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Climate change adaptation planning for an internationally important wetland, the Muir–Byenup System Ramsar Site in south-west Australia

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Abstract. Wetlands, already declining worldwide because of human activities, are at increasing risk from climate change. Despite the Ramsar Convention requirement to maintain the ecological character of wetlands listed as internationally important, there is little guidance for wetland managers to actually do this, let alone plan for and implement adaptation to climate change. This study developed a checklist for planning climate change adaptation and used it to consider adaptation options for the Muir–Byenup System Ramsar site in Australia. Under climate change the site will be subject to future warming and drying, affecting hydrology, bird breeding and feeding, vegetation, peat and threatened species. Fire and wetland acidification are likely to increase. The study found that planning for climate change adaptation had not been widely undertaken for Ramsar sites and, where it had, managers mainly planned information gathering activities and 'no regrets' actions rather than innovative or transformative approaches. New management approaches and policy settings that encompass the dynamic nature of wetlands are needed because maintaining wetlands in their current state will be difficult under climate change. The development and sharing of targeted information and training for wetland managers and stakeholders could facilitate a better understanding and uptake of adaptation at wetlands.

Keywords: climate change adaptation, ecological character, Ramsar Convention, wetland management.

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Introduction

Wetlands are valuable ecosystems that have declined rapidly during the past 100 years in response to human activities (Ramsar Convention 2018*a*; Darrah *et al.* 2019). Climate change, already a threat to wetlands globally, will continue into the foreseeable future to put inland and coastal fresh and saline wetlands under increasing pressure (Moomaw *et al.* 2018; Arias *et al.* 2021). The vulnerability of wetlands to climate change can be reduced by global mitigation actions, such as reducing greenhouse gas emissions and sequestering carbon, and through adaption actions. In particular, adaptation (such as building ecosystem resilience) is needed because, despite mitigation actions taken now, some climate change impacts are already locked in due to past emissions (Pachauri and Meyer 2014; Intergovernmental Panel on Climate Change 2018; Department of Agriculture, Water and the Environment 2021).

There are 172 parties (countries) to the Ramsar Convention and 2434 listed wetlands covering an area of ~254 678 517 ha (www.ramsar.org, accessed 5 December 2021). Parties to the Convention commit to maintaining the ecological character of wetlands they list as internationally important (known as Ramsar sites) under the Convention (Davidson 2018). This includes taking measures to respond to threats such as climate change. The Ramsar Convention has recognised climate change as a serious threat to wetlands and has urged parties to take action to protect wetlands by enhancing their resilience (Ramsar Convention 2008). The Convention has also noted the important role wetlands can play in nature-based climate change adaptation (Ramsar Convention 2012).

Currently there is little experience internationally in climate change adaptation planning for Ramsar wetlands and little guidance to specifically support wetland managers to undertake climate change adaptation planning that aligns with the requirements of the Ramsar Convention (Lukasiewicz *et al.* 2016*a*; Finlayson *et al.* 2017).

Given this situation, we assessed the capacity for wetland mangers to undertake effective climate change adaptation planning through a literature review, interviews with Ramsar site managers and adaptation planning workshops for two Australian Ramsar wetlands. In this paper we highlight the Muir–Byenup System Ramsar wetland in south-west Australia as a case study to explore climate change adaptation as a wetland management tool at a site already experiencing significant climate change-induced impacts, including drying and acidification of its peat-based components (Lane *et al.* 2017) and increased fire occurrence (CSIRO and Bureau of Meteorology 2020; Intergovernmental Panel on Climate Change 2021). The case study contributes to a limited but growing international knowledge base about the challenges faced by Ramsar wetland managers in planning management responses to climate-related drivers of wetland change.

Case study: Muir–Byenup System Ramsar wetland, south-west Western Australia

Description of the study area

The Muir–Byenup System Ramsar site is an inland wetland located 55 km east-south-east of the town of Manjimup in south-west Western Australia (Fig. 1).

The site covers an area of 10 600 ha, of which ~7000 ha is wetland comprising a suite of partly interconnected lakes and swamps (Fig. 2) in an internally draining catchment. The wetlands vary in size, salinity (saline to fresh), permanence (seasonal to permanent) and substrate (peat and inorganic). The Muir–Byenup System was listed under the Ramsar Convention in 2001, being considered internationally important for its peat-based wetlands, which are rare in Western Australia, for supporting threatened species including *Diuris drummondii* (tall donkey orchid), *Nannatherina balstoni* (Balston's pygmy perch) and *Botaurus poiciloptilus* (Australasian bittern), and for providing habitat that supports critical life stages, such as moulting of *Tadorna tadornoides* (Australian shelduck) and the breeding and significant numbers of waterbirds, including migratory species. Many of its species are found nowhere else in the world (Farrell and Cook 2009).

As required under the Convention, the site is described in a Ramsar Information Sheet (see https://rsis.ramsar.org/RISapp/files/RISrep/AU1050RIS.pdf, accessed 21 January 2022) and a detailed ecological character description (Farrell and Cook 2009). Although there is no site-specific Ramsar management

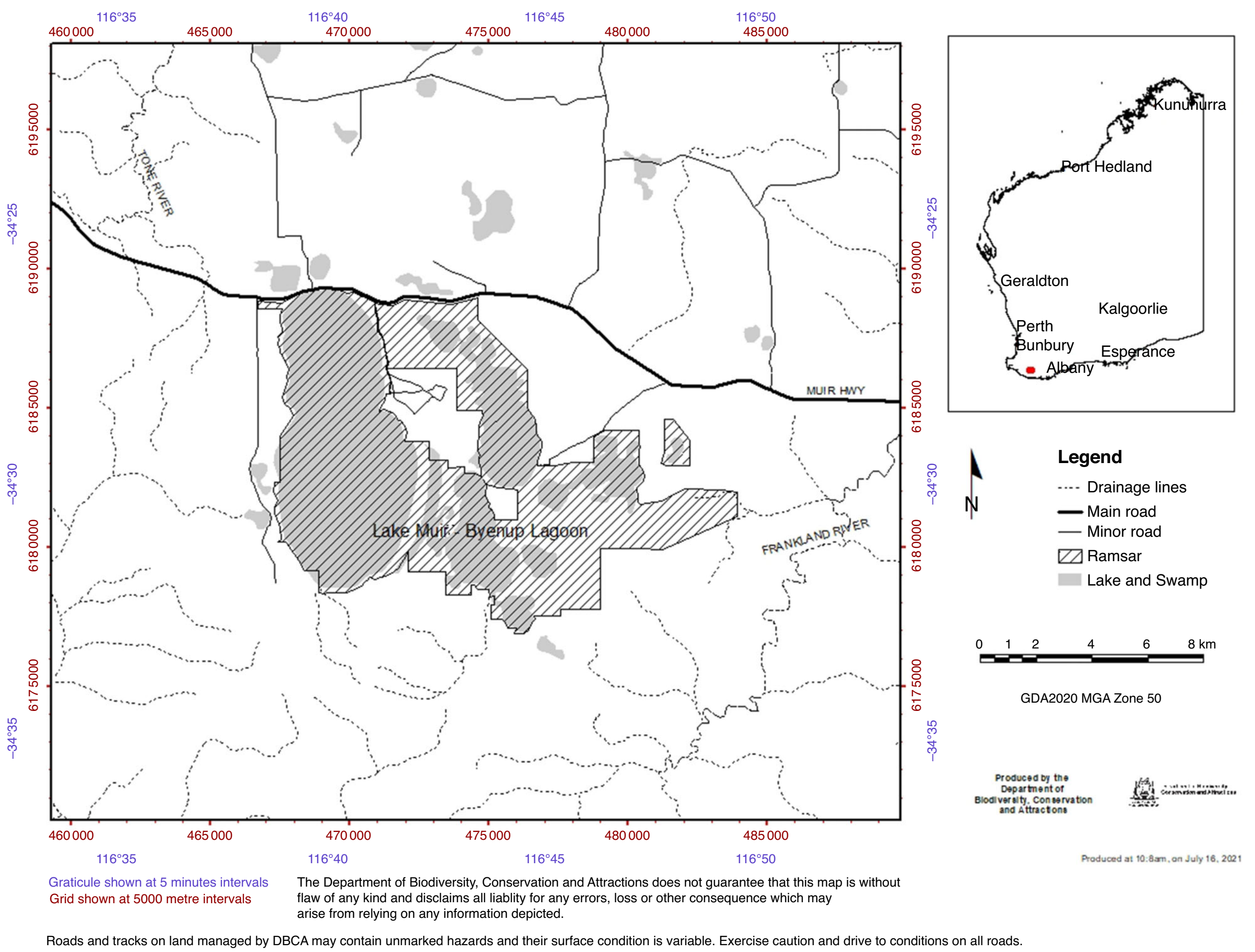

Fig. 1. Location of the Muir–Byenup wetlands in south-west Western Australia, indicated by the red dot on the map. Map supplied by the Department of Biodiversity Conservation and Attractions, 2021.

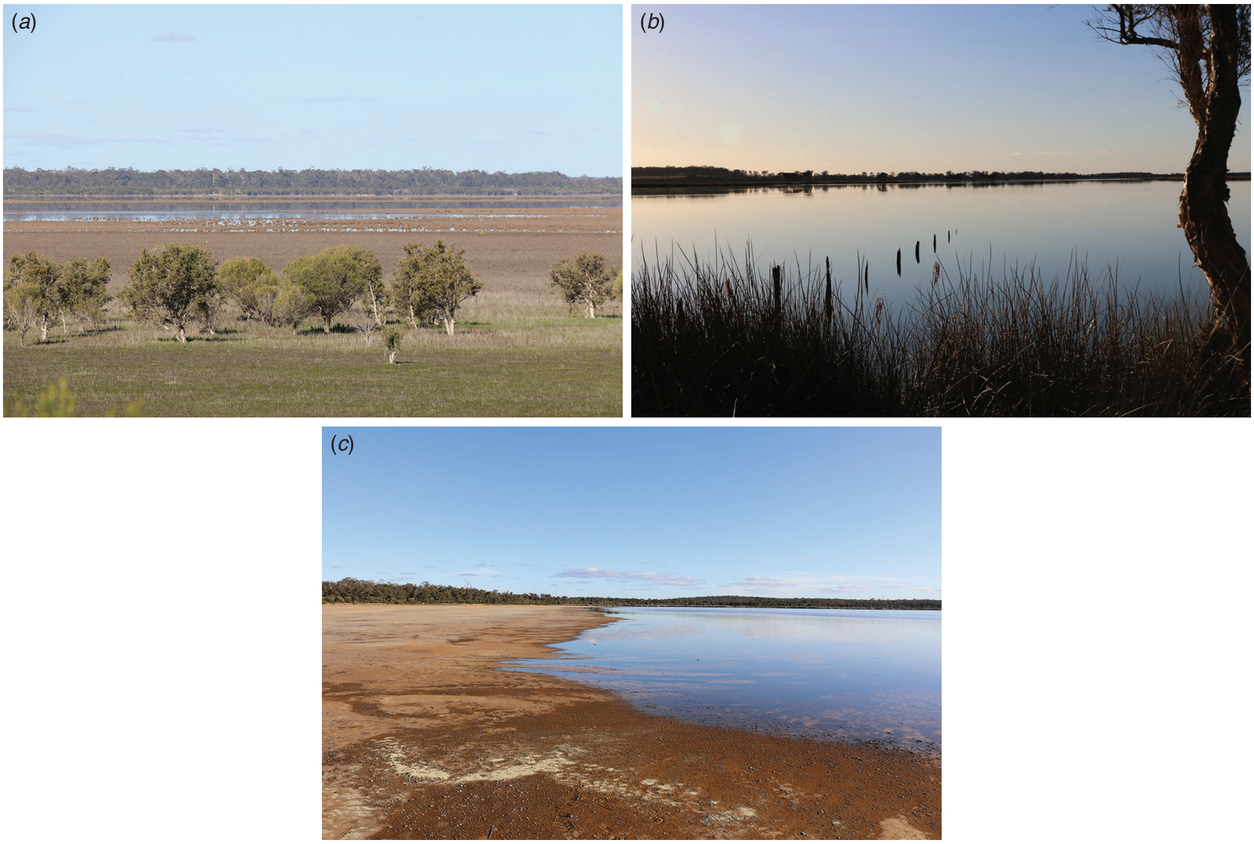

Fig. 2. Muir–Byenup System Ramsar site, south-west Australia (photographs taken by G. Partridge). (*a*) Lake Muir is an internally draining, naturally saline, shallow, evaporating basin known to have supported more than 20 000 waterbirds during past periods of high water levels, although it is often dry. (*b*) Byenup Lagoon is a permanent waterbody with areas of peat that dry seasonally. Drying is likely to increase under climate change, damaging the peat system. (*c*) Tordit–Garrup Lagoon with oxidised acid sulfate soils. Drying of this previously permanent waterbody led to acidification.

plan, management of the site is described under the Perup Management Plan 2012, a regional conservation area management plan encompassing several national parks and nature reserves (Department of Environment and Conservation 2012). Threats to the ecological character of the system were documented in the ecological character description as secondary salinity, disturbance of potential acid sulfate soils, grazing, introduced species and inappropriate fire regimes (Farrell and Cook 2009).

South-west Western Australia experiences a moderate Mediterranean climate with warm to hot, dry summers and cool, wet winters. Climatic changes have been documented for this part of Australia. In particular, rainfall has decreased by $\sim$20% since 1910 (CSIRO and Bureau of Meteorology 2020; Intergovernmental Panel on Climate Change 2021).

Associated with rainfall reductions and increased temperatures, the drying climate is expected to increase fire weather, further threatening ecosystems. Fire is a major threat to peatlands and can completely destroy these ecosystems (Pemberton 2005). Regular monitoring of the depth, salinity and pH of wetlands in south-west Western Australia between 1977 and 2016 indicated drying of some wetlands, including within the Muir–Byenup System (Lane *et al.* 2017). Of note, in 2016 the Tordit–Garrup wetland, within the Muir–Byenup System, experienced reduced groundwater inputs resulting in drying of the peat-based wetland and exposure of acid sulfate soils, leading to acidification (M. Coote, pers. comm., 16 April 2018).

Such climate-induced changes in water quality and hydrology may lead to changes in ecological character. Under Article 3.2 of the Ramsar Convention, a notification of change is required if the ecological character of a site has changed, is changing or is likely to change as a result of technological developments, pollution or other human interference (Ramsar Convention 1971). However, Australian Government guidance for wetland managers in Australia on the application of Article 3.2 indicates that where climate change is likely to be the principle cause of identified ecological change, and until such time as the Convention provides guidance of an approach to this issue, it will not be an accepted basis on which to make an Article 3.2 notification (Australian Government 2009). The changes that have been described for the Muir–Byenup System Ramsar site have not been reported under Article 3.2 of the Convention (Ramsar Convention 2018*a*). Given this situation, it may be worthwhile revisiting a past request to the Convention to consider how climate change will affect the ecological character of wetlands and to provide guidance for wetland managers (Ramsar Convention 2013).

Climate change and Ramsar wetlands: the need for adaptation planning

Climate change and the Ramsar Convention

Resolutions from Ramsar Convention Conferences of the Parties urge contracting parties to manage their wetlands wisely to increase their resilience to climate change (Ramsar Convention 2008) and to maintain or improve the ecological character of wetlands to promote the ability of wetlands to contribute to nature-based climate change adaptation (Ramsar Convention 2012). Other resolutions encourage the restoration of coastal wetlands in relation to their role in disaster risk reduction (Ramsar Convention 2015*a*), blue carbon values (Ramsar Convention 2018*b*) and the value of peatlands as carbon sinks (Ramsar Convention 2008).

Target 12 of the Ramsar Strategic Plan 2016–2024 specifically includes climate change mitigation and adaptation:

> Restoration is in progress in degraded wetlands, with priority to wetlands that are relevant for biodiversity conservation, disaster risk reduction, livelihoods and/or climate change mitigation and adaptation. [Ramsar Convention 2015*b*, p 10]

Ramsar Convention publications that provide technical and policy guidance in relation to climate change include a briefing note on wetland restoration for climate change resilience (Fennessy and Lei 2018), a framework for assessing the vulnerability of wetlands to climate change (Gitay *et al.* 2011) and a briefing note on blue carbon in Ramsar wetlands (Convention on Wetlands 2021). The Convention has not issued detailed guidance on climate change adaptation planning for wetlands or on how this could relate to wise use and the maintenance of ecological character.

Adaptation planning approaches for natural resource management

Many authors have contributed to the literature on climate change adaptation approaches for natural systems and some of these approaches are specific to protected areas (van Kerkhoff *et al.* 2019), including Ramsar wetlands (Finlayson *et al.* 2017) and national parks (Tanner-McAllister *et al.* 2017; Jacobs *et al.* 2019).

Addressing existing threats is a primary management response to climate change vulnerability because it is recognised that increasing resilience is likely to reduce vulnerability (Department of Agriculture, Water and the Environment 2021; Finlayson *et al.* 2017).

Building resilience could include strategies such as riparian restoration to increase shade and maintain water temperature, flow restoration, increasing the size of protected areas, protecting refugia and restoring connectivity (James *et al.* 2013; Lukasiewicz *et al.* 2016*a*; Finlayson *et al.* 2017). Strategies such as these are seen as 'no regrets' responses: regardless of the emissions scenario and resulting climate change impacts that play out, they are likely to provide ecosystems benefits (Hallegatte 2009). These approaches may be the easiest to consider because they are incremental (Abel *et al.* 2016), currently accepted and practiced management actions. However, managers of natural resources are recognising the inevitability of ecosystem change and the need to invest in additional approaches that account for this (Jacobs *et al.* 2019).

Several authors have referred to the need for 'transformative' adaptation approaches that respond to the likelihood that changes, such as the impacts on biodiversity and ecosystems caused by global drivers of change, are no longer gradual, but rapid and widespread (Abel *et al.* 2016; Wyborn *et al.* 2016; Colloff *et al.* 2017).

A recurring concept, although expressed in different ways, is a progressive adaptive approach through time that responds to changes, triggering new approaches as thresholds (such as climate variables including temperature and rainfall; or ecosystem responses such as species decline) are reached (Abel *et al.* 2016; Finlayson *et al.* 2017; van Kerkhoff *et al.* 2019). Placing adaptation approaches within a continuum from resilience building, 'no regrets' actions through to 'transformative' (such as species translocation and novel ecosystems) can be called an adaptation pathways approach. An adaptation pathways approach allows resource managers to deal with high levels of uncertainty, especially regarding the timing and extent of future changes, and to identify solutions (actions) that will be progressively put in place as needed. Some adaptation pathways approaches focus broadly on timing, such as actions to take now, soon or later when ecological transformation is imminent (Finlayson *et al.* 2017; van Kerkhoff *et al.* 2019), negotiation of a range of stakeholder views using criteria for sequencing actions from incremental to transformative (Abel *et al.* 2016), engaging key stakeholders in a climate-based risk assessment (Jacobs *et al.* 2019) or whether to accept or resist change (Tanner-McAllister *et al.* 2017).

Natural resource management planning, and especially in an adaptation pathways context where uncertain futures are being explicitly considered, should be based on the best available data and with engagement of a range of stakeholders.

Climate change data are improving all the time and this is enabling a greater understanding of changes that have occurred and more certainty for future projections (Arias *et al.* 2021). In Australia, national-level historic and current climate data are provided by the Bureau of Meteorology (see http://www.bom.gov.au/, accessed 4 February 2022) and can be tailored to specific locations. For example, Fig. 3 shows historic rainfall anomalies for south-western Australia and illustrates the progressive drying referred to above.

Information and tools to explore climate data and projections are provided through the Climate Change in Australia (CCIA) website (see http://www.bom.gov.au/, accessed 26 January 2022). The CCIA site (see http://www.climatechangeinaustralia.gov.au/, accessed 26 January 2022) also provides links to state-based projections that provide higher-resolution and local-scale information. Such information is important for adaptation planning.

The inclusion of historic land use at a site and within its catchment is an important information component for designing restoration actions such as those being considered as part of an adaptation pathways approach (Gann *et al.* 2019; Bachmann 2020).

Stakeholder engagement, as an input to adaptation planning, has also been identified as critical by many authors (e.g. Abel *et al.* 2016; Jacobs *et al.* 2019; van Kerkhoff *et al.* 2019).

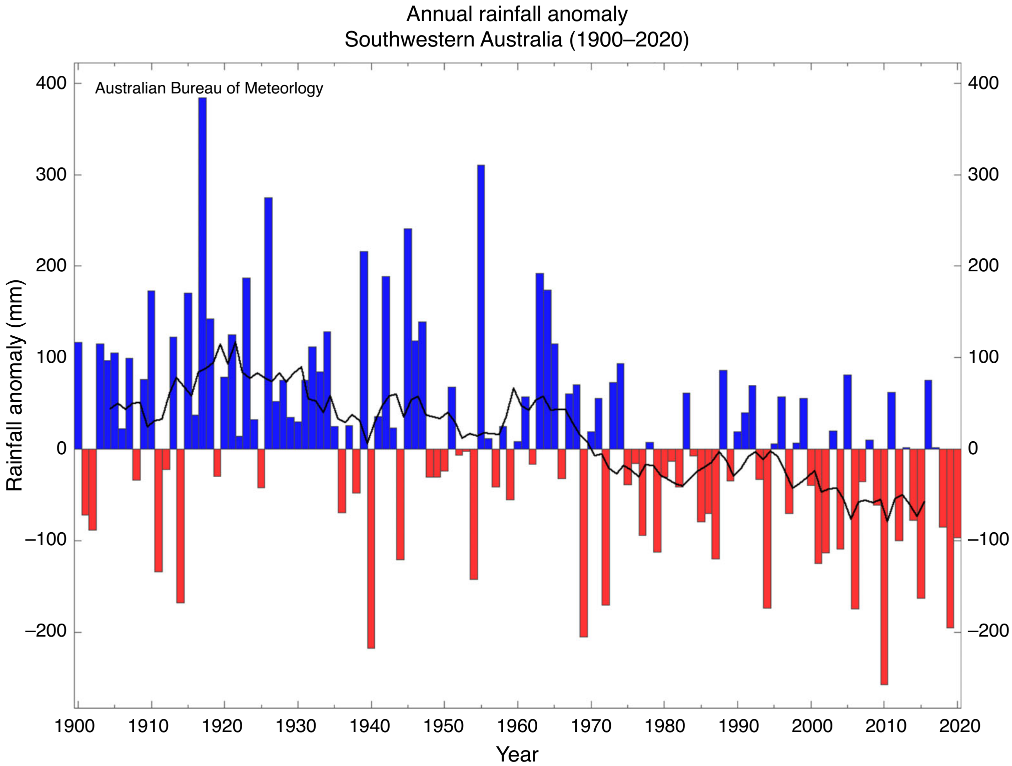

Fig. 3. Annual rainfall anomaly south-western Australia (1900–2020; Bureau of Meteorology 2021) based on a 30-year climatology (1961–90). The black line indicates 10-year running averages. https://creativecommons.org/licenses/by/3.0/au/.

Partnerships with Indigenous communities and Indigenous land management experts is also identified as being essential for management planning (National Environmental Science Program 2021).

Adaptation planning for Ramsar wetlands

Documented experience in adaptation planning and implementation with respect to Ramsar wetlands, and for wetlands more broadly, is limited and, as mentioned, there is a lack of suitable guidance from the Ramsar Convention. In Cambodia, adaptation planning has commenced for the Koh Kapir Ramsar site where, following a vulnerability assessment, several adaptation actions were identified (Sorn and Veth 2019). These included new zoning restrictions, awareness raising and changes to institutional arrangements to allow increased stakeholder participation in management. No on-ground actions were included. A basin-level climate change adaptation plan for the Lake Victoria Basin in Africa identified adaptation actions that targeted management planning, improving the availability and dissemination of information, technological innovations for water harvesting and storage and improved funding mechanisms (Lake Victoria Basin Commission 2018). For Mediterranean wetlands, Medwet, an umbrella organisation that became a Ramsar Regional Initiative, noted that climate change had been mostly neglected in wetland conservation planning in the Mediterranean region (Medwet 2019). In the US, a study of the California Central Valley wetland area, part of which is Ramsar listed, found that securing additional water supplies to restore key habitat was a primary adaptation action, along with implementation of new and existing technologies to monitor habitats and waterbird populations to inform climate change adaptation decisions by site managers (Matchett and Fleskes 2017).

Many of Australia's 66 Ramsar sites are likely to be at risk of change in ecological character as currently described, associated with climate change in combination with other impacts. Along with the Muir–Byenup System, the Riverland (Newall *et al.* 2016) and Kakadu National Park Ramsar wetland (Bayliss *et al.* 2018; Asbridge *et al.* 2019) are experiencing declines or changes attributed to climate change.

Several studies focusing on climate change adaptation and Ramsar wetlands, including the Macquarie Marshes (Bino *et al.* 2013) and the Coorong and Lakes Alexandrina and Albert sites (Gross *et al.* 2012), were published by the Australian National Climate Change Adaptation Research Facility (NCCARF). Both reports noted the importance of environmental water allocations as primary options for adaptation. Institutional arrangements for water sharing were also found to be a critical part of addressing climate change impacts to the wetlands. Another NCCARF report looking at freshwater refugia and their potential to contribute to future climate change adaptation responses included a case study for a selection of Ramsar sites (James *et al.* 2013). The report found that under climate change the Ramsar wetlands may fail to continue to provide climate refuges and that a fundamental shift in conservation frameworks may be needed. A further study in Kakadu National Park, a Ramsar site subject to future climate-driven sea level rise, found that the likely creation of completely different ecosystem states would mean that current management approaches will no longer be appropriate. Adaptation approaches were suggested, including local mitigation of seawater intrusion, maintaining existing freshwater refugia (even though they may eventually be lost) and increasing research knowledge and targeted monitoring programs to reduce uncertainty (Bayliss *et al.* 2018).

Climate change vulnerability assessment has not been widely undertaken for specific Ramsar sites and management actions for climate change adaptation have not been prioritised by site managers according to climate change risk.

Materials and methods

Preparation for the study involved a literature review and a brief questionnaire administered by email to government representatives with responsibility for Ramsar wetlands. A draft climate change adaptation checklist, to support Ramsar site managers to undertake improved climate change adaptation planning, was developed during the preparatory stage.

Prior to the project commencing, approval was gained from the Charles Sturt University Human Research Ethics Committee (H19014).

A qualitative 'participatory research' approach (Hennink *et al.* 2011) underpinned the research. A workshop was undertaken for the Muir–Byenup System wetland in Western Australia (managed by the Department of Biodiversity, Conservation and Attractions). The chief investigator (G. Partridge) collaborated with participants (Ramsar wetland managers and other stakeholders) to identify a problem (how climate change is likely to affect the ecological character of the specific wetland site) and develop a solution (completed climate change adaptation checklist and adaptation plan). The site was selected for the study on the basis of suitable climate change issues being present at the site and on the willingness and capacity of site managers to participate.

Participant selection was based on advice from the natural resource management agency with whom the workshop was undertaken. This was to help ensure that participants were likely to have an interest in or connection to the site.

The climate change adaptation planning workshop was held at Manjimup, the closest town to the site and the location of the responsible Parks and Wildlife office. The workshop was attended by 13 participants, including state and commonwealth government officers, consultants and university researchers with expertise in wetlands policy and programs, climate change policy and science, water resource management, catchment management, parks management, aquatic ecology, geohydrology and hydrology.

The workshop was structured around developing a shared understanding of the values for which Muir–Byenup System wetlands were listed as internationally important, the current threats and impacts affecting those values, the nature of climate change projections for the region, the likely impacts from climate change on the identified wetland values and potential adaptation actions.

One week after the workshop, data were collected from workshop participants by an emailed questionnaire to provide reflection on the workshop process. The questionnaire used mainly pre-coded (fixed alternative) questions and each question also offered an open-ended, optional opportunity to elaborate (Sarantakos 2013).

Voice recordings of workshops were transcribed manually. Participants' names were initially identified in a transcript of workshop discussions so that information could be verified directly with participants if needed. Transcripts were coded into meaningful categories, based on content analysis (Brynman 2016). Emergent categories were determined iteratively by the chief investigator (G. Partridge) following initial review of the transcripts using NVivo (ver. 12, see https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/support-services/nvivo-downloads).

Results

At the workshop, participants discussed issues within the context of maintaining the ecological character of the Muir–Byenup wetlands, threats (including climate change), potential adaptation actions and Ramsar Convention requirements. As an overarching theme, the ongoing trend of a drying climate in south-west Western Australia and the impact of this on peat-based wetlands through fire and reduced water availability was a dominant focus.

Ecological character: how the wetland system is valued as a Ramsar site

Discussions about the ecological character of the site were those that referred to one or other part of the definition of ecological character, including: (1) ecological components, such as different wetland types, birds, invertebrates, vegetation and peat; (2) wetland processes, particularly hydrology and water quality; and (3) ecosystem services, such as hydrological regulation and conservation value.

The Muir–Byenup System was described by workshop participants as comprising a diversity of wetlands including a large permanent lake (Byenup) and a large (at the time almost dry) wetland (Lake Muir). Much time was given to discussing the Tordit–Garrup wetland, a small, shallow wetland that had already dried due to the hotter, drier climate that had led to reduced groundwater levels.

The functioning of the Muir–Byenup System and the interconnection between component wetlands and the underlying geology was frequently referred to as being complex:

> …how complex the wetlands are, going from permanent to seasonal, having peat and inorganic sediments, having fresh water, having saline water. It's such as complex system. [Muir–Byenup workshop participant]

> The geology is complex, we've got a slide showing the fault lines going through there and its incredibly complex. [Muir–Byenup worskshop participant]

This perceived complexity was important because it may have limited the confidence with which site managers could nominate effective actions to address current and future threats to ecological character, particularly the peat component, by acidification and fire.

Waterbirds were referred to more than other biological components. This was not unexpected given that waterbird diversity and abundance is one of the reasons for the site's Ramsar listing, and any change would likely adversely affect its ecological character. Participants discussed the damage to reed beds from acidification and the destruction of peat from the combined effects of acidification, drying and fire, and the resulting habitat loss and impact on Australasian bitterns (a threatened bird species).

Another strong focus of discussion was the declining diversity of endemic invertebrates that was likely to be exacerbated under ongoing climate change. This is important because the invertebrate biodiversity is seen as underpinning the ecological character of the site:

> So generally, the values of the birds, the fish, the macroinvertebrates, the vegetation and in particular the endemic nature of many of those components – so it's the fact that they were locally or regionally endemic that was really important and there were some concerns … that maybe some of those had disappeared, so that was an important value. [Muir–Byenup workshop participant]

Threats and impacts on the ecological character of the site

The main threats and impacts referred to by workshop participants were acidification, climate change, altered hydrology, loss of connectivity, land use, fire and lack of funding.

Participants spent a significant part of the workshop discussing the acidification of the Tordit–Garrup component of the Ramsar site. Reduced rainfall since the 1970s had caused drying of the wetland, subsequent exposure of acid sulfate sediments and acidification of the wetland. A ramification of the acidification and resulting destruction of reed beds and peat was a possible change in the ecological character of the site. The participants expressed concern that a continuation of the drying trend (both reduced rainfall and increased temperatures) under climate change presented an increased risk of further acidification events. This was associated with a sense of hopelessness because there did not seem to be many options to prevent or fix this problem. For example:

> It [the peat] loses the robustness to respond to change. You've always got to put it on a life support system. If you're not going to have a solution you're going to walk away. So I guess whatever we're going to do we've got to understand that inherently the system will change and we have to manage that change. So I guess the first point is no false expectation. [Muir–Byenup workshop participant]

It was also noted that under climate change increased evapotranspiration associated with higher temperatures would reduce water availability and lead to altered hydrological regimes in the wetlands. The site was already experiencing decreased annual rainfall, as well as changes to the seasonal patterns of rainfall, and this was expected to continue into the future.

Changes to the hydrology and the associated increases in acidity and salinity and reduced connectivity between wetland areas were mentioned frequently during the workshop. Participants considered that these impacts would reduce the biodiversity value of the wetland habitats. Changes to hydrological regimes likely to be experienced under climate change were seen as particularly serious because they affect the critical biodiversity components of the wetland (birds, fish, invertebrates, vegetation and peat) and potentially lead to changes in the ecological character.

Participants further spoke about the impact to the Ramsar site from past land use activities. The Muir–Byenup System had been affected by the establishment of pine (*Pinus radiata*) and blue gum (*Eucalyptus globulus*) plantations on adjacent land, which reduced water availability for the wetlands. The plantations had largely been removed in recent years, but the extent of recovery was unknown and considered to be an important knowledge gap.

Fire was also identified as a current threat to critical components, especially peat, large areas of which had already been destroyed by fire. Participants linked the future drying and warming under climate change to a likelihood of increased fire frequency and increased threat to peat. This was considered very important because of the key role of peat in regulating the hydrology of the system and providing habitat for bird species:

> In Tordit–Garrup you saw one of the big issues of course, is with the lower water levels. Those peat beds – hundreds of hectares – don't get inundated with water any more … and those cracks … you can actually poke sticks right down. As it gets drier and drier fire becomes a major issue. When they do catch on fire – it's a significant volume of peat. [Muir–Byenup workshop participant]

Ramsar site management requirements

Discussions about site management requirements included data issues, catchment management approaches, social issues and Ramsar Convention documentation and policies.

Workshop participants referred to a lack of monitoring and data as an impediment to the implementation of adequate management responses to the threats and their impacts. This is important for Ramsar site management because of the need to detect and report changes in the ecological character, and in the context of climate change adaptation because the development of appropriate adaptation actions needs to be based on the best available scientific information.

There was a focus on needing better knowledge about the system's hydrology and treatments for acidification, as well as improved peat mapping and fire management, and capacity to analyse invertebrate and bird data to inform climate change adaptation options. These issues were widely accepted as critical, and could be seen as a shortfall in the management responses.

Issues around Ramsar documentation requirements were also included in site management discussions. For example, Ramsar paperwork (such as updating of Ramsar Information Sheets) was seen as overly time-consuming and resource intensive, diverting scarce resources away from much-needed on-ground management.

Adaptation options to address threats and impacts to the ecological character of the Ramsar site

Workshop participants considered climate change adaptation options including information generation, on-ground adaptation actions, policy adaptation, stakeholder engagement and communication in general. Although the workshops were climate change adaptation workshops, the adaptation theme was discussed less frequently than other themes. This is considered to be significant and could highlight a lack of knowledge about suitable adaptation options for the complex threats and impacts that were earlier identified, thus being an impediment to planning for and undertaking adaptation actions.

Improved information through monitoring, research and analysis to better understand and target appropriate actions, was the adaptation option most often mentioned. The following information actions were proposed:

- foster research to enhance knowledge of how the system functions to:
  - facilitate effective water management
  - better understand the hydrological response to removal of blue gum and pine plantations;
  - better understand potential acidification treatment, such as lime application and introduction of carbon sources, including the establishment or expansion of bulrushes (*Typha orientalis*)
- evaluate hydrological measures, including water transfer between the wetlands and from surface drainage from cleared land towards the wetlands
- establish effective monitoring, data storage and evaluation systems
- improve peat mapping to support better targeting of fire suppression.

When participants spoke about adaptation approaches, it was mostly not about proposing specific actions, but rather a generalised or theoretical discussion. This information sharing was likely to have been of value to the participants and may have been reflected in questionnaire responses that highlighted the usefulness of the workshop regarding enhanced knowledge, the value of new ideas, different perspectives and expert knowledge.

Participants were familiar with the adaptation approach of promoting system resilience, for example:

> …trying to maintain current health of the system gives it some robustness to change. So, in terms of your management it might be best to focus on those systems which are really healthy at the moment and try and look after those as best you can. [Muir–Byenup workshop participant]

An issue raised was whether investment in maintaining an important component of a system would be worthwhile if that investment would be needed long-term (and therefore overly costly) to maintain the ecological character under changed climatic conditions:

> The other problem, once you start … do you put the system on a life support because then you've got to manage it forever… [Muir–Byenup workshop participant]

Few on-ground actions were suggested. Those that were, were about building resilience. Others included implementing a trial planting of a carbon source such as *Typha* to treat acidification at the Tordit–Garrup lagoon and implementing improved fire suppression for peat beds.

Workshop participants identified planning policies as a mechanism that could be used to support Ramsar sites to adapt to climate change. Land use planning policies were highlighted as being important.

There was some discussion about institutional communication and engagement, such as a proposal to set up a state government interdepartmental meeting or process to coordinate actions that affected the Ramsar site, as well as a desire to have better communication with land holders to leverage mutually beneficial actions.

Discussion

Wetland managers and other stakeholders who were participants in the climate change adaptation workshop acknowledged the changes to the climate that had already occurred and ongoing changes that are projected to occur. This acknowledgement was seen as an indication that the reality of climate change was recognised and that the discussions were not bedevilled by denial or scepticism about climate change. Eliot *et al.* (1999) had earlier noted when assessing the vulnerability of the wetlands of Kakadu National Park (in northern Australia) to climate change that raised awareness of the implications was an important step in securing community and government support for adaptation.

Participants drew on their combined knowledge of the ecological character of the site and existing threats and, with the overlay of climate change, discussed likely future threats and impacts as well as possible adaptation measures. Future climate change was considered to be a threat likely to result in significant impacts. This outcome was not unexpected because the likelihood of widespread significant impact to ecosystems from climate change is increasingly recognised (Dunlop *et al.* 2013; Pachauri and Meyer 2014; Lukasiewicz *et al.* 2016*b*), and for wetlands in particular (Eliot *et al.* 1999; Kingsford 2011; Finlayson *et al.* 2017).

Site-specific issue of threats to peat-based wetlands

The climate change-driven threat to peat-based wetlands dominated workshop discussions. The site was not subject to significant anthropogenic threats other than from climate change. The drying climate trend in south-west Western Australia and increased fire weather, along with the associated threats of reduced groundwater levels, acid sulfate soil exposure, acidification and significant and more frequent bushfire events, have been documented (Department of Environment and Conservation 2012; Department of Water 2015; CSIRO and Bureau of Meteorology 2020). The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Arias *et al.* 2021) highlights the climate-induced rainfall reductions and increased fire weather in south-west Western Australia and the likelihood that these trends will continue into the future. The destruction of peatlands globally and nationally by recent fire events has been publicised, for example globally (Ramsar Convention 2018*c*), in Victoria, Australia (ABC News 2020) and in Indonesia (UN Environment Program 2019). The value of peatlands for hydrological regulation, biodiversity habitat, carbon storage and other social and economic benefits including contributing to the UN Sustainable Development Goals is also well documented internationally (Ramsar Convention 2018*d*; Global Peatlands Initiative 2021).

Threats to peatlands from anthropogenic pressures and climate change, and therefore the need for their conservation and restoration, have been nominated as a priority through several resolutions of Ramsar Conferences of Parties (e.g. Resolutions VII.11, VIII.17, X.24; XII.11; XIII.13; www.ramsar.org, accessed 5 July 2021). Measures such as listing of additional peat-based Ramsar sites and the allocation of water resources for rewetting drying peatlands have been put forward (Ramsar Convention 2018*c*).

Despite available knowledge about the value of and current and future threats to peatlands, there was a sense of frustration and even some hopelessness among participants in the Muir–Byenup System workshop. This suggests a significant knowledge gap about relevant climate change adaptation options and that there may not be a solution other than to accept that the peat system may be lost. This may also be the case for the management of peat-based wetland systems elsewhere, particularly those where specific water allocations are not possible or feasible, such as those with poorly understood hydrology, those located remotely or those that are prone to drying or catastrophic wildfire.

Need for greater understanding of adaptation options

Most adaptation discussion within the workshop was related to non-on-ground actions. The dominance of actions relating to information and inclusion of stakeholder engagement, communication and policy adaptation is consistent with adaptation planning outputs from Australia and other regions of the world. In Australia, studies conducted for the NCCARF program, including for the Macquarie Marshes Ramsar site (Bino *et al.* 2013) and the Coorong and Lakes Alexandrina and Albert Ramsar site (Gross *et al.* 2012), noted that although environmental water allocations were primary options for adaptation, better institutional arrangements (policy adaptation) for water sharing were needed. The Macquarie Marshes work also noted that ecological response modelling was important in helping identify adaptation opportunities (Bino *et al.* 2013).

Examples from other regions of the world include adaptation plans from the Koh Kapir Ramsar site in Cambodia (Sorn and Veth 2019), the Lake Victoria Basin in Africa (Lake Victoria Basin Commission 2018) and the California Central Valley wetland area, part of which is Ramsar listed (Matchett and Fleskes 2017). Adaptation options considered in these examples included changes to institutional arrangements to allow increased stakeholder participation in management, improving the availability and dissemination of information, technological innovations for water harvesting and storage, improved funding mechanisms and habitat monitoring to inform future management decisions.

In the present study, workshop participants expressed frustration regarding capacity to do anything. A participant in the Muir–Byenup workshop said:

> My concern is we know the triggers, we know the threats … they're well understood by everyone in this room… But my concern is what are we going to do about it?

Questionnaire responses also expressed this frustration: for example, '…did not define clear on-ground responses' (Muir–Byenup workshop participant).

Workshop participants, although demonstrating an understanding of climate change issues and how they would affect Ramsar sites, may not have had adequate knowledge about climate change adaptation and lacked sufficient understanding of approaches that could be applied at their site within the context of the Ramsar Convention and its requirement to maintain ecological character. Lack of knowledge and associated lack of confidence in this specific area may have led to an unwillingness or lack of capacity to discuss it. Participants in the workshops reflected (in questionnaire responses) that one of the benefits of the workshops was the opportunity to be exposed to site-specific information, including climate change data, and to share a range of perspectives about the site and climate change adaptation.

The failure to engage effectively on climate change adaptation suggests that information resources and training in relation to climate change adaptation and its practical application in the Ramsar context are needed. The positive reflections of workshop participants on the value of the workshops for information sharing suggests that such for a are one suitable avenue for providing information. Others may include specific management guidelines and policy documentation.

Climate change adaptation actions in response to threats at Ramsar wetlands

Potential adaptation actions generated from the workshop discussions, such as facilitating effective water management, extending site boundaries and fire suppression, contribute to building site resilience. They are in the existing management toolkit and can also be categorised as 'no regrets' approaches (Lukasiewicz *et al.* 2016*b*) or 'incremental' (Abel *et al.* 2016). Managers are generally familiar with and comfortable to suggest such actions.

Other actions, including the application of lime and carbon sources for treating acidification at the Tordit–Garrup component of the Muir–Byenup site, are more experimental and not yet in the accepted Ramsar management toolkit. Transferring water from one wetland to another at Muir–Byenup, where this may not have occurred naturally, is an engineering solution and may also involve trade-offs between wetland components of the site. These approaches are ones that mangers may consider when climate impacts worsen: the actions that could be taken soon in the approach described by Finlayson *et al.* (2017) or based on increasing level of risk (Jacobs *et al.* 2019). Novel adaptation approaches, including the translocation of species that may be lost or the storage of genetic material and other such approaches that focus on accepting change and facilitating transition to a new ecosystem type, were not seriously considered in the workshop. If these transformative actions were familiar to and accepted by the workshop participants, perhaps their implementation would have been suggested.

No specific adaptation actions were proposed to address the loss of endemic invertebrate species or threatened species (bitterns), an issue at Muir–Byenup. This may be due to a lack of knowledge, in which case resources and training could help. Translocation or assisted migration are considered important options for maintaining species, particularly for highly valued or rare species (James *et al.* 2013). There is some recent experience with translocations of fish from the Darling River in south-eastern Australia where mass fish kills attributed to drought and overallocation of water resources occurred (Vertessy *et al.* 2019). Translocations have been recommended to conserve already threatened species that have been affected by bushfires in Australia in 2019–20 (Australian Government 2020*a*). Making information and case studies about such adaptation options available to Ramsar site managers could support a proactive approach to climate change adaptation planning.

Starting with 'no regrets', incremental actions such as fire management combined with system monitoring and research to support future decisions about applying actions that may currently be unknown, risky or expensive (engineering actions, novel planting, preserving species off-site) resemble the steps in a climate change adaptation pathways approach (Abel *et al.* 2016; Siebentritt and Stafford Smith 2016; Finlayson *et al.* 2017; van Kerkhoff *et al.* 2019). For the Muir–Byenup site, later steps in the pathway, to be activated if certain climatic, species loss or other thresholds are reached, may include novel and engineering options. There is a level of uncertainty being faced by managers of the Muir–Byenup System Ramsar site that relate to their capacity for decision making. This would include uncertainly about exactly how the climate will change, how species and communities, as well as hydrology and wetland extent, will respond and about policy and regulatory responses and future directions. Some of these uncertainties were discussed in the workshop (e.g. thermal and hydrological tolerances of species). The adaptation pathways approach is a way to manage such uncertainty, facilitate community participation in decision making and consider multiple possible outcomes (Abel *et al.* 2016; Siebentritt and Stafford Smith 2016; van Kerkhoff *et al.* 2019; Finlayson *et al.* 2021). Although the adaptation pathways approach is still developing, it is likely to prove to be a useful addition to the Ramsar management toolkit. The provision of knowledge and training to Ramsar site managers Australia wide to support their use of this approach would be beneficial, as would further pilot studies. It would also be very worthwhile to build on the initial work undertaken with stakeholders associated with the Muir–Byenup site by undertaking further work to specifically develop an adaptation pathway plan.

Improved information supported by better monitoring, research and analysis was frequently mentioned by workshop participants and was categorised as an appropriate adaptation option. Although these activities are standard tools for wetland management, there have been significant advances in recent years that may not yet have been adopted. For example, a Ramsar technical report (Rebelo *et al.* 2018) recommends the use of Earth observations from space technology for wetland inventory, assessment and monitoring. Such tools are now more readily available, accessible and cost-effective and could underpin the use of an adaptation pathways approach. In Australia, a government agency has developed a Water Observations from Space web service (Geosciences Australia 2021) that includes products such as a wetlands insight tool that can help managers visualise and track wetland changes. Such spatial information, combined with local-scale climate projections, can provide a richer picture of current and future scenarios to inform adaptation planning.

Limited stakeholder engagement was undertaken for the Muir–Byenup adaptation planning workshop. This was largely due to resource constraints and was a shortcoming of the study, particularly with respect to Indigenous stakeholder engagement. Experience in successful Indigenous engagement through partnerships is growing, and future climate change adaptation planning efforts could be supported through the application of specific guidance such as the Indigenous partnership principles (National Environmental Science Program 2021).

With enhanced capacity supported by an adaptation pathways approach, better data, including downscaled climate projections, system monitoring and case study examples of adaptation options, as well as broader stakeholder participation, it is possible that a more detailed set of adaptation options could be generated for the Muir–Byenup System wetlands. This may include options such as implementing monitoring using Earth observations from space, off-site conservation of macroinvertebrates, the use of Indigenous-led fire management and experimental implementation of engineered water transfers between wetlands. Such options are hypothetical, actions only likely to be adopted if the stakeholders themselves are involved and have had ownership of the process to develop the adaptation pathway.

Maintaining ecological character under climate change: need for policy adaptation

Uncertainties associated with the kinds of ecosystem transitions that may take place under climate change and what management responses would be appropriate and acceptable under Ramsar Convention policies and guidelines that relate to the maintenance of ecological character may also have contributed to the failure of the workshop to come up with substantial adaptation actions.

Conservation approaches based on conserving biodiversity 'as is', akin to maintaining ecological character, are unlikely to be feasible under climate change (Groves *et al.* 2012; Dunlop *et al.* 2013; Colloff *et al.* 2017; Prober *et al.* 2017; Tanner-McAllister *et al.* 2017). Significant changes to biodiversity, water regimes and other components and processes that make up ecological character are likely under climate change. Although biodiverse wetland ecosystems may still exist and support viable communities under climate change, they could be very different wetland types to those that exist now. Australian studies have highlighted the likelihood that there will be transitions to different wetland types, with associated changes to vegetation structure and function (Department of Sustainability and Environment 2013), and that many Ramsar sites may no longer fulfil their wetland conservation role (James *et al.* 2013). These examples of ecosystem transitions highlight the likelihood of changes in ecological character (as currently interpreted) at Ramsar sites and that managers will not be able to manage sites as they do now.

Marin and Finlayson (2019) have emphasised the need to further investigate future changes in ecosystems, including wetlands sites that can already be described as novel ecosystems (*sensu* Hobbs *et al.* 2014), including understanding triggers of potential shifts in ecological regimes and thresholds for critical variables to enable managers and local communities to anticipate and respond to those changes. Given the synergistic links that occur between climate change and other drivers of change in wetlands (Finlayson *et al.* 2013), such research would seem beneficial for developing and implementing adaptation measures for wetlands affected by climate change. This link between climate change and the emergence of novel or hybrid ecosystems has been raised in decisions taken by the contracting parties to the Ramsar Convention (Ramsar Convention 2013), but has not attracted the attention being proposed for all ecosystems by Marin and Finlayson (2019).

For Ramsar-listed wetlands, an interpretation that the requirement to maintain ecological character as described at a particular point in time (often taken to be the time of listing; Finlayson *et al.* 2021) precludes maintaining the dynamic nature of the wetland, including successional and evolutionary change as proposed by Finlayson (1996), and may be perceived to be unrealistic given the projected future climate, and to constrain the kinds of adaptation actions that that could be applied. The Ramsar Convention and its underpinning policies came about at a time before climate change was widely understood or recognised as a threat. Despite climate change having been raised at Ramsar Conferences since 2002, the Convention does not provide detailed or decisive guidance for managing the effects of climate change (Finlayson *et al.* 2017). Ramsar site managers may be reluctant to undertake management actions that would actively not preserve or maintain the specific values that a Ramsar site was listed for, such as the occurrence of endemic macroinvertebrates, a threatened bird species or a specific wetland type such as peatland. Although the loss of one or more value may affect the specific features of a Ramsar-listed wetland, it may not mean that the wetland no longer qualifies as a Ramsar site if it was listed on the basis of multiple criteria for listing Ramsar sites. Because the wetland only needs to meet one of the nine criteria for listing, the loss of one or even more criteria would not mean it was no longer eligible for Ramsar listing if it still met one criterion, possibly even a different one to the original listing, a scenario described by Pittock *et al.* (2010).

Managers, including those who participated in the case study workshop, may feel conflicted with respect to planning adaptation actions that support a site to transition to a different future state or preserve species off-site rather than try to restore the site, a scenario proposed for the Ramsar site near the mouth of the Murray River in south-east Australia (Finlayson *et al.* 2021). At the same time, managers and local communities are likely to also feel frustrated at the inevitability and enormity of ecosystem change taking place as the climate changes and the current lack of solutions.

In light of the dilemma faced by wetland managers as the climate continues to change and wetlands are affected to the extent that restoration is not feasible, the Ramsar concepts of ecological character and responding to change in ecological character, as currently perceived, may no longer be fit for purpose. These concepts need to be examined and potentially refined, and suitable guidance developed to support effective climate change adaptation, as also suggested by Marin and Finlayson (2019) when considering wetlands as novel ecosystems as a consequence of climate change.

Water management as an adaptation action

Water management is a key adaptation tool for wetlands, especially those in regulated systems (Kingsford 2011), including Ramsar wetlands. For many wetlands where climate change impacts have been assessed, water management is considered the primary, or only, feasible adaptation action (Cross *et al.* 2012; Bino *et al.* 2013; Matchett and Fleskes 2017).

There are limited options for managing environmental water in the Muir–Byenup System, which is unregulated with limited human use. This provides the advantage of fewer anthropogenic impacts, but also means that there is little capacity to move water around to protect key refugia or other critical system components as the climate becomes warmer and drier.

The Muir–Byenup System is also considered to have complex and poorly understood geohydrology. For example, because the likely outcomes of taking water from one part of the system to treat another part are uncertain, they could represent a risk.

Effects on site hydrology resulting from historic land use, particularly impacts from blue gum plantations during their life and since their removal, were noted in the workshop as a knowledge gap. The presentation and discussion of documented historical information could have been an important addition to the workshop process had it been available and may have underpinned adaptation options. Such an approach is recommended in restoration ecology (e.g. Bachmann 2020; Gann *et al.* 2019).

There are many other Ramsar sites, both in Australia and internationally, that have greater capacity to apply climate change adaptation actions made possible through water management. The knowledge base about environmental flow requirements and mechanisms developed in highly regulated systems, such as most of the Murray–Darling Basin, Australia, may provide useful insights for many Ramsar wetlands once the information becomes more widely available. Although some information has recently been published on the use of environmental flows in the Murray–Darling Basin (Koehn *et al.* 2020), there are also concerns that these measures may not be as effective as anticipated (Chen *et al.* 2021; Kirsch *et al.* 2021; Ryan *et al.* 2021). There is every possibility though that the adoption of complementary measures to assist with the restoration of the rivers and wetlands in the Murray–Darling Basin (Baumgartner *et al.* 2020) may provide synergies with the ‘no regrets’ adaptation measures mentioned above.

Some Australian Ramsar wetlands, such as the Macquarie Marshes and Narran Lakes, as well as other significant wetlands, such as those in the lower and mid-Murrumbidgee River catchment (Gayini Nimmie Caira and Yanga wetland areas), have received environmental water allocations (Australian Government 2018, 2020*b*, 2021; NSW Department of Planning, Industry and Environment 2021). Monitoring and assessment reports, for example those of the Commonwealth Environmental Water Office (CEWO) Long-term Intervention Monitoring program (Australian Government 2020*c*), and other analyses or critiques, such as those by Campbell *et al.* (2021) targeting vegetation, Koehn *et al.* (2020) focusing on native fish flow requirements and Chen *et al.* (2021) questioning the effectiveness of the CEWO e-watering actions, are valuable information sources to guide future adaptation actions.

Conclusion

Climate change adaptation planning and implementation for internationally important wetlands has not been widely undertaken or reported. Lack of experience and knowledge of adaptation options may continue to impede effective wetland management as climate change impacts are increasingly felt.

The Muir–Byenup System Ramsar wetland in south-west Australia has been and continues to be subject to climate change impacts that are altering its ecological character. This unique and complex peat-based biodiversity hotspot featuring a high degree of endemism is drying out, becoming acidic and is at risk from damaging bushfire events. To date, there is no specific plan for tackling this problem. This situation is likely to be repeated at other peat-based and high-value wetlands globally.

Programs for applying experimental approaches and for research directed towards restoration of peat-based and other high-value wetlands are needed to build the knowledge base in wetlands adaptation planning and implementation. The development and dissemination of targeted information, guidance and training for wetland managers and stakeholders could facilitate better understanding and uptake of climate change adaptation options at Ramsar-listed and other valuable wetlands.

The development of contemporary climate change-related policy and guidance at the level of the Ramsar Convention would help support relevant and effective adaptation actions by wetland managers at all levels. This would contribute to an improved outlook for the conservation of wetlands and the valued ecosystem services they provide globally.

Data availability

The data that support this study cannot be publicly shared due to ethical or privacy reasons and may be shared upon reasonable request to the lead author if appropriate.

Conflicts of interest

C. M. Finlayson is the Editor-in-Chief of *Marine and Freshwater Research*. Despite this relationship, he took no part in the review and acceptance of this manuscript, in line with the publishing policy. The authors declare that they have no further conflicts of interest.

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