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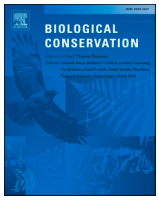

Building capacity for climate adaptation planning in protected area management: Options and challenges for World Heritage

Jess Melbourne-Thomas [a,b,*], Brenda B. Lin [c], Mandy Hopkins [d], Rosemary Hill [e], Michael Dunlop [f], Nicholas MacGregor [g,u], Samuel D. Merson [g], Caitlin Vertigan [h], Luke Donegan [i], Marian Sheppard [j], Jacqui Meyers [f], Linda Thomas [a], Lola Visschers [k], Bianca McNeair [l], Lance Syme [m], Chrissy Grant [n], Nicholas Pedrocchi [o], Patricia Oakley [o], Amy Stevens [p], Denis Rose [q], Erin Rose [q], Jade Gould [n], John Locke [r], Lynda Maybanks [s], Tracy Ireland [t]

[a] CSIRO Environment, Hobart, Australia
[b] Centre for Marine Socioecology, University of Tasmania, Hobart, Australia
[c] CSIRO Environment, Brisbane, Australia
[d] Centre for Applied Climate Sciences, University of Southern Queensland, Toowoomba, Australia
[e] James Cook University, College of Science and Engineering, Cairns, Australia
[f] CSIRO Environment, Canberra, Australia
[g] Parks Australia, Canberra, Australia
[h] Port Arthur Historic Site Management Authority, Port Arthur, Australia
[i] Fremantle Prison, Fremantle, Australia
[j] CSIRO Environment, Aspendale, Australia
[k] School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom
[l] Australian Institute of Marine Science, Crawley, Australia
[m] Kayandel Archaeological Services, Sydney, Australia
[n] University of the Sunshine Coast, Sunshine Coast, Australia
[o] Gathaagudu (Shark Bay), Australia
[p] Murujuga Aboriginal Corporation, Dampier, Australia
[q] Gunditj Mirring Traditional Owners Aboriginal Corporation, Melbourne, Australia
[r] BioCultural Consulting, Queensland, Australia
[s] Wirrinyah First Nations Conservation Services, Ipswich, Australia
[t] Faculty of Arts and Design, University of Canberra, Canberra, Australia
[u] Durrell Institute of Conservation and Ecology (DICE), School of Anthropology and Conservation, University of Kent, Canterbury, United Kingdom

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ABSTRACT

Response and adaptation to the impacts of climate change is a vital and increasing requirement for protected area management. On the ground managers of cultural and natural values in protected places have requested practical guidance on how to undertake climate change impact analysis, vulnerability assessment, and adaptation planning together with enhanced capacity for planning with partners, rightsholders and stakeholders. In this paper we explore how co-development and subsequent testing among World Heritage site managers, Indigenous experts and researchers, produced guidance for assessing, responding to and planning for the impacts of climate change on the diverse values of World Heritage sites in Australia. We draw on the diversity of cultural and natural heritage values associated with the terrestrial, coastal and marine environments in Australian World Heritage sites, and the broad range of institutional contexts in these sites, to highlight considerations of relevance to other protected areas (including other World Heritage sites around the world, Ramsar wetlands and marine protected areas). Our paper highlights that, for climate adaptation planning to become a normal part of management, there is a need for ongoing capacity building, including around the use of climate information to inform adaptation planning and implementation, as well as integrating Indigenous perspectives. Building capacity may involve trial and error, negotiation, sharing, sourcing and interpreting new information, and changes in

* Corresponding author at: CSIRO Environment, Hobart, Australia.
E-mail address: Jess.Melbourne-Thomas@csiro.au (J. Melbourne-Thomas).

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expectations. It will require novel and more dynamic relationships between partners and stakeholders. Managers should include capacity building for climate adaptation planning and implementation as a specific climate adaptation task in their planning.

1. Introduction

Protected areas are highly vulnerable to climate change, with impacts such as increasing temperatures, heavier rainfall and rises in sea level exacerbating the effects of other pressures, such as habitat loss and degradation, the spread of invasive species and direct impacts from tourism visitation (Bruno et al., 2018; Osipova et al., 2020). Protected land is already under intense human pressure, even as terrestrial protected areas are recognised as important reservoirs for biodiversity conservation (Gray et al., 2016; Jones et al., 2018), including as core areas that can enhance the resilience of wider landscapes in a changing climate. In ocean environments, marine biodiversity is being degraded by climate change and numerous stressors (e.g. fishing, habitat loss and pollution), and projected climate change impacts in the ocean in the twenty-first century will further disrupt the composition and functioning of the ecosystems currently protected within the world's marine protected areas (Bruno et al., 2018). While global stabilisation of greenhouse gas concentrations in the atmosphere is ultimately required to address climate change impacts on protected places, the inertia of the climate system means that even if the targeted limits for global warming are met, increasing impacts of climate change will continue for multiple decades (IPCC, 2023). Adaptation action is therefore essential as part of ongoing protected area management (Gross et al., 2016), and is recognised as an inherently "transdisciplinary" activity, requiring collaboration among different scientific disciplines, rightsholders, stakeholders (Serrao-Neumann et al., 2021), and inclusion of diverse knowledge systems (Orlove et al., 2023).

Guidance has previously been co-distilled between researchers and managers, drawing on past experiences and publications, to support adaptation planning for protected areas, including the U.S. National Park Service's "Planning for a Changing Climate" (NPS, 2021), Natural England and the Royal Society for the Protection of Bird's (RSPB's) "Climate Change Adaptation Manual" (NE-RSPB., 2019) and the International Union for the Conservation of Nature's (IUCN's) "Adapting to Climate Change" (Gross et al., 2016). This guidance highlights the need to consider multiple issues such as objectives, potential climate impacts, institutional settings, policy and legal contexts, and social issues (Rannow et al., 2014, Rannow and Nuebert, 2014) and to incorporate key frameworks such as resistance-resilience-transformation (Morecroft et al., 2012; Peterson St-Laurent et al., 2021), resist-accept-direct (e.g. see Lynch et al., 2022 and associated articles in the same journal special issue), and scenario planning (Miller et al., 2022). Building on the findings in this existing rich literature, we present, for the first time to our knowledge, guidance that has been co-developed (sensu Fleming et al., 2023) and subsequently tested for World Heritage in Australia, through collaboration among researchers (from several disciplines), managers, Indigenous experts, and their diverse knowledge systems.

The diverse range (e.g. urban and regional, marine and terrestrial) and geographic coverage of World Heritage sites makes them a valuable context for providing guidance on management of climate change in protected areas more generally. Indeed, many World Heritage sites have multiple protected area designations and various layers of environmental and heritage protections at national, state or local levels – for example, over 100 World Heritage properties are also designated as Ramsar sites, in whole or in part (UNESCO, 2018). World Heritage arguably poses a particular challenge in that it includes both cultural and natural heritage (see UNESCO, 2021 for definitions of cultural and natural heritage), with approximately 4 % of sites being listed for both. Cultural and natural heritage values are impacted in distinct (but sometimes overlapping) ways and may require different kinds of management actions.

World Heritage sites are already experiencing the impacts of climate change and managers need to respond in a way that will be robust into the future and that preserves values that are important to different groups of people (Seekamp and Jo, 2020, Lin et al., 2023). Some guidance specific to World Heritage is available to support climate change adaptation planning for natural sites (Perry and Falzon, 2014) and integrated vulnerability assessment for cultural sites (Sesana et al., 2018). The Australia ICOMOS (International Council on Monuments and Sites) Charter for the Conservation of Places of Cultural Significance *aka* 'The Burra Charter' (ICOMOS, 2013) gives a head start to dealing with the complexity of issues around climate change adaptation by explicitly acknowledging constant change in sites and distinguishing between conservation to retain the cultural significance of a site, and preservation to retain an existing state or retard its deterioration (with the former being the objective of site management). Some existing tools are being trialled to allow site managers to rapidly assess climate change risk to both natural and cultural World Heritage values (CVI, 2023), although without inclusion of adaptation planning. Guidance is also available to assess climate change vulnerability of the ecological character of Ramsar sites, which recognises that some aspects of ecological character will persist, while other aspects will change (Dunlop and Grigg, 2019). These publications and their findings form an important part of the foundation for our process of co-development and subsequent testing of climate change adaptation guidance for World Heritage sites, based on our collaboration in Australian sites.

An important challenge for protected area managers is accessing and using climate change information in formats suitable to support decision making and planning that will be robust under future climate conditions, noting that typical planning horizons are not on the multi-decadal scale of climate and climate change (e.g. see Lemos et al., 2012; Cross et al., 2022; Miller et al., 2022). In addition, inclusion of Indigenous perspectives and pathways, embedded in their diverse knowledge systems and world views, is increasingly recognised as critical for effective management of nationally and globally significant sites (e.g. Carmichael et al., 2018), and in considering adaptive solutions to climate change (Townsend et al., 2020; Orlove et al., 2023). Indigenous peoples have asserted their rights, interests, and knowledge of World Heritage for many decades, and worked hard to protect them from inappropriate development (Disko and Tugendhat, 2014). However, processes that include Indigenous people as equal partners and co-authors in providing management guidance for globally significant sites are at an early stage of development (although with significant exceptions, e.g. Hill et al., 2011, Smith et al., 2019).

1.1. Approach

In this paper we describe the outcomes from co-development and subsequent testing of practical guidance for undertaking climate change impact analysis, vulnerability assessment, and adaptation planning for World Heritage sites in Australia (Fig. 1, Melbourne-Thomas et al., 2022). Researchers, World Heritage site managers and an Indigenous Reference Group, comprising Traditional Owners from a number of World Heritage sites collaborated throughout (Indigenous Reference Group members are co-authors of this paper). The co-development process involved working with all 20 World Heritage sites in Australia (see CSIRO et al., 2022 for full outcomes), with some sites undertaking a more detailed vulnerability assessment. We describe the key elements of the guidance, highlighting how and where the approach is applicable to other protected area designations.

We use three case studies to explore how the co-development process itself helped build capacity for undertaking climate change vulnerability assessment and allowed for sharing of information between scientists, managers, stakeholders, and rightsholders to create space for diverse perspectives and knowledge systems within the process. These three case studies – Kakadu National Park, the Australian Convict Sites, and the Willandra Lakes Region – represent contrasting and complementary examples of World Heritage sites (in terms of physical location, management arrangements, Traditional Owners, and the nature of climate impacts). We also consider aspects of how capacity might be built, at the institutional level and among multiple stakeholders and rightsholders, to undertake adaptation planning and to implement adaptation pathways, based on the most relevant climate change projections and scenarios, for World Heritage management more broadly.

2. Understanding climate change impacts and vulnerability in the context of World Heritage management

In the context of World Heritage, vulnerability can be considered as the potential for, and consequences of, impacts on key attributes that express Outstanding Universal Value (OUV; see Box 1). Using a structured approach to assessing vulnerability and resultant risk allows managers to make the best use of available climate, ecological and cultural knowledge, to inform the development of processes to manage that risk in an ongoing way (De Lange et al., 2010; Makondo and Thomas, 2018) (Fig. 1). The approach to assessing vulnerability presented here (Fig. 2) was co-developed by researchers, World Heritage managers and Indigenous experts, drawing on previous work that developed a framework for considering and responding to impacts of climate change on landscapes (e.g. Aspden et al., 2013; Speakman et al., 2013). It is based on a recognition that the values of a site are the ultimate focus of management, and therefore of considering vulnerability and risk; however, detailed assessment of impacts will often be clearer at the level of the individual attributes that underpin those values. Broadly, the approach starts by identifying the multiple values, and the attributes that underpin them. Assessment of potential impacts is then undertaken at the level of attributes, and findings are drawn together to consider implications for persistence and change of values. These steps are outlined in more detail below.

1. The first step is to identify the values held by diverse people about a particular site. This includes OUV and other values that may be formally listed – for example some World Heritage sites are also listed as Ramsar sites or may be protected as national parks, Indigenous or marine protected areas, National Heritage places and so on – or unlisted. This step emphasises the importance of beginning with a common understanding of values and reflecting the perspectives of rightsholders and stakeholders.
2. With values identified and agreed, the second step is to identify more specific attributes that underpin those values. In some cases, attribute and value will be similar (for example, a high priority species), in others a broad value (such as unique landscapes or living culture) may be supported by many different attributes.

   An impact analysis is then conducted on each important attribute. This considers the pressures to which attributes are likely to be exposed and the intrinsic sensitivity of the attributes to those pressures, to identify potential impacts on attributes. Importantly, this includes consideration not just of direct pressures that have been observed to date or are anticipated in the future. It involves consideration of direct climate change impacts (such as temperature increase or sea level rise), indirect climate-related changes (like changes to bushfire frequency and intensity), interactions between these factors and also the impacts that may arise from the policies and practices of others (like the consequences of increased drought if nearby or upstream land managers are not able to change their practices in response). A range of information can, and should, be drawn on in this step. For example, climate projections can provide information about possible future regional climates (see Section 2.1), while managers' knowledge of a specific site can help identify locations in that site that might be more exposed to, or protected from, the general changes that the region may experience. Climate projections and local and Indigenous knowledge can also inform assessments of the timing of potential impacts – whether these impacts are already occurring, or if they might occur in the next few years or in the coming decades.

   As part of the practical process of considering impacts, scenario analysis can help managers to envision what a particular site or region might look like at different future timeframes, and so help in thinking through potential impacts (Peterson et al., 2003; Mahmoud et al., 2009; Miller et al., 2022). Scenario analysis helps decision-

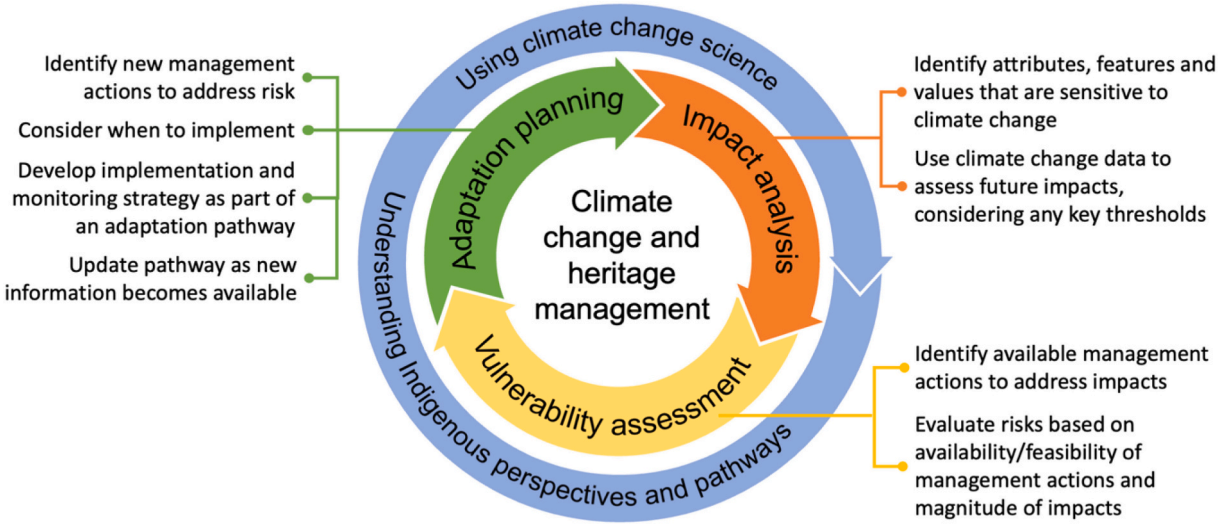

Fig. 1. Overview of a co-developed process for climate change impact analysis, vulnerability assessment and adaptation planning in managing climate change impacts on World Heritage values (modified from Melbourne-Thomas et al., 2022). The steps are underpinned by the use of climate change science and understanding Indigenous perspectives and pathways. This framework has been co-developed with World Heritage managers, rightsholders and stakeholders in Australia, drawing on their diverse knowledge systems, and is framed around identification of attributes of both cultural and natural heritage that express Outstanding Universal Value.

Box 1
Understanding Outstanding Universal Value of World Heritage sites.

To be considered of Outstanding Universal Value and inscribed on the World Heritage List, sites* must: meet at least one of 10 criteria (see https://whc.unesco.org/en/criteria/), meet conditions of integrity (natural sites) or integrity and authenticity (cultural and mixed cultural and natural sites) and have adequate management and protection measures in place to safeguard their future.
Outstanding Universal Value is one of the central ideas underpinning the World Heritage Convention. Broadly, its meaning follows the common-sense interpretation of each word:

- Outstanding – for sites to be of Outstanding Universal Value they should be exceptional, or superlative; they should be the most remarkable places on earth.
- Universal – sites need to be outstanding from a global perspective. World Heritage does not aim to recognise sites that are remarkable only from a national or regional perspective.
- Value – what makes a site outstanding and universal is its "value" (or its natural and/or cultural worth). This value is determined based on standards and processes set out in the World Heritage Operational Guidelines (UNESCO, 2021).

Integrity relates to the 'wholeness and intactness' of a heritage site and how it conveys the values it holds. Integrity can also relate to the size of a site (sufficient size to continue to represent the values) and to any threats affecting it (will the values continue to exist?).
The requirement for authenticity relates only to cultural properties (including mixed cultural and natural sites). Broadly, it requires an original, authentic or true cultural expression of the values of a site, in material or conceptual form, and cannot be represented by a copy or recreation.
*We note that the terms *site* and *property* are both used to refer to areas or locations that are World Heritage listed. In this paper we use the term site.

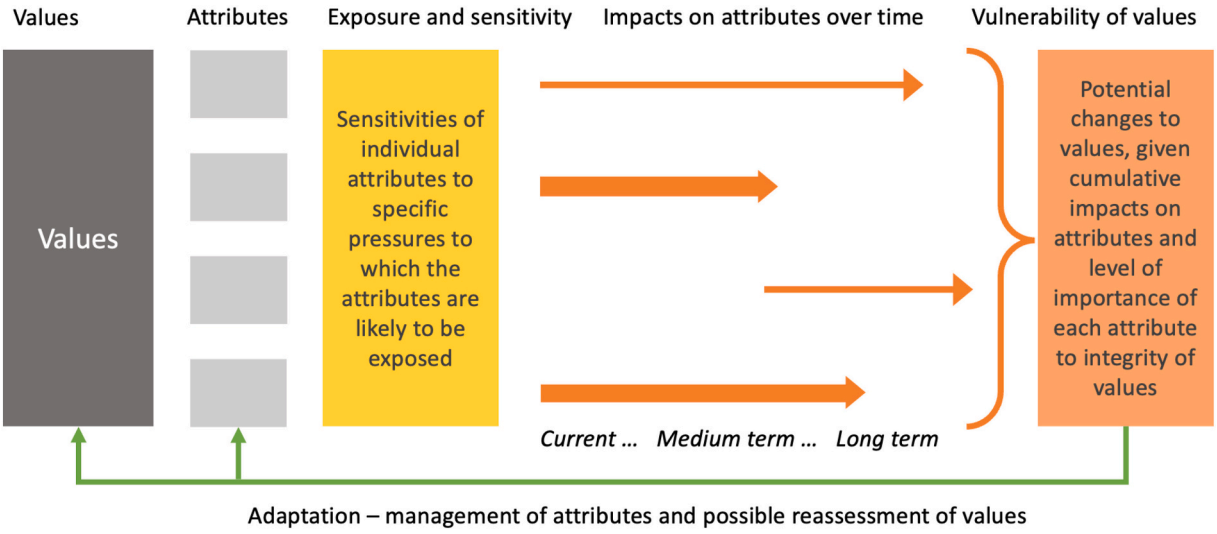

Fig. 2. Schematic representation of how the vulnerability of values can be considered in the context of future climate change impacts. Identifying the individual attributes that underpin values, and the exposure and different sensitivities to climatic changes of those attributes, informs assessment of climate change impacts over time. Cumulative impacts on attributes determine vulnerability of values, which then informs planning for adaptation (the management of attributes under climate change and possible reassessment of values).

makers visualise what future conditions or events are probable or possible, what their consequences or effects might be, and how to respond to, or benefit from, the future conditions even in the face of uncertainty (e.g. Shaw et al., 2009). A critical aspect of scenario analysis is the selection of a set of scenarios that cover a reasonable variety of future outcomes, both favourable and unfavourable. If rates of change are critical then fast and slow scenarios might need to be considered (e.g. see CSIRO, 2018).

3. The results of the impact assessment are then brought together to draw conclusions about the vulnerability of values. Vulnerability of a value will depend on the predicted impacts on individual attributes and on the level of importance of each attribute for the value. The likelihood of values persisting or changing can then be assessed, and the timing of change estimated (based on the timing of impacts on attributes identified in the previous step). The ultimate purpose of this step is to identify risks to conservation goals, as the foundation for subsequent adaptation planning (see Section 3). This requires careful consideration, and – like all decisions in conservation – will depend on the values and perspectives of managers and stakeholders. Change to, even complete loss of, a particular attribute may or may not be deemed to be significant to persistence of a value; this will depend partly on biophysical realities but also on the perspectives of the people who hold that value.

At this point, assessment of vulnerability needs also to consider adaptive capacity, in the context of what management actions might be available to address impacts on important attributes, and how effective those actions might be. A low level of adaptive capacity (including where currently available management actions are insufficient to address current or future climate change impacts), especially in relation to a projected high level of impact, can be

considered as leading to a high level of vulnerability, which translates to a high level of risk (Melbourne-Thomas et al., 2022).

Mapping values onto a 'persistence-change' spectrum (Dunlop and Grigg, 2019) can be an illuminating approach to inform risk assessment and adaptation planning. It is possible that many values will be assessed as likely to persist (either because their underpinning attributes will not change under projected climatic changes and continuation of current management, or because the values will remain despite change to attributes), other values will be deemed to be likely to change regardless of management, and a third group of values will be 'in the middle' (that is, at risk of changing if management is not undertaken to ensure persistence of critical underpinning attributes). It is this middle part of the spectrum that may be most valuable to focus on. Vulnerability, in the context of managing protected areas under climate change, can be seen as *the risk of failing to maintain important attributes (and the values they support) that could persist under future climate change*. This viewpoint will help to focus efforts in a cost-effective way, to build management strategies that recognise that natural and cultural values do not exist in stationary environments (Lin et al., 2023), and to avoid maladaptation.

The structured process outlined above can be applied flexibly depending on the complexity of the site being considered and on the resources available to undertake the process. It can be undertaken in a very simple qualitative way to rapidly scan for the most important issues, or in a very detailed and semi-quantitative way.

A concept that has relevance to multiple parts of process is that of 'thresholds'. There are several ways in which this concept applies, with distinct definitions, reflecting both the hierarchical approach to assessment of impacts and vulnerability and the intention for the process to be applicable in trans-disciplinary contexts:

(i) In heritage identification and management, the term 'threshold' refers to points on a scale of importance (from local to regional, national, or global) that must be reached to have that level of importance ascribed to the values of a site. This is based on characteristics including rarity, representativeness, exceptionality, integrity, authenticity and condition (Ireland et al., 2020; Lin et al., 2023). Exposure of sensitive attributes to impacts can degrade associated values sufficiently to cross heritage thresholds (e.g. from globally to nationally significant). This concept is important for informing the inclusion of values for consideration in step 1, and in the consideration of vulnerability and risks in step 3.

(ii) Second, thresholds can be identified as the points at which change would occur because of climate change. For an individual attribute, this is the point at which tolerance of a pressure would be exceeded by exposure to that pressure. For a value, it is the point at which cumulative changes to underpinning attributes would lead to a change in the value to the point that it would be degraded or lost.

Thresholds resulting in changes to individual attributes may be reached at a lower level of exposure to a pressure, or at an earlier point in time, than thresholds resulting in changes to a value – for example aspects of an ecosystem may change without the overall structure and character of the system changing (Morecroft et al., 2012). As noted above, identification of thresholds in changes to values will be partly subjective and depend on how fundamental an attribute is deemed to be for persistence of the value.

These two types of threshold ((i) and (ii)) come together in consideration of whether changes to values would potentially lower their heritage listing, for example from being globally significant to only nationally or locally significant, and so affect the site's Outstanding Universal Value.

2.1. Using climate change information in vulnerability assessment

The use of climate change information – specifically climate projections – underpins impact analysis and vulnerability assessment and helps ensure that both assessments and management actions are effective and robust given expectations for future climate (Mahmoud et al., 2009; Cross et al., 2022; Miller et al., 2022). Climate-effective management also requires information on seasonal/short-term climate to manage risks relating to near-term weather impacts and fluctuating conditions on the outcomes of particular management actions (e.g. replanting being affected by drought) (Tulloch et al., 2020). However, the use of climate information (both short-term and long-term) is often a task requiring specialist expertise, which may be a barrier to World Heritage managers and other decision-makers, depending on the context.

Providing practical guidance to increase climate literacy among managers, Indigenous rightsholders and stakeholders – and to reduce the barrier to accessing and using climate change projections – will help support more robust vulnerability assessment (and in turn, adaptation planning). For example, there is a need to better communicate that climate projections do not aim to provide a sequence of events but rather to simulate how the entire climate system responds to change and so provide a plausible range for future climate conditions (Lemos et al., 2012). Therefore, climate change projections are averages for a period, not single measurements. Effective vulnerability assessment requires regional-specific guidance on known biases of particular models, down-scaled products and climate variables. It may also require direct involvement of experts – with associated costs to management agencies in many situations. A key element of building capacity for adaptation planning in heritage management (and more broadly) is lowering this accessibility barrier for climate change information.

World Heritage site managers in our team have varying levels of familiarity with the use of climate change information in vulnerability assessment. Some sites had access to existing climate assessments for particular variables (e.g. sea level rise) while others faced challenges of a lack of down-scaled products for their particular region (e.g. some offshore islands). In general, improved guidance was required about how to translate uncertainty associated with climate information into impact and vulnerability assessment, and through to decision making. Engagement processes that provided opportunities for knowledge sharing about recent climate-related trends and changes (including key events and Indigenous knowledge, related to seasonal calendars, for example) were generally more effective in facilitating discussion about future change and the use of climate projections (consistent with previous findings, e.g. Meadow et al., 2015, Bamzai-Dodson et al., 2021).

2.2. Indigenous perspectives and leadership

Working with Indigenous people and their knowledge systems is critical for effective management of both heritage and climate change (Orlove et al., 2023; Disko and Tugendhat, 2014). Indigenous Peoples' community control and governance of sharing knowledge and perspectives is vital for having their voices heard, including in the context of World Heritage and climate change management (Hill et al., 2020a; Janke et al., 2021; Morgan-Bulled et al., 2021; Lin et al., 2023). In many regions, Indigenous Peoples are taking control of their own heritage and Country, using best practices, and seek to be supported in growing their initiatives – not responding to somebody else's initiatives (Fischer et al., 2022). The Indigenous Reference group for this project displayed extraordinary commitment and leadership throughout, using video-conferencing and online interactive tools to overcome challenges of remoteness and crowded personal responsibilities that precluded face-to-face meetings.

Enabling Indigenous leadership in climate change vulnerability assessment and adaption requires appropriate cultural governance to be in place for activities to address Indigenous knowledge and perspectives

on climate change (David-Chavez and Gavin, 2018; Woodward et al., 2020; Melbourne-Thomas et al., 2022). This can be in the form of a project steering committee, and/or a co-design team and include processes to build and promote: (i) clearly defined roles and responsibilities in stakeholder relationships; (ii) engagement of Elders and Traditional Owners, including women and youth; (iii) the use of right knowledge for the right Country (respect for traditional knowledge); and (iv) rights-based, equitable and sustainable development of World Heritage sites (Melbourne-Thomas et al., 2022). Agreements need to be in place to ensure Indigenous Cultural and Intellectual Property Rights are protected, and that best practices for Free, Prior and Informed Consent ethics and cultural protocols are followed (David-Chavez and Gavin, 2018; Woodward et al., 2020).

Long-term honest and robust relationships, based on trust, respect and reciprocity, between Indigenous Peoples and the other World Heritage managers are vital to enable two-way exchange of knowledge to help understand and care for Country in the face of climate change (Woodward et al., 2020). Such relationships enable more effective involvement of research agencies and universities in discussions between Indigenous and scientific knowledge systems relevant to climate change and facilitate broader understanding of cultural assets and biocultural diversity (inclusive of its financial significance), intangible Indigenous Cultural Heritage values and the relationship between landscape and Indigenous Peoples.

Bringing Indigenous knowledge and perspectives of climate change to assess impacts and vulnerability needs care and attention. Consideration of past and ongoing impacts of colonisation and alignment with Traditional Owners' own strategies is vital (Hill et al., 2020b; Lyons et al., 2020). It is necessary to recognise that climate change is not just a technical problem, but rather requires the expertise and knowledge of multiple systems, and this includes the cultural knowledge, practices, values, and worldviews of Indigenous Peoples and local communities (Orlove et al., 2023). Facilitating leadership by and long-term relationships with the right People for a given World Heritage site are also key strategies for effectiveness (Woodward et al., 2020, Melbourne-Thomas et al., 2022).

2.3. Case study: Kakadu National Park

Kakadu National Park is the second largest terrestrial national park in Australia (and one of the largest in the world's tropics) and is one of four Australian properties included on the World Heritage List for both outstanding cultural and natural values. It contains art and archaeological sites showing thousands of years of Indigenous culture and history, and it preserves the greatest variety of ecosystems on the Australian continent. Kakadu is also a listed Ramsar site that meets all 9 criteria for identifying wetlands of international importance under the Ramsar Convention. The joint management arrangements in the park between Bininj/Mungguy and the Director of National Parks are critical to the maintenance of the World Heritage values for which Kakadu National Park is recognised.

A climate change vulnerability assessment for Kakadu was undertaken in 2021. A two-day workshop in Jabiru was preceded by an initial assessment of vulnerability (following the process outlined above), conducted by a small team, and based on recent scientific research for the park, together with climate change information. This information provided background and context for the workshop. On the first day of the workshop, members of the Kakadu Indigenous Research Committee (IRC) were invited to share their perspectives on climate change impacts in the park. This process asked "What do you care about at Kakadu National Park?", "What things might change under future climate?", "What things might survive?", and taking into consideration current management "What are you worried about and how worried are you?". This was supported by visual prompts such as symbols for different landscapes and climate change impacts, arrows, and faces with different emotions. The second day of the workshop progressed these discussions with both the IRC and members of the Kakadu Research and Management Advisory Committee, a sub-committee of the Kakadu Board of Management, using the change-persistence approach described in Dunlop and Ryan (2016) and Dunlop and Grigg (2019), and consideration of management actions to address climate change impacts.

Key climate change threats identified through the vulnerability assessment process for Kakadu were rising sea levels (leading to coastal erosion and saltwater inundation of wetlands), increases in extreme temperatures and heatwaves, changed fire regimes, more intense cyclones, and increased intensity of extreme rainfall events. Observed and projected impacts on natural values included potential loss of biodiversity in savanna, woodland and riparian rainforest due to fire and weeds, impacts on biodiversity from extreme temperatures in stone country, and changes to wetland systems (with implications for the Ramsar listed ecological character of these wetlands). Impacts on cultural values included degradation and damage to rock art from fire, extreme rainfall, and potentially sea level rise and flooding at some sites, as well as impacts on living culture as a result of ecological change. Infrastructure and tourism in the park were also identified as being vulnerable to climate change. The connection between people and Country in Kakadu potentially has a high vulnerability to climate change, because living on, and looking after, Country requires the Bininj and Mungguy People being able to access Kakadu to conduct traditional burning, tell stories, speak in language, visit sacred sites, connect with the spirits of the old people and pass on knowledge to younger generations. Climate change poses a risk to these activities by potentially limiting Indigenous people's ability to go on Country and by causing changes in/loss of valued cultural landscapes and key species. Changes to living conditions and impacts on infrastructure may also reduce the ability and incentive for Indigenous people to remain on their traditional lands.

There was a significant variation in the assessed vulnerability of attributes to climate change in this large and complex park, with different implications in terms of risks to values (as illustrated in Fig. 2): some values might change because of changes to important underpinning attributes; many values are likely to persist despite change of attributes beneath them; and in other cases both values and underlying attributes are likely be relatively unchanged under future climate scenarios. Because Kakadu is such a large site with a very broad range of values, the capacity to prioritise risks through climate change vulnerability assessment – undertaken in a collaborative and inclusive manner – is an important step to enable adaptation planning. Outcomes from this process are currently informing the development of an updated climate change strategy for Kakadu.

2.4. Case study: Australian Convict Sites

The Australian Convict Sites (ACS) provide a valuable case study in diverse stakeholders and needs because the property consists of 11 complementary sites across Australia, in Western Australia, New South Wales, Norfolk Island and Tasmania. The sites range from Fremantle Prison in the west to Kingston and Arthur's Vale Historic Area in the east, a distance of 5500 km, and from the Old Great North Road in the north to Port Arthur Historic Site in the south, a distance of 1500 km. These sites represent a cultural history of Australia's convict past in the settlement of Australia by European colonisers. Having 11 sites across Australia means that the sites span several climatic zones (from Mediterranean in the west to temperate in the south and sub-tropical in the mid-north), cover 4 time zones and include a diverse range of physical settings and scales from remote islands and rugged bushland to major cities. Additionally, each site has its own management systems in place to oversee a broad range of programs and initiatives, ranging from conservation of built and archaeological structures, site collections, site interpretation and experiences, to buildings and works program, maintaining heritage grounds and gardens, and managing extensive collections.

Working with the scientists, the managing staff of ACS and individual site managers we conducted a climate change vulnerability assessment over a sixth month period in 2021/2022. To do so, the ACS management committee socialised the process through committee meetings to discuss goals and how the results of the vulnerability assessment may affect future management of the sites and the ACS as a whole. To understand the climate change impacts, potential future impacts, and current levels of resourcing and management at each site, teams within the sites met with scientists online to work through the process outlined above. Each site undertook a site-level vulnerability assessment that was then aggregated to a property level to consolidate and prioritise overall vulnerabilities faced by the ACS.

Frequently stated impacts on sites included the increased frequency of storm events damaging built infrastructure, with water intrusion into buildings also damaging historical items of significance. Most locations maintain facilities for tourism and historical education, and therefore must renovate and rehabilitate damaged buildings and items (such as cloth or books) in the traditional manner of construction, which is time consuming and expensive. In sites that are in regions that experience bushfires, fire controls may rely on water from nearby rivers, which are unreliable in drought conditions, and therefore present large potential vulnerabilities to the preservation of built or cultural materials. Many convict sites are also on islands where wave action and sea level rise are increasingly damaging structures, landscapes, and cultural materials with water intrusion and salt.

Although the sites were dispersed across Australia, having an active coordinating officer be involved in the assessment at each site helped to allow the diverse stakeholder voices to be heard as well as create a central point for sharing knowledge. The committee process also enabled properties to collectively discuss outcomes and make decisions on next steps, considering steps that would assist multiple sites at once and considering prioritisation to make best use of limited resources.

2.5. Case study: Willandra Lakes Region

The Willandra Lakes Region is in the southwest, semi-arid zone of New South Wales and contains a relict lake system with fossil remains that date from the Pleistocene as well as archaeological evidence of human occupation dating from 45 to 60,000 years ago. The Willandra Lakes Region is another example of a site that has both natural and cultural heritage as a mixed World Heritage site and it is a location of spiritual connection to Country from time immemorial. Governance of this site is complex as it encompasses national parks, private land, and represents three Traditional Owner groups (the Barkandji/Paakantyi, Mutthi Mutthi and Ngiyampaa Aboriginal tribes). Due to the complex range of rights holders and stakeholders on this site, Willandra Lakes has a multi-stakeholder governance structure that is guided by an Aboriginal Advisory Group as well as a Ministerial World Heritage Advisory Committee and Intergovernmental Management Committee. These groups bring together private landholders, researchers, state and Commonwealth governments as World Heritage representation for advice and decision-making.

The Willandra Lakes site ran a climate change vulnerability assessment over a three month period, developed through online workshops (due to Covid-19 restrictions) that included the large group of stakeholders. Because the Willandra Lakes site already had a strong governance structure in place, it was possible to bring together stakeholders relatively easily to work through the vulnerability assessment as a group. This provided space and time for group members to consider what has already been observed within their lifetime, historical observations and stories that have been passed down through time, and how past changes and adaptation could impact on actions in future.

Through discussions, it became clear that increased drought across seasons and increasing temperatures were leading to the erosion of topsoil that was increasingly exposing Aboriginal cultural heritage. This exposure of Aboriginal cultural heritage affects spiritual connection to Country for the cultural owners of the land; thus, protection of cultural heritage was the value of utmost concern. The conversation across the group also considered other challenges for the site including the decline in water availability to people and animals under drought conditions and observations of changes in ecological and natural cycles of bush tucker that is important to the communities. The acknowledgment of these changes and potential increases in climate extreme in the future led to a rigorous discussion of what management was in place already (e.g. covering Aboriginal cultural heritage items with cloths to protect and preserve them, revegetation to prevent erosion), how these management options would hold up against changes in climate (e.g. how long can vegetation survive under extreme drought conditions?), and what options were available for the future (e.g. developing an inventory of Aboriginal cultural heritage on the property).

The initial workshop led to two additional workshops to continue the conversations about how the working groups could consider processes to preserve and manage the landscape. This also provided the space and time to co-write a climate vulnerability assessment as a group, in which priorities, gaps in knowledge, and next steps for action could be developed collectively.

3. Adaptation planning to manage climate change impacts on World Heritage values

Adaptation planning provides a process in which to consider the risks and reduce vulnerability to current and future climate change. Adaptation can be *autonomous (also known as spontaneous)* in response to changes, as has generally happened in response to short-term climate variability in the past (McCarthy et al., 2001). Alternatively, it can be *planned*, with strategic, long-term decisions made at an organisation- or government-wide level. Adaptation could also be *incremental*, to maintain the essence and integrity of a system or process, or *transformational*, where changes are made to the fundamental attributes of a system in response to climate change (Kates et al., 2012). Planned adaptation, particularly for transformational change, requires knowledge of climate change, the increasing severity of impacts, and information on uncertainty about rates of change.

Many management actions to address climate change will be the same as current management actions – just undertaken more often or intensely (e.g. enhanced fire-fighting capability; enhanced invasive species control) – or variants of existing actions (e.g. greater emphasis on physical separation between flammable vegetation and assets such as larger firebreaks; responding to new invasive species, possibly including invasive native species) (e.g. Mason et al., 2021). Some new management actions will be required, such as flood protection where there was none previously, relocating assets, and new technological interventions (e.g. Macgregor and van Dijk, 2014; Prober et al., 2019; Mason et al., 2023) (Box 2). In cases where climate change is likely to lead to changes in the character or OUV of a site, there may need to be a re-evaluation of the objectives of and strategies for managing a site (e.g. accommodating novel ecological communities, letting some populations decline, managed retreat of shorelines; Seekamp and Jo, 2020). There may also be a need to consider vulnerability at different spatial scales (sometimes across wider areas than might previously have been done) and in some cases aim to retain values across a wider landscape while accepting local change as part of adaptation planning (Johnston et al., 2013; Macgregor and van Dijk, 2014; Rannow et al., 2014).

Adaptation planning that is underpinned by knowledge of the system/site being managed and the factors that affect its resilience, capacity in using climate change information, understanding adaptive management, and integrating Indigenous perspectives, can develop and implement new adaptive actions. Without these underpinning elements, adaptation planning will tend by default to draw on existing management capacities – with their explicit and implicit understandings and expectations – and seek out actions oriented towards resisting change and limiting efforts to management of current, non climate-related

Box 2
What kinds of adaptation actions are available for World Heritage management?

There are a broad range of actions that constitute adaptation. Those that involve not accepting some level of fundamental change in values may not be effective. For natural heritage attributes, adaptation interventions can be grouped according to whether they are actions to: (i) reduce exposure to a particular climate-related threat (e.g. translocation, habitat modification, shading, engineering); (ii) reduce sensitivity (e.g. supplemental feeding, enhancing gene flow), or (ii) increase adaptive capacity by reducing other stressors (e.g. pest/weed eradication, predator management) (IPCC, 2007).
For cultural heritage, climate change adaptation options can be grouped according to whether they are: (i) direct intervention (e.g. relocation or replication of a cultural site); (ii) options for building resilience (e.g. via protective legal designation or reducing other stressors such as feral animals); or (iii) options to build stakeholders' adaptive capacity (e.g. consultation and communication about vulnerability, establishing partnerships and sharing knowledge, providing training for local stakeholders) (Carmichael et al., 2020).
In practice, integrated management for climate change adaptation will draw from (and integrate across) both of these lists, noting that not only are natural and cultural heritage interlinked, but many adaptation actions will affect both natural and cultural values (Lin et al., 2023). Different options are of course associated with different costs and benefits, as well as trade-offs. Dilling et al. (2015) suggest that decision makers faced with adapting to climate change must consider the dynamics of vulnerability in a connected system—how choices made in one part of the system might impact other valued outcomes or even create new vulnerabilities. They suggest the need for greater engagement with various stakeholders on the trade-offs involved in adaptation actions and for improving communication about the complicated nature of the dynamics of vulnerability.

threats to increase general resilience. Resisting change might be effective in the short term for low levels of climate change, but in the face of larger changes it could be very expensive and less effective (Seekamp and Jo, 2020, Peterson St-Laurent et al., 2021, Lynch et al., 2022). Actions to resist physical impacts on a specific attribute of OUV might damage the authenticity, intangible cultural significance, or broader values of a site (Sesana et al., 2018), especially noting that there is not necessarily a direct relationship between condition and significance (ICOMOS, 2013). Regardless of the mix of resisting or adapting to change in medium- to long-term objectives, consideration of thresholds for future changes in management should be factored into the intent and design of the short-term actions, as short-term strategies to resist change can make later adaptation actions more difficult.

Adaptation planning specifically addresses the increasing nature of impacts and uncertainty about rates of change through design of an adaptive and progressive 'pathway' of actions through time (Fazey et al.,

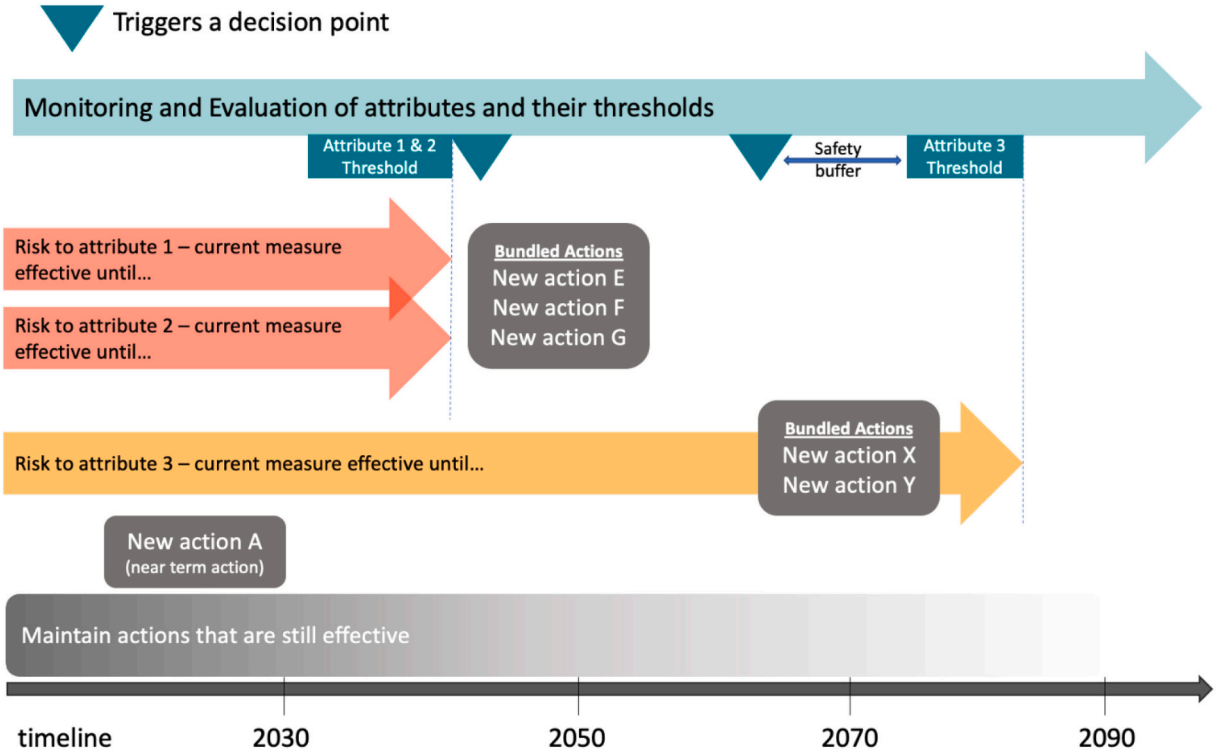

Fig. 3. Example visualisation of an adaptation pathway for World Heritage (from Lin et al., 2022) in which risk thresholds for particular attributes that underpin OUV are related to decision triggers for sets of adaptation actions. The thresholds are shown as dashed vertical lines, which trigger decision points for different risks to attributes (shown as red and orange arrows). In this approach, the triggered actions are bundled together, and may be implemented in advance of a particular threshold being reached (in the example case shown by the orange arrow) to create a safety buffer. Current actions that are still effective are maintained in this pathway, but the number of these actions that remain effective into the future is likely to decline. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2016; Werners et al., 2021). This reduces the requirement for the vulnerability assessment to consider multiple magnitudes and timeframes of climate change by building in flexible options that can be actioned at different points in the future. The process starts with scoping implications of change in terms of OUV, protection and conservation objectives and management plans/actions. It then works backwards from the changes in practice needed to enable adaptation, to the implications for present day management. These different considerations are then combined into an adaptation pathways process (Fig. 3) in which monitoring and evaluation of the status of different attributes informs the timing of decision making processes that can trigger new adaptation actions once identified thresholds are reached (or in advance of thresholds being reached, for higher risk contexts where a safety buffer might be important).

The pathways approach to climate adaptation has been developed specifically to address the continually unfolding nature of climate change and the uncertainties associated with it, giving planners a way to integrate anticipated possible future changes into current management, so that plans are flexible, relevant in the near term but forward looking and proactive (Smith et al., 2011; Wise et al., 2014; Gorddard et al., 2016; van Kerkhoff et al., 2019; Hill et al., 2020b). In particular, this approach enables future decisions about more significant changes in policy and practice (e.g. if, and when, to relocate assets) and helps avoid 'maladaptive' actions that may be effective in the near-term but in the future make impacts worse or hinder adaptation (e.g. sea walls, especially where they provide a sense of security that leads to increased investment or failure to enable more sustainable solutions). The pathways approach also helps plan adaptive transitions from a focus on values that are most at risk now to a focus on values that have greater chance of persisting *with effective management* as the climate continues to change (e.g. transition from preserving specific ecological communities to maintaining the ecological health, resilience and evolutionary capacity of whatever new communities emerge). Finally, the pathways approach to climate adaptation supports Indigenous adaptation pathways when: (i) effective methods for co-production between scientific and Indigenous knowledge are used; (ii) Indigenous people have ongoing connection to their traditional territories to maintain their Indigenous knowledge; and (iii) the relationship between the Indigenous people and the nation-state empowers local decision-making and learning.

4. Building capacity for adaptation planning in protected area management

The need for capacity building for climate change adaption planning in protected area management is broadly recognised (e.g. Lemieux et al., 2011; Perry, 2015; Peterson St-Laurent et al., 2022), but it is important to also recognise that adaptation needs to be a 'whole-of-system' process. So, the adaptation work of managers needs to be supported by adaptation by their partners, rightsholders and stakeholders (as highlighted in the case studies presented above for World Heritage site in Australia). As well as changes in management (and the practical tools that support planning for these changes), adaptation will include changes in policy, attitudes, behaviour, livelihoods and so on. Ideally, eventually, adaptation planning will become a normal part of site planning: the regular planning cycle and operational management processes will routinely incorporate consideration of climate change. However, for this to be possible significant capacity is needed, and building that capacity should be seen as a specific climate adaptation task.

Adaptation capacity is needed across the whole system that contributes to the management of World Heritage sites and protected areas more generally. That is, it involves site managers and also their partners, including contractors and volunteers; expert advisors and researchers; planners, policymakers and funders; rightsholders; and local communities and other stakeholders (Sesana et al., 2018). These partners don't need to be across all aspects of climate impacts and adaptation, but they do all have critical roles to play in enabling climate adaptation, in the same way as they have a critical role in enabling current site management. The difference is that, in the case of adaptation, the specifics of those roles are not well established in many cases: adaptation is relatively new, there is a lot to learn, no one quite knows what outcomes will be possible or how to achieve them, nor what trade-offs and changes in expectations will need to be negotiated. A lot of trial and error, negotiation, sourcing and interpreting new information, and changes in expectations will occur, requiring novel and more dynamic relationships between the partners across the system. The co-development process we undertook with World Heritage sites in Australia also highlighted some uncertainty about where and how to avoid unrealistically holding on to key values and attributes of World Heritage sites and protected areas without recklessly letting go, that is, how to accommodate change without lowering management standards (see also Lin et al., 2023).

Researchers, managers and their partners will need to collectively discover what aspects of climate impacts are most important for their site, how the site might change, and how different values might be affected. They will need to consider what changes are uncertain and which uncertainties matter, and how to strategically deal with uncertainties in decision-making over time. The Australian case studies presented above provide examples of what some of this process can look like for World Heritage sites that differ in scale, management arrangements, and types of values. The case studies and broader work that was undertaken with World Heritage sites in Australia also highlighted that the co-development process itself helped to build capacity for climate change vulnerability assessment and adaptation planning, by bringing people together and by sharing knowledge about climate impacts and options. World Heritage managers (and protected area managers more generally) will need to continue work with researchers, partners, stakeholders and rightsholders to imagine different futures and negotiate on what successful outcomes might be in each future. They will also need to integrate possible future changes in climate, ecology, cultural values, management and policy with current priorities and management programs so that current activities are enabling of future adaptation decisions and actions.

The management actions undertaken in a changing climate will be highly specific to the context of each site. They will depend on the nature of the impacts on the site, its particular attributes and broader significance, community expectations, the current management activities, the broader system supporting management at the site and the existing capabilities across that system. There will, however, be some processes to build adaption capacity into planning systems that will be common across many sites. These include an incremental approach to learning more about climate change and adaptation, both in general and as applies to the site, and starting with specific climate change assessment and planning activities, to build adaptation capacity. As capacity is built, site managers can incorporate consideration of future climate change into policy, planning and management systems, and undertake regular review, evaluation and iterative change as part of adaptive management.

5. Conclusions

World Heritage sites are already experiencing the impacts of climate change and managers need to respond in a way that will be robust into the future and that preserves values that are important to different groups of people. The co-developed approach presented here for climate change vulnerability assessment and adaptation planning can help support this process – for World Heritage, Ramsar sites and for other protected areas and heritage places. A key feature of the approach is that it is underpinned by the use of climate change information and by understanding Indigenous perspectives and pathways. It also provides a structured approach to understand the interplay between climate change impacts on attributes, vulnerability and possible changes to

values, and to use that understanding to inform discussion about acceptable and realistic thresholds of change. Importantly, the approach is designed to enable the development and implementation of new adaptive actions, rather than drawing on existing management capacities alone. Operationalising 'on-the-ground' climate change adaptation and adaptation planning requires education, collaboration and capacity building – addressing these needs is an urgent task given the rate and scale of climate change impacts on significant sites around the world.

CRediT authorship contribution statement

Jess Melbourne-Thomas: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation. **Brenda B. Lin:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Mandy Hopkins:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Rosemary Hill:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Michael Dunlop:** Writing – original draft, Methodology, Investigation. **Nicholas MacGregor:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation. **Sam Merson:** Writing – original draft, Methodology, Investigation. **Caitlin Vertigan:** Writing – original draft, Methodology, Investigation. **Luke Donegan:** Writing – original draft, Methodology, Investigation. **Marian Sheppard:** Writing – original draft, Project administration, Methodology, Investigation. **Jacqui Meyers:** Writing – original draft, Methodology, Investigation. **Linda Thomas:** Project administration, Methodology, Investigation. **Lola Visschers:** Writing – original draft, Methodology, Investigation. **Bianca McNeair:** Validation, Methodology, Investigation. **Lance Syme:** Validation, Methodology, Investigation. **Chrissy Grant:** Writing – original draft, Validation, Methodology, Investigation. **Nicholas Pedrocchi:** Validation, Methodology, Investigation. **Patricia Oakley:** Validation, Methodology, Investigation. **Amy Stevens:** Validation, Methodology, Investigation. **Denis Rose:** Validation, Methodology, Investigation. **Erin Rose:** Validation, Methodology, Investigation. **Jade Gould:** Validation, Methodology, Investigation. **John Locke:** Validation, Methodology, Investigation. **Lynda Maybanks:** Validation, Methodology, Investigation. **Tracy Ireland:** Validation, Methodology, Investigation.

Declaration of competing interest

The authors have no conflicts of interest to declare.

Data availability

No data was used for the research described in the article.

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