, stakeholders and communities in adaptation or preservation interventions in the polar regions is still relatively limited. This may warrant an improved integration of scientific information with local or indigenous community perceptions (McNamara et al., 2021), values and ways of knowing for a more inclusive, just and sustainable climate change adaptation decision-making in the Arctic. Salvage excavation and documentation of ICH together with virtual reality and museum exhibitions globally could be used as climate change adaptation solutions for ICH in Antarctica (Dawson & Levy, 2016; Pearson et al., 2010).

5 | DISCUSSION

Cultural heritage, the record of cultural diversity and identity at a global level, represents a major societal challenge as its preservation must play a part in sustainable development in the polar regions. Documenting cultural heritage sites, using the latest technological advancement and inter- and transdisciplinary research in monitoring and assessing their present condition, will lead to better management and adaptation measures against destruction and the loss of cultural diversity (Vanderlinden et al., 2020). The digitization of cultural heritage has the prospects of generating tremendous amounts of high value data that can inspire creation and innovation for cultural dissemination to a large audience. The study of Walker, 2020, showed that this can be done by employing the latest commonly used non-invasive methods in monitoring, evaluation, and management of the current state of ICH, such as unmanned aerial vehicles which have been under-used in the study of the polar regions ICH. The 2012–2014 3D laser scanning of the historic whaling stations of South Georgia with subsequent virtual tours is, although sub-Antarctic, counted among important virtual polar heritage projects. The UK and New Zealand Antarctic Heritage Trusts use VR for broader study and public engagement with the historic Huts in Antarctica. These methods can offer a fuller picture and complement each other when it comes to permafrost related processes analysis and 3D visualization, especially when applied in assessing the climate threats to ICH. The study of Nicu, Rubensdotter, et al., 2021 showed the application of 3D laser scanning to one of the most iconic ICH on Svalbard (shown in Figure 1d). Also, the 3D data can be easily transformed into short movies which can be played in museums to raise awareness of the danger that climate change poses to ICH in the polar regions (CyArk, 2019).

Historic structures, sites and past landscape management offer valuable information on how past societies adapted to climate change (Fatorić & Egberts, 2020; Sesana et al., 2018). Arctic and Antarctic vulnerable landscapes and ICH can be used to communicate a larger message about the challenges of climate change and inform future mitigation and adaptation measures. There is a need to develop and implement institutional frameworks and policies for climate change adaptation of Arctic and Antarctic heritage. Rockman and Hritz (2020) emphasized the importance of climate change and heritage partnerships, outreach through existing multi-disciplinary methods and strategic investment in bridging the gap between climate change research and policy.

6 | CONCLUSIONS

In this Focus Article, current literature on climate change impacts on ICH and adaptation in the polar regions was analyzed. Despite a growing body of research on the intersection of climate change and cultural heritage globally, studies in the polar regions are still in their infancy. Out of the 40 papers analyzed in this review, more than half of them are published in the last 3 years. However, this does not compensate for the time elapsed since the creation of the Nordic Action Plan in 1999, and the subsequent UNESCO acknowledgement of climate change impacts on Arctic cultural heritage in 2009. More than two decades were needed for increasing research on climate change impacts on ICH in the polar regions to be realised. It would be extremely useful that, for future research and actions in the field, the practicing scientists make more use of journals that are indexed in WoS, rather than publishing only reports, conference proceedings, and so on.

This review showed that the main trending topic (based on keywords analysis) in the field of climate change and ICH is impact of permafrost thawing on ICH in the Arctic. The most common cryospheric hazards were sea ice decline related hazards (coastal erosion), followed by biological degradation, debris flows and thaw slumps. Much more attention should be given to coastal erosion, which is shown in this study as a serious hazard to coastal Arctic ICH. Following the latest climate change scenarios in the Arctic, it has been observed that many of the studied areas such as Svalbard and Greenland and their ICH are very vulnerable to future changes. In Antarctica, the major climate change risks are increase in coastal erosion rates and wind action, as well as growth of damaging fungi and algae that can exacerbate corrosion of metal components of ICH. There is a shortage of research concerning the effects of debris flows and thaw slumps on ICH in the polar regions. A pan-Arctic susceptibility model for thaw slumps combined in a multi-hazard approach, would shed light on future locations of thaw slumps and other cryospheric hazards, and could be used in both cultural heritage and infrastructure management. Furthermore, half of the analyzed publications reported on climate change adaptation or preservation responses for ICH in polar regions. This emphasizes the need for continued research on adaptation actions for a wide variety of ICH, including integration of local and indigenous knowledge in adaption decision-making processes. The limitation of the present study is that it ignores unpublished (gray) literature. Yet, inclusion of gray literature can be biased according to the author's background and field of research.

AUTHOR CONTRIBUTIONS

Ionut Cristi Nicu: Conceptualization (lead); data curation (equal); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (equal); project administration (lead); resources (lead); software (equal); supervision (lead); validation (equal); visualization (lead); writing – original draft (lead); writing – review and editing (equal). **Sandra Fatorić:** Data curation (equal); formal analysis (supporting); investigation (supporting); methodology (equal); resources (supporting); software (equal); validation (equal); visualization (supporting); writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

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