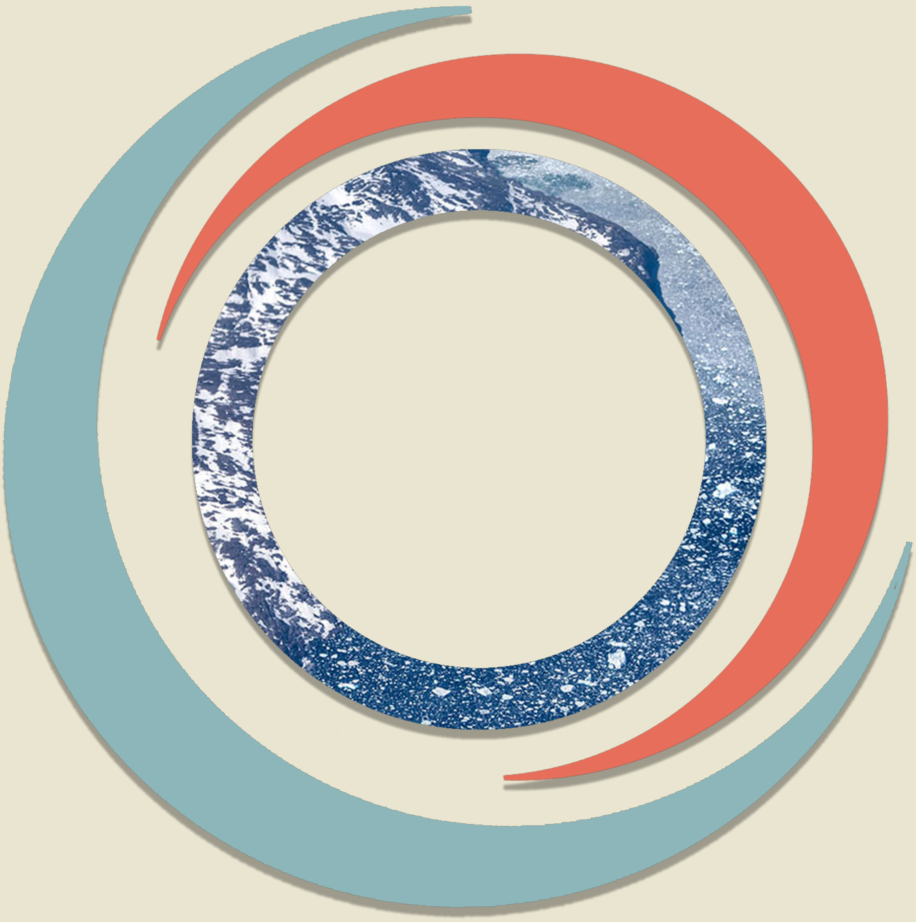
Impacts, Vulnerability, and Understanding Risks from Climate Change to Culture and Heritage



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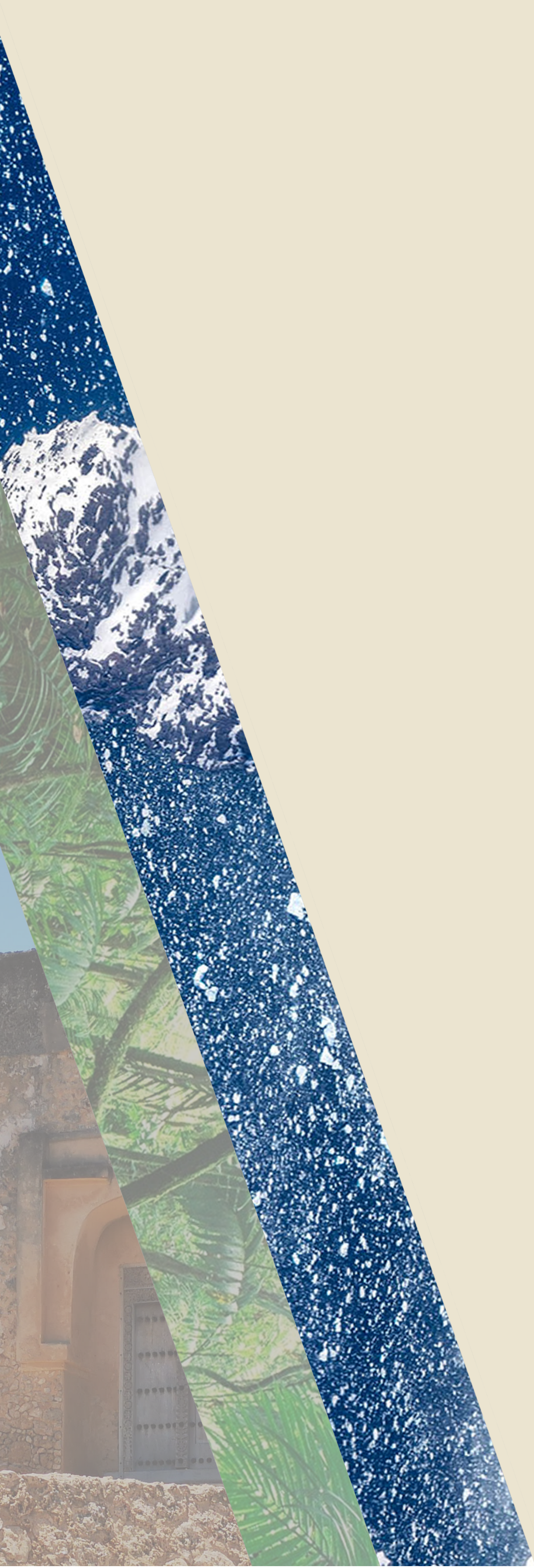
INTERNATIONAL CO-SPONSORED MEETING ON
CULTURE, HERITAGE & CLIMATE CHANGE



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China Cultural Heritage

Foreword

As co-chairs of the Scientific Steering Committee of the International Co-Sponsored Meeting on Culture, Heritage, and Climate Change (ICSM CHC) we are delighted to write this foreword for this important publication, and to congratulate the authors on their valuable exploration of climate impacts, vulnerability, and understanding risks of climate change for culture and heritage. This publication is one of three commissioned by the ICSM CHC in early 2022 as a provocateur for attendees.

The proposal for the ICSM CHC was a response to growing calls for international attention to culture, heritage, and climate change including by the Intergovernmental Committee -established under the UNESCO 1972 Convention concerning the protection of the World Cultural and Natural Heritage-, which requested, already in 2016, the UNESCO World Heritage Centre and the Advisory Bodies to the World Heritage Committee to work with the Intergovernmental Panel on Climate Change (IPCC) with the objective of including a specific chapter on natural and cultural World Heritage in future IPCC assessment reports. These calls were a recognition that there exist significant gaps in understanding the many connections between culture and the human past and the modern phenomena of climate change, as well as a need to advance the contributions of culture and heritage to climate change mitigation and adaptation.

The proposal, first proposed by the International Council on Monuments and Sites (ICOMOS), was agreed by the Co-Chairs of the Working Groups of the Intergovernmental Panel on Climate Change (IPCC), endorsed by the IPCC Executive Committee in June 2020, and co-sponsorship confirmed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in July 2020 with which a collaborative concept note for the meeting was finalized by the Co-Chairs of the Scientific Steering Committee. The ICSM CHC was held virtually over five days from 6 - 10 December 2021 bringing together approximately 100 participants from a wide range of backgrounds. The meeting participants represented 40 countries across all six continents. 40% of the participants were from the Global South and 61% of the participants were women. The participants included Climate Scientists, Culture and cultural and natural heritage experts and practitioners, Natural Science experts and practitioners and representatives from indigenous peoples and local communities.

During the ICSM CHC, participants discussed a wide range of topics including the systemic connections of culture, heritage, and climate change, the roles of culture and heritage in transformative change and alternative sustainable futures and, aided by this paper, loss, damage, and adaptation for culture and heritage. Themes within this topic included the collective understanding of uncertainty, the need to identify common factors for vulnerability and resilience, and the relationship between impacts, power, and interpretations of climate change.

A draft of this paper was prepared by a diverse group of scholars and heritage practitioners from around the world. This draft was shared with the ICSM CHC meeting participants and then revised by the group following inputs from the meeting. As a provocation piece written to promote conversation and debate, its contents intentionally reflect the views and opinions of the authors and do not necessarily represent the view of the co-sponsors of the meeting. Attention to culture is an indispensable enabling condition to transformative climate action and climate resilient sustainable development. It is increasingly recognized that the lack of attention to culture can lead to poor adaptation and inadequate mitigation outcomes. As the urgent need for effective, equitable climate action becomes ever clearer, we hope this paper gains a wide audience and it makes an important contribution to a topic that requires greater attention.

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Executive Summary

Climate change is already impacting multiple types of heritage across all regions of the world. {3.2; 6.1; 7.1; 7.2}

Future climate change poses increased risks to heritage globally, including losses and damages to heritage of current and future generations and particularly severe impacts on the intangible cultural heritage of Indigenous communities. {3.2; 6.1; 7.1; 7.2}

Climate change impacts on heritage are not being studied consistently nor systematically, which is reflected in heritage coverage in IPCC assessments and special reports. {3.2}

There is a global imbalance in the number of publications assessing the impact of climate change on heritage between different regions. Regional, national and sub-national disparities are also observed (example of Australia East vs. West). As a result, it is difficult to know if what we know about the impact of climate change on heritage is just a reflection of where the science is funded rather than where or when heritage is being affected by climate change. {6.1; 7.1; 7.2}

Impacts of climate change on the broader economic benefits (besides tourism), and social and cultural value of heritage are neither investigated nor reviewed globally and rarely explored regionally or locally. {6.1; 7.1; 7.2}

Disparities in climate change / heritage publications appear to be determined by research funding, income inequality (within and between countries), colonial legacy (research ties and relationships between former colonies and colonising countries), legal systems of heritage protection (imbalance between natural and cultural heritage depending on the country/region), local vs. international interest in heritage, the language of publication (focus on English excluding other significant scientific languages such as French, Spanish, or Japanese). {7.1; 10.1}

Improvement of data reliability and resolution allows for more nuanced reconstructions of impacts of past climatic events, facilitating historically important factors of societal adaptation processes proportional to those changes. Yet they do not provide straightforward solutions for contemporary anthropogenic climate change as the scale of recent changes across the climate system are unprecedented over many centuries to many thousands of years. {8}

Alignment of climate change risk terms may facilitate collaboration between climate science and heritage research fields and enhance the likelihood of uptake by large climate change assessments like the IPCC. Innovative methods, especially those which are ideal for assessing social and cultural vulnerability, are needed to integrate the value of intangible cultural heritage with assessments of climate change risk. {4; 9; 10.1; 10.2}

There is opportunity for climate change / heritage research to embrace transformational, inter- and transdisciplinary, and decolonial principles to address a range of the research and practice challenges as the field matures. {10.2}

Impacts, Vulnerability, and Understanding Risks from Climate Change to Culture and Heritage

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1. Introduction

Climate change poses an existential threat to multiple dimensions of culture and heritage. Human-induced climate change is already producing weather and climate extremes in every region across the globe (IPCC, 2021). Climate hazards have become more severe as global warming has increased (IPCC, 2021). Observed changes to the climate system include widespread and rapid impacts on the atmosphere, oceans, cryosphere and biosphere, increases in the frequency and intensity of heat extremes, marine heatwaves, heavy precipitation, droughts, and intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover, glaciers, and permafrost (IPCC, 2021).

There has not yet been a systematic assessment of the impacts of these climate hazards on heritage. Every region of the world is projected to increasingly experience concurrent and multiple changes as a result of global warming (IPCC, 2021), with the potential for accumulative impacts on heritage. For example, hundreds of thousands of significant archaeological, cultural, and natural heritage sites along the coasts of every continent are threatened by sea level rise, and many will be lost or damaged (Reimann et al., 2018; Vousdoukas et al., 2022). Further, low-likelihood but high-consequence outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events (e.g., extreme heat which follows a cyclone), can also pose a risk to heritage. These major events may produce substantially larger impacts than those currently within IPCC assessments, and are now within the very likely range of future warming (IPCC, 2021).

White Paper 2 covers five main themes of research, policy, and practice including review of: a) coverage of heritage in recent reports by the Intergovernmental Panel on Climate Change (IPCC); b) risk terminologies in heritage, developed by UNESCO, ICOMOS, IUCN, ICOM, ICCROM and other culture and heritage-related organisations, and IPCC use for potential cross-walk between the two fields; c) types and severity of impacts, vulnerability, and risks; d) the geographic distribution of impacts, vulnerability and understanding risks; e) existing tools for identification, monitoring, and comparison of the impacts, vulnerability, and understanding risks to heritage from climate change (see Section 2). Across these themes, special attention is given to losses and damages from climate change, gaps in knowledge and knowledge production, and the cross-cutting themes of governance and capacity to learn from the past are made where relevant to impacts, vulnerability and understanding risks.

The scope of this white paper is extensive due to the diversity and quantity of heritage types and climate change impacts. Culture and heritage encompass natural and cultural heritage, both tangible and intangible, including the creative economy and its cultural industries. Tangible heritage can be immovable and movable; immovable cultural heritage includes archaeological sites, historical buildings and structures, monuments, and landscapes (The United Nations Educational, Scientific and Cultural Organization (UNESCO, 1972), whereas museum collections and archives represent movable tangible heritage. Intangible cultural heritage includes practices, representations, expressions, knowledge, and skills inherited from our ancestors and passed on to our descendants (UNESCO, 2003). Natural heritage encompasses geological features, ecosystems and biodiversity (UNESCO, 1972), which support social-ecological systems. Many of these dimensions of culture and heritage are physically exposed and vulnerable to climate hazards and potentially affected by direct and indirect impacts from climate change.

This white paper therefore focuses on the impacts, vulnerability, and risks to heritage from climate change and reviews our current knowledge as a primer for the International Co-Sponsored Meeting on Culture, Heritage, and Climate Change (ICSM CHC) held in December 2021. In doing so it contributes to scoping the potential key focus areas of research for the 7th Assessment Round of the IPCC (2022 onwards) and the coming decades. Reflecting on the findings from sections 4-9, this research presents seven broad challenges for further climate change /heritage discussion:

1. How to systematically identify the range of impacts of climate change on heritage commensurate with the diversity, quantity, and severity of those impacts;

2. How to integrate all determinants of climate change risk in assessment of impacts on heritage;

3. What is the essential climate change risk terminology needed for alignment of research and practice?

4. How can large-scale assessments better evaluate the impacts of climate change on heritage, and what risks those impacts pose?

5. What are the essential roles and responsibilities of stakeholders necessary to assess climate change impacts, including those of Loss and Damage from climate change?

6. What are the essential modalities and methods necessary to assess climate change impacts on, and risks to heritage?

7. What can be learnt from the past to inform climate adaptation?

This white paper aims to align with and complement White Paper 1: 'Knowledge Systems' and White Paper 3: 'Heritage Solutions.' It therefore does not concentrate on adaptation or solutions as these are addressed in White Paper 3. Although special attention is given to impacts, vulnerability, and understanding risks for Indigenous communities and their respective knowledge systems, deeper scoping and richer discussion of these can be found in White Paper 1.

2. Overview of Guiding Questions

This white paper focuses on the effects and consequences of climate change on cultural and natural heritage and the creative economy, with key attention to how these are represented and understood through concepts of risk and loss and damage.

Questions addressed in White Paper 2: 'Impacts and Risks' include:

- How have effects and consequences of climate change (inclusive of concepts such as risk, vulnerability, impacts, loss, and damage) for, on, and from cultural and natural heritage and the creative economy been incorporated into recent IPCC reports (particularly Special Reports 1.5C, SRCCL, SROCC)? What has changed or been added over the course of these reports? What gaps are evident and remain unaddressed?

In published scientific and professional literature,

- How do definitions and approaches to effects and consequences of climate change on cultural and natural heritage and the creative economy relate to or otherwise cross-walk with the IPCC AR6 definition of risk (Reisinger et al., 2020) and the United Nations Framework Convention on Climate Change (UNFCCC) definition and uses of loss and damage?

- What is the state of knowledge regarding types, diversity, and severity of effects and consequences of climate change for, on, and from cultural and natural heritage and the creative economy, including disasters and extreme events?

- What is the state of knowledge regarding the geographic distribution (with attention to scale from communities to countries and regions, as well as globally) of such effects and consequences and how they may develop across different climate scenarios?

- What is the range of existing tools for identifying, monitoring, and comparing these effects and consequences, with particular attention to the concept of vulnerability? What gaps and needs for new tools are evident?

This White Paper also highlights the following cross-cutting issues where feasible:

Cultural governance:

- Where have major definitions of heritage been made and how do these intersect with attention to (or lack of) climate impacts and response?

- Are there instances in which cultural heritage has improved security or reduced stress? What are situations in which cultural heritage has been or may be used as a source or focus of stress?

- Governance also speaks to management of scientific and climate-relevant information and creation and maintenance of collaborative frameworks. What are the range and outcomes of case studies that have productively and effectively linked nature and culture approaches? Where have these worked well and where is more work needed?

Capacity to learn from the past:

- What is the state of knowledge on connections between past environments and environmental change and temporal, causal, and other interconnections with past human activity? Where are the methodological gaps in translating insights from centuries or millennia of human-environment experience into meaningful approaches to contemporary climate science and response?

- Learning from the past requires asking questions of it. How well do questions that climate science, adaptation, and mitigation communities have about the human past and the nature of human behaviour and society align with questions that researchers ask about these topics?

3. Methods

Review of five main bodies of climate change and heritage literatures were conducted to gain an understanding of how climate change impacts, vulnerability, and risks are understood across climate change assessment and heritage scientific and professional literatures. Key word searches and an extensive review of the literature were conducted exploring the state of knowledge on effects and consequences for risks to heritage, and the methods used to assess vulnerability, while also drawing on existing assessments, as appropriate (Perry, 2011; Morgan et al., 2016; International Council on Monuments and Sites (ICOMOS) Climate Change and Cultural Heritage Working Group, 2019; Perry, 2019; UNESCO-WHC, 2021). First, review of IPCC reports explored coverage of heritage in its assessment of climate change impacts, vulnerability, and projected risks. This used key word searches and a snowball method of associations based on what was found. Second, a review of key climate risk terms was conducted for recent IPCC and heritage literatures which explored definitions and approaches to understanding impacts and risks from climate change for heritage. Third, a literature review explored types, diversity, and severity of effects and consequences of climate change for heritage, including disasters and extreme events. This was followed by a systematic review of global and regional climate impacts on heritage which is elaborated in the Sections 3.1-3 below. This included a supplementary focus on the capacity to learn from the past. Finally, a literature review was conducted to explore the methods for characterising vulnerability of heritage to climate change.

3.1 Global assessment

The global systematic review was conducted using the Web of Science database. Cultural sites are defined using five phrases, using the asterisk wildcard to include permutations of each phrase (Orr, Richards and Fatorić, 2021):

- 'cultural resourc*' AND 'climat* chang*': n=45 articles
- **'cultural heritag*' AND 'climat* chang*': n=253 articles**
- 'historic* heritag*' AND 'climat* chang*': n=8 articles
- 'heritag* site*' AND 'climat* chang*': n=152 articles
- 'historic* environment*' AND 'climat* chang*': n=49 articles

Natural sites are defined using the following seven phrases:

- 'natur* heritag*' AND'climat* chang*': n=34 articles
- 'natur* sit*' AND 'climat* chang*': n=18 articles
- 'natur* reserv*' AND 'climat* chang*': n=169 articles
- **'protect* area*' AND 'climat* chang*': n=874 articles**
- 'natur* conservat*' AND 'climat* chang*': n=96 articles
- 'heritag* conservat*' AND 'climat* chang*': n=15 articles
- 'bio*cultural' AND 'climat* chang*': n=27 articles

A screening of the publications focusing on climate change and heritage was conducted. A subset of 165 cultural and 1136 natural site English-language articles published between 2016 and 2020 were selected (aligning broadly with assessment window of AR6 of the IPCC). Analyses were undertaken both globally and the different geographical regions defined in this assessment (see Supplementary Material 1): Global, Africa, Asia, Europe, North America, South America, Central America, Middle East, Australasia, Arctic, Small Island Developing States (SIDS), Antarctica, Oceans, Seas, and

Unsituated. As classifying the publications into regional coverage was not mutually exclusive, the final number of publications per geographical region is 167 and 1169 for cultural and natural heritage, respectively.

'Natural heritage' is herein used and understood as per the UNESCO World Heritage Convention (UNESCO, 1972), however, conservationists not working in the World Heritage (WH) context use the term 'protected areas' (IUCN World Commission on Protected Areas –IUCN WCPA). The term 'protected areas' covers a range of designations and IUCN WCPA has established six categories based on the management objectives of the different protected areas. Other terms used for specific types of protected areas are Indigenous and community conserved areas (ICCAs) and other effective area-based conservation measures (OECMs), the latter in the context of the Convention of Biological Diversity. Climate change research focusing on natural heritage uses terms connected to ecology and landscape ecology (e.g., ecosystems, ecosystems services, biodiversity, species, habitats, etc.) which refer to natural heritage.

For the purposes of this review, the presence of cultural heritage was acknowledged in many protected areas; for example, some protected areas are WH cultural properties (e.g., cultural landscapes), and yet in some protected areas cultural heritage is not recognised, especially that associated with local communities and Indigenous peoples. Modern nature conservation used the principle of eviction of Indigenous peoples and communities from national parks which were enclosed and freed from human intervention (except of that of the managers and researchers working in those protected areas along with visitors). Currently, within the nature conservation sector, the inclusion and recognition of Indigenous peoples has increased, as well as the role of protected areas within or adjacent to urban settlements, resulting in the concept of urban protected areas, and the development of the programme IUCN Urban Alliance, for example.

3.2 Regional analysis

The regional analysis was based on the systematic review (based on Web of Science) and an additional qualitative review. The qualitative regional assessment conducted a broader search by using other research databases such as Google Scholar, Science Direct, Taylor and Francis, Emerald, and Elsevier in order to include items that may be unavailable on the Web of Science database for reasons such as copyright or because the literature is considered as 'grey' literature. The countries assessed for each region are defined in Supplementary Material 1. The methods for Africa, the Middle East and the Americas are presented here. Although English was the language most frequently used in this regional assessment, researchers used Spanish, French, and Portuguese as needed. Additional literature explored for the regional qualitative assessment but not cited in the text is available in the Supplementary Material 2.

3.2.1 Africa and Middle East

For Africa and the Middle East, literature reviews were conducted at country level. Two searches were undertaken up to Page 10 on Google Scholar to capture non-peer-reviewed literature. The first used the search terms 'heritage', 'climate change', and 'country name', the second used the terms 'archaeology', 'climate change', and 'country name'. The search included all literature from 2011-2021 as well as select texts pre-2011. Both cultural and natural heritage literature were included in the search for the Middle East, while only cultural heritage was included in the African search. The assessment for Africa's natural heritage was obtained from the systematic review.

3.2.2 North, Central and South America, and the Arctic

The literature search was conducted using Google Scholar, Science Direct, Taylor and Francis, Emerald, Elsevier databases, in addition specific journals such as *International Journal on Heritage Studies* and *Journal of Cultural Heritage Management and Sustainable Development*.

The assessment used both Spanish and English (keywords in Spanish: Patrimonio Cultural, Cambio Climático, paisajes culturales, América, Peru, Colombia, Argentina, Bolivia, Chile, Ecuador, and keywords in English: cultural heritage, climate change, Canada, Colombia, Argentina, Bolivia, Chile, Ecuador, Canada, United States, Mexico). Not all countries in the South and Central America region were individually covered. Only articles that address climate change impacts to cultural (tangible and intangible) and natural heritage were compiled. The review was limited to literature that deals with impacts/threats to heritage from 2015-2021. Some additional articles were considered because of the focus or coverage, but none from earlier than 2010.

Mexico is regarded in the heritage literature as part of the Latin American region. In terms of both types of heritage and its official language (Spanish), heritage research in Mexico is aligned with Central and South America, including the Caribbean, since a long coastal area of Mexico is on the Caribbean Sea. Several island territories and other territories in the Caribbean and South America are territories of European states, so in terms of this research, they are connected to Europe; however, climate change impacts and types of heritage are connected to their geographical area. Several countries of those territories have English or French as their main language, which means that their scientific literature on heritage is written in those major languages.

3.3 The state of conservation system

The UNESCO State of the Conservation system (SOC) reports are classified into 14 factors affecting WH properties. The search in SOC was limited to the terms 'climate change and severe weather events' identified by the following sub-categories: storms (including tornadoes, hurricanes/cyclones, gales, hail damage, lightning strikes, river/stream overflows, extreme tides), flooding, drought, desertification, changes to oceanic waters (changes to water flow and circulation patterns at local, regional or global scale, changes to pH, changes to temperature), temperature change, and other climate change impacts. It is acknowledged that other events linked to climate change are categorised under different factors, such as wildfires under the factor 'sudden ecological or geological events' and 'local conditions affecting the physical fabric' that can be affected by climate change-induced change in humidity and temperature. However, these categories are not assessed in this global review.

4. Consideration of Heritage in Previous IPCC Reports

4.1 Coverage of heritage in earlier IPCC assessments (pre-2018)

The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications, and potential future risks, as well as to put forward adaptation and mitigation options. The IPCC prepares comprehensive assessment reports about the state of scientific knowledge on climate change, its impacts and future risks, and options for reducing the rate at which climate change is taking place.

IPCC reports have engaged with heritage and its respective literatures, including information on archaeological and historical investigation, ethnographies, and Indigenous, local, and traditional knowledge systems and practices (Kohler and Rockman, 2020), but it was not until the Fifth Assessment Report of the IPCC (AR5) that more substantive heritage aspects were considered (IPCC, 2014c; IPCC, 2014a; Kohler and Rockman, 2020). Across all AR5 reports (IPCC, 2013; IPCC, 2014a; IPCC, 2014b; IPCC, 2014d), discussions of heritage references impacts from climate change on cultural and natural landscapes, Indigenous peoples, and the use of traditional practices (Morel, 2018). There is a general inclusion of social and cultural determinants of vulnerability to climate change and climate hazards across the AR5 reports (Morel, 2018). Assessments of heritage that considered concerns of Indigenous peoples were under-represented prior to the 6th Assessment Report of the IPCC (AR6). However, references to Indigenous knowledge and local knowledge (LK) increased 60% from AR4 to AR5 (114 articles since 2014). Additionally, AR5 highlighted the exposures and vulnerabilities of Indigenous populations to climate change risks related to socioeconomic status, resource-based dependence, and geographic location (Ford et al., 2016; IPCC, 2019b) (see Glossary for working definitions of Indigenous knowledge and LK). There is increasing recognition that scholarly fields such as archaeology, which focus heavily on heritage, have more to offer than IPCC assessments have considered to date, particularly for understanding vulnerability to climate change and climate action (Kohler and Rockman, 2020; Morel and Ammerveld, 2021).

Loss and Damage (L&D) is now considered the third pillar of climate action under the UNFCCC (Mechler et al., 2019; van der Geest and Warner, 2020), alongside climate change mitigation and adaptation, and is an important framing for impacts, vulnerability, and risks to heritage from climate change. AR5 highlights future risks with emphasis on extreme weather events and economic impacts but gives less attention to observed and current losses and damages from slow-onset processes and non-economic losses (van der Geest and Warner, 2020), both of which are important for cultural and natural heritage (Mechler et al., 2020). Yet there are only two explicit heritage references in AR5 framed in terms of L&D, neither are quantified, and both reflect narrow geographic scope. The Summary for Policy Makers notes: 'Disaster loss estimates are lower-bound estimates because many impacts, such as loss of human lives, cultural heritage, and ecosystem services, are difficult to value and monetise, and thus they are poorly reflected in estimates of losses' (IPCC, 2014e: 19). Chapter 23 of AR5 notes, climate change and sea level rise may damage European cultural heritage, including buildings, local industries, landscapes, archaeological sites, and iconic places (IPCC, 2014b). In general, AR5 concentrates more on losses and damages in high-income regions, with less attention to regions that are most at risk, such as small island states (SIDS) and least developed countries for which the L&D mechanism was designed (van der Geest and Warner, 2020). This may arise from differences between regions; for example, in Europe there is greater focus on tangible cultural heritage (such as the historic built environment), with L&D quantified in that manner. In contrast, in SIDS or least developed countries, there is a greater focus on potential loss of settlements (which includes heritage) and intangible heritage that is not so easily quantifiable in economic terms. Whatever the reason, the lack of focus on L&D has potentially significant implications for heritage across these regions which stand to face undocumented impacts from climate change without recognition or possible compensation.

The impacts of climate-change related loss and damages on cultural expression are immeasurable, such as loss of identity associated with attachment to place, memory, ancestry, and memorialisation. This is particularly acute for small islands. The past is used by members of a group in forging identity. Social memory toggles between the past and present, relying on material mnemonics and ritualised traditions to reinforce and re-establish a sense of belonging to a place and to a group. The loss of a homeland is not simply a loss of tangible and intangible heritage, it is the loss of all of the physical, social, ideological, sacred, and treasured elements that come together and encapsulate who we are. This cannot be measured but the loss will be profound.

4.2 IPCC Special Reports

The IPCC produces special reports on topics agreed to by its member governments. This research was developed concurrently with and complements the publication of the WGII AR6 in July 2022 with a focus on the three special reports that were commissioned to provide scientific assessments of climate change: 1) global warming of 1.5°C above pre-industrial levels and the importance of keeping warming below 2°C (IPCC, 2018), 2) desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (IPCC, 2019a), and 3) the oceans and cryosphere (IPCC, 2019b).

4.2.1 IPCC Special Report on 1.5 degrees of warming

The IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways (SR 1.5), focuses on strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (IPCC, 2018). SR 1.5 identifies types of heritage impacted by climate change to include: environmental and cultural heritage (IPCC, 2018: 245), landscapes (IPCC, 2018: 256), Indigenous peoples and their livelihoods (IPCC, 2018: 9), the Arctic and its Indigenous people, coral reefs, mountain glaciers and biodiversity hotspots (IPCC, 2018: 11, 254), and UNESCO cultural World Heritage sites (Marzeion and Levermann, 2014; IPCC, 2018: 257). Although not explicitly referred to as heritage, the SR1.5, notes that there are 305 terrestrial animal and plant species from Pacific Island developing nations threatened by climate change and severe weather (IPCC, 2018: 218).

On balance, the SR1.5 emphasises how Indigenous knowledge and LK can inform adaptation, rather than focusing on Indigenous knowledge and LK systems themselves. Although impacts are assessed with confidence language they are never quantified. Impacts on Indigenous communities include the concerns, sovereignties, experiences, and accuracy in climate and weather predictions drawn from altered bioclimatic indicators.

The SR 1.5 climate hazards such as sea level rise (including associated salinisation, flooding, and erosion) (Marzeion and Levermann, 2014; IPCC, 2018: 257) tropical storms, and hurricanes (IPCC, 2018: 353) as posing a risk to heritage.

SR1.5 identifies the impacts of forced displacement and destruction of cultural heritages (IPCC, 2018: 353). This identification is relevant for assessing L&D from climate change, but not described as such. Impacts, risks, and vulnerabilities are described as being spatially located in the coastal zone for sea-level rise (Marzeion and Levermann, 2014; IPCC, 2018: 257) but without consistent spatial specificity for other heritage types, climate hazards or impacts which constrains the overall view of potential climate risk to heritage and culture. Impacts and risks are not explicitly linked to heritage dimension of wetlands (e.g., Ramsar sites) nor heritage in human settlements in the SR1.5.

4.2.2 IPCC Special Report on Land

The IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (IPCC, 2019a), (SRCCL) identifies the impacts, vulnerabilities, and risks to heritage including to cultural heritage (IPCC, 2019a: 53), Indigenous knowledge and LK systems, and practices regarding subsistence food practices (IPCC, 2019a: 470).

With over 200 references to Indigenous knowledge and LK in the SRCCL, significant emphasis is placed on the potential relationships between adaptation and heritage (e.g., Cross-Chapter Box 13 | Indigenous and local knowledge, IPCC 2019a). However, far less attention is paid to impacts on Indigenous knowledge and LK systems themselves; moreover, impacts are not quantified. Despite this, the SRCCL reports that 'there is robust evidence documenting the marginalisation or loss of Indigenous and local knowledge' associated with desertification in drylands (IPCC, 2019a: 284), and 'some evidence of urbanisation leading to the loss of Indigenous and local ecological knowledge' (IPCC, 2019a: 289).

No individual climate hazards are explicitly linked to heritage in the SRCCL, although there is recognition of the potential impact of 'extreme events on cultural heritage' (IPCC, 2019a: 688), and general reference to the interaction between climate change generally and land degradation as well as climate shocks on traditional food systems. Climate impacts and risk to heritage in the SRCCL makes no explicit connection to L&D from climate change to human settlements or wetlands (e.g., Ramsar sites).

4.2.3 IPCC Special Report on the Oceans and Cryosphere

The IPCC Special Report on Oceans and Cryosphere in a Changing Climate (IPCC, 2019b), commonly referred to as the SROCC, identifies impacts, vulnerabilities, and risks to heritage types including glaciers (IPCC, 2019b: 59, 171), coral reefs (Heron et al., 2017; IPCC, 2019b: 541), landscapes (IPCC, 2019b: 626), and Indigenous knowledge (IPCC, 2019b: 16). Forty-six UNESCO Natural World Heritage Sites (WHSs) include glaciers within their boundaries; of these, between 8 and 21 are predicted to experience a complete glacier extinction by 2100 (under medium and high emissions scenarios). This extinction would compromise the Outstanding Universal Value (OUV) placed on these natural WHSs (IPCC, 2019b: 171).

The SROCC discusses these risks to heritage from climate hazards: increased global average warming (IPCC, 2019b: 171), sea-level rise (IPCC, 2019b: 69), more powerful tropical storms (IPCC, 2019b: 171), flood outbursts (glacial), landslides and coastal erosion (IPCC, 2019b: 112), heat stress (Heron et al., 2017; IPCC, 2019b: 541), drought (agricultural and hydrological), and wildfire (lightning strikes).

The SROCC identifies the very high probability of severe impacts and risks from sea-level rise to Arctic communities and urban atoll islands, highlighting the differential impact on those with limited ability to adapt due to the limited adaptation options available, nature of the hazard or impacts, and compounding impact of hazards on socioeconomic vulnerabilities (IPCC, 2019a).

The 240 references to Indigenous knowledge and LK in the SROCC emphasise how they can inform adaptation (e.g., Cross-Chapter Box 4 | Indigenous and Local Knowledge in Ocean and Cryosphere Change, IPCC, 2019b). Less attention is paid to impacts on Indigenous knowledge and LK systems themselves, and where identified these impacts are not quantified. Impacts also include cultural loss associated with glacier retreat and changes in landscape, which affects food availability and access within herding, hunting, fishing, and gathering areas, harming the livelihoods and cultural identity of Arctic residents including Indigenous cultures (IPCC, 2019b,). These impacts can potentially lead to rapid and irreversible loss of culture, Indigenous knowledge, and LK (Ford et al., 2016; IPCC, 2019b, p. 664).

Geographically, heritage in the SROCC is described as at risk across Low-Lying Islands and Coasts (LLIC), including SIDS (IPCC, 2019b: 69), snow- and ice-covered peaks of mountainous regions (Bosson et al., 2019; IPCC, 2019b: 171), and coral reefs in shallow seas (Heron et al., 2017; IPCC, 2019b: 541). Also, the transboundary nature of climate change risk is acknowledged for culture (IPCC, 2019b, p. 45).

Climate impacts on and risk to heritage in the SROCC makes no explicit connection to L&D from climate change, human settlements nor wetlands (e.g., Ramsar sites).

4.3 Synthesis of IPCC Special Reports

Across the three IPCC special reports, the term ‘heritage’ is mentioned with explicit reference to impacts, vulnerability, or risks from climate change five times in SR1.5, 4 times in SRCCL, and six times in the SROCC. Although a broad range of heritage types and climate hazards are identified (see Table 1), there is no systematic approach to categorizing the impact, risk, and vulnerabilities of climate on heritage. Further, the impacts and risks that are identified are usually qualitatively described with little specificity, and only quantified in a handful of instances, once in the SR1.5 for risk from sea-level rise to coastal UNESCO World Heritage sites (Marzeion and Levermann, 2014; IPCC, 2018: 257), and twice in the SROCC including observed and projected impacts on two UNESCO listed natural site types, namely glaciers (Bosson et al., 2019; IPCC, 2019b: 171) and coral reefs (Heron et al., 2017; IPCC, 2019b: 541).

Table 1: Impacts and Risks to Heritage: *Synthesis across the three IPCC Special Reports (SR1.5, SRCCL, and SROCC)*

Range of heritage types assessed	UNESCO Cultural World Heritage sites UNESCO Natural World Heritage sites Environmental and cultural heritage Glaciers Biodiversity hotspots Coral reefs Landscapes Indigenous peoples and their livelihoods
Climate hazards identified to affect heritage	Sea-level rise (including associated salinisation, flooding, and erosion) Tropical storms and hurricanes Increased global average warming Flood outbursts (glacial) Landslides Coastal erosion Heat stress Drought (agricultural and hydrological) Wildfire (form increased aridity and lightning strikes)
Impact types (general)	Forced displacement Destruction of cultural heritages Burnt area Extinction Loss of 'Outstanding Universal Value' attributes
Impacts specific to Indigenous communities	Negative impacts on their sovereignties; experiences; food systems; food security; access to traditional fishing or hunting areas; traditional diets; aesthetic aspects; marine recreational activities; marginalisation or loss of indigenous and LK; cultural loss associated the glacier retreat and changes in landscape values; mental health; transport safety; knowledge about the ocean; rituals; self-sufficiency; marine recreational activities; and reduced accuracy in climate and weather prediction.
Geography/locations of impacts	Across Low-Lying Islands and Coasts (LLIC) Small Island Developing States (SIDS) Snow- and ice-covered peaks of mountainous regions Drylands Arctic Shallow seas (hosting coral reefs)

5. Approaches to Understanding Impacts and Risks from Climate Change to Heritage

5.1 General observations

Across professional and scholarly heritage literature and recent IPCC reports, different priorities shape the way in which terms such as 'risk' and 'loss and damage' are conceptualised, defined, and used (see Table 2). There are a few existing areas of potential cross-walk between heritage and IPCC terms, depending on the focus of the research, and both orientation and the composition of the author team.

Table 2: Common Terms in IPCC and Heritage Literature

Heritage application of term	Terminology	IPCC application of term
Used interchangeably with threats, no specific usage	**Risk**	Specifically defined, measurable with confidence statements of uncertainty
Used interchangeably with threats, no specific usage	**Hazard**	A determinant of risk
Broad definition used	**Exposure**	A determinant of risk
Broad definition used	**Vulnerability**	A determinant of risk
'Loss and Damage' and 'loss and damage' used interchangeably	**Loss and damage**	Uppercase L&D and lowercase losses and damages define different kinds of loss and damage
Broad use of the term	**Mitigation**	Wide application unless used in relation to greenhouse gas emissions then strictly defined
Used mostly in the context of the ability of heritage to adapt	**Adaptation**	Used almost always in the context of human and natural systems

There exist broad disparities in structure, focus, terminology, and language between different scientific and professional bodies, and academic disciplines, represented by IPCC and heritage fields. In IPCC reports, 'risk' is measurable and includes confidence statements of uncertainty. Scholarly heritage literature almost never conceptualises risk as a measurable outcome of the interaction of hazards, exposure, and vulnerability. 'Mitigation' is used according to its broad definition in heritage fields, namely the action of reducing the severity, seriousness, or painfulness of something, but also in some cases in its narrow IPCC definition when prefaced by term 'greenhouse gas' mitigation. While IPCC usage of the term adaptation is common in the context of human and natural systems, in heritage literatures it is used to describe the ability of heritage to adapt.

On the other hand, UNESCO has been exploring and managing the impacts of climate change on WH. In 2006, UNESCO prepared a report on predicting and managing the impacts of climate change on world heritage and provided a strategy to assist parties in implementing appropriate management responses. This report was followed in 2008 by a compilation of case studies on climate change and world heritage, and a policy document on the impacts of climate change on world heritage properties. In November 2015, the General Assembly of States Parties to the World Heritage Convention adopted a new policy on sustainable development, which integrated strengthening resilience to natural hazards and climate change (UNESCO-WHC, 2021).

In general, where the authorship of climate change /heritage literature includes a climate scientist there is better alignment of uses of both heritage and IPCC terms. The recent report by ICOMOS, *The Future of Our Pasts* (International Council on Monuments and Sites (ICOMOS) Climate Change and Cultural Heritage Working Group, 2019) aligns closely with the structure, terminology and language of IPCC reports while heritage remains the principal focus of the report; it is a potential model for climate change / heritage professional reporting. In IUCN reports, 'risk' aligns with IPCC usage of the term. However, despite UNESCO's long-standing engagement with climate change considerations, their recent climate change / heritage reports do not align closely with the structure, terminology, and language used in IPCC reports.

5.2 Risk

The IPCC definition of risk considers 'the potential for adverse consequences.' Hazards, exposure, vulnerability, and response to climate change interact to create risk (Reisinger et al., 2020) (Figure 1).

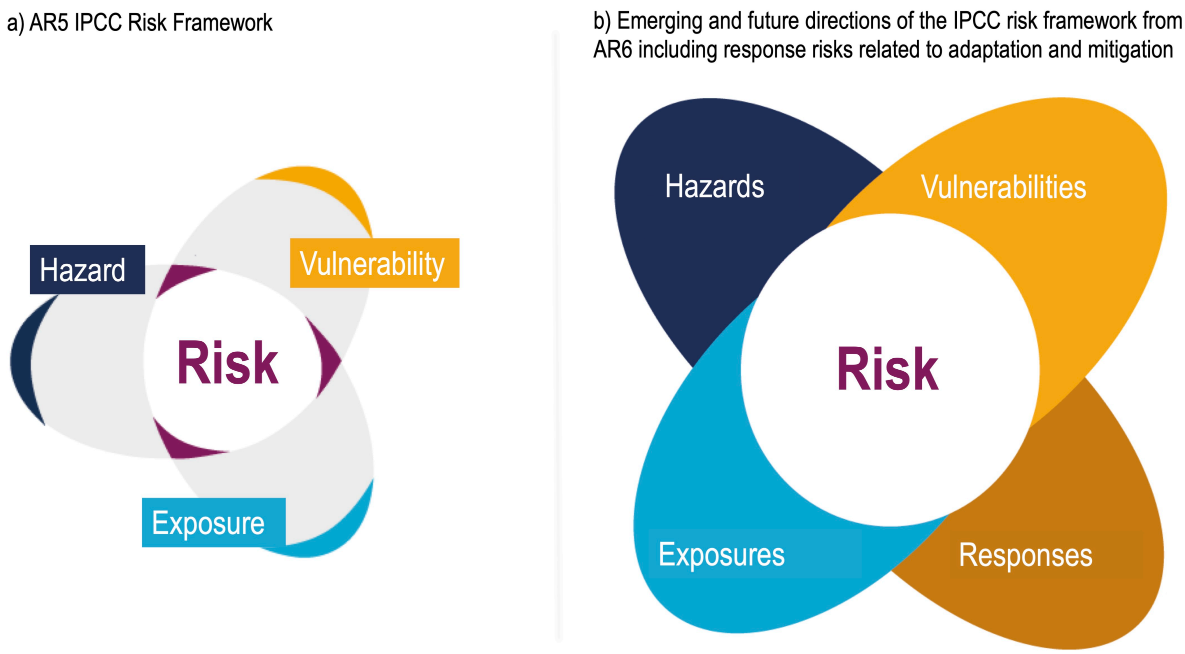


Figure 1: The IPCC Risk Framework

(a) An explicit risk framing emerged in the IPCC SREX and WGII AR5 where risk is conceptualised as a function of the interaction of climate hazards, vulnerability and exposure. (b) Since AR6, the role of responses to climate change in modulating the determinants of risk is a new emphasis and one important to heritage management and adaptation to climate change. The petals now also recognise multiple determinants of risk in hazards, vulnerabilities, exposures and responses to better represent the ways in which responses modulate each of these risk determinants and capture the multidimensionality and complexity of climate change risk (Ara Begum et. al., 2022).

A significant change from previous reports is that risk involves 'impacts' and 'responses,' to climate change (Simpson et al., 2021)[1, 2]. The determinants of risk are:

- The magnitude and likelihood of climate-related hazards,
- Level of exposure, and
- Degree of vulnerability,

While risk from responses can also include the:

- Inability to achieve intended objectives,
- Negative side-effects of response implementation (Reisinger et al., 2020; Simpson et al., 2021; IPCC, 2022).

Hazard, exposure, and vulnerability are terms that can be applied to understand how heritage values may be impacted by climate change and how heritage differs in relation to likely impact and options for management and adaptation. For example, Forino et al. (2016) developed a Cultural Heritage Risk Index based upon the formal integration of hazard, exposure, and vulnerability as determinants of risk (see Box 1).

In 2007, UNESCO reviewed the principal climate change risks and impacts on cultural heritage and on WH properties worldwide (Colette et al., 2007). Although based only on a qualitative survey, they estimated that 125 WHSs were threatened by climate change. In Table 1 of that assessment, climate change risk is used as a proxy of climate hazards highlighting inconsistency with IPCC usage of the term. There is also a preference in Colette et al. (2007) to use the terms 'climate change threats' or 'climate threats' as categories for climate hazards such as hurricanes or sea-level rise, which does not align with IPCC usage of terms.

How responses to climate change affect vulnerability and exposure is increasingly important considering interventions can be applied to decrease its vulnerability (Forino et al., 2016). Yet there are observed and projected limits to adaptation that result in residual risk, and in cases where inappropriate responses with unintended consequences can lead to maladaptation (Berrang-Ford et al., 2021; Eriksen et al., 2021; Simpson et al., 2021). Maladaptation is an important IPCC term concerning risk to heritage as it captures how actions may lead to increased risk of adverse climate-

[1] In AR6 risk is defined as 'The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making (see also risk management, adaptation and mitigation). In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs) (see also risk trade-off). Risks can arise for example from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions. See also Hazard and Impacts (consequences, outcomes).'

[2] The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

related outcomes, increased vulnerability or exposure to climate change, or diminished welfare, now or in the future, diminishing the heritage's capacity to cope and adapt (IPCC, 2019b)

Box 1: Applying the IPCC Risk Framework: Djenné Traditional Building Methods, Mali

Inhabited since 250 B.C., Djenné is characterised by the intensive and remarkable use of earth, specifically in its architecture. The city's mosque, which is of great monumental and religious value, is an example of this. The town is renowned for its civic constructions, using the distinctive style of verticality and buttresses. It is also known for elegant houses with intricate facades. These traditional houses, of which nearly 2,000 have survived, are built on hillocks as protection from the seasonal floods (UNESCO-WHC, 2021).

Increasing variability in rainfall and temperature (hazard) has increased risk to the Djenné mosque and the town's traditional building methods. Low rainfall affects mud quality by lowering river levels and reducing fish stocks. Reduced ability to effectively re-mud traditional buildings increases the exposure of the buildings and interrupts traditional knowledge and practices tied to re-mudding performances, negatively impacting intangible cultural heritage elements. Changes in rainfall and temperature also diminish response options, because calcified fish bones are needed for good quality mud. Poverty makes it difficult to buy good quality mud, which increases pre-existing vulnerability and erodes capacity for adaptation and site protections (Joy, 2016; Brooks et al., 2020; Siriman and Wang, 2021). This case also highlights how impacts on tangible heritage are interconnected with impacts on intangible heritage (Simpson et al., 2022).

In contrast, scientific heritage literature uses the term risk in multiple ways. Examples include 'climate risk' or 'significant risk' (Markham et al., 2016) and risk is used interchangeably with the term 'threat.' Heritage practice descriptors of 'flood risk' or 'climate risk' used in heritage literatures are technically incorrect uses of the IPCC term (e.g., (Carmichael et al., 2018; UNESCO-WHC, 2021). In scientific heritage literature, the IPCC determinants of risk (exposure, hazard, vulnerability, and response) are generally used in isolation and separate from risk.

There is no definition for 'threat' in current IPCC glossaries nor in heritage literature. UNESCO uses the term factors (https://whc.unesco.org/en/factors/) but 'threat' is largely used in the scientific literature. In some academic heritage literature 'threat' and 'hazard' are used interchangeably which conflates the IPCC usage of hazard as a determinant of risk (e.g., (Carmichael et al., 2018; Bosher et al., 2020).

5.3 Loss and Damage

The SR1.5 states that 'Loss and Damage' (capitalised letters) refers to the impacts of climate change, including extreme events and slow-onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change. Lowercase 'loss and damage' has been taken to refer broadly to harm from *observed* impacts and *projected* risks. The UNFCCC now acknowledges that real limits to adaptation are likely, highlighting the importance of L&D (Tschakert et al., 2017). The IPCC changed its definition of the terms 'loss and damage' in the IPCC (2019a) to reflect the (United Nations Framework Convention on Climate Change (UNFCCC), 2013) recognition of these limits and trade-offs and to differentiate between the political debate over L&D for SIDS (Boyd et al., 2017; Mechler et al., 2019) and generic losses and damages.

Heritage is impacted by both L&D (across SIDS) and losses and damages to heritage generally. For heritage, L&D refers to adverse measured outcomes to both tangible (loss and damage) and intangible (loss) aspects of cultural and ecological systems due to climate change (IPCC, 2014a; IPCC, 2018; IPCC, 2019a).

UNESCO (2021) refers to L&D and loss and damage interchangeably and has not yet distinguished between L&D and 'losses and damages', highlighting the need for clearer guidance on the use of both terms (Mechler et al., 2019). Further, the IUCN (Bennun et al., 2021) use 'loss' on its own to refer to biodiversity loss, habitat loss and loss or gains (see also IPCC, 2019a).

6. Geographical Distribution

This section first presents a global view of the distribution of climate change / heritage research and then regional assessments for Africa, Asia, Australasia, Antarctica, Europe, Middle East, North America, the Arctic, Small Islands and Developing States, and South and Central America. Potential factors affecting the global distribution of the production of climate change / heritage knowledge and its consequences are discussed in Section 10.1.

In general, there is a global imbalance in the number of publications assessing the impact of climate change on heritage between different regions. Regional, national and sub-national disparities are also observed (e.g., between eastern and western Australia). As a result, it is difficult to know if what we know about climate impacts on and risks to heritage is just a reflection of where the science is funded rather than where or when heritage is actually being affected by climate change.

6.1 Global distribution

The global distribution of published scientific and professional literature informs the state of knowledge regarding types, diversity, and severity of climate impacts on heritage. Concentrations of known impacts tend to align with locations of research production and heritage practice, as well as nodes of recognised heritage, rather than by global distribution of heritage vulnerability to climate change. The following geographic analysis highlights what is currently known, while also identifying regions in which knowledge of effects and consequences of climate change for heritage is lacking.

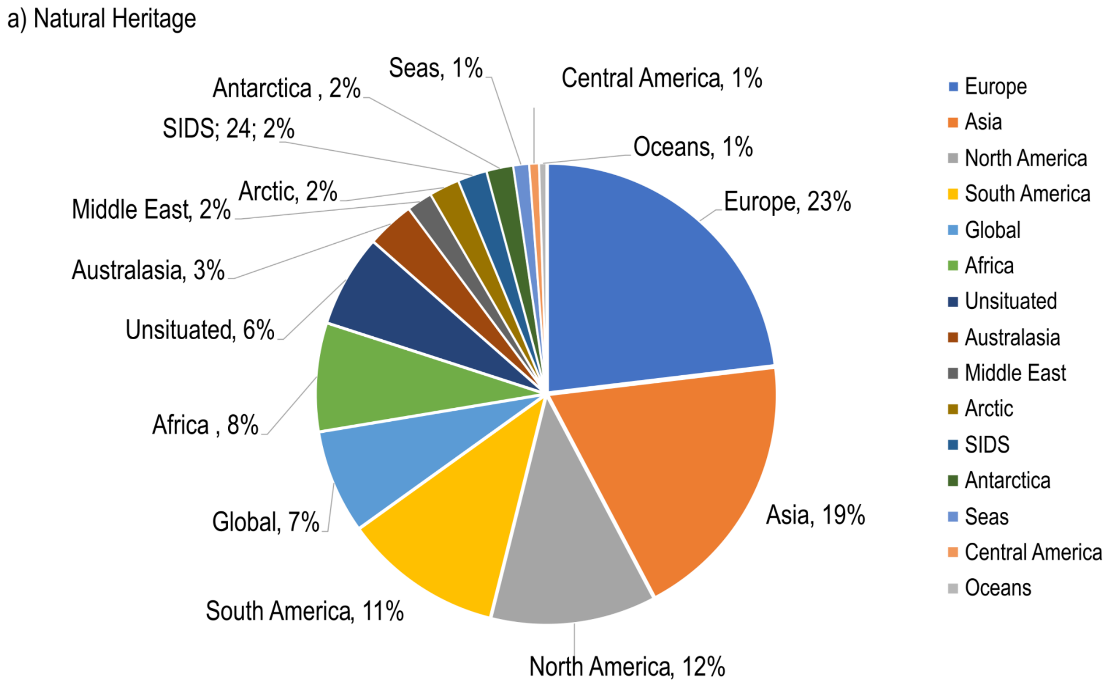
The distribution of climate change heritage literature (in English) is highly diversified and disparate depending on the geographical regions and the type of heritage (Figure 2). The term 'heritage' is not used consistently in the literature: very few publications about natural heritage (5%, n=63) used the term 'heritage' compared with most publications for cultural heritage (85%, n=141).

Cultural heritage literature, which accounts for 13% of this assessment, is concentrated in Europe and North America (56% of cultural climate change / heritage literature). Global studies, analysing climate change effects on cultural heritage, focus on the impacts on the heritage tourism sector (Hall, 2016; Hall et al., 2016). Additionally, global studies document the use of the communicative power of heritage, as well as organisations such as UNESCO or the Society for American Archaeology, to mobilise stakeholders around climate adaptation and mitigation (Samuels, 2016; McGovern, 2018; Lafrenz Samuels and Platts, 2020). While research on climate adaptation and mitigation strategies for the cultural heritage field has been growing since 2017, it is still relatively limited in comparison to research on the physical impacts of climate change on individual buildings, monuments, or sites (Orr et al., 2021). The impacts of climate change on the broader economic, social, and cultural value of cultural heritage (besides tourism), are not investigated globally and rarely explored regionally or locally.

Few papers have discussed the effects of climate change on maritime archaeological heritage. Although the field is strategically positioned to engage with climate change and sea-level rise science (McDonald, 2015), maritime archaeologists are rarely involved in the climate discussion (Wright, 2016). Underwater archaeological sites, historic buildings, and cultural landscapes are perceived at risk from sea-level rise through the deterioration of their equilibrium with their environment (Perez-

Alvaro, 2016; Wright, 2016). In addition to impacting the submerged heritage, sea-level rise could inundate 136 WHSs by 2100 (Perez-Alvaro, 2016). Scientists have deemed measures for mitigating climate change impacts on cultural submerged sites and coastal archaeology insufficient, and called for increased protection of these sites.

Glacial archaeology is a sub-discipline within archaeological and heritage studies that has emerged in the last decade. Due to the global distribution of glaciers, this field is inherently interdisciplinary, international, and integral to the science of climate change (Dixon et al., 2014). The discovery of Ötzi the Iceman, found eroding from the ice in the Tyrolean Alps in 1991, was a catalyst for action amongst archaeologists who recognised the tension between extraordinary preservation of ice patch remains and their fragility once exposed (Taylor et al., 2021). The vast majority of ice patch finds worldwide have been recovered in three major regions: the Alps, Norway, and northern North America (Reckin, 2013), but accelerating global warming will undoubtedly bring to light more archaeological remains in the coming decades, which will require increasing sophistication in scientific methods of recovery, analysis, and interpretation (Taylor et al., 2021). Ötzi demonstrated how site contamination leads to significant loss of information, demonstrating that archaeological remains emerging from ice melt should be treated forensically for full recovery (Holden, 2003; Müller et al., 2003; Oeggl, 2009). In many regions throughout the world, Indigenous people occupy high altitude and high latitude environments, and their knowledge and observations can provide important sources of information about climate change impacts on glaciers, which can inform archaeological recovery (Taylor et al., 2019; Taylor et al., 2021). Working with Indigenous communities to better understand the landscapes where ice patch finds have been recovered have successfully enabled the prediction of the locations of further archaeologically rich ice patches (Reckin, 2013) that are in danger of exposure.



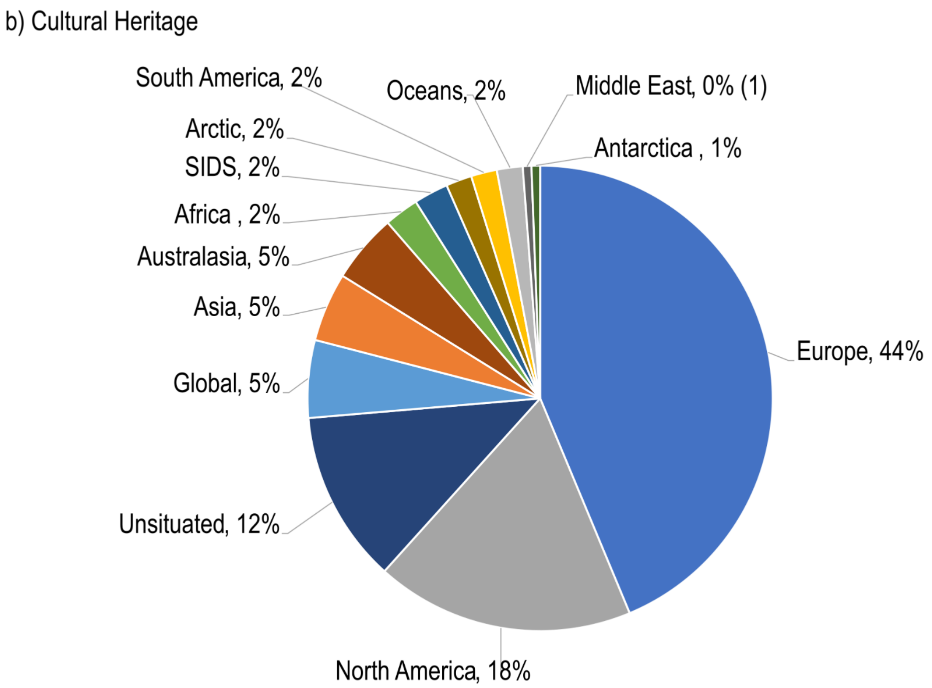


Figure 2: Regional Distribution of English Language Scientific Literature on Climate Change and Natural and Cultural Heritage based on a Systematic Review

a) Literature on natural heritage shows concentrations in Europe (blue) and Asia (orange). b) Literature on cultural heritage shows a concentration in Europe (blue) followed by North America (grey).

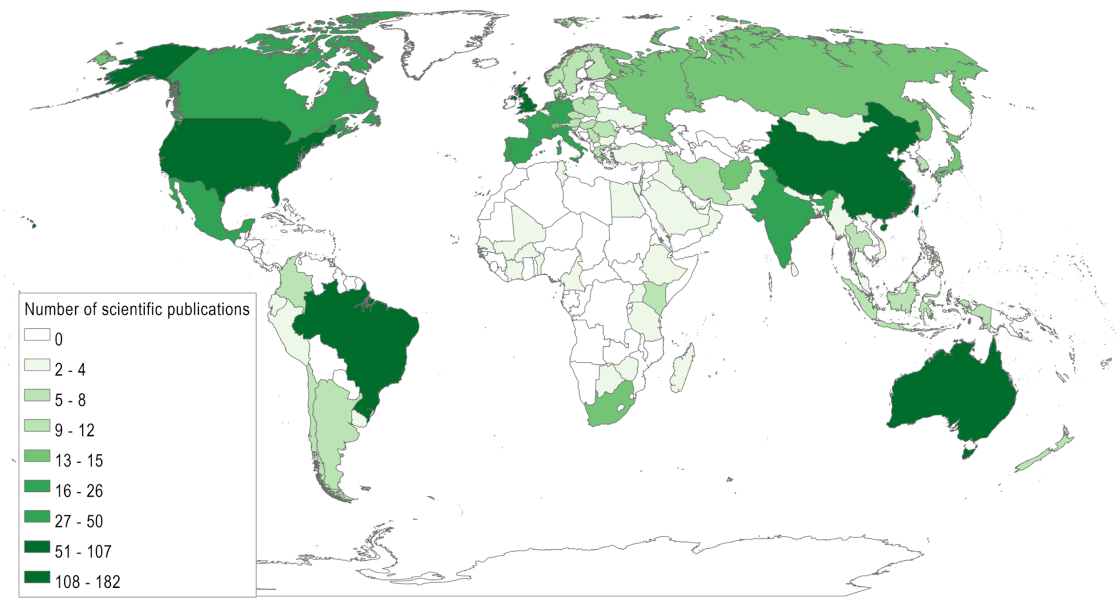
Natural heritage literature accounts for 87% of the review. Sixty-five percent of these publications covered Europe (23%), Asia (19%), North America (12%) and South America (11%). Half of the publications had their main interest in biodiversity conservation, environmental sciences and ecology (n=580). About 10% of the publications were multidisciplinary. Only seven multidisciplinary publications explored the social or socioeconomic impacts of climate change on natural heritage sites; (Weijerman et al., 2016), assesses management scenarios. Other articles consider tools for decision-making and their impact on the socio-ecological costs and benefits (including traditional and non-traditional approaches, local communities and regional and national planning strategies) (Carmenta et al., 2016; Cuenca et al., 2018; Vale et al., 2018; Tittensor Derek et al.; Boschetti et al., 2020). Likewise, only a few articles (n=11, Global, South and North America and SIDS) analyse the effects of climate change on ecosystem services. In order to respond to the dynamic climate-biodiversity reality and support the durability of ecosystem services, the international community must strengthen biodiversity conservation through restoration efforts (Shaver and Silliman, 2017) and adopt proactive management reforms (in conjunction with reactive management), including climate change adaptation strategies (Tittensor Derek et al.; Hutchings et al., 2020). Restoration and conservation of protected areas are part of natural climate solutions (Griscom Bronson et al., 2017) and nature-based solutions (https://www.iucn.org/theme/nature-based-solutions) that have the potential for large additional climate mitigation and support the delivery of the Paris Climate Agreement (Dinerstein et al., 2019).

Climate change impacts literature focusing on natural maritime heritage has explored climatic variability, ecosystem health, decision-making, and protected areas connectivity. It includes sea-level rise impacts on sea turtle nesting beaches (Great Barrier Reef Foundation, 2012; Varela et al., 2019), the linkage between climate change and challenges faced in the governance of marine protected areas and territories (Anne et al., 2018; Morrison et al., 2019), and climate change effects on coral reefs and other coastal vegetated systems (Ellison, 1994; Perry et al., 2018; Fine et al., 2019). Coastal ecosystems (e.g., mangroves, reefs, sea grasses, or sand dunes) play an important role in responses to coastal adaptation to future sea-level rise, erosion and flooding, and are key components of coastal human and non-human systems resilience to future climatic changes (Spalding et al., 2014; Pascal et al., 2016; World Bank Group, 2016; Gracia et al., 2018).

Polar regions are undergoing important changes in the land and seascape which are particularly vulnerable to climate change (Wenzel et al., 2016). In 2017, there was an ice volume of 12,000 km3 stored in WH glaciers. By 2100, 33% to 60% of that cumulative ice volume is expected to be lost (Bosson et al., 2019). World Heritage glaciers are suggested to be analogous to endangered umbrella, keystone, and flagship species, whose conservation would secure wider environmental and social benefits at global scale (Bosson et al., 2019). Natural heritage literature of the polar regions covered the impact of climate change on Arctic and Antarctic and maritime heritage sites. The global analysis included assessments of marine conservation challenges (Harris et al., 2018; Pudełko et al., 2018), exploration of marine conservation tools and approaches (Wenzel et al., 2016; Nyman, 2018), evaluation of the marine protected areas scenarios and effectiveness (Hughes et al., 2016; Dahood et al., 2020), and biodiversity monitoring (Parker et al., 2019).

Eighty-three percent of first authors of publications related to cultural sites are based within Europe (50%) or North America (33%), resulting in a Euro-American centricity of production of cultural climate change / heritage research. For natural heritage, Asia claims nearly a quarter, decreasing the contributions of European (35%) and North American (22%) authors (see Figure 3).

a) Natural Heritage



b) Cultural Heritage

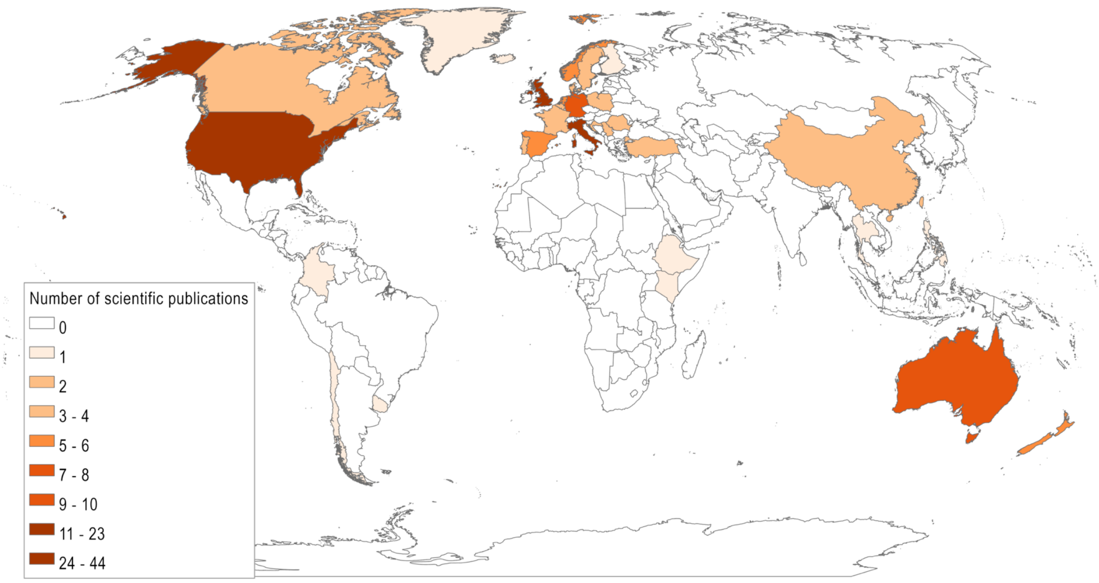


Figure 3: Country-based Distribution of First-Author Affiliations for Natural and Cultural Heritage Sites for English Language Scientific Publications.

a) Distribution of first author affiliations for climate change and natural heritage literature shows the highest concentrations in China, Australia, the United Kingdom, Brazil, the United States of America and Alaska. b) Distribution of first author affiliations for climate change and cultural heritage shows the highest concentrations in Italy, the United Kingdom, the United States of America, and Alaska.

Since 1985, 89 WHSs were impacted by climate change, with 27% situated in Africa (n=24) (see Table 3). Table 3 lists the 89 WHSs that have been included on the List in Danger since 1985 (currently 52 sites are considered in danger); 14 of these were listed because of climate change. The List in Danger intends to increase international awareness of the threats and encourage counteractive measures and international cooperation. Among the 14 sites endangered by climate change there is a predominance of cultural sites (n=10). Africa and the Middle East have the highest number of WHSs in danger from climate change (n=8, 60%). Natural WHS endangered by climate change are situated in Africa, Central America, North America, and SIDS, while cultural sites are in Africa, Asia, South America, and the Middle East.

Table 3: World Heritage Sites Impacted by Climate Change

Number of World Heritage Sites for which the Outstanding Universal Value (OUV) was impacted by climate change from 1985, and number of sites listed in the List in Danger with a focus on sites endangered by climate change (created using UNESCO World Heritage Centre State of Conservation Information System (SOC) – https://whc.unesco.org/en/soc/). The number of sites (total and in the List in Danger) affected by climate change are highlighted in yellow (CC = number affected by climate change; LD = number in the List in Danger; LD CC = number in the List in Danger and affected by Climate Change). Note: This table does not reflect the full range of heritage at risk from climate change, but those recognised WHSs that can be measured. There is likely a vast number of unrecognised sites that are more vulnerable due to climate and non-climatic factors which also require urgent assessment.

Regions	Word heritage impacted by climate change (CC)	Percentage (%)	State parties CC	Natura l CC	Cultural CC	Mixed CC	List in Danger (LD)	State parties LD	Natural LD	Cultural LD	Mixed LD	List in Danger climate change (LD CC)	State parties LD CC	Natural LD CC	Cultural LD CC
Africa	24	27%	19	6	17	1	35	18	17	17	1	4	4	1	3
Europe	21	24%	11	3	17	0	14	11	2	12	0	0	0	0	0
Asia	15	17%	12	7	8	0	10	8	2	8	0	1	1	0	1
South America	8	9%	5	0	7	1	9	8	5	4	0	2	2	0	2
Central America	7	8%	4	1	5	1	2	2	1	1	0	1	1	1	0
Middle East	6	7%	4	1	5	0	14	5	0	14	0	4	2	0	4
North America	4	4%	4	3	0	0	2	1	2	0	0	1	1	1	0
Australasia	2	2%	1	2	0	0	0	0	0	0	0	0	0	0	0
SIDS	2	2%	2	1	3	0	3	3	2	1	0	1	1	1	0
Global	89	100%	62	24	62	3	89	56	31	57	1	14	12	4	10

Importantly, WH threats reporting and the 'in danger' listing process are not a comprehensive record of all climate risk to WHSs. A 2020 analysis of 238 natural sites revealed that there are at least 41 natural sites that have never been certified as in danger, despite reported threats that are equal to or higher in intensity than those that have been certified as in danger (Morrison et al., 2020a; Morrison et al., 2020b). These 'technically in danger' sites (see Figure 4) include places like the Great Barrier Reef, which has been severely impacted by climate change in recent years but remains off the List in Danger (Morrison, 2021). A subsequent analysis of all 29 World Heritage-listed reefs confirmed substantial under-reporting of climate impacts across all reefs (Morrison et al., 2020a; Morrison, 2021). Indeed, while it was known that the first World Heritage-listed coral reef bleached in 1979, climate reporting did not actually commence until 1991. Further, while UNESCO reporting on climate change has steadily increased–mainly as a result of a series of environmental NGO petitions–it still maintains a significant time lag (up to 10 years in some cases). These deficiencies reflect the fact that UNESCO has traditionally shied away from seeking to influence nonlocal threats like climate change, effectively delegating responsibility to other conventions (e.g., the UN Framework Convention on Climate Change) (Morrison et al., 2020b). Some nation-states also engage in counter-productive strategies to keep their sites off the List in Danger and prevent UNESCO from using climate impacts as a reason for listing a site as in danger. These counter-productive strategies are typically driven by nations with low economic complexity and high dependence on limited high-value natural resource industries (e.g., mining), irrespective of overall level of economic development (Morrison et al., 2020b; Morrison, 2021).

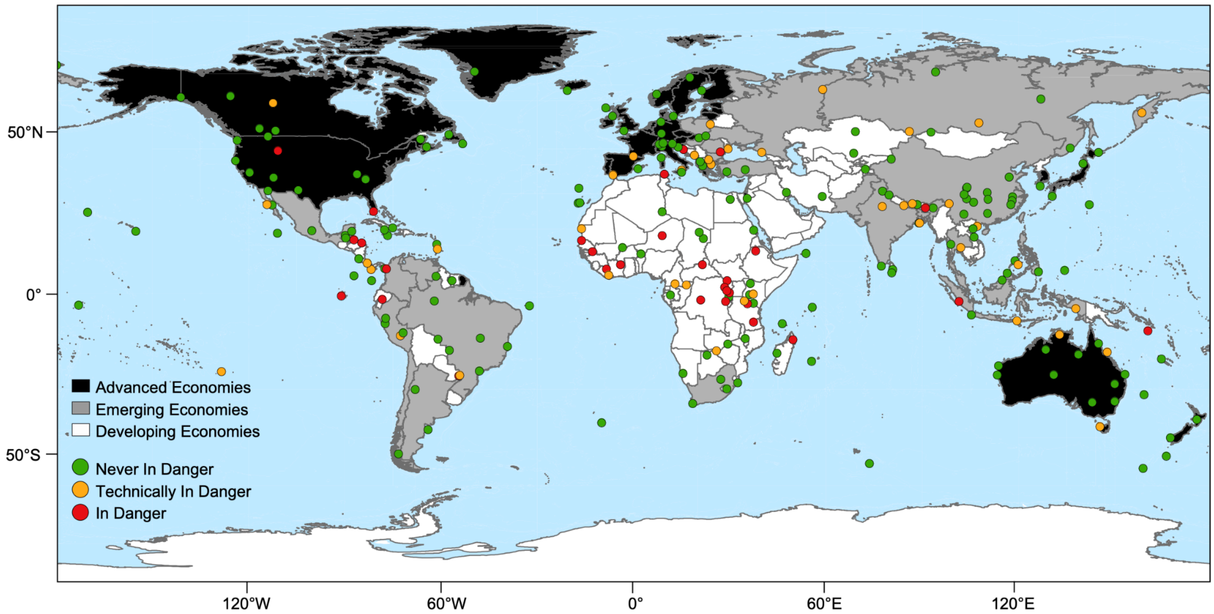


Figure 4: Emergence of 'Technically in Danger' Natural WH Sites

Figure 4 shows reporting, deliberation and certification patterns for 238 natural and mixed (natural and cultural) sites were assessed; 41 sites have never been certified as WH in Danger despite reported threats that are equal to or higher in intensity than those certified as WH in Danger (reproduced with permission from Morrison et al., 2020b).

A nature-culture dichotomy affects the objectives and foci of research in nature conservation and cultural heritage sectors. The near absence of the concept of heritage from the natural conservation sphere might be linked to the notion of heritage being rooted in heritage conservation, for example of works of art. In actuality, 'natural features, geological and physiographical formations' of specific value have been widely and internationally characterised as heritage in the 1972 UNESCO's World Heritage Convention (UNESCO, 1972). Although this dichotomy can be useful to acknowledge the intrinsic value of nature (Kopnina, 2016), and for a more nuanced understanding of how people relate to the non-human, especially for Indigenous cultures (Nadasdy, 2005), it is essential to support inter-, multi-, and transdisciplinary approaches to heritage research and management towards climate resilience (Fatorić and Seekamp, 2017; Orr et al., 2021).

Box 2: Intangible Cultural Heritage and Climate Change

Intangible cultural heritage, or living heritage, refers to the practices, representations, expressions, knowledge and skills, that communities pass on from generation to generation in response to their environment, their interaction with nature, and their history (UNESCO, 2003, Article 2). Living heritage therefore embodies human experience accumulated over centuries, while at the same time being dynamic and responsive to the context and needs of each generation.

In 2020, the UNESCO General Assembly of States Party adopted the 'Operational Principles and Modalities for Safeguarding Intangible Cultural Heritage in Emergencies' [https://ich.unesco.org/en/operational-principles-and-modalities-in-emergencies-01143].

These principles have the dual role of intangible cultural heritage in emergencies such as those related to climate change. Intangible cultural heritage is simultaneously under threat from emergencies and a valuable resource drawn on by communities to help them prepare for, respond to, and recover from various types of emergency situations. In the context of the rising number of climate-change induced disasters, they prompt communities to think about how intangible cultural heritage may be at risk from climate change and how it may adapt to changing circumstances. Additionally, there are different uses for intangible cultural heritage in terms of monitoring climate change effects, societal adaptation, and in fostering community resilience for climate change mitigation (UNESCO-WHC, 2021).

As the primary safeguarding actors, communities should always be involved in the identification of how their living heritage may be affected by climate change and what measures are needed to safeguard it. Communities should also be involved in discussions about how they might draw on their living heritage as a resource for enhancing their resilience to climate change and for facilitating recovery from climate-related disasters. The methodology of community-based needs identifications, as described in the 'Operational Principles and Modalities', can serve as a starting point when reviewing the impact of climate change on specific traditions and practices, and for understanding how their safeguarding may help communities address the multiple challenges they face. Such an approach is instrumental for developing context-specific safeguarding actions that respond to concrete needs of communities on the ground (UNESCO-WHC, 2021).

6.2 Regional analysis

The following sections will provide a regional analysis of the geographic distribution of impacts, vulnerability and understanding risks as represented in the literature. Regions covered generally align with the continental regions of the IPCC and include Africa; Asia; Australia, New Zealand and Antarctica; Europe; the Middle East; North America and the Arctic; Small Islands; and South and Central America. Supplemental Material 1 identifies the countries that are classified within each region.

6.2.1 Africa

Africa is culturally rich, contains a wide diversity of heritage types, and each country has domestic priorities concerning the safeguarding of its cultural heritage. For the purposes of this analysis, North African countries have been incorporated into the African continent following IPCC conventions, although UNESCO recognises North Africa as part of the Arab states.

Less than two percent of global literature on climate change and cultural heritage research has focused on African heritage (Fatorić and Seekamp, 2017), leaving the continent poorly represented in the most recent global literature reviews of climate change / heritage literature (Brooks et al., 2020; Orr et al., 2021; Westley et al., 2021). Although representing 16% of the total world population, only eight percent of global literature on climate change and cultural heritage research has focused on African heritage (Fatorić and Seekamp, 2017). Socioeconomic factors such as poverty and low levels of climate literacy compound the paucity of scholarly literature on climate change / heritage impacts on the African continent (Simpson et al., 2021).

In general, natural heritage sites have received the most research attention in Africa. There are four African WHSs on the endangered list where climate change is reported as a factor:

- Niokolo-Koba National Park, Senegal,
- Archaeological Site of Leptis Magna, Libya,
- Timbuktu, Mali,
- Royal Palaces of Abomey, Benin.

Recently, UNESCO has highlighted other sites that might be at threat of global warming and sea-level rise or encroachment of the Sahara Desert:

- Bwindi Impenetrable National Park, Uganda,
- the Ruins of Kilwa Kisiwani and Songo Mnara, United Republic of Tanzania,
- the Cape Floral Region Protected Areas, South Africa,
- Lake Malawi National Park, Malawi
- the Ancient Ksours of Mauritania (Markham et al., 2016).

There has been a considerable increase in literature written about Africa in the past five years. Seventy-seven percent of climate change-cultural heritage literature about Africa has been written since 2015. Kenya, Egypt, and Ghana are comprehensively represented in the literature. Countries with limited literature were distributed across the whole continent but primarily clustered in Southern

Africa (Botswana, Namibia, and South Africa), Central Africa (Angola, Cameroon, and Congo) and North Africa (Tunisia and Algeria) (Figure 5). South Africa, the best-funded country in Africa for climate change research, has very few articles relating to climate change impacts on cultural heritage, three in total and only one since 2015. Instead, South Africa's literature on cultural heritage concentrates on post-apartheid reconstructions of heritage, supporting the view that research interests tend to follow key national policy concerns. However, South Africa had the highest number of natural-heritage-climate publications in comparison to the other African countries (n=15). Not all countries in Africa have literature on climate change impacts on cultural heritage (of the 54 countries in Africa, only 15 had literature on climate change's impacts on cultural heritage prior to 2010, and only 21 countries in 2015) with at least one country in every region not represented by climate change-cultural heritage literature. The distribution of the literature appears to be affected by factors including climate change research funding, national / governmental policies (e.g., tourism or environmental sustainability) and the interest of countries or scholars in climate change impacts on cultural heritage.

There is a clear division in the focus of climate change-cultural heritage literature between North Africa and sub-Saharan Africa (see Figure 5). North African literature is focused on climate change considerations for archaeological and built heritage, often related to tourism, whereas literature in west, central, south and east Africa concentrates on sustainability through traditional livelihoods and knowledge. This may have a historical relationship with European archaeological exploration of 'Old World' archaeology in North Africa, which has subsequently become important for tourist income from the Global North where people have traditionally had an interest in classical and 'Old World' heritage.

There is a clear distinction between the emphasis on tangible heritage in North Africa when compared with the rest of Africa (Figure 6). East Africa stands out with the greatest difference between tangible and intangible heritage with almost three times the number of publications on intangible heritage.

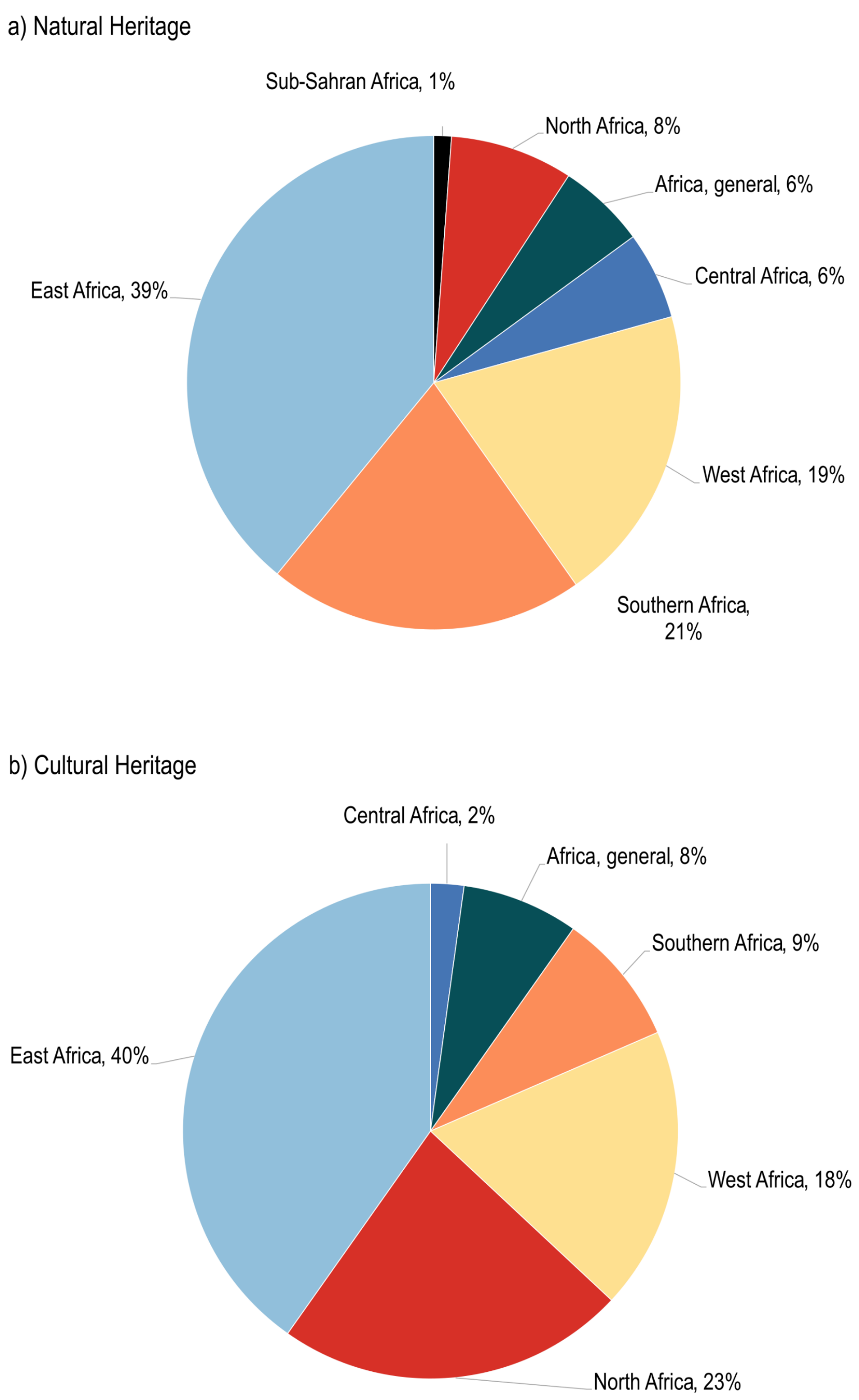


Figure 5: Regional Distribution of Climate Change and Cultural Heritage Literature in Africa.

a) Literature on natural heritage shows concentrations in East Africa (sky blue), Southern Africa (orange) and West Africa (yellow).
b) Literature on cultural heritage shows concentrations in East Africa (sky blue), North Africa (red) and West Africa (yellow).

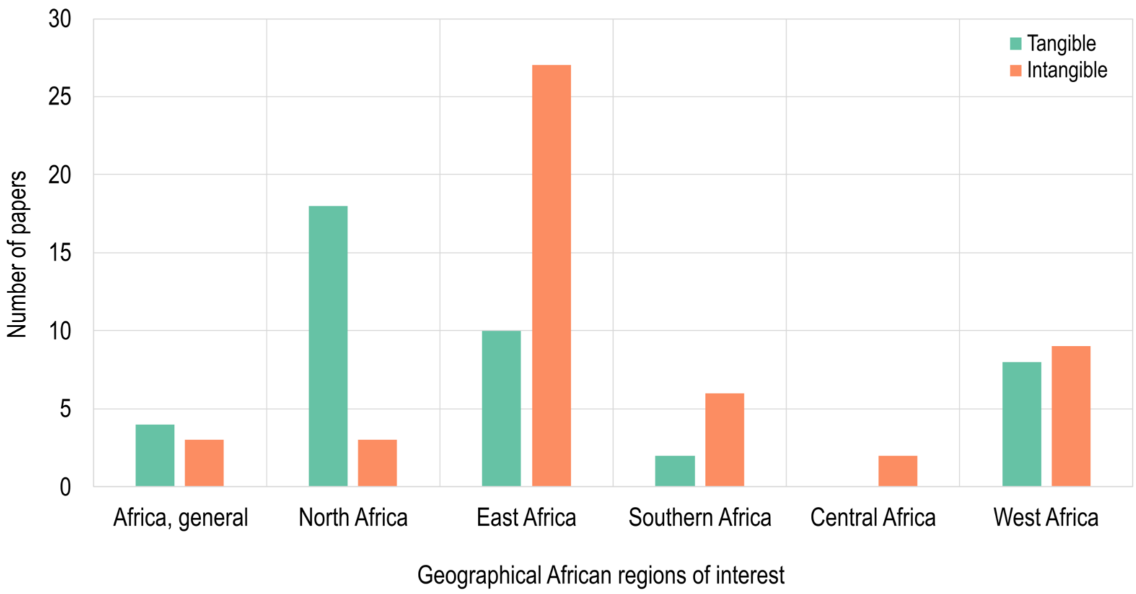


Figure 6: Regional Distribution of Literature on Climate Change and Tangible and Intangible Cultural Heritage Literature in Africa.

6.2.2 Asia

On the Asian continent, scientific literature on the impacts of climate change mainly focuses on natural heritage. Cultural heritage research is more recent (2017 onward) and focuses on the impacts of climate change on agricultural and built heritage such as rice terraces (Ducusin et al., 2019; Brimblecombe et al., 2020; Udeaja et al., 2020), the effects of extreme events such as flooding and land cover change, and on the spatial use of cultural ancestral and urban WHSs and their communities (Chim et al., 2019; Fumagalli, 2020; Kittipongvises et al., 2020). The literature also explores the impacts of climate change on intangible cultural heritage, such as climate change effects on Mongolia's Kazakh pastoral herders' cultural values and the ecological knowledge expressed in their music, instruments, textile and social gatherings (Post, 2018).

Nearly half of the continent's natural heritage literature (n=108) focuses on China, although English-language literature about cultural heritage is scarce. Natural heritage literature focuses on climate-related aspects of biodeterioration (Wu et al., 2017), anthropogenic environmental and land use change (Feng et al., 2016; Qian et al., 2019), habitat and species conservation (Li et al., 2017), and ecological restoration (Jiang and Zhang, 2016). For economic and political reasons, China's conservation sector generally lacks local approaches to community-engaged, government-led, grassroots-initiated, or international project-led heritage conservation (Fan, 2014). This results in difficulty in establishing a comprehensive conservation strategy for the country that incorporates climate change considerations and the inconsistent application of international conservation approaches that are introduced by donor agencies (Zhou, 2006; Fan, 2014). Compliance with conservation procedures in the Principles for the Conservation of Heritage Sites in China (the first set of national guidelines for cultural heritage practice in China) is impeded by lack of financial support for conservation projects, especially in West and Central China (ICOMOS-China, 2002) and inhibits motivation for cultural heritage protection in provinces and cities (Zhu, 2012).

The Chinese government has introduced numerous legislative acts for the protection of China's cultural heritage in the past few decades (Gruber, 2007). While the English-language climate change heritage literature is scarce in China, we acknowledge the country's deep sense of its history and heritage in addition to a bourgeoning tourist sector that focuses on this heritage. The lack of literature might be linked to the use of English language, and to the terminology used in defining and presenting heritage studies in the grey and scientific literature. Similarly, the importance of heritage values has recently been increasingly recognised and protection measures diversified as Japan has matured in terms of its society and economy (Kakiuchi, 2014). However, in the English-language climate change / heritage literature, climate change does not emerge as a priority in the assessment of the threats and their impacts on the human and non-human values of heritage.

India follows China with the second-highest number of publications on climate change / heritage (9%). The literature on India explores the importance and needs for community involvement in the assessment and implementation of policy for conservation (Kaur et al., 2008; Hassan et al., 2019; Sharma et al., 2020). Governmental mitigation strategies include developing sustainable tourism and buffer zones for protected areas and safeguarding the wild and Ecosystem Service Valuation (Singh, 2016; Hassan et al., 2019). Literature on climate change impacts on the built heritage (almost 100,000 unprotected sites), crafts sector (the economic foundation of most tribal and marginalised communities) or cultural WHSs is scarce. Only one recent study has assessed the effects of pressures such as rapid urbanisation, increasing housing demand, and climate change on the disappearance of Surat heritage (Udeaja et al., 2020). The lack of climate change impacts research might result from the various challenges of India's cultural heritage conservation and management sector, such as improper heritage awareness, lack of coordination among the stakeholders, inadequate funding as well paucity in understanding the (fast) growing demands in heritage tourism (Gantait et al., 2018).

After China and India, climate change / natural-heritage research across Asia includes a growing body of research from South, East and Southeast Asia, with less from North, West and Central Asia. Across South Asia, research has identified the impact of climate change on biodiversity in Nepal (Bhattacharjee et al., 2017), protected areas of Myanmar (Nwe et al., 2020), Indigenous transhumance system in the Himalayas (Aryal et al., 2016a; Aryal et al., 2016b), changing patterns of vegetation, greening along an altitudinal gradient in the eastern Himalayas (Li et al., 2016; Lamsal et al., 2018) sea-level rise and its associated habitat loss for both the endangered Bengal tiger (Mukul et al., 2019) and for mangroves in the Sundarbans (Mondal, 2018). Projected risks are identified for threatened invertebrates from plant invasions associated with climate change in protected areas of Sri Lanka (Kariyawasam et al., 2020), changes in distributions of snow leopard and their prey (blue sheep) under climate change in the Himalaya (Aryal et al., 2016a; Aryal et al., 2016b) and the Himalayan Musk Deer (Lamsal et al., 2018), migration limits to endemic seeds in the Himalayas and the conservation effectiveness of the current National Nature Reserves on the Tibetan Plateau in protecting the endemic plants in the face of climate change (Yan and Tang, 2019), and the projected impact of sea-level rise on the Ganges-Brahmaputra-Meghna delta (Brown et al., 2018). Greater stability and resilience to climate impacts have been observed for alpine forests that have seen a longer history of conservation on the Tibetan Plateau (Li et al., 2019).

Across Southeast Asia climate change / heritage research has identified projected risks to protected areas (Trisurat, 2018), the critically endangered Eld's deer in the Emerald Triangle Protected Forests Complex of Thailand, Cambodia, and Lao PDR (Trisurat and Bhumpakphan, 2018), exposure of

Indonesia's protected areas to sea-level rise (Suroso and Firman, 2018), habitat of Borneo's endangered highland species such as the Hose's civet (Mathai et al., 2019), and the projected impact of future forest cover change on the ability of Southeast Asia's protected areas to provide coverage to the habitats of threatened avian species (Singh, 2020).

Across East Asia climate change / heritage research has identified impacts on traditional herders in South Gobi, Mongolia (Mijiddorj et al., 2020), and shifts in aquatic insect composition in protected area tropical forest streams in Hong Kong attributed to three decades of warming associated with climate change (Dudgeon et al., 2020). Projected risks are identified for the Kenting Coral Reef, Taiwan (Lee et al., 2019), and Hong Kong's butterflies (Cheng and Bonebrake, 2017), vulnerable habitats for subalpine firs inside and outside of current protected areas of the Korean Peninsula (Yun et al., 2018), and risk from non-native species projected to flourish in protected areas under climate change in Japan (Takafumi and Thomas Edward, 2017).

In Western Asia climate change / heritage research has identified areas of high conservation value that are at risk by invasive plants in Georgia under climate change (Slodowicz et al., 2018). No climate change / heritage research was identified for Northern Asia and Central Asia.

There has been little English-language literature on climate change / cultural-heritage research across Asia. The authors predict such literature may be written in Chinese, Russian, Korean, Japanese, and other languages in Asia where there are centres of heritage scholarship that would not necessarily be identified by the methods used in this review. In the Philippines, the Batad Rice Terraces of Ifugao, a Globally Important Agricultural Heritage System and UNESCO WHS, a vulnerability assessment found the terraces at risk from climate change impacts (Ducusin et al., 2019). Brimblecombe et al. (2020) note that although climate change is well recognised as an important issue in Japan, there has been little interest from scientists or the public on the potential threat it poses to heritage. The researchers mapped Tokyo's built heritage with potential risks to museums and historic buildings from temperature increase, sea-level rise, changes in humidity, flooding, rainfall intensity, and typhoons. Each are expected to have more severe hazards under climate change but do not provide a quantitative assessment of identified risks.

6.2.3 Australia, New Zealand, and Antarctica

Australia's climate change / heritage literature exhibits significant domestic knowledge production for cultural sites. Most officially recognised cultural landscapes in Australia are Indigenous places, where the Western distinction between culture and nature does not exist (Lennon, 2016). The literature considering potential impacts from climate change on sites described as cultural heritage includes:

- Assessment of climate change adaptation options conducted for Kakadu National Park and the Djelk Indigenous Protected Area, Arnhem Land, Australia (Carmichael et al., 2020),
- Vulnerability assessment of urban heritage sites to flooding in Brisbane City, Australia (Espada et al., 2017),

- Community-level assessment of exposure and sensitivity to climate impacts of the relative cultural value of archaeological and cultural heritage sites for local and Indigenous management and adaptation (Carmichael et al., 2018),

- And the development of an assessment index for climate change-related risk for cultural heritage protection in Newcastle, Australia (Forino et al., 2016)

Climate change / heritage literature in Australia on natural sites traditionally focuses on risk assessment for the physical and ecological properties of the natural systems. It includes:

- Assessment of climate change impacts on park values on four Queensland World Heritage National Parks in Australia (Tanner-McAllister et al., 2018) and on Australia's coral reefs (Gilmour et al., 2019),

- Risk to biodiversity hotspots from sea-level rise (Bellard et al., 2016) and to endangered rainforest shrub and orchids from average temperatures exceeding current range limits (Shimizu-Kimura et al., 2017; Wraith and Pickering, 2019),

- Projected plant invasions of alien vegetation in protected areas under future climate scenarios (Wang et al., 2017; Wan et al., 2018), and changes to mangrove range shifts and future nature reserve planning under climate change (Fazlioglu et al., 2020),

- Climate policy and heritage governance, triggered by multiple and back-to-back mass bleaching of Australia's Great Barrier Reef in 2016-17 (Hughes et al., 2017; Morrison, 2017).

Climate change / heritage literature in New Zealand on natural sites includes projections of the impact of climate change on glacier tourism in the Fox and Franz Josef Glaciers in Westland Tai Poutini National Park (Stewart et al., 2016).

Climate change / heritage literature on Antarctica includes assessment of changes in glacier margin positions between 1979 and 2018 in the Antarctic Specially Protected Area 128 (ASPA-128) on King George Island, South Shetland Islands, Antarctica (Pudełko et al., 2018), assessment of impacts of climate change on terrestrial and botanical biodiversity, and seabirds in Antarctica's specially protected areas (Hughes et al., 2016; Olech and Słaby, 2016; Southwell et al., 2017; Wauchope et al., 2019).

6.2.4 Europe

Climate change / heritage literature in Europe is a large and mature corpus underpinned by substantial resources relative to other regions. The primary emphasis of this literature focuses on understanding climate change and heritage at the country and territory scale (Daly et al., 2021; Orr et al., 2021), predominantly in the form of hazard assessment. Some countries have made notable contributions to understanding risk more holistically, incorporating exposure and vulnerability, such as Scotland (Harkin et al., 2018). There are also some notable instances of regional-scale assessment (characterised by similar climates, e.g., (Carroll and Aarrevaara, 2018; Rosina et al., 2019). More infrequently, literature compares several countries across Europe that vary in climate (for exmaple, Coelho et al., 2019; Sesana et al., 2019). Collaborations across regions are facilitated by robust and well-established funding mechanisms, such as targeted calls within the Horizon Europe programme and the Joint Programming Initiatives on Climate and Cultural Heritage and Global Change; the latter are increasingly interested in identifying opportunities to provide joint funding for research, networking, and career development.

There have been a few notable cases in which climate change hazards and vulnerability have been evaluated for the European continent (for example, the Noah's Ark project, see European Commission, 2010). However rapid advances in the accuracy, resolution, and availability of remote sensing data and climate projections, as well as a deeper understanding of the mechanisms of physical change and how these relate to environmental conditions, suggests there is an opportunity for reanalysis.

Despite its strength in research, policy, and practice on the physical impacts of climate change on heritage, there is a need for a deeper understanding of the role of heritage in adaptation and societal transformation (Fatorić and Biesbroek, 2020). This is likely to be further supported by research, policy, and practice informed by the European Green Deal, an ambitious initiative to transform the European Union into a modern, resource efficient and competitive economy, ensuring no net zero emissions of greenhouse gases by 2050 and economic growth decoupled from resource use.

6.2.5 Middle East

The Middle East is poorly represented in the field of climate change / heritage research literature. Three of the thirteen countries (Kuwait, Qatar, and the United Arab Emirates) have no climate change / heritage literature from 2015 to 2021. Whereas Western scholars write the region-wide literature, lead authors appear to be well represented by local scholars at a country level. The country with the most literature is Iran, which is probably due to its high literacy rate, exposure to climate change, and its role as the first country in the Middle East recognised for its responsibility to climate change (Mansouri Daneshvar et al., 2019). The Iranian climate / natural heritage literature focuses on endemic plants and establishment of new biodiversity hotspots, connectivity, and habitat suitability (Morovati et al., 2020), traditional agriculture, and cultural landscapes (Abdolalizadeh et al., 2019). The relative paucity of cultural heritage literature for Iran may be due to limitations on tourism from Western countries arising from international sanctions on the country.

Although not represented well in climate change / heritage literature, Saudi Arabia has a strong commitment to heritage with awareness of impacts and solutions and an active presence on the World Heritage Committee. For example, in 2018 at the 42nd session of the World Heritage Committee, the Kingdom of Saudi Arabia was able to successfully overturn the recommendation made by ICOMOS not to inscribe the 'Al-Ahsa Oasis on the World Heritage List (Hølleland and Wood, 2020). The lack of available climate change / heritage literature is therefore incongruous unless it is related to other national political or policy agendas affecting heritage science. For example, for an oil-producing country, highlighting the impacts of climate change to heritage may not be considered within national interests when considering responsibility and accountability for losses and damages from climate change. Other countries in the Middle East focus on changes in forest distributions, ecotourism, geoconservation and endangered species. There is also no available literature on the effects of climate change on Israel's cultural heritage. The negligible publications related to natural heritage explore sustainable development impacts on biodiversity (Peri and Tal, 2020), economic implication of nature rehabilitation (Akron et al., 2017), green urban development (Troupin and Carmel, 2018) and forest foliage effect on air bio-depollution (Uni and Katra, 2017).

There are 4 WHSs on the endangered list in the Middle East where climate change is listed as a contributing factor:

- Old City of Sana'a, Yemen,
- Old Walled City of Shibam, Yemen,
- Ashur (Qal'at Sherqat), Iraq,
- Old City of Jerusalem and its Walls, Jerusalem (Site proposed by Jordan).

Box 3: Impacts on Indigenous Peoples, Knowledge Systems, and Lifeways

Widespread loss of sea ice in the Arctic is reducing habitats for key species and impacting the livelihoods of Indigenous peoples who depend on snow, glaciers, and sea ice for their livelihoods (IPCC, 2019b). Pikialasorsuaq in Baffin Bay is the Arctic's largest area of open water surrounded by ice, and is also one of the most biologically productive regions in the Arctic (Barber et al., 2001). Adjacent Inuit communities depend on Pikialasorsuaq for their food security and subsistence economy (Hastrup et al., 2018). They use Qaujimajatuqangit, an Indigenous knowledge (IPCC, 2019b). The sea ice bridge north of the Pikialasorsuaq is no longer forming as reliably as in the past, resulting in a polynya (an area of open water surrounded by sea ice) (Ryan and Münchow, 2017; IPCC, 2019b). These changes are disrupting the livelihoods of Inuits, with negative impacts on food and water security, travel and transport, and culture (IPCC, 2019b).

6.2.6 North America and the Arctic

For this review, three countries and territories are assessed in North America: Canada, the United States, and Greenland; Mexico is discussed in South and Central America's section due to language and cultural links[3]. In North America, three WH properties have reported impacts of climate change:

- Waterton Glacier International Peace Park, Canada/USA;
- Wood Buffalo National Park, Canada; and
- Everglades National Park, USA.

The Everglades is the only North American property on the List in Danger. These properties are inscribed as natural heritage and represent three sensitive ecosystems to climate change: mountain

[3] Mexico, within the UNESCO system, is considered part of Latin America and the Caribbean region.

glaciers, boreal forest, and coastal subtropical wetland. North American climate-heritage literature emphasises natural protected areas, such as the Rocky Mountains, USA (Halofsky and Peterson, 2018; Halofsky et al., 2018) or Lake Tahoe (Long, 2019), followed by built heritage and urban areas. In contrast to Europe's emphasis on built heritage, there is greater focus on natural heritage, Indigenous cultures and archaeological sites in Canada and the USA. The national park model in the US has placed higher value on natural over cultural heritage (Runte, 1990), while precolonial human transformation of landscapes was acknowledged only recently (Denevan, 1992).

Several studies have assessed climate change impacts on archaeological resources (Rankin et al., 2017; Hollesen et al., 2018). Most publications are concentrated in the Arctic region, including assessment of climate change impacts on (1) Indigenous livelihoods and (2) archaeological sites, historically covered (and protected) by ice, that are exposed due to ice thawing or, conversely, are submerged by sea-level rise (Andrachuk and Pearce, 2010; Hollesen et al., 2017; Rankin et al., 2017; Hollesen et al., 2018; Britton and Hillerdal, 2019; Marsadolov et al., 2019; Fenger-Nielsen et al., 2020; Yen and Li, 2020). The literature also explores shoreline changes (O'Rourke, 2017), their impacts on livelihoods and coastal heritage (Reeder-Myers, 2015; Casey and Becker, 2019; Dawson et al., 2020) and climate change effects on cultural landscapes (Brabec and Chilton, 2015; Melnick et al., 2015; Page, 2015).

In addition to direct climate change effects, secondary effects have been assessed on cultural heritage (more specifically in the Arctic). These include the relocation and migration of population from areas containing important archaeological resources due to accelerated climate change, which placed loss of territory and place attachment at the forefront of climate change impacts on cultural heritage (Herrmann, 2017; St. Amand et al., 2020). Nevertheless, more systematic research on institutional structures of knowledge production is needed regarding climate change impacts on urban heritage and Indigenous peoples' territories, so as to support communities attempts to define their future in a climate-altered world; this also requires addressing colonial legacy and human rights (Bronen and Cochran, 2021).

Box 4: Anishinaabeg Hydromythology as a Climate Impact Explainer
(Inuit Canada)

Anishinaabeg people inhabit the boreal forests of Canada, in the provinces of Manitoba and Ontario. Part of their traditional lands and provincial protected areas have been inscribed in the World Heritage List in 2018, based on the outstanding interaction of Anishnaabe culture with their environment under the name Pimachiowin Aki, the land that gives life. Anishinaabe stories entail a hydromythology, embodied in the Ojibwe mythical creature Mishipizhu, an underwater panther and powerful manitou (spirit). Mishipizhu is a protector of natural resources and a mediator between the water, land, and sky beings. As guardian of resources, he is immortal, reappearing to punish anyone who attempts to upset the balance of eco-social relations. Mishipizhu hydromyths can be used today to understand critical eco-cultural changes and impacts. From an anthropological perspective, Mishipizhu is a powerful metaphysical icon of the Ojibwe imagination. His active presence serves as an important indicator of traditional ecological knowledge about a moral landscape that supports cultural resilience and a useful metaphor for how the impacts of climate change manifest within the ecology (Nelson, 2013).

6.2.7 Small Islands and Developing States (SIDS)

The 39 SIDS constitute a disparate group in terms of polities and heritage traditions, distributed between the Atlantic, Indian, and Pacific oceans. They present several common vulnerabilities in the context of climate change impacts on heritage, including small areas of land relative to marine territory; generally lower-lying land surfaces; coastal concentrations of heritage resources and thus a high degree of exposure to sea-level rise; and limited state capacity or resources available to counter these threats (Siegel et al., 2013). More positively, SIDS communities manifest strong kinship networks, enduring cultural traditions, and long histories of adapting to environmental change (Henry and Jeffery, 2008; Cooper and Peros, 2010; Kelman, 2010).

Existing research concentrates on the relationship between heritage and hazards, such as cyclones and el Niño Southern Oscillation (ENSO) events. However, there has been less investment on how climate change affects those hazards and their potential risk to heritage. The research literature tends to be restricted to localised case studies. It is published in multiple languages (dominated by English and French), but regional overviews are rare (Allam and Jones, 2019). Funding for heritage research and safeguarding is derived almost entirely from external sources and reflects external research agendas, resulting in disparate, project-centric literature with limited national or regional coordination of questions relating to climate change.

The scope for climate change impacts to the 34 SIDS World Heritage sites is relatively well documented (https://whc.unesco.org/en/sids/). East Rennell, Solomon Islands, is the only WHS on the List in Danger where changes to oceanic waters and storms have been identified to pose risk to heritage. There is a tendency for WH in independent Pacific states to favour cultural landscapes (e.g., Chief Roi Mata's Domain in Vanuatu) and polities with ties to former colonising powers are more likely to nominate natural sites (e.g., Lagoons of New Caledonia). Marine environments and maritime heritage contribute significantly to the heritage profiles of most SIDS, but are poorly documented and obviously vulnerable to climate change impacts (Ezcurra and Rivera-Collazo, 2018; Henderson, 2019). The nexus between heritage sites, cultural industries and tourism income is particularly important in most SIDS, but also directly at threat from climate change effects such as sea-level rise, flooding of urban heritage, coral bleaching and the transformation of ecological resources vital to cultural production and performance (Hall et al., 2016; Allam and Jones, 2019; Cámara-Leret et al., 2019).

A strength of many SIDS is the intangible cultural heritage of their vibrant communities, reflecting dynamic traditions still strongly linked to place (Crook and Rudiak-Gould, 2018). The likely impact of climate change on these highly adaptive traditions is uncertain. Still, relocation and the separation of communities and heritage places and contexts appears to present the most profound threat to the ongoing transmission and safeguarding of intangible cultural heritage (Kim, 2011).

Box 5: Climate Change / Heritage and Local Languages

Global conversations on heritage and the impacts of climate change to heritage sites, structures, objects, and practices are predominantly tracked in English. A handful of other major transnational languages (e.g., French, Spanish, Arabic) are engaged, or at least the target languages of translations. Relevant discourse conducted in most other languages is all but invisible in most international fora, but their existence, significance, and the perspectives that they could contribute on the impacts of climate change should be recognised. For example, literature in Portuguese treats topics including Guinea-Bissau's politics of adaptation to climate change social challenges (Santy and Valencio, 2018) and for Cabo Verde in relation to climate change effects on tourism (Fernandes and Barbosa, 2020). Tourism also figures heavily in local discussions of climate change and endangered heritage in the Maldives, a country frequently pointed to as a dramatic case of a small island nation at the front lines of the global climate crisis. However, there remains a considerable disconnect between the English-language genres of impact assessment reports for tourist resort developments and writings on cultural heritage in the vernacular Dhivehi language, which tend to explore details of particular sites, objects, or practices (digital repositories for which include the Saruna archive of the Maldives National University (http://saruna.mnu.edu.mv) and Favvaru (http://favvaaru.mv), managed by the Dhivehi Language Academy). In the exponentially larger island nation of Indonesia, reader demographics support more diverse printed and online discourse in which issues of heritage and climate change are linked to discussions ranging from social justice in ecotourism villages in the face of COVID-19 restrictions (Sastika, 2021) to environmental considerations for architectural preservation (Giri et al., 2021; Sastika, 2021).

6.2.8 South and Central America

The South and Central American regions include many countries, and usually referred to as Latin America and the Caribbean or LAC (e.g., UNESCO's regions). There was no significant difference in the quantity of literature found in Spanish compared to English (28 Spanish; 25 English; 1

Portuguese[4]). The literature is spread across a diversity of journals and covers a wide range of disciplines, including archaeology (Jijón Porras, 2019), geography (Modeen, 2021), urban planning (Zancheti, 2019; Osorio Guzmán et al., 2020), anthropology (de Lima, 2019) and architecture (Silvero et al., 2019; Prieto et al., 2020). The regional literature focuses on coastal cities exposed to sea-level rise and flooding and the transformation of land-based heritage into underwater heritage (Perez-Alvaro, 2016; Márquez et al.; Jijón Porras, 2019). This could be due to the importance of El Niño Southern Oscillation (ENSO), associated with heavy rain, drought, flooding, ocean warming, and tropical cyclones in the region. Its frequency and intensity are being altered by climate change, affecting coastal heritage. This is also reflected on the 15 WHSs at threat from climate change in Central and South America, particularly vulnerable to storms and flooding. Six of the 52 properties inscribed in the World Heritage List in Danger are in Central and South America.

In three of them, climate change (more specifically flooding) is a contributing factor:

- Río Plátano Biosphere Reserve, Honduras,
- Coro and its Port, Venezuela,
- Chan Chan Archaeological Zone, Peru.

The climate-heritage literature addresses common challenges in the region (Cevallos, 2013; Blancas et al., 2020; Iwama et al., 2021), referring mostly to the role of Indigenous and local knowledge in climate change monitoring, adaptation, and policymaking. Other regional studies refer to the vulnerability and adaptation of Latin American cities to climate change (Margulis, 2016; Rodríguez Aldabe, 2018; González-Rivadeneira and Villagómez-Reséndiz, 2020) and in the same line, several studies have focused on specific cities, which include historical centres and urban heritage (Samaniego, 2012; de Araújo, 2015; Zanetti et al., 2016; Zancheti, 2019; López, 2021). Climate change is seen to have stronger negative impacts on vulnerable groups such as Indigenous communities across South and Central America, highlighting the need for safeguarding Indigenous and local knowledge at risk from the impacts of climate change (Parraguez-Vergara et al., 2016; IPCC, 2018; IPCC, 2019a; Haboucha, 2020).

Compared to other countries in the region, Brazil has a larger literature on the impacts of climate change for both natural and cultural heritage. This literature focuses on impacts on farming cultures and livelihoods (Bragança et al., 2016; Machado Filho, 2016; de Lima, 2019; Modeen, 2021), in particular in cities with historical urban areas (de Araújo, 2015; Zanetti et al., 2016; Osorio Guzmán et al., 2020), and on impacts of climate change on tourism (da Silva Santos and Marengo, 2020).

Another common topic refers to the impact of climate change on agro-ecosystems and landscapes of heritage value (Villarreal Molina, 2015; Rotger, 2018), such as wine (Fourment et al., 2020), coffee plantations (Bragança et al., 2016; Duque Escobar et al., 2019), terraces (Bocco et al., 2019), and other traditional agricultural systems (Chávez La Torre and Llerena Ortega, 2015; Magaña Cruz and Mora Yela, 2018; Coronel-Alulima, 2019).

[4] The one article in Portuguese was identified through the search in the specific country (Brazil) in English. No specific search was done in Portuguese.

The Amazon, which covers a larger geographical area of four countries in South America, is the focus of forest conservation (Valera Camacho and Hernández Galindo, 2019), and traditional livelihoods, economy, and future of the populations (Pinho et al., 2015; Pinho, 2016; de Lima, 2019; Portugal and Michel, 2020). In areas where agriculture is the main activity, climate change can have an impact on cultural heritage as well (including cultural practices associated with natural ecosystems, rituals, and spiritual associations).

The impacts of climate change on heritage places and resources are not being studied as an interdisciplinary field consistently or systematically at a regional or country-specific level. More research is needed with the cooperation and co-production of knowledge between scientists, Indigenous peoples, and communities on climate research. This research should utiliz\se Indigenous and LK to inform climate change research in the region. Regional conversations are needed, especially when large and important ecosystems, such as the Amazon basin, present transboundary risks to heritage and require transboundary cooperation and governance responses. For cultural heritage, transboundary WH properties like the Qapaq Ñan could be explored for further collaboration on climate change impacts research on cultural landscapes and intangible cultural heritage.

7. Types of Climate Change Impacts on and Risks to Heritage

The implications of climate change for heritage are diverse and complex due to the variety of global climate and environmental changes, compounded with local anthropogenic factors (such as pollution and urbanisation), as well as the diversity of heritage, including its characteristics of value. An exhaustive and systematic evaluation of the effects and consequences of climate change for heritage cannot be suitably undertaken in the context of this white paper. There have been recent efforts to do so for movable heritage, archaeological resources, buildings and structures, cultural landscapes and protected areas, associated and traditional communities, underwater heritage, and intangible cultural heritage (Perry, 2011; Morgan et al., 2016; International Council on Monuments and Sites (ICOMOS) Climate Change and Cultural Heritage Working Group, 2019; Perry, 2019; UNESCO-WHC, 2021, pp. 72-89). This section will explore the characteristics of the literature through the lens of the hazard-exposure-vulnerability risk framework (see Section 5.2), to analyse and critique the ways in which understanding of the effects and consequences have been approached.

7.1 Vulnerability

7.1.1 Understanding change

The heritage field has engaged with inevitable changes that will impact the ability to safeguard heritage for current and future generations (UNESCO, 1972) and the need for the response to this to be sustainable (Barthel-Bouchier, 2016). Understanding of the vulnerability of heritage to climate change has thus been informed by the significant attention that has been paid to understanding mechanisms and rates of relevant material change, specifically that induced by the broad environmental changes (e.g., (for example, Carll and Highley, 1999; Siegesmund and Snethlage, 2011). By necessity, this area of research is diverse and expansive, often encompassing niche communities centred around specific materials, heritage typologies, or mechanisms: for example, one community is studying salt weathering of inorganic building materials in the built environment[5]. Yet, understanding mechanisms and rates of material change attributed to anthropogenic climate change is still nascent.

The concept of vulnerability in the climate-natural heritage literature can be perceived through different lenses: the 'sensitivity' to change of the natural ecosystem, and its biodiversity and the induced or existent 'vulnerability' of the socioeconomic and cultural systems that use a heritage site (Harvey and Woodroffe, 2008; Gaki-Papanastassiou et al., 2010; Su et al., 2015; Sudha Rani et al., 2015). More broadly, the field has generated an understanding of heritage within its cultural, political, and economic context (the journal Heritage and Society is a prominent example of this). Crucially, scientific, technical, and socioeconomic understanding of heritage has typically been generated outside the context of climate change. Despite this, within the hazard-exposure-vulnerability framework, it underpins representation of the vulnerability of heritage to climate change: that is, the likelihood that heritage will be impacted when exposed to certain climate conditions.

[5] The Proceedings of the Fifth International Conference on Salt Weathering of Buildings and Stone Sculptures (Lubelli, Kamat, and Quist [eds.], 2021), was 364 pages in length.

The question of vulnerability can be summarised as: 'How well do we understand the potential for such events /outcomes to occur, and how much does this potential depend on climate change, policy design or socioeconomic variables?' (Reisinger et al., 2020, p. 8). Similarly, the frequency and severity of disasters and extreme events is affected by climate change (Otto, 2019; Raymond et al., 2020). In general, the effects and consequences of climate change for heritage during disasters and extreme events have been studied less than the more gradual changes induced by anthropogenic climate change or changes in social, cultural, and economic contexts in response to it. Attribution science that robustly assesses the impacts of anthropogenic climate change separately from environmental exposure (both long-term change and extreme events) is emerging as a key direction within the broader field of climate risk (Strauss et al., 2021); attribution science for climate change risk to heritage is nascent.

In some instances, a disaster or extreme event may result in rapid and permanent loss of heritage (Cookson et al., 2019). In other circumstances, one challenge to studying the effects and consequences of disasters and extreme events for heritage is that the long-term implications may not be immediate: for example, the immediate effect of flooding on a heritage building will, in the short-term, increase the water content of the structure. The long-term consequences of flooding, including recurring events, may negatively impact human health and comfort, as well as cause long-term structural change (Holický and Sýkora, 2010) and extinctions (Price, 2019).

7.1.2 Representations of likelihood and uncertainty

Risk should represent evidence fairly, providing a traceable account describing its evaluation (Mastrandrea et al., 2011). This includes representation of likelihood and uncertainty. Therefore, it is imperative to capture the current state of how likelihood and uncertainty are understood and represented in climate change and heritage scientific literature. One of the challenges for researchers who study heritage is that there is a diversity in the types of evidence that documents the impact of climate change. Kohler and Rockman (2020: 639) identify that 'the sorts of verbal arguments that archaeologists often use to build cases for causal relationships are less likely to be assessed by IPCC readers as demonstrating causation with high confidence than are arguments that use formal statistical machinery whose probability of error can be read directly.' The discrepancy discussed by Kohler and Rockman means that evaluation of physical impacts on heritage, underpinned by projections or models with associated statistical confidence and error, are more likely to be integrated into broader discourse. Yet, there is increasing acknowledgement that the IPCC demands unreasonable evidence thresholds in comparison with the level of evidence required in a legal, regulatory, or public policy context (Lloyd et al., 2021). There is an urgent need to promote a collective understanding and use of representations of uncertainty and likelihood, within both IPCC and heritage-related fields, in line with the relevant broader communities to foster cross-disciplinary collaboration and impact. This has significant implications for accounting for losses and damages to heritage from climate change (Stuart-Smith et al., 2021). One way this can be done is for the IPCC to adopt the category 'more likely than not' as a level of proof (Lloyd et al., 2021).

7.2 Hazard

In the IPCC hazard, vulnerability, exposure and response framework, a hazard is a phenomenon that can induce change in heritage. Referring to a climatic event or trend as 'hazard' relies on an assessment of the potential consequences of this climatic change (Reisinger et al., 2020; IPCC, 2022). Within heritage literature, there is a tendency to apply this interpretation to impacts and effects more broadly: put another way, both 'impact' and 'effect' implicitly carry a negative connotation (i.e., the change is assumed to compromise or result in the loss of heritage value). The idea of 'sensitivity to change', defined as the possibility for change without adverse impacts on heritage significance, has also been proposed within an archaeological context (Previtali et al., 2018).

Hazard assessment within climate change /heritage evidence has recently focused on changes in:

- Long-term conditions, including sea-level rise (Marzeion and Levermann, 2014; Varela et al., 2019), temperature (Wood et al., 2019), relative humidity (Bylund Melin et al., 2018; Ciantelli et al., 2018), ocean acidification (Heron et al., 2017), climate variability and seasonality (Orr et al., 2018), erosion (Sabour et al., 2020).
- Frequency, magnitude, and duration of extreme events, including storms, flooding, wildfires (McGovern, 2018; Sardella et al., 2020; Sevieri and Galasso, 2021).
- Phenology (Delgado et al., 2018; Hille Ris Lambers et al., 2021), and the spread and distribution of ecosystems and their components (Tang et al., 2020; Thornton et al., 2020).

While there are good examples of comprehensive hazards assessment where several types of hazards are considered (European Commission, 2010; Harkin et al., 2018; Bosher et al., 2020), most assessment for heritage has focused on a single type of hazard.

Which hazards are studied and in which contexts is primarily driven by a qualitative or experiential understanding of those hazards which are most relevant for a particular scenario of heritage and context (see Section 6). It is difficult to determine whether this approach has produced evidence that is targeted toward strategic needs. For example, the recent Future of our Pasts identified 'increased water vapour content in the air' as a key climate impact driver for heritage (International Council on Monuments and Sites (ICOMOS) Climate Change and Cultural Heritage Working Group, 2019), giving examples of the consequences this would have for several types of heritage. On a global scale, widespread decreases in relative humidity near the surface are observed over the land in recent years (IPCC, 2013). While this does not rule out the potential for negative impacts due to increased water vapour content in the air, it highlights the limitations of hazard assessment undertaken in a generalised way. Similarly, potential benefits for heritage, due to changes in the environment that could be considered as hazards, have been assessed (Prieto et al., 2020). This emphasises the need for a deeper understanding of the local variation and phenology of hazards that are particularly relevant to heritage.

Natural heritage sites are exposed to the compound effects of local anthropogenic threats and climate change. The IUCN Outlook undertaken in 2020 reported that climate change is now the most common current threat to all natural WHS and already impacting a third of all sites (Osipova et al., 2020).

7.3 Exposure

Exposure can be understood as the proximity and sensitivity of attributes affecting the value of heritage. Exposure can be represented by several types of evidence: protected status (with accompanying description), databases or registries (including metadata), and local or Indigenous understanding. In the case of structured evidence (e.g., databases), the heritage value may be implicit: for example, databases of national housing stock that includes year and method of construction can be a subset for structures that may have traditional features and other elements of value.

Exposure has been evaluated in many ways in climate change /heritage evidence:

- A single instance of heritage in its local context, e.g., a particular site (e.g., (Ravanelli et al., 2019);
- A collection of heritage with similar attributes in the same environmental context, e.g., museums and historic buildings in Tokyo (Brimblecombe et al., 2020);
- A representative collection of a certain type of heritage in a geopolitical region, e.g., monuments in Portugal (Figueiredo et al., 2020) or timber-framed structures in Chile (Prieto et al., 2020);
- A particular context but incorporating a range of types of heritage, including intangible heritage, with varying attributes mirroring an epidemiological approach (Westley, 2019).
- A global perspective on a set of geophysical and biological characteristics of protected areas such as marine protected areas (Hameed et al., 2017), or terrestrial sites (Elsen Paul et al., 2020);
- A specific protected feature in a local context such as habitat loss of the Bengal tiger in the Sundarbans, Bangladesh (Mukul et al., 2019);
- A climatic region such as tropical protected areas exposed to climate change and deforestation (Tabor et al., 2018);
- Globally, primarily for natural heritage (Segan et al., 2016; Hoffmann and Beierkuhnlein, 2020).

The literature predominantly evaluates exposure in data-driven or data-informed ways, resulting in a bias toward listed and protected heritage, and areas in which heritage is well-documented and well-described. This is likely due to exposure being evaluated within the broader context of risk: both vulnerability and hazards—but especially hazards—are commonly evaluated using data-driven approaches. Despite this, value-based vulnerability assessments have been promoted by the research community as an alternative (Grossi and Brimblecombe, 2005; Heilen et al., 2018).

Informal, local, and traditional representation and understanding of exposure in climate change /heritage risk assessment can inform existing research. Examples include laboratory study informed by the attributes of earthen architecture across Europe constructed before WWII (Kozlowska, 2019), or indices based on the attributes of rainwater goods that could be applied to several types of built heritage (Orr and Cassar, 2020).

Box 6: World Heritage Glaciers in the Face of Climate Change

There are approximately 19,000 glaciers within fifty WHSs. This corresponds to 10% of the Earth's total number or glaciers (Bosson et al., 2019). Some WH glaciers are iconic record holders like the highest and the longest on Earth or one of the fastest and largest iceberg producers in Greenland. Glacier evolution modelling shows diverging pathways:

- In the most pessimistic scenario, failing to drastically cut greenhouse gas emissions would lead to the melting of around 60% of current WH glacier volume by 2100, very likely causing the irreversible glacier disappearance on our planet.
- In the most optimistic scenario, cutting rapidly greenhouse gas emissions could safeguard around 66% of the current volume by 2100; under this limited warming, ice melt would progressively slow in the future, allowing most of WHSs to conserve glaciers.

Even though they exist in sites with a special protection status, WH glaciers respond exactly the same way as their 'unprotected' neighbours. The nature conservation laws used to restrict human activities on these sites are powerless to limit the consequences of a global phenomenon like climate change. Hence, as for other areas and types of heritage impacted by climate change, the only effective way to conserve WH glaciers is to mitigate climate change by limiting greenhouse gas emissions (Bosson et al., 2019).

Overall, exposure analysis to date has broadly focused on climatic change and variability, but not necessarily anthropogenic climate change. Characterising the vulnerability of heritage to climate change is a mature and developed field as it draws on a significant body of research more broadly interested in understanding changes in heritage caused by the environment. There is a need for a deeper understanding of the local variation and phenology of hazards that are particularly relevant to heritage. Across all three components of this risk framework is a need to agree and take up more standardised representations of uncertainty and likelihood.

8. Capacity to Learn from the Past

Much can be learnt from the recent past, particularly the past three decades, as the climate change signal has become more pronounced and the impacts from climate change have become more severe. Yet the further back in time we go the more complicated it becomes to identify risk-reducing responses to climatic changes that could be implemented in the present (see Figure 7). Environmental changes over the past 8,000 years are dwarfed by the magnitude, pervasiveness, and rates of change of anthropogenic climate change currently observed and projected for the coming century (IPCC, 2018; IPCC, 2019b; IPCC, 2019a; Kaufman et al., 2020; Boivin and Crowther, 2021; IPCC, 2021). It is therefore important to avoid drawing false equivalencies of impacts and risk between the climate of past civilisations and those under current anthropogenic climate change.

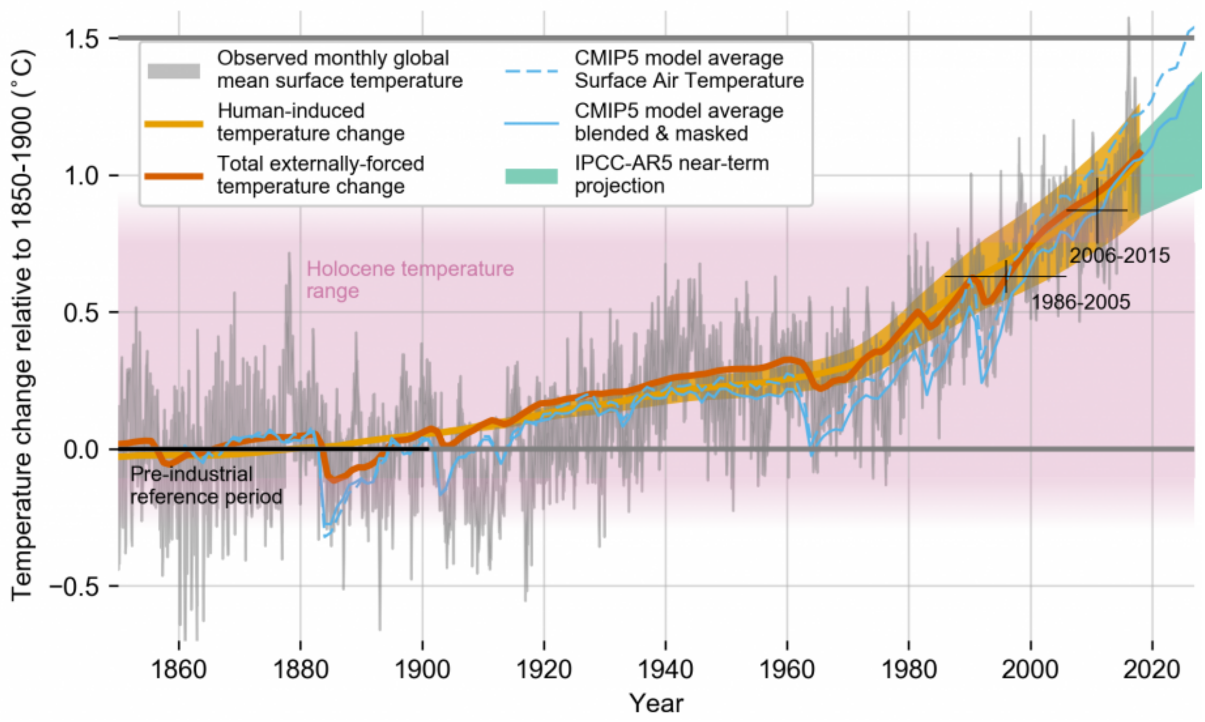


Figure 7: Global Mean Surface Temperature Over the Period of Instrumental Observations

Human-induced (yellow) and total (human- and naturally-forced, orange) contributions to these GMST changes are shown. Thin blue lines show the modelled global mean surface air temperature (dashed) and blended surface air and sea surface temperature accounting for observational coverage (solid). The pink shading indicates a range for temperature fluctuations over the Holocene (IPCC, 2018).

Even so, used cautiously, the past can provide a rich data source for climate change /heritage research. For example, archaeological records provide a unique source of direct data on long-term human-environment interactions and examples of ecosystems affected by differing degrees of impact (Hambrecht et al., 2020). Such records can support our understanding of changes in the climate through establishing baselines, and can be used to understand the implications of human decision-making and its impacts on the environment (Hambrecht et al., 2020). For example, Australian Aboriginal groups' Indigenous oral history provides empirical corroboration of the sea-level rise 7,000 years ago (Nunn and Reid, 2016), and how their seasonal calendars detect unusual changes today (Green et al., 2010; IPCC, 2019a). Importantly, they can also provide behavioural indications of how humans respond to environmental changes, particularly those significantly outside their historical climatic patterning and how such responses affect risk. For example, past failures can reveal non-viable or maladaptive solutions (Boivin and Crowther, 2021). Conversely, Indigenous fire stewardship can assist with reviving important cultural practices while protecting human communities from increasingly severe wildfires (Hoffmann and Beierkuhnlein, 2020).

Correlating past climate change, its impacts, and societal change relies on careful calibration of different kinds of archaeological evidence and climate proxy data (Izdebski et al., 2016; Finné et al., 2019; Jones et al., 2019). At a regional scale, climatic change recorded in deep-sea cores, lake cores, and speleothems can be calibrated against regional archaeological records such as settlement abandonment or land use change over time.
(see PAGES LandCover6K https://pastglobalchanges.org/science/wg/landcover6k/intro).

At a local (archaeological site) level, pollen records, anthracological evidence, and botanical and animal remains, can aid the reconstruction of local land use (Campbell et al., 2011). However, land use may not represent true environmental conditions due to anthropogenic modifications such as agriculture, so local environmental evidence independent of land use, such as stable isotopes of terrestrial and freshwater snails, is also required for an accurate picture of the land cover around archaeological sites (Leng and Lewis, 2016; Prendergast et al., 2016).

Several studies have proposed connections between climatic change and cultural change in the past. Many of these studies record maladaptations such as the collapse of the Akkadian empire (Weiss, 2017) and the Late Bronze Age upheavals in the Eastern Mediterranean (Kaniewski et al., 2019). Another significant example is the collapse of Classic Maya civilisations of the 8^{th}-10^{th} centuries. A combination of factors, including increasing temperatures and drought (Evans Nicholas et al., 2018) in relation to landscape degradation, soil erosion, and increasing warfare and problems in food production, precipitated the downfall or relocation of many lowland Mesoamerican societies.

In contrast, there is a growing body of research focussed on positive adaptations in the past and how they might inform our understanding of adaptation into the future, such as the study of climate change impacts on prehistoric and pre-Columbian societies in the Andean region (Ecuador, Peru, Bolivia) (Bush et al., 2015; Moseley, 2019; Vargas et al., 2020). An example of adaptation to the impacts of a changing climate is observed in the agricultural practices and crop choices shaped by contemporary climate conditions around Lake Pomacoches, Peru. The wet and cool lake environment would have been problematic for agriculturists and the maize cultivation has been abandoned (during wet times) or moved back from the shoreline over a 3500-year history (Bush et al., 2015). Another example is the spread of cattle pastoralism in Africa in the middle Holocene (from 6400 BP) which appears to have been in response to climatic deterioration (Brooks, 2006), and in the central Sahara, pastoral populations intensified transhumance and use of highland areas as lowland areas became drier from 6000 to 5000 BP (Clarke et al., 2016). Likewise, during the same period in the Levant there is clear evidence of a reduction in the proportion of pigs and a concomitant increase in wool-bearing sheep, demonstrating an advantageous adaptation in animal husbandry to increasing aridity (Clarke et al., 2016). Some societies were even able to exploit a drying climate. The Garamantian kingdom in central Libya is probably the clearest example of a society emerging as a consequence of increasing aridity. Not only were they able to exploit the strategic position of their capital city, Garama, as a gateway between the North African coastal Roman towns and the lucrative Saharan caravan trade with sub-Saharan Africa, they were also in a position to leverage climatic deterioration in the form of aridification by controlling access to crucial irrigation technology, such as the construction of foggara (Brooks, 2006). Connectivity and control of that connectivity provided a means by which climate change could be used to advantage (Zhang et al., 2020; Burke et al., 2021). Ironically, it was not increasing aridification that led to the demise of the Garamantian kingdom, but increasing warfare on its borders precipitated by a weakening Rome. Thus, the Garamantians show us that connectivity through economic, political, technological, and social networks leads to increased societal resilience. In contrast, communities that were isolated in the past appear to have been more vulnerable to climate change as it exacerbated existing vulnerabilities.

Indigenous and traditional knowledge can be used for addressing climate change through their potential influence on adaptation (Chávez La Torre and Llerena Ortega, 2015), policy, decision-making, and communication (Cevallos, 2013; Alvarado and Bámaca-López, 2020; Blancas et al., 2020; González-Rivadeneira and Villagómez-Reséndiz, 2020). Lessons from the past can also apply to non-human species, such as the 'endangered living fossils' concept, representing unique and threatened species lineage with an exceptional evolutionary heritage that survived dramatic climate change periods, which is proposed as an additional criterion for IUCN prioritisation of flora and fauna (Vargas et al., 2020).

The reliability and resolution of climate, environmental and archaeological lines of evidence are predictably better the more recent the data. For example, the reconstruction of human responses and adaptations to the Late Antique Little Ice Age and the Medieval Little Ice Age, draws upon an ensemble of climatic, historical, archaeological and ecological evidence and data sets such as tree-ring series, sea cores, lake cores, speleothems, ice cores, pollen, historical, archaeological, art and literature. The integration of this diverse range of evidence allows for a more nuanced reconstruction of human responses to climate change (Degroot, 2018; Peregrine, 2020).

9. Review of Methods for Characterising Heritage Vulnerability to Climate Change

The methods employed to assess the impacts and risks to heritage posed by climate change reflect the diversity of those impacts and risks (Orr et al., 2021). The methods used to evaluate hazards within climate change risk for heritage are similar to those used to assess hazards for other aspects of environment and society (e.g., Forzieri et al., 2016). Exposure assessment has broadly been approached for individual sites (or a small collection of sites), through an understanding of 'types of heritage' (see Section 7) or regional evaluation (see Section 6). Due to its variability and relatively mature state of knowledge compared to hazard and exposure (see Section 7), the focus of this section will be on understanding methods that have been used to assess the vulnerability of heritage to climate change.

9.1 Physical vulnerability

Physical vulnerability is primarily assessed using a range of physical investigation techniques, which are typically adapted from their primary applications to determine responses of heritage to their environment context:

Measurement

- Non-destructive testing from civil engineering, especially for on-site evaluation (Porco et al., 2014; Haugen et al., 2018; Shabani et al., 2020).
- Environmental monitoring (Anaf et al., 2018).

Simulation

- Laboratory testing, including samples (Oliveira et al., 2019) and small-scale reproductions (Lubelli et al., 2018) and proxies that have undergone simulated weathering (e.g., (Nogueira et al., 2020).
- Modelling (Howard et al., 2016; Richards et al., 2020).

Observation

- Surveys (Cutko, 2009; Mosoarca et al., 2017; Woodcock and Furness, 2021).
- GIS and remote sensing (Liu et al., 2019), especially in the context of disasters and extreme events (Reeder-Myers and McCoy, 2019).

An overarching challenge within understanding physical vulnerabilities of heritage in the face of climate change is the complex and stochastic nature of the processes involved (Viles and Turkington, 2005), including hysteresis (Garbe et al., 2020).

9.2 Social and cultural vulnerability

Social and cultural vulnerability are primarily assessed using social-scientific qualitative methods including interviews, surveys, and questionnaires (Orr et al., 2021). Despite being less frequent, mixed methods approaches combining data-driven computation with surveys of residents to understand community perspectives result in a nuanced understanding of non-economic barriers to characterising vulnerability (Kittipongvises et al., 2020). Similarly, value-based definitions of vulnerability must be understood through community-informed processes (Ghahramani et al., 2020; Seekamp and Jo, 2020) which can incorporate a range of qualitative and quantitative methods: which communities to engage with, and how, should be determined on a case-by-case basis. However, vulnerability should be considered in its broader context: it is important to recognise the ways in which local policy impacts vulnerability, especially for traditional communities in remote areas (Ford et al., 2007).

Nakashima et al. (2012) report on published scientific and grey literature on the contribution of local and Indigenous knowledge to the understanding of global climate change. It focuses on post-AR4 literature and includes inputs from the international expert meeting on 'Indigenous Peoples, Marginalized Populations and Climate Change: Vulnerability, Adaptation and Traditional Knowledge' held in Mexico City in 2011 co-organised by UNU, UNESCO, IPCC, SCBD, UNDP. The authors conclude that 'despite the high exposure-sensitivity, Indigenous peoples and local communities are actively responding to changing climatic conditions and have demonstrated resourcefulness and resilience in the face of climate change' (Nakashima et al., 2012, p. 8). They maintain that even though Indigenous communities present a higher degree of exposure sensitivity, they also show a considerable adaptive capacity, which increases their resilience.

Iwama et al. (2021) reviewed the extent to which participatory approaches, including citizen science, have been used in the study of slow-onset events related to climate change in Latin America and the Caribbean. They found that although scientists recognise the importance of local and Indigenous knowledge in climate research, the role of local observations is not fully recognised, reinforcing 'the dominant power structures of academia' (Iwama et al., 2021, p. 38). Some projects have been identified in the region as showing potential for co-production of knowledge and use of multiple knowledge systems in climate research, e.g., System Observation and Monitoring in the Indigenous Amazon (SOMAI) and Cemaden-Educação in Brazil, and Proyecto Glaciares in Peru. Importantly, they suggest that to develop structures for the incorporation of local observations of climate change, Indigenous and LK systems, with their narratives and cosmological views, need to be 'equally weighted whilst being understood in their own context' (Iwama et al., 2021, p. 37).

A wide range of community-based climate vulnerability adaptation tools are implemented for adaptation, disaster risk reduction, and food and nutrition security (McLeod et al., 2015; Reimann et al., 2021). These tools can be applied at a community scale for climate change heritage assessments. The Climate Vulnerability and Capacity Analysis (CVCA) is a tool that adopts the IPCC definition of vulnerability to guide practitioners in analysing vulnerability to climate change (Care International, 2019). It identifies livelihood assets as fundamental for adaptive capacity. Another example is CRiSTAL (Community-based Risk Screening Tool – Adaptation and Livelihoods), developed in collaboration with the IUCN to help planners and managers develop adaptation strategies based on identifying the most resources at risk from climate change (IISD, 2012).

9.3 Mixed vulnerability assessment

Mixed vulnerability assessments determine the compounded vulnerability from the physical, cultural, and socioeconomic impacts of climate change; they include climate scenarios and impact-adaptation algorithms:

- Scenario-based models, such as the Dynamic Interactive Vulnerability Assessment (DIVA) for integrated assessment of coastal zones produced by the EU-funded DINAS Coast consortium (Vafeidis et al., 2006, 2008) that can be applied globally and locally.

- Indicator based systems, such as Eurosion, an initiative for sustainable coastal erosion management in Europe (European Commission, 2004); or the Deduce projects that define 27 indicators for sustainable development at a European, national, regional and local level (Roux et al., 2013).

- Index-based methods: Multiscale coastal vulnerability index integrating three elements: (1) coastal characteristics, (2) coastal forcing, and (3) socioeconomic data (McLaughlin, Andrew and Cooper, 2010).

9.4 Vulnerability frameworks and procedures

Vulnerability is a key part of assessment frameworks and procedures for characterising the 'state-of-play' for heritage egardless of whether they focus on climate change or are broader in scope. The representation of vulnerability within these frameworks are typically metrics, such as arithmetic or weighted means of factors (Gornitz, 1991). As discussed by Zanetti et al. (2016), there are a wide range of vulnerability indices that are relevant to heritage, these are typically created for local contexts and then adapted (for a Coastal Vulnerability Index, see also (Gornitz, 1991; Özyurt and Ergin, 2009; Sudha Rani et al., 2015). In wider literature, these are generally focused on physical vulnerability, and this has emerged in heritage-specific index development as well (Daly, 2016; Daly, 2019). Heritage-specific indices such as that proposed by Zanetti et al. (2016) and the framework of Sesana et al. (2019), as well as a heritage-specific Climate Vulnerability Index (Day et al., 2019; Day et al., 2020), are more inclusive of the social, cultural, and environmental context in which heritage is embedded. Another excellent example of the CVI approach, emphasising the social and cultural vulnerability of local communities, is the CVI Orkney (Day et al., 2019). Indices for extreme events are less prevalent in literature (Forino et al., 2016; Orr and Cassar, 2020), perhaps owing to the difficulty of characterising and parameterising this vulnerability.

Two systems have been developed for the global monitoring of WH properties: the SOC system, as mentioned above, which is part of the World Heritage System, and the IUCN World Heritage Outlook developed only for natural and mixed properties. The focus of the monitoring is the conservation of their Outstanding Universal Value (OUV). If cultural and heritage value that is not specified as part of a site's OUV are being affected or impacted by climate change, this would not be reported in these systems:

- The State of Conservation reports (https://whc.unesco.org/en/soc/) focus on a set of factors affecting WH properties. Originally using the term 'threats.,' in 2008, a list of 14 categories of factors was established. One of these categories is 'climate change and severe weather events.' Even though the system does not refer to vulnerability, properties for which State of Conservation reports are discussed during the World Heritage Committee sessions represent those that are either most affected or more likely to be affected by an imminent threat to the conservation of their OUV. Thus, the vulnerability of properties is characterised by the frequency of reporting climate change as a factor affecting their OUV, combined with other factors that might reduce their resilience (e.g., management and institutional factors). Characterising vulnerability, as defined by the IPCC, (i.e., applied to systems quantitatively), for cultural properties, would require a reframing of heritage as a system and the development of a framework for heritage practitioners that will offer low-tech and high-tech assessment options.

- The IUCN World Heritage Outlook (https://worldheritageoutlook.iucn.org/home-page) was launched in 2014 to (1) track the state of conservation of all natural WHSs over time, (2) identify the most pressing conservation issues affecting natural WHSs informing the international community and (3) raise awareness about the importance of biodiversity conservation. The methodology provides a projection of whether the site is likely to conserve its OUV over time based on the assessment of three aspects: the current state and trend of values, the threats affecting those values, and the effectiveness of protection and management. The outlook results are divided into four projections: critical, significant concern, good with some concerns, and good. The latest outlook assessment (Osipova et al., 2020) points at climate change as the most prevalent current threat to the conservation of natural WHSs. This methodology is not based on the IPCC vulnerability assessment, even though it can support efforts to identify natural WHSs that are more prone to lose their OUV.

10. Discussion

10.1 Knowledge gaps

There has been no systematic assessment of the range of heritage types at risk from climate change, nor of the range and severity of climate impact drivers, and of losses and damages to heritage from climate change. More is needed to understand how hazards affect heritage at the site-level, including integration of physical, socioeconomic, cultural vulnerability, and exposure of individual sites. Limited evidence is provided in the recent IPCC assessment on impacts to specific sites on the World Heritage List (only assessed for sea-level rise and Glaciers) (see Section 4.2). This reflects current gaps in the peer-reviewed and practice literature and large thematic and regional gaps in both quantitative and qualitative research that would inform large climate assessments (see Sections 6.1; 6.2; 7.3 and 10.1). Yet the types of heritage currently identified as impacted by climate change, the range of climate hazards, the severity of observed impacts, and the inequitable distribution of their impacts are alarming, particularly on Indigenous communities. These observations indicate that heritage faces severe, immediate, increasing, and existential risks and L&D from future warming levels and necessitates the mobilisation of substantial resources for climate change /heritage assessment.

Although adaptation is commonly referred to in both the climate change /heritage literature and IPCC Special Reports, there is a lack of knowledge on whether responses to climate change are reducing risk in general and limited evidence for heritage. Greater specificity is needed to show how responses to climate change are affecting exposure, vulnerability, or impact. To date, IPCC reports have not described risk to heritage in terms of cascading or compounding impacts (Simpson et al., 2021). Due to their potential severity, cascading or compounding risk, particularly those associated with compound climate events, are at the forefront of climate science and their absence in IPCC reports indicates a slow uptake in application to heritage. Yet this is important for heritage as climate change presents multidimensional impacts with unpredictable feedback loops and second or third order outcomes (IPCC, 2018; Simpson et al., 2021). Further, risks from responses to climate change need to be identified and their trade-offs and co-benefits with adaptation and broader developmental goals identified (Simpson et al., 2021). IPCC reports have also not described risk to heritage with attention to detection and attribution of anthropogenic climate change impacts on heritage. As impacts and risks are important to inform understanding of adaptation effectiveness, these gaps mean we currently lack knowledge of the effectiveness or feasibility of available adaptation options for heritage at current and future global warming levels (Mechler et al., 2020; Singh et al., 2020; Williams et al., 2021).

Although there is an emerging use of terms like hazard, exposure, and risk in climate change /heritage research and practice, there currently exists no authoritative glossary for cross-walk between climate change assessment and heritage research and practice. As our understanding of climate change risks evolves, so also definitions of risk keep evolving, for example the role of response as a driver of risk in the AR6 definition of the IPCC (Simpson et al., 2021). While there may be room to embrace diverse and evolving perspectives on terms to ensure their richness, a significant knowledge gap exists for where and when greater specificity or rigidity in definitions and their application to various audiences is necessary or helpful for assessment of climate change impacts on heritage.

There is an underrepresentation of several types of heritage within the understanding of impacts of climate change for cultural heritage particularly for:

- Intangible heritage (Kim, 2016; Orr et al., 2021).
- Underwater heritage (Perez-Alvaro, 2016; Iwabuchi, 2021).
- Indoor cultural heritage, especially those in lacking climate control such as air-conditioning (Huijbregts et al., 2012; Mazurczyk et al., 2018).

Robust risk assessments, incorporating exposure, hazard, and vulnerability of heritage, are needed. These need to be underpinned by sufficient understanding of these aspects of risk, which require a ramping up of innovation in collecting, processing, and interpreting data that represent them.

A growing understanding of the risk concerns how responses to climate change affect risk, vulnerability, exposure and other response options (Reisinger et al., 2021). More broadly, there is a need to develop research that can measure the risk to heritage induced by climate-related migration, displacement, and relocation policies (Herrmann, 2017; Brooks et al., 2020).

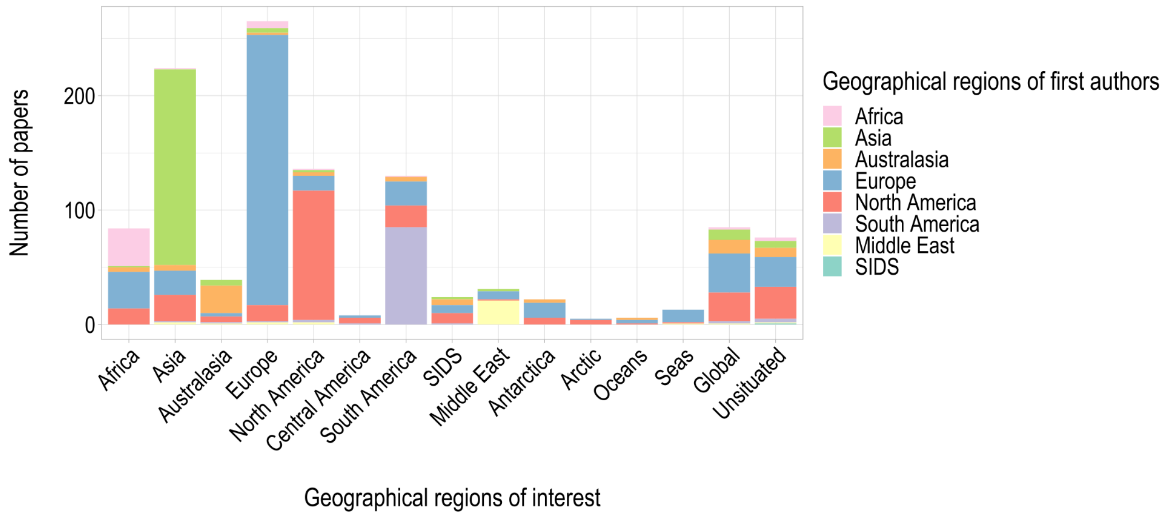
There is a clear discrepancy between the areas of research in the literature available for cultural and natural heritage. With more than 60% of natural heritage-climate publications focusing on biodiversity conservation, environmental sciences and ecology, and only a negligible fraction with a primary or secondary interest in social sciences, the latter is left out of the conversations related to conservation of natural heritage in the climate change context. A similar pattern is observed for cultural heritage literature, for which more than 45% focuses on environmental sciences, archaeology, green & sustainable science & technology, and geosciences. In the last three decades, natural and technical sciences for research on climate change received 770% more funding (research grants) than the social sciences, with only 0.12% of all research funding allocated to the social sciences for climate mitigation (Overland and Sovacool, 2020). In climate change /heritage research, the social aspect (and social innovation) of climate change adaptation and mitigation measures is the least researched despite its importance for sustainable transitions (Whitmarsh et al., 2011).

One limitation for the assessment of climate change impacts on sites designated as 'natural' heritage sites is the research focus on the natural values for which the sites are protected and designated at the expense of other natural values and human values. In addition to their cultural value, 'natural' heritage sites are of great importance in all three knowledge systems: Indigenous, local, traditional, scientific. Indigenous Peoples and local communities are increasingly recognised as key to the protection and management of protected areas. Future climate change impact assessment on heritage value should take account of the direct and indirect impacts on the human communities that are part of the social-ecological systems of heritage sites.

The quantitative and qualitative reviews demonstrate uneven regional attention to climate change impacts on heritage. Moreover, the imbalance in the literature assessed is also reflected on the focus on tangible heritage at the expense of intangible heritage, which can be due to the availability of assessment tools for the tangible aspects of human and non-human systems. Similarly, knowledge inequality in the climate change heritage literature mirrors the attention to universal /cosmopolitan definitions of heritage in contract to Indigenous and local perspectives and views on the concept of heritage, which are harder to access, collect and compare.

Climate change /heritage research is also affected by inequalities between and within countries (Simpson et al., 2022). In addition to addressing systemic inequities, reducing spatial inequality by decentralising funding at global and local levels is crucial for effective heritage conservation in the climate change context, i.e., increasing 'access relative to needs' from climate change and extreme weather events (Meredith et al., 2019).

a) Natural Heritage



b) Cultural Heritage

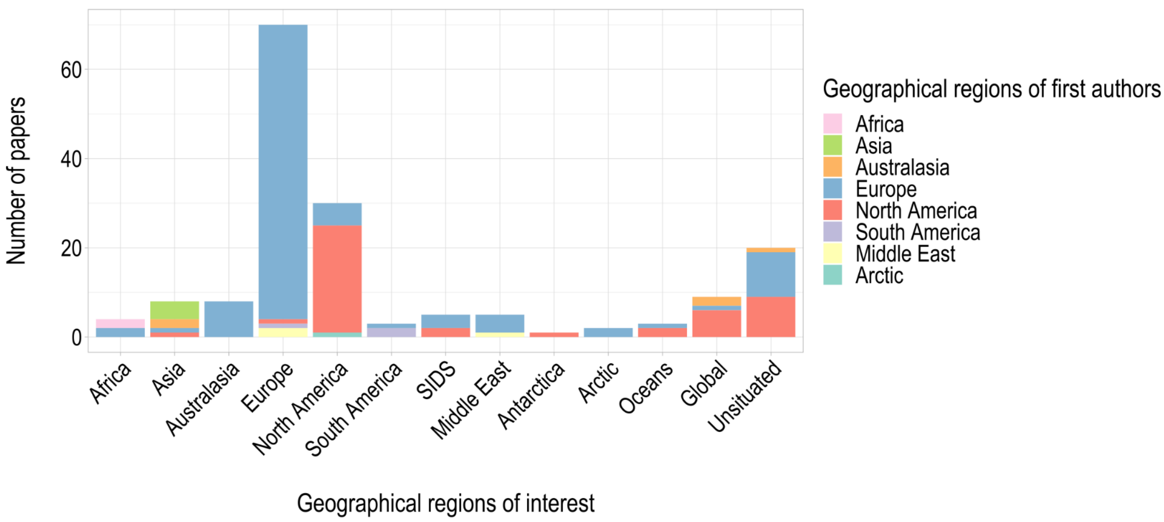


Figure 8: Unequal Distribution of Climate Change /Heritage Knowledge Creation

Number of English language papers on a) cultural and b) natural heritage for different geographical regions and regions of first authors of climate change-heritage research. Concentrations of research focus on Europe and North America, while these regions also contain the highest number of first-author scholars producing this research (adapted from Simpson et al., 2022).

Most research collaborations still take place within a small group of countries and researchers (Skupien and Rüffin, 2019; Overland and Sovacool, 2020; Simpson et al., 2022). For natural sites, 80% of first authors' countries of affiliation are in Europe, North America, and Asia. In comparison, 83% of first authors of cultural-heritage-climate publications are based in Europe and North America (see Figure 7). Africa and Central America are the only continental regions for which more than half of the natural heritage assessments are based in institutions in Europe and North America (~55% and ~90% for Africa and Central America, respectively) (Figure 8 and Table 4). This reproduces a colonial pattern in knowledge production and research relationships of heritage-climate change research and exacerbates the imbalance in heritage literature distribution. Yet, the decolonisation of heritage-climate research can play an important role in reinforcing adaptation actions locally and globally through empowering local research and practices and recognition of local and Indigenous heritage (Simpson et al., 2022).

There is a need to foster multi-method approaches that can develop a more holistic and systemic understanding of vulnerability. There is also a need to incorporate the vulnerability of heritage to climate change into existing reporting and monitoring mechanisms. There are several frameworks and methods that have been proposed for measuring the vulnerability of heritage to climate change; to date, there has been no systematic evaluation of these approaches. Specifically, there is a need to promote those that incorporate vulnerability in a comprehensive sense (including social and cultural vulnerability).

Table 4: Distribution of Climate Change /Heritage Literature

Summary of the regional distribution of the literature, factors affecting the distribution and the focus of the research for the cultural and natural heritage sectors. *The representation of regional affiliations gives the percentage of a specific region's literature for which the first authors affiliations is within the region. (e.g., 94% of the literature assessing cultural heritage in Europe has its first authors based in European institutes and universities).*

Regions	Systematic review (%)		Factor of distribution of literature	General comment	Representation of regional affiliations (%)		Focus of research	
	Cultural (175 publications /region)	Natural (1198 publications /region)			Cultural	Natural	Cultural	Natural
Europe	43.7	23.1	Collaborations across regions are facilitated by robust and well-established funding mechanisms	Hazard and vulnerability assessment; adaptation strategies; policies	94	89	Historic, built, archaeological and coastal heritage; hazard, vulnerability and impact assessments; adaptation approaches; coastal assessment; vulnerability to SLR, flood and erosion; planning, monitoring and management	Habitat and species conservation, distribution, loss and decline; impacts assessment; protected areas planning processes and strategies in different political contexts; environmental protection; climate change policies, legislations and nature conservation; stakeholders' analysis and governance innovations; climate adaptation strategies, valuation of ecosystem services; marine and forest conservation; risk reduction; coastal marine biodiversity and ecosystems; habitat restoration; ecosystem services valuation
Asia	4.8	19.2	Lack of financial support for conservation projects; lack of domestic approaches to community engagement government-led, grassroots-initiated, or international project-led heritage conservation; improper heritage awareness; lack of coordination among the stakeholders; inadequate funding as well paucity in understanding the (fast) growing demands in heritage tourism	Focus on natural heritage	50	76	Agricultural and built heritage; cultural ancestral, traditional, Indigenous and ecological knowledge; urban places and their communities; impacts of extreme events; intangible heritage; heritage awareness; stakeholders' analysis	Habitat and species conservation and loss; ecological restoration; conservation effectiveness; sea-level rise impacts; sustainable tourism; ecosystem services valuation
North America	18.0	11.6	Colonial legacy; well-established funding mechanisms	Focus on natural heritage; Indigenous cultures and archaeological sites; separation between natural and social heritage	80	83	Build heritage; urban areas; precolonial human transformation of landscapes	Natural protected areas; ecosystem valuation; conservation measures and approaches; connectivity; tourism; adaptation and responses; policies and legislations; habitat and species distribution, conservation and loss; invasive species; coastal assessments; marine and forest conservation
South America	1.8	11.2	Exposure to hazards and extreme events; importance of Indigenous and local knowledge	Coastal hazards; archaeology; geography and urban planning; Indigenous and local knowledge	67	65	Coastal cities; sea-level rise impacts; vulnerability flooding, underwater heritage; cultural ancestral, traditional, Indigenous and ecological knowledge; cultural and agricultural landscapes	Habitat and species conservation, distribution; forest conservation (Amazon); impact assessments; endangered species and hotspots; management
Unsituated	12.0	6.5	-	-	-	-	-	-

Regions	Systematic review (%)		Factor of distribution of literature	General comment	Representation of regional affiliations (%)		Focus of research	
	Cultural (175 publications /region)	Natural (1198 publications /region)			Cultural	Natural	Cultural	Natural
Global	5.4	7.3	-	-	-	-	-	-
Africa	2.4	7.6	Lack of climate change research funding; governmental policies (i.e., tourism or environmental sustainability); interest of countries and scholars in climate change impacts on cultural heritage, socioeconomic factors such as poverty and levels of literacy	North Africa (cultural focus) Sub-Saharan Africa (natural focus) dichotomy Most represented: Kenya, Egypt and Ghana	50	40	Archaeological and historical build heritage	Sustainability through traditional livelihoods and knowledge; national parks conservation; forest conservation; management; impacts assessments; adaptation strategies
Australasia	4.8	3.3	-	-	0	62	Cultural landscapes, Indigenous places, archaeological sites, indigenous and local management and adaptation, climate change assessment index	Risk evaluations for the physical and ecological properties of natural systems, plant invasions, sea-level rise, glaciers tourism
Small Islands and Developing States	2.4	2.1	Disparate, project-centric literature with limited national or regional coordination of questions relating to climate change	Relationship between heritage and hazards (extreme events such as cyclones)	0	0	Localised case studies: sea-level rise, flooding of urban heritage coral bleaching and the transformation of ecological resources vital to cultural production and performance, relocation and the separation of communities and heritage places	
Arctic	1.8	2.1	-	-	-	-	Indigenous livelihoods, archaeological sites, relocation and migration of population, cultural landscapes, glacial archaeology	Effects on ice dependent species, marine conservation, loss of snow and ice
Antarctica	0.6	1.9	-	-	-	-	-	Change in glacier margin positions, terrestrial and botanical biodiversity, seabirds' conservation
Middle East	0.6	1.8	Lack of climate change research funding; lack of financial support for conservation projects	Poorly represented Most represented: Iran	20	68	Traditional agriculture, cultural landscapes	Endemic and endangered species, biodiversity hotspots, connectivity, habitat suitability, forest distribution, ecotourism, geoconservation
Seas Oceans	0.0 1.8	1.1 0.5	- -	- -	- -	- -	Maritime archaeological heritage,	Species distribution, marine and coastal habitat conservation, coral reef vulnerability and adaptation, sea-level rise impacts on biodiversity, nature-based solutions for coastal protection
Central America	0.0	0.7	Lack of climate change research funding; lack of financial support for conservation projects	-	0	0	-	Conservation priorities and connectivity pathways, biodiversity decline,

10.2 Challenges presented by this research

Considering the knowledge gaps identified above, key challenges for climate change /heritage research and practice are presented here as a synthesis of the findings and a primer for future discussion.

10.2.1 To systematically identify the range of impacts from climate change on heritage commensurate with the diversity, quantity, and severity of its impacts.

There is a mature, diverse, and growing understanding of the vulnerability of heritage to changes in the environment, social, economic, and cultural contexts (see Sections 4, 7 and 9). There is also growing recognition that anthropogenic climate change is already impacting multiple types of heritage across all regions of the world (see Sections 4 and 6). Further, future climate change poses increased risks to heritage globally including L&D to heritage of current and future generations and particularly severe impacts on the intangible cultural heritage of Indigenous communities (see Section 4). However, the literature and knowledge of anthropogenic climate change and its impacts on heritage is less developed and we have no comprehensive list of types of heritage affected by climate change (see Section 4). The challenge remains how to systematically identify the range of impacts from climate change on heritage commensurate with the diversity, quantity, and severity of its impacts. This challenge is compounded by diversity of heritage types, flux, and scales.

10.2.2 To integrate all determinants of climate change risk in assessment of impacts on heritage.

Hazard assessment is prevalent within climate change /heritage literature, and exposure has been understood and evaluated in several ways (see Section 9). There remains a significant opportunity to assess the risk posed by climate change to heritage in a robust way that adequately incorporates its vulnerability, relevant hazards, exposure, and responses to climate change, including adaptation and mitigation (Simpson et al., 2021) (see Sections 5, 7 and 9). Additionally, there is a need to understand these risks at multiple scales relevant to heritage, and to identify regions between which there is an opportunity for collaborative knowledge exchange. This, in turn, can inform the understanding and prioritisation of climate impact drivers of relevance for local- and regional-scale assessment. At a minimum, climate change considerations need to be integrated into Heritage Impact Assessments and Environmental Impact Assessments for heritage sites and policies. For example, the Dakhla Atlantique Port project did not carry out an assessment of the impact of construction of the port on the increasing vulnerability of the Ramsar wetland site to climate change for Baie d'Ad-Dakhla (site 1470); although Morocco does often carry out environmental impact assessments in advance of development (Benfadil, 2016).

10.2.3 To identify and develop the essential climate change risk terms needed for alignment of climate change /heritage research and practice.

The use of a common language of climate change impact and risk terms will likely be important in bringing heritage and IPCC understandings of risk to a level of coherence that would support assessment. While ICOMOS has made substantive changes in the last two years to align more closely with IPCC risk terminology, there remains a challenge for other heritage bodies, such as UNESCO and to a lesser extent the IUCN, to align consistently (see Section 5).

10.2.4 To transform large climate change assessment products /modes to better assess heritage-specific risks, impacts, vulnerability and adaptation to climate change.

The IPCC could more systematically and comprehensively mainstream heritage into its sectoral and regional chapters, include cultural aspects, and identify local level impacts with quantitative and qualitative assessment where possible (see Table 5, Section 4).

Table 5: Integrating Heritage into IPCC reports

(Entry points listed aim to complement the existing coverage in special reports discussed in Section 4. They are a primer for consideration and not an exhaustive list. The dichotomy between natural and cultural heritage are for listing purposes only and not intended to indicate strict categorisation).

IPCC sectoral chapters	Natural heritage	Cultural heritage
Terrestrial and freshwater ecosystems	Wetlands, Ramsar sites, Biosphere reserves, forests, protected areas	Rock art sites, built heritage
Oceans and coastal ecosystems	Coral reefs, mangroves, Ramsar sites,	Shipwrecks, Roman harbours, underwater heritage, historical ports, and fortifications
Water	Mountain protected areas with glaciers and lakes	Foggara, ancient cisterns, water systems
Food and fibre	Biocultural heritage	Traditional lifeways e.g., pastoralism, itself an ancient response to increasing aridity, cultural landscapes (e.g., rural landscapes)
Cities and settlements	Protected areas, Biosphere reserves, Geoparks	World heritage cities towns, vernacular architecture traditional building methods, cultural landscapes (e.g., historical urban parks)
Health and wellbeing	All natural heritage	All cultural heritage
Economies, Poverty and livelihoods	Protected areas, Biosphere reserves, Geoparks	Intangible heritage Indigenous and local knowledge, cultural landscapes (e.g., rural landscapes), historical towns

Further, large climate assessments like the IPCC need to transparently and explicitly map out key knowledge gaps of impacts and risks to simulate research and funding into under-researched sectors and regions. Where such research can advance understanding of downscaled detection and attribution to anthropogenic climate change, such knowledge will likely be useful for future progress on understanding and managing L&D to heritage from climate change.

10.2.5 To identify the essential roles, responsibilities and stakeholders necessary to assess climate change impacts, including those of Loss and Damage from climate change.

The fundamental principle of common but differentiated responsibilities and respective capabilities, is one of the basic pillars of UNFCCC (Mechler et al., 2019; Mechler et al., 2020). Yet, it remains unclear what role and contributions various stakeholders will play in identification, quantification and addressing L&D from climate change to heritage (see Section 5). More broadly, the value-driven approach to heritage decision making can inform risk assessment within the wider context of climate change. Heritage valuation by international or local governmental or non-governmental organisations, is linked to its local /global intrinsic natural values or socio-economic or cultural benefits. This affects the funding and focus of researchers and heritage practitioners. The overlaps of protection and recognition at local, national, or international levels might play an important role in the availability of climate-heritage literature. For instance, a World Heritage Site recognised by its OUV might call for more attention and resources at national level, and sometimes international level, as its significance has been recognised at a global scale. A natural protected area (i.e., National Park) might be recognised as a cultural landscape at the international level (i.e., World Heritage List) and therefore possibly studied for its cultural benefits at a global level, but for its ecosystem goods or services provided to local communities at a national level. Related fields, such as infrastructure (Field and Look, 2018), have begun to adopt value-driven approaches: the heritage field can and should advocate for wider adoption by demonstrating its suitability for assessing risk through interdisciplinary collaboration. This will likely bear most fruit where a value-driven approach is able to identify losses or damages to OUV (see Section 9). Further, climate change /heritage research and practice will need to find a balance in valuation between climate change impacts on potentially incommensurable heritage values. For example, how to give proportional value to impacts on ski resorts compared with impacts on Indigenous peoples which require different methods, stakeholders, and levels of focus.

10.2.6 To develop novel research modalities and methods necessary to assess climate change impacts on heritage.

To holistically address heritage vulnerability, we need to rethink interdisciplinarity (Schipper et al., 2021), moving beyond mixed methods toward plural and co-existing perspectives that build on multiple epistemologies. Against the backdrop of a need for robust evidence that is typically underpinned by fundamental and theoretical work underpinned by method and theory, case study-based practice-led research can help to achieve this 'new paradigm' for interdisciplinarity, especially when they are participatory, including citizen science (Davies, 2020) and crowd-sourced data (Kumar, 2020), and incorporating Indigenous and LK (Nakashima et al., 2012). Such recent work has shown a need to establish closer links between resilience and vulnerability. To scale up our understanding of vulnerability requires an improvement in knowledge exchange, data sharing and digital literacy (Albuerne et al., 2018; Otero, 2022), and standardisation of practice to enable comparability and build up a comprehensive understanding of vulnerability (see Sections 5, 7 and 9).

There is opportunity for climate change /heritage research and practice to embrace transformational, inter- and transdisciplinary, and decolonial principles to address a range of the research and practice challenges as the field matures (Simpson et al., 2022). Despite recent interest in decolonising heritage research (ICCROM, 2019; Breunlin, 2020), decolonial approaches are not yet widely established in climate change /heritage scholarship and practice (Simpson et al., 2022). Recognising that colonisation led to Euro-American centricity, dispossession, racism, and ongoing power imbalances in how climate change /heritage research is produced and used is an important first step. The next step is committing to actively undoing those systems and ways of thinking through transformations to climate change /heritage research agenda setting, funding, training, access, and governance (Simpson et al., 2022).

10.2.7 To keep learning from the past

History and archaeology provide insight into the ways in which societies adapted to climate change in the past and crucially show us the outcomes of those adaptations both advantageous and disadvantageous relative to the scale of impacts they experienced. Much can be learnt from the recent past, yet the further back in time we go the more complicated it becomes to identify clear lessons for the present on impacts and risk-reducing responses to climatic changes. While the past cannot be a perfect analogue, it can an provide empirically grounded legacy for reflecting on the efficacy and feasibility of adaptation to the current and projected impacts associated with anthropogenic climate change.

11. Conclusion

Although heritage is present in IPCC literature (Assessment Reports and Special Reports), this inclusion is unsystematic, superficial, and not inclusive of the vast diversity of types of heritage and risks posed by climate change. Further, the impacts or risks that are identified are usually qualitatively described with little specificity, and only quantified in a handful of instances. One of the challenges for incorporating heritage into IPCC assessments is the diversity of terminology, the variety of use within heritage literature and practice, and the discrepancy of this terminology to that used by IPCC and broader climate risk literature.

The risks climate change poses to heritage have been assessed in a diverse range of ways. The vulnerability of heritage to climate change draws on a rich and diverse body of knowledge placing heritage in its environmental, social, economic and cultural contexts. Despite this, climate change risk assessment has focused on hazard assessment. Yet there are significant opportunities to evaluate heritage climate risk holistically, with an emphasis on social and cultural vulnerability and the systemic nature of climate change impacts on heritage. This should be driven by novel, interdisciplinary approaches that move beyond mixed methods toward plural and co-existing perspectives that build on several epistemologies.

Systematic review of the literature shows unequal distributions of climate change /heritage knowledge and knowledge production for both cultural and natural heritage. Most studies concentrate on Europe and North America. Global knowledge production, indicated by first authors of studies, is also centred in these regions. Outside Europe and North America knowledge production of English-language climate change /heritage knowledge closely aligns with former British colonies presenting challenges to climate change /heritage knowledge production outside such regions, particularly for holders of Indigenous knowledge and local knowledge.

Climate change impacts are exacerbating environmental, social, and cultural risks to heritage. There are significant opportunities for improving heritage representation in international climate change policy, while also transforming the frameworks and methods in which our understanding of the effects and consequences of climate change for heritage are developed. For climate change /heritage research and practice to be equitable there is an urgency to diversify the geographic distribution of the current state of knowledge and incorporate a broad range of heritage stakeholders and local and Indigenous knowledge into climate change /heritage risk assessment.

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Glossary of IPCC Terms

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2019b).

Adaptation limits: The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions.

Hard adaptation limit – No adaptive actions are possible to avoid intolerable risks.

Soft adaptation limit – Options may exist but are currently not available to avoid intolerable risks through adaptive action (IPCC, 2019b).

Cascading impacts: Extreme weather /climate events occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional, and are associated more with the magnitude of vulnerability than with that of the hazard (IPCC, 2019b).

Cultural heritage:

- Monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of special value from the point of view of history, art or science;

- Groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, area of special value from the point of view of history, art or science;

- Sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of special value from the historical, aesthetic, ethnological or anthropological point of view (UNESCO, 1972, Article 1).

Culture: The whole complex of distinctive spiritual, material, intellectual and emotional features that characterise a society or social group. It includes not only the arts and letters, but also modes of life, the fundamental rights of the human being, value systems, traditions, and beliefs (UNESCO, 1982).

Climate change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the UNFCCC, in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC, 2019b).

Detection and attribution: Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%. Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence (IPCC, 2019b).

Exposure: The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2019b).

Hazard: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (IPCC, 2019b).

Heritage: Heritage is a cultural and social and engages with acts of remembering that work to create ways to understand and engage with the present. Heritage is a multi-layered performance - be this a performance of visiting, managing, interpretation or conservation - that embodies acts of remembrance and commemoration while negotiating and constructing a sense of place, belonging and understanding in the present (Smith, 2006, p3). It can also be understood as Heritage as 'a set of attitudes to, and relationships with the past' (Harrison, 2013, p. 14).

Impacts (consequences, outcomes): The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather /climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial (IPCC, 2019b).

Indigenous knowledge: Refers to the understandings, skills, and philosophies developed by societies with long histories of interaction with their natural surroundings. It is passed on from generation to generation, flexible, adaptive in changing conditions, and increasingly challenged in the context of contemporary climate change (IPCC, 2019b).

Intangible heritage: The intangible cultural heritage means the practices, representations, expressions, knowledge, skills–as well as the instruments, objects, artefacts and cultural spaces associated therewith–that communities, groups and, in some cases, individuals recognise as part of their cultural heritage. This intangible cultural heritage, transmitted from generation to generation, is constantly recreated by communities and groups in response to their environment, their interaction with nature and their history, and provides them with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity. For the purposes of this Convention, consideration will be given solely to such intangible cultural heritage as is compatible with existing international human rights instruments, as well as with the requirements of mutual respect among communities, groups and individuals, and of sustainable development (UNESCO, 2003, Articles 1 and 2).

The intangible cultural heritage (…) is manifested inter alia in the following domains:

> **(a)** oral traditions and expressions, including language as a vehicle of the intangible cultural heritage;
> **(b)** performing arts;
> **(c)** social practices, rituals and festive events;
> **(d)** knowledge and practices concerning nature and the universe;
> **(e)** traditional craftsmanship.

Local knowledge: What non-Indigenous communities, both rural and urban, use on a daily and lifelong basis. It is multi-generational, embedded in community practices and cultures and adaptive to changing conditions (IPCC, 2019b).

Loss and Damage, and losses and damages: Research has taken the term 'Loss and Damage' (capitalised letters) to refer to political debate under the UNFCCC following the establishment of the Warsaw Mechanism on Loss and Damage in 2013, which is to 'address loss and damage associated with impacts of climate change, including extreme events and slow-onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change.' The expression 'losses and damages' (lowercase letters) has been taken to refer broadly to harm from (observed) impacts and (projected) risks (Mechler et al., 2019).

Maladaptation: Actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas (GHG) emissions, increased vulnerability to climate change, or diminished welfare, now or in the future. Maladaptation is usually an unintended consequence. See also Adaptation and Adaptive capacity (IPCC, 2019b).

Natural heritage: Natural features consisting of physical and biological formations or groups of such formations, which are of special value from the aesthetic or scientific point of view; geological and physiographical formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of special value from the point of view of science or conservation; natural sites or precisely delineated natural areas of special value from the point of view of science, conservation or natural beauty (UNESCO, 1972).

Resilience: The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and transformation (IPCC, 2019b).

Risk: The Potential for Adverse Consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species (IPCC, 2019b).

Sea-level change (sea-level rise /sea-level fall): Change to the height of sea level, both globally and locally (relative sea-level change) at seasonal, annual, or longer time scales due to (1) a change in ocean volume as a result of a change in the mass of water in the ocean (e.g., due to melt of glaciers and ice sheets), (2) changes in ocean volume as a result of changes in ocean water density (e.g., expansion under warmer conditions), (3) changes in the shape of the ocean basins and changes in the Earth's gravitational and rotational fields, and (4) local subsidence or uplift of the land. Global mean sea-level change resulting from change in the mass of the ocean is called barystatic. The amount of barystatic sea-level change due to the addition or removal of a mass of water is called its sea-level equivalent. Sea-level changes, both globally and locally, resulting from changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric. Barystatic and steric sea-level changes do not include the effect of changes in the shape of ocean basins induced by the change in the ocean mass and its distribution (IPCC, 2019b).

Small Island Developing States (SIDS): as recognised by the United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, are a distinct group of developing countries facing specific social, economic and environmental vulnerabilities (UN-OHRLLS, 2011). They were recognised as a special case both for their environment and development at the Rio Earth Summit in Brazil in 1992. Fifty-eight countries and territories are now classified as SIDS by the UN-OHRLLS, with 38 being UN member states and 20 being Non-UN-Members or Associate Members of the Regional Commissions (IPCC, 2019b).

United Nations Framework Convention on Climate Change (UNFCCC): The UNFCCC was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' The provisions of the Convention are pursued and implemented by two treaties: the Kyoto Protocol and the Paris Agreement (IPCC, 2019b).

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2019b).

World Heritage: Cultural or natural heritage of outstanding universal value. Outstanding universal value means cultural or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity (UNESCO, 2019).

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Supplementary Material

Supplementary Material 1: Regional Classifications used

Africa

1. Algeria
2. Angola
3. Benin
4. Botswana
5. Burkina Faso
6. Burundi
7. Cameroon
8. Cape Verde
9. Chad
10. Congo
11. Ivory Coast
12. Djibouti
13. Egypt
14. Equatorial Guinea
15. Eritrea
16. Ethiopia
17. Gabon
18. Gambia
19. Ghana
20. Guinea
21. Guinea-Bissau
22. Kenya
23. Lesotho
24. Liberia
25. Libya
26. Madagascar
27. Malawi
28. Mali
29. Mauritania
30. Mauritius
31. Morocco
32. Mozambique,
33. Namibia
34. Niger
35. Nigeria
36. Rwanda
37. Senegal
38. Seychelles
39. Sierra Leone
40. Somalia
41. South Africa
42. Sudan
43. Swaziland
44. Tanzania
45. Togo
46. Tunisia
47. Uganda
48. Zambia
49. Zimbabwe

Asia

North Asia

1. Mongolia
2. Russia-East- of- Urals

East Asia

1. South Korea
2. Japan
3. North Korea
4. China
5. Taiwan-province of China
6. Macao Special administrative Region
7. China- Hong Kong- Special Administrative Region

Southeast Asia

1. Myanmar
2. Malaysia
3. Timor Leste
4. Thailand
5. Vietnam
6. Indonesia
7. The Philippines
8. Brunei
9. Peoples Republic of Cambodia
10. Laos People's Democratic Republic
11. Papua New Guinea

South Asia

1. Afghanistan
2. Pakistan
3. Bhutan

4. Nepal
5. Bangladesh
6. Sri Lanka
7. India

West Asia

1. Armenia
2. Georgia
3. Israel
4. Palestine
5. Jordan
6. Azerbaijan
7. Syria
8. Yemen
9. United Arab Emirates
10. Saudi Arabia

Central Asia

1. Kazakhstan
2. Kyrgyzstan
3. Tajikistan
4. Turkmenistan
5. Uzbekistan

Australasia

1. Australia
2. New Zealand

Europe

1. Belgium
2. Denmark
3. France
4. Ireland
5. Italy
6. Luxembourg
7. Netherlands
8. Norway
9. Sweden
10. Iceland
11. Germany
12. Austria
13. Cyprus
14. Switzerland
15. Malta
16. Portugal
17. Spain
18. Liechtenstein
19. San Marino
20. Finland
21. Hungary
22. Poland
23. Bulgaria
24. Estonia
25. Lithuania
26. Slovenia
27. the Czech Republic
28. Slovakia
29. Romania
30. Andorra
31. Latvia
32. Albania,
33. Moldova
34. Ukraine
35. Republic of North Macedonia
36. Russian Federation
37. Croatia
38. Georgia
39. Armenia
40. Azerbaijan
41. Bosnia
42. Herzegovina
43. Serbia
44. Monaco
45. Montenegro

Middle East

1. Bahrain (West Asia)
2. Iran (West Asia)
3. Iraq (West Asia)
4. Israel (West Asia)
5. Jordan (West Asia)
6. Kuwait (West Asia)
7. Lebanon (West Asia)
8. Oman (West Asia)
9. Saudi Arabia (West Asia)
10. Syria (West Asia)
11. Qatar (West Asia)
12. United Arab Emirates (West Asia)
13. Yemen (West Asia)

North America

1. Canada

2. The United States
3. Greenland

SIDS

1. Anguilla
2. American Samoa
3. Antigua and Barbuda
4. Cook Islands
5. Cape Verde
6. Aruba
7. Federated States of Micronesia
8. Comoros (Africa)
9. Bahamas
10. Fiji
11. Guinea-Bissau
12. Barbados
13. French Polynesia
14. Maldives (South Asia)
15. Belize
16. Guam
17. Mauritius
18. British Virgin Islands
19. Kiribati
20. São Tomé and Príncipe (Africa)
21. Cuba
22. Marshall Islands
23. Seychelles
24. Dominica
25. Nauru
26. Singapore (North Asia)
27. Dominican Republic
28. New Caledonia
29. Grenada
30. Niue
31. Guyana (South America)
32. Northern Mariana Islands
33. Haiti
34. Palau
35. Jamaica
36. Papua New Guinea
37. Montserrat
38. Samoa
39. Netherlands Antilles
40. Solomon Islands
41. Puerto Rico
42. Timor Leste
43. Saint Kitts and Nevis
44. Tonga
45. Saint Lucia
46. Tuvalu
47. Saint Vincent and the Grenadines
48. Vanuatu
49. Suriname
50. Trinidad and Tobago
51. United States Virgin Islands

South America

1. Brazil
2. Argentina
3. Peru
4. Colombia
5. Bolivia
6. Venezuela
7. Chile
8. Paraguay
9. Ecuador

Central America

1. Costa Rica
2. El Salvador
3. Guatemala,
4. Honduras,
5. Nicaragua
6. Panama

South and Central America

1. Mexico (North America)

Oceans

1. North Atlantic Ocean
2. Southern Ocean
3. Pacific Ocean
4. Southern Ocean

Seas

1. North Sea
2. Baltic Sea
3. Mediterranean Sea
4. Red Sea

Unsituated (studies with no specific geographic situations)

Antarctica

Arctic

Global (global studies)

Supplementary Material 2: Extended bibliography of uses and definitions of heritage and IPCC terms considered by the authors but not cited in-text, see https://doi.org/10.25375/uct.19623456