



UNDERSTAND | ADAPT | TRANSITION

Queensland Climate Adaptation Strategy

Biodiversity and Ecosystems Climate Adaptation Plan



This sector adaptation plan was developed in partnership with the biodiversity and ecosystems sector, supported by the Queensland Government. Sector adaptation plans are important components of the *Queensland Climate Adaptation Strategy*, facilitating industry-led responses to the challenges presented by climate change.

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Foreword

We have known for decades that biodiversity loss and the loss of integrity of natural systems is a global problem.

The 1992 World Scientists' Warning to Humanity set out the scale of the problem, and the 2017 follow up reinforced the message. We are losing species at a rate similar to those in the five previous great extinction events of the planet's history. The *Millennium Assessment*, the *Living Planet Report* and the Stockholm Environment Institute's analysis of a safe operating space for humanity all tell the same story. The known numbers of sample species of mammals, birds, amphibians and fish are generally down to about 40 per cent of the 1970 levels, and known species are going extinct at an alarming rate. The problem is compounded by our limited knowledge of existing species, meaning we are also losing species we haven't even recognised.

Queensland has a wide range of habitats and species, with global biodiversity hotspots such as our tropical rainforests and the Great Barrier Reef. So we should be especially concerned about the need to preserve our remaining biota. In principle, our elected representatives agreed to that when the Council of Australian Governments (CoAG) adopted the National Strategy for Ecologically Sustainable Development (NSED) in 1992. The NSED commits us to a pattern of development that does not reduce opportunities for future generations, with a specific stated obligation to protect our biodiversity and maintain the integrity of natural systems.

Historically, we have lost species because of habitat destruction, introduced species and chemical pollution. Those pressures are not abating, but they are now being supplemented or amplified by climate change.

As this report notes, we have already seen significant changes to our climate, 'with very substantial change projected for coming decades'. The rate and scale of change is uncertain, at least partly because we cannot predict future developments that will affect greenhouse gas sources and sinks: cleaner energy supply systems, more efficient energy use and land use changes. We do know that further climate change is inevitable, even with aggressive emission reduction strategies, because of the time lags in the system. Most of the carbon dioxide we are releasing now by burning fossil fuels will still be in the atmosphere and changing the climate at the end of this century. As is true globally, we are handicapped by our limited knowledge of the local biodiversity. The majority of species have not yet even been identified.

These limitations mean there is an urgent need for what this report provides: 'high level direction for policy, planning, research and operational responses'. The *Biodiversity and Ecosystems Climate Adaptation Plan* sets out seven principles to guide our actions, based on the concept that we should manage what cannot be avoided and try to avoid what can't be managed.

As most people are aware, there are physical limits to the potential for adaptation. So a top priority is an urgent and concerted approach to mitigation. As the Queensland Climate Transition Strategy recognises, 'a zero emissions future is needed to avoid the serious and pervasive threats posed by climate change'. It is equally important to have an adaptation strategy that responds flexibly to emerging issues. Since the future rate and scale of climate change is uncertain, we will need adaptive management based on effective monitoring of outcomes. That will demand a serious investment of resources.

This report sets out the principles for responding to the biodiversity crisis being accelerated by climate change. As a matter of urgency, it is our collective responsibility to implement those principles.

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Executive summary

Queensland's biodiversity and ecosystems not only have intrinsic value but continue to provide a wealth of ecosystem services to Queenslanders which underpin our health and wellbeing, quality of life, and the ongoing strength of our economy.

Queensland is facing a future of increasing biodiversity loss and ongoing declines in ecosystem integrity and function, in part due to human-induced changes in our climate such as increasing temperature, changed rainfall patterns, and more intense heatwaves, droughts, fires, cyclones and floods. As well as the direct impacts of these climatic changes, climate change will compound the effects of habitat loss, pollution and invasive species.

The *Biodiversity and Ecosystems Climate Adaptation Plan* (the Plan), seeks to lay the groundwork for a future of more collaborative and strategic problem-solving, planning and on-ground action to minimise the negative impacts of climate change on Queensland's biodiversity and ecosystems.

The Plan was developed under the *Queensland Climate Adaptation Strategy 2017–2030* (Q-CAS) which is part of the Queensland Government's Climate Change Response. The National Climate Change Adaptation Research Facility (NCCARF) and Cath Moran Ecological Consultancy led the development of the Plan using a participatory and collaborative approach to engage researchers, policymakers, planners, on-ground managers and people working in engagement and advocacy. The Queensland Department of Environment and Science funded the Plan's development.

The Plan provides Queensland with a reminder of the changes already impacting on our natural systems and of the changes still to come. The Plan draws attention to what the sector sees as a key issue: inadequate prioritisation in the decision-making of Queensland's economic sectors of the adaptation of Queensland's biodiversity and ecosystems.

Section 1 of the Plan describes its scope and outlines how it was developed. **Section 2** summarises the risks from climate change for Queensland's biodiversity and ecosystems and highlights the climate-change impacts already being experienced. **Section 3** summarises existing work in the sector and identifies gaps and barriers to management for the adaptation of biodiversity and ecosystems. **Section 4** of the Plan presents the actions recommended by the sector.

The Plan sets out **seven adaptation principles** to guide adaptation planning, decision-making and management for biodiversity and ecosystems under climate change (**Section 4.2** and **Appendix 4**):

1. Use dynamic, evidence-based and transparent strategies to facilitate autonomous adaptation of biodiversity and ecosystems.
2. Prioritise the maintenance of viable ecological processes and functions.
3. Consider longer timeframes and larger spatial scales in planning.
4. Use flexible and adaptive evidence-based decision-making processes and practices to help account for uncertainty.
5. Collaborate across sectors and jurisdictions to maximise co-benefits and minimise maladaptive outcomes for biodiversity and ecosystems.
6. Collaborate within the biodiversity and ecosystem sector to improve the exchange and co-production of knowledge, including through equitable governance and management partnerships with Aboriginal and Torres Strait Islander Peoples.
7. Recognise that adaptation planning does not diminish the urgent need to reduce greenhouse gas emissions.

To apply these seven adaptation principles, the Plan outlines **five action areas** under which fit **19 adaptation actions**, each with corresponding indicative actionable steps (**Section 4.3**).

The five action areas and 19 adaptation actions are:

1. **Develop the sector's capacity to incorporate climate change adaptation into management decisions and practices.**
 - 1.1 Develop a central, authoritative source of guidance and tools for managing Queensland's biodiversity and ecosystems under climate change.
 - 1.2 Develop an understanding of adaptation options for Queensland that are likely to be important in the future under different plausible scenarios of climate change.

- 1.3 Invest in retaining and sharing existing knowledge as well as co-developing new knowledge to support on-ground management practices for adaptation.
- 1.4 Increase investment in the collection of baseline information and data and develop strategic, long-term monitoring programs to track change and to help understand ecological limits, thresholds and tipping points.
- 2. Develop decision-making and adaptation planning systems that work across all sectors to support the persistence of biodiversity and ecosystems.**
 - 2.1 Develop dynamic management objectives that support adaptation of biodiversity and ecosystems at the various scales of planning and implementation needed.
 - 2.2 Build planning, legislation and decision-making mechanisms that prioritise management of Queensland's biodiversity and ecosystems for adaptation and promote engagement across all sectors.
 - 2.3 Develop and support decision-making mechanisms that provide realistic opportunities for engagement with the breadth of stakeholders across the sector.
 - 2.4 Promote community understanding of the values of biodiversity and ecosystems, and the threat of climate change to these values.
- 3. Invest in building landscape resilience.**
 - 3.1 Build a practical understanding of ecosystem resilience in the context of adaptation of biodiversity and ecosystems. Provide guidance on implementation.
 - 3.2 Revise and adjust legislation, policies, plans, and programmatic efforts to allow adequate space for nature to respond adaptively to climate change.
 - 3.3 Resource the continued development of fine-scale spatial mapping of potential climate change refugia and key habitat areas across Queensland with the view to prioritising protection and restoration action.
 - 3.4 Include future values, future risks and new evidence-based approaches in strategic interventions for managing existing threats to biodiversity and ecosystems.
- 4. Implement a statewide response to provide leadership and support to local and regional responses.**
 - 4.1 Demonstrate a statewide action focused response to the recommendations of the Plan that aligns action at regional and local scales.
 - 4.2 Review and adjust Queensland's natural resources and planning policy and legislation to include recognition of climate change as a fundamental threat to natural systems.
 - 4.3 Support the integration of climate change adaptation into regional management planning processes for biodiversity and ecosystems, including for protected areas and surrounding landscapes and seascapes.
 - 4.4 In leading whole-of-government action to reduce net greenhouse gas emissions, prioritise adaptation options that align with a zero net emissions future.
- 5. Improve knowledge and understanding through collaboration and partnership.**
 - 5.1 Develop and support a community of practice across the sector to share knowledge and experience, implement cooperative research, and align work relating to adaptation.
 - 5.2 Enable equitable and meaningful partnership with and leadership by Aboriginal and Torres Strait Islander Peoples in adaptation planning, decision-making and action.
 - 5.3 Support cooperative research.

Section 5 of the Plan provides guidance on how to progress these actions by outlining opportunities to build on existing work and possible sources of innovative funding. The Plan distinguishes actions that can start immediately and which would support subsequent actions, including the following four adaptation actions:

- i. Develop a central, authoritative source of guidance and tools for managing Queensland's biodiversity and ecosystems under climate change. (**Action 1.1**).
- ii. Demonstrate a statewide action-focused response to the recommendations of the Plan that aligns action at regional and local scales (**Action 4.1**).
- iii. Support the integration of climate change adaptation into regional management planning processes for biodiversity and ecosystems, including for protected areas and surrounding landscapes and seascapes (**Action 4.3**).

- iv. Develop and support a community of practice across the sector to share knowledge and experience, implement cooperative research, and align work on adaptation (**Action 5.1**).

Implementing the Plan will require strong sustained support and collaboration across the biodiversity and ecosystems sector. This will involve transforming legislation and institutions so that decision-making processes prioritise biodiversity and ecosystems. Collaboration across the biodiversity and ecosystems sector will be crucial to developing new, integrated and timely knowledge to support adaptation planning, decision-making and management of biodiversity and ecosystems under climate change.

Equitable partnerships with and leadership by Aboriginal and Torres Strait Islander Peoples is identified as being an important part of the collaboration called for under the Plan. Collaboration with other sectors will also be critical to both avoid risks and capitalise on opportunities arising from decisions made in other sectors, including about their own adaptation to climate change. Cross-sectoral collaboration under the Plan will also help to avoid inadvertently worsening social vulnerability as a result of managing Queensland's biodiversity and ecosystems for adaptation to climate change.

This sector-led Plan sets out a road map for partnership with the Queensland Government to develop the tools and resources needed to manage for the adaptation of Queensland's biodiversity and ecosystems to climate change.

1. Introduction

The goal of the *Biodiversity and Ecosystems Climate Adaptation Plan* (the Plan) is to provide high-level direction for policy, planning, research, engagement, advocacy and operational management to minimise the negative consequences of climate change for Queensland's biodiversity and ecosystems.

It provides a mechanism for stakeholders to work with the Queensland Government and one another to progress priority management directions, address complex and crosscutting issues, identify opportunities and seek potential financing mechanisms.

The Plan is part of the Queensland Government's approach to climate change adaptation under the *Queensland Climate Adaptation Strategy 2017–2030* (Q-CAS^a).

The Q-CAS aims to contribute to realising the vision of an innovative and resilient Queensland that manages the risks and harnesses the opportunities of a changing climate. The Q-CAS sets out 18 actions within four distinct but complementary streams of work or 'pathways' that focus on adaptation planning in relation to:

- the community broadly ('People and knowledge')
- local areas and regions ('Local governments and regions')
- key economic sectors ('Sectors and systems')
- Queensland Government ('State Government'), which also provides coordination and oversight for the above three pathways.

The Plan is one of eight 'sector adaptation plans' in development under the 'Sectors and systems' pathway. The plans are designed to address the specific adaptation needs of major economic sectors, as well as those of natural systems. While the Plan formally sits under the 'Sectors and systems' pathway, it also has links to the work occurring under the 'State Government' pathway of the Q-CAS, under which development of a Government Adaptation Action Plan (GAAP) is progressing.

The GAAP will guide the Queensland Government in managing climate risks to its assets and operations, and demonstrate the Government's leadership in climate adaptation action in Queensland. The Queensland Government is responsible for a range of tangible and intangible assets that are exposed to climate change risks, such as infrastructure, staff, and protected areas. The Queensland Government also implements many policies, programs and services that may support (or inhibit) adaptation action across Queensland.

To facilitate adaptation planning under the 'Sectors and systems' pathway, the Q-CAS identifies four complex issues that cut across all sectors and systems, and are to be accounted for in sector adaptation planning processes as follows:

- community and social services
- finance and insurance
- natural resources and environment
- research and development.

In terms of the lifespan of the Q-CAS, a review of effectiveness is to occur every three to five years and recommended changes implemented. Revisions to sector adaptation plans, including this Plan, are expected to occur as part of this broader review process.

1.1 Scope

The 'sector' has been identified as people and organisations that influence and implement management of Queensland's rich biodiversity and ecosystems (see Appendix 1, Table A.1). This

^a <http://www.qld.gov.au/environment/climate/adapting>

includes planning, policy development, on-ground operations, research, engagement and advocacy. It involves many units and teams in state and local governments, as well as agencies supporting World Heritage Areas (WHAs), Aboriginal corporations, natural resource management (NRM) groups, catchment management groups, private organisations and landholders, researchers, industry, community and special interest groups.

In the Plan, biodiversity and ecosystems are taken to include all terrestrial, freshwater, coastal and marine ecosystems within Queensland's jurisdiction. The Plan has a statewide scale of focus and as such considers biodiversity and ecosystems within both public and private jurisdictions, and within and outside of protected areas. It is beyond the resources and intent of the Plan to undertake detailed assessment of climate change impacts or adaptation options for specific species, ecosystems, regions, properties or locations.

1.2 The Plan's role in relation to reducing greenhouse gas emissions

The Plan has been developed on the understanding that there are limits to adaptation for biodiversity and ecosystems. Rapid global reduction in greenhouse gas emissions (mitigation) and accelerated carbon sequestration will be needed to avert widespread loss of biodiversity and associated changes in the composition, structure and function of many ecosystems. Even if all emissions from human activity ceased tomorrow, the climate would continue to change for many decades, with unavoidable risks 'locked in'. We know that with strong mitigation, there will be less need for adaptation. However without mitigation, climate change impacts will be too great for most adaptation options (Figure 1).

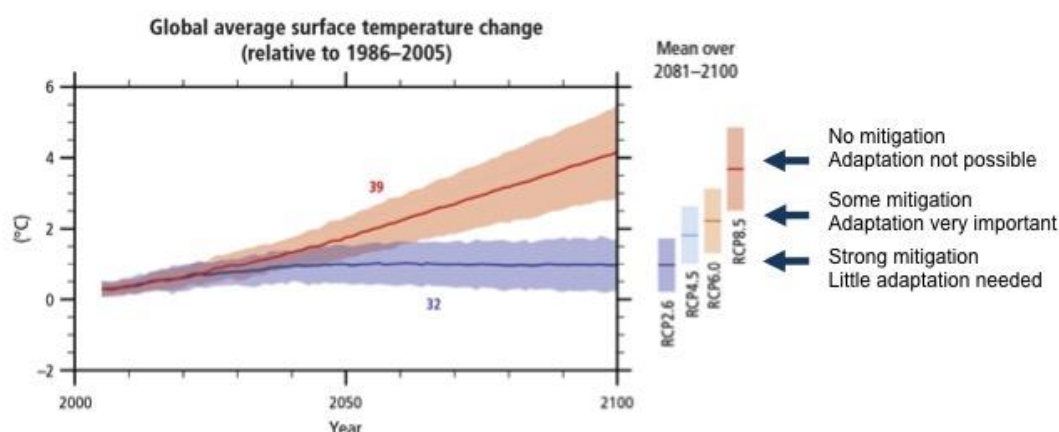


Figure 1 There is an important relationship between mitigation (reduction of greenhouse gases in the atmosphere) and adaptation. Modified from IPCC 2014²¹

The Queensland Government's target of zero net emissions by 2050 recognises that a zero emissions future is needed to avoid the serious and pervasive threats posed by climate change, not only for natural systems, but more broadly for Queensland.³⁶ A call for continued and ongoing investment and action to reduce greenhouse gases in the atmosphere underpins the Plan, with rapid and substantial mitigation the only way to enable the autonomous adaptation and persistence of many of Queensland's species and ecosystems.

1.3 How the Plan was developed

The Queensland Government's Department of Environment and Science (DES) contracted the National Climate Change Adaptation Research Facility (NCCARF) and Cath Moran Ecological Consultancy to engage with the biodiversity and ecosystems sector in Queensland to develop a sector adaptation plan for Queensland's biodiversity and ecosystems. The Biodiversity and Ecosystems Climate Adaptation Plan (the Plan) was the result of that development process. Figure 2 summarises the process.



Figure 2 Schematic of the Plan's development process

1.3.1 Project governance

At the project's inception, the Queensland Government established a steering committee (see list of members in Appendix 1, Table A.3). A partnership between the project steering committee and the contracted project team set the project scope and direction, identified and engaged the sector's stakeholders and reviewed the project's outputs. Members of the steering committee represented the Climate Change Policy branch of DES's Environmental Policy and Planning division, DES's Conservation and Sustainability Services division and its Protected Area Strategy and Policy division, as well as Natural Resource Management Regions Queensland (NRMQR) and the Queensland Council of Social Service (QCOSS).

1.3.2 Identifying the biodiversity and ecosystems sector and stakeholders

Those with a stake in Queensland's biodiversity and ecosystems include people and organisations that either influence or are affected by the outcomes of decisions about biodiversity and ecosystems (Appendix 1, Tables A.1 and A.2). Developing the Plan primarily involved engaging with those people and organisations with the potential to influence adaptive opportunities for biodiversity and ecosystems (Table A.1).

Within the biodiversity and ecosystems sector, we identified four management 'domains' that correspond with the sphere of influence over the management of biodiversity and ecosystems. The four domains are:

- research/knowledge-building (e.g. universities, CSIRO, Traditional Owners, consultants, private conservation organisations, Queensland Government – e.g. Science Division of DES, Queensland Herbarium)
- policy/planning (e.g. three tiers of government, world heritage management, Aboriginal shire councils and corporations, NRM bodies, consultants, industry groups)
- operations (e.g. national parks rangers, Indigenous rangers, local government, private conservation organisations, catchment groups, Landcare, NRM groups, community groups, carbon fund managers and participants, land management businesses)
- engagement and advocacy (e.g. conservation NGOs, NRM groups, local government partnership programs, industry groups, individuals).

These management domains were confirmed during workshops (see Section 1.3.3) where participants agreed that their work was covered by one or more of these domains.

1.3.3 Sectoral engagement

The broad aim of the engagement process was to provide stakeholders with an opportunity to contribute to the development of the Plan. Stakeholders were asked to describe existing work, identify priority issues, gaps and barriers to action, and potential recommendations for advancing adaptation in the biodiversity and ecosystems sector.

Stakeholder engagement included the following activities:

- Semi-structured interviews and discussions targeted people involved in early adaptation research, reports, policies, projects and/or management for Queensland (see list in Appendix 1).
- A discussion paper reviewed the current state of managing biodiversity and ecosystems for adaptation to climate change.
- An online survey collated responses to the discussion paper and proposed plan framework (see summary, Appendix 3).
- Face-to-face workshops held in Cairns (7 June 2018) and Brisbane (13 June 2018).
- Online workshops held twice in July 2018 to capture additional remote participants unable to attend face-to-face workshops.

In total, 128 people participated in interviews and workshops (Appendix 1, Table A.3), and 61 people responded to the online survey.

The relatively short timeframe, together with limited resourcing for the project, precluded extensive, detailed engagement. This was a barrier to engaging with people in remote or regional areas of Queensland. In particular, the process was not well suited to engaging with Aboriginal and Torres Strait Islander peoples or with stakeholders in western Queensland. Feedback indicated that a lengthier engagement process, including one-on-one meetings on country or on location, would have led to greater success in these cases. It was also suggested that sitting fees may be needed to cover the time required to participate in workshops, meetings or review processes for those whose time is not covered by an employer. Incorporating this feedback into the implementation and subsequent iterations of the Plan is likely to improve the breadth of engagement.

1.3.4 Finalising the Plan and peer review

A draft of the Plan was prepared during June and July 2018 and reviewed by members of the steering committee, chairs of the World Heritage Area Scientific Advisory Committees and five experts. In addition, the draft executive summary and key action areas were circulated to workshop participants for comment. Review comments have been incorporated into the final version of the Plan.

2. Summary of climate risks for biodiversity and ecosystems

2.1 Climate

Climate variability is a feature of Queensland's environment. Since the early 1900s, human activities and greenhouse gas emissions have changed climate trends (see summary in Appendix 2.1, Table A.4).

CSIRO and Australia's Bureau of Meteorology (BOM) released a comprehensive presentation of downscaled climate projections for Australia and its major bioregions in 2015.^b The Climate Change in Australia website provides a reliable source of climate projections for Australia's regions. The Queensland Government has complemented this work with climate projections for Queensland, together with regionally focused information products.^c They are now working to develop more fine scale information for Queensland's regions based on selected climate futures.

The extent of climatic changes we face in Queensland depends on the degree to which global greenhouse gas emissions are reduced in the future. Table A.4 (Appendix 2) presents an overview of recent and projected climate change for Australia and Queensland.

For Queensland, higher average and extreme temperatures present significant risks especially in far western Queensland, which has already recorded the greatest temperature increases in Australia. Queensland's marine areas will also experience warming and extreme heat events as well as more acidic waters. The entire Queensland coast will be impacted by rising sea levels. In addition, rising sea level and saltwater intrusion into groundwater systems will impact coastal mangroves, floodplains and wetlands.

Extremes of climate will be some of the earliest and potentially damaging changes for the state. Periods of extreme heat are projected to become hotter and to last for longer. Although the projected trend in droughts is not clear, it is anticipated that the south of the state will be likely to experience more droughts by the end of the century. Increased fire weather can also be expected to affect large areas of the state. Extreme rainfall is projected to bring more frequent, prolonged and widespread flooding. In all regions, changed flow and flood regimes will impact streams and wetlands. And finally, it is expected that we will experience more intense and slow moving cyclones that track further south in the state.

2.2 Implications of climate change for biodiversity and ecosystems

Natural ecosystems and water supply have been identified as the sectors most vulnerable to climate change in Australia.⁵⁰ The risks and outcomes of climate change for biodiversity and ecosystems will be complex, with existing stressors likely to be amplified, interactions between species altered and broad changes in how our biodiversity and ecosystems look and function.⁴³ Figure 3 provides examples of the links between climate risks and biodiversity outcomes. Biodiversity and ecosystems might be affected by the interaction of multiple changes at once (represented as 'Cumulative impacts' in Figure 3), with a number of different scenarios possible.

Regions of Queensland that are thought to be particularly vulnerable to climate change impacts include: western Queensland, the Wet Tropics, the Great Barrier Reef (GBR) in general and marine regions in the southern part of the GBR, the Gulf of Carpentaria and South East Queensland.⁵⁵ Ecosystems identified as highly vulnerable include: tropical savanna woodlands, drier rainforest types, coastal floodplains and wetlands as well as ecosystems at high altitudes and those representing centres of endemism or high diversity (e.g. the Australian Wet Tropics).⁵⁵

^b www.climatechangeinaustralia.gov.au

^c <https://www.qld.gov.au/environment/climate/resources>

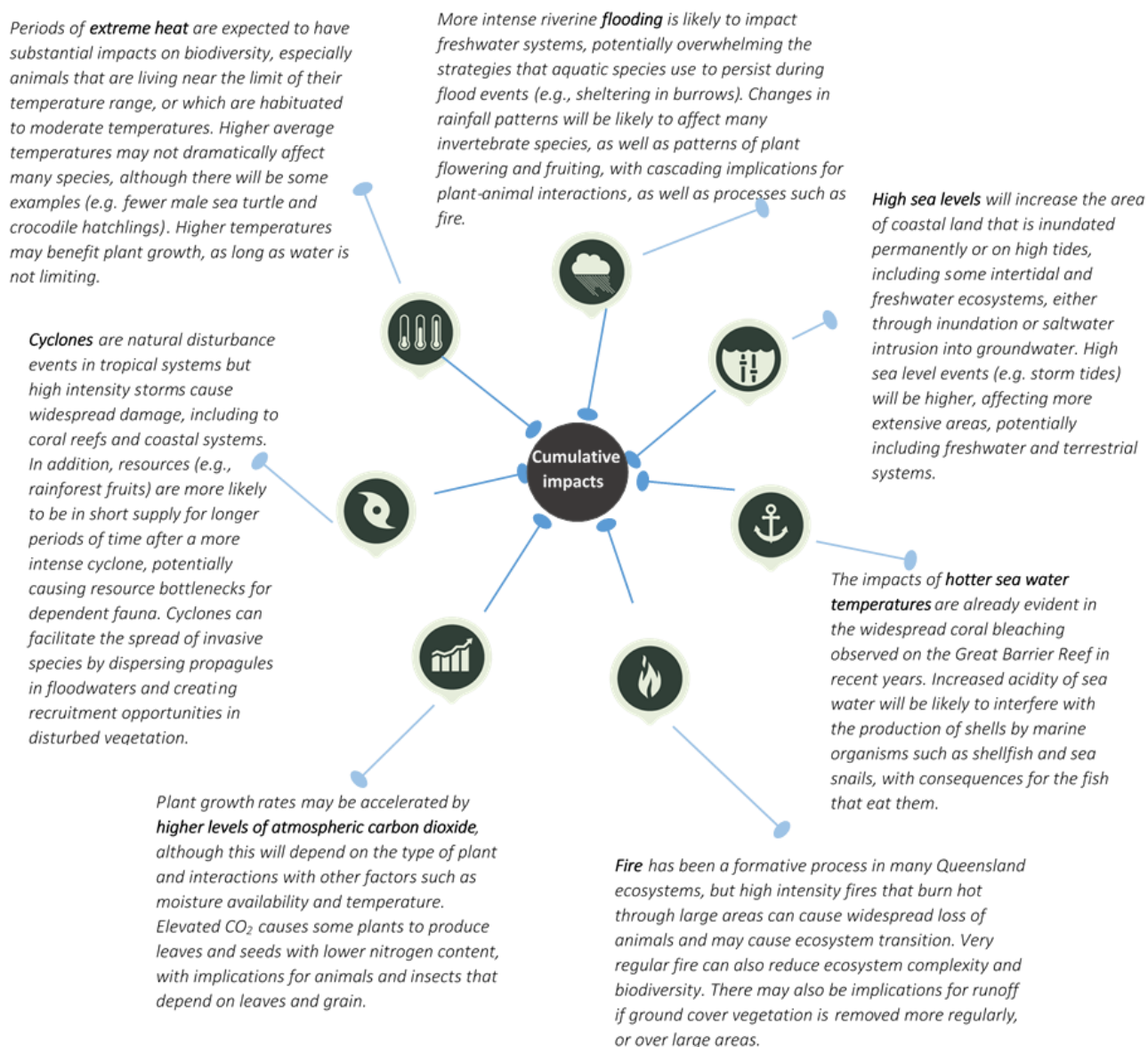


Figure 3 Examples of potential implications of projected climate changes for biodiversity and ecosystems.^{3, 23, 25, 30, 39}

The potential climate change risks for biodiversity and ecosystems are complex. We describe these in greater detail in Appendix 2.2, Table A.5. Key potential outcomes can be summarised as including:

- changes in distribution and abundance of species, including invasive pests (e.g. contraction or expansion to areas of suitable climatic conditions)
- changes in individual biology (e.g. growth rates, life cycle, flowering, behaviour)
- changes in biotic interactions (e.g. pollination, predation)
- changes in species assemblages (e.g. shift in dominant over-storey tree species)
- exacerbation of existing stressors (e.g. new invasive species, more extreme fire behaviour)
- a decline in ecosystem services (e.g. reduced water quality, agricultural potential and recreational value).

Specific ecosystem types will face their own particular challenges. Examples of impacts on terrestrial, freshwater, coastal and marine ecosystems are summarised below.^{3, 4, 23, 30}

2.2.1 Terrestrial ecosystems

Terrestrial biodiversity in Queensland has already undergone significant change as a result of land clearing (including habitat loss and fragmentation), extraction (e.g. mining, commercial forestry), intensive land use (e.g. stock grazing), inappropriate fire regimes and invasive species. Climate change is likely to amplify many of these pressures.

Ecosystems and species that have been identified as being particularly vulnerable include:

- species already living close to their thermal limits (e.g. rainforest reptiles) that may experience increases in temperature that rapidly exceed their climate tolerance²⁴
- high altitude, montane systems where a lifting cloud base and increasing temperatures mean no available or accessible (without human intervention or translocation) areas of comparable climatic conditions⁵⁷
- 'dry rainforests' that exist at the edge of their climatic envelope in patchy distributions and which, under a regime of more intense and extensive fires, could conceivably be replaced by more open vegetation types²⁴
- ecosystems dominated by eucalypt species (e.g. ironbarks), particularly where projected heatwave conditions coincide with prolonged drought.²⁴

2.2.2 Freshwater ecosystems

Freshwater systems have already been impacted by a range of factors including runoff from development, sedimentation and chemical pollution, diversion of water to other uses (e.g. irrigation), fragmentation (e.g. through dams and causeways), changed channel morphology and invasive species. Climate change impacts (direct and indirect) on freshwater ecosystems might include:

- increasing water temperatures
- changes in hydrological cycles, water regimes and timing of spring and autumn events
- changes in river flows (e.g. increased flash flooding), sediment and nutrient transport and water quality (e.g. salinity)
- sea water inundation of coastal freshwater systems and saltwater intrusion into groundwater
- increased acidity in fresh water bodies
- increased evaporation in shallow and ephemeral water bodies and wetlands
- altered connectivity within freshwater ecosystems and their catchments^{4,5}
- increased intensity and frequency of storms and associated flood events.⁴

The potential negative outcomes include longer stratification periods in reservoirs and lakes resulting in reduced levels of dissolved oxygen and more algal blooms;⁵ substantial changes in species abundance, distribution, behaviour, and productivity; and geographic changes in ecosystem types and changes in ecosystem services. Cascading impacts can cause significant declines in ecosystem services. For example increased productivity in cyanobacteria may result in algal blooms that can reduce the availability and quality of fresh water, limit recreational opportunities and impact fish stocks.

2.2.3 Coastal ecosystems

Coastal ecosystems have already been heavily impacted by vegetation clearing, dredging, in-filling of wetlands, removal of dunes, run-off and pollution. Climate change is likely to exacerbate many of these impacts. Particular climate change impacts and outcomes for coastal biodiversity and ecosystems are listed below.

- Higher sea levels will potentially flood coastal terrestrial habitats, change the salinity regime of estuaries and coastal freshwaters and cause saltwater intrusion in aquifers.
- Rising seas and greater coastal erosion will exacerbate the 'coastal squeeze' on ecosystems between the ocean and the hard boundaries of urban development. This will limit a general landward migration of shallow marine and intertidal habitats in response to climate change.

- The increased ocean depth from rising sea levels will impact light availability for seagrasses, coral systems and macro-algae. Deeper waters over existing reefs will change wave energy resulting in changes in coastal erosion and deposition processes.
- Increased frequency and intensity of heavy rainfall episodes will increase freshwater inputs to estuarine environments. This is likely to have consequences for fish breeding and migration. Increased intensity also has the potential to change sediment dynamics and the quantity and quality of terrestrial run-off into freshwater habitats.
- More intense extreme weather events are likely to impact ecosystem services and the recovery of these functions. For example, damage to mangrove nursery habitats for fish, and damage to reefs and dunes that are important in wave attenuation and coastal protection. 31

2.2.4 Marine ecosystems

Marine ecosystems experience impacts from the harvesting of marine resource (e.g. commercial and recreational fishing), chemical and plastic pollution, run-off and sedimentation, disease outbreaks and invasive species (e.g. crown of thorns, algal blooms).

Climate change will affect marine systems in various ways, including both direct effects on the physiology, fitness and survivorship of marine species as well as indirect effects via habitat degradation and changes to ecosystems. We would anticipate cascading effects on the food and recreation industries in particular. Specific climate change impacts on marine systems can be expected to include examples listed below.

- More frequent floods will increase concentrated pulses of freshwater plumes, increased nutrient and sediment loads.
- Marine heatwaves will result in more widespread death of organisms.
- An increase in cyclone intensity will result in more damage to coral and increased beach erosion.
- Increases in atmospheric carbon dioxide levels will result in increasingly acidic ocean water. This in turn will weaken the shells and skeletons of calcifying organisms (e.g. corals, molluscs).
- Changes in ocean currents and timing of seasonal upwelling are likely to impact migration timing and routes, reproduction and larval dispersal of a range of marine organisms.15,19, 33

We can expect to see flow-on effects of these impacts to people and communities that depend on marine species for food, cultural practice or livelihoods.

Coral reef ecosystems are at a particularly high risk of loss, even under low greenhouse gas emissions scenarios. Ocean warming disrupts the symbiosis between coral and zooxanthellae resulting in coral bleaching, while ocean acidification interferes with calcification. Further, warmer waters, more nutrient run-off and higher sea levels favour macro-algae. Under these conditions we would expect to see widespread decline of coral diversity and cover and a transition to systems dominated by algae.

2.3 Implications of climate change for managing biodiversity and ecosystems

We are already seeing changes in species distributions, the timing of biological events, and the state of ecosystems in response to climate change⁴³ and even with large reductions in greenhouse gas emissions we can expect ongoing, widespread impacts on biodiversity and ecosystems.

To a large extent, biodiversity and ecosystem adaptation to climate change will happen autonomously (i.e. independently of human intervention and management). Autonomous adaptation will depend on the inherent capacity of individuals, populations, species and ecosystems to respond in ways that enable their persistence under different climatic conditions (adaptive change).

In contrast with adaptation in other sectors, direct human control over how nature adapts to climate change is very limited. Direct intervention options such as translocation exist, but are risky, expensive

and likely to be impractical for a large number of species. Therefore, the focus of management to facilitate the adaptation of biodiversity and ecosystems may be to increase the likelihood of adaptive change in natural systems primarily by protecting or creating adaptive opportunities.

The ability of natural systems to adapt to changing conditions is limited. The rapid pace of human-driven climate change will challenge the capacity of natural systems to adapt through dispersal ability, evolution, and phenotypic or behavioural plasticity. In addition, some of the autonomous responses of biodiversity and ecosystems to climate change may not be adaptive (i.e. may not enable their persistence), for example if changed timing of reproduction results in greater offspring mortality.

Well-designed management of natural systems, including using new approaches, may make it more likely that changes in biodiversity and ecosystems lead to effective adaptation (i.e. desirable outcomes are achieved). If we do not change our approach to natural systems to one that supports climate adaptation, we risk missing opportunities to help biodiversity adapt. At worst, our management could unintentionally make it more difficult for natural systems to adapt (i.e. maladaptive outcomes). While many existing approaches to biodiversity and ecosystem management (e.g. protected areas, increased habitat connectivity, increased habitat area) will remain relevant and effective, managing climate change presents a number of new challenges including the following:

- climate change impacts will be felt across long time scales and large spatial scales (including across jurisdictions)
- there is a worsening (though sometimes alleviation) of existing pressures under climate change
- the need to make management decisions with substantial uncertainty (e.g. around what global efforts will be taken to reduce greenhouse gas emissions, how biodiversity and ecosystems will actually respond to climate change and management interventions).

Throughout the Plan, 'management of biodiversity and ecosystems for adaptation to climate change' refers to human management that is intended to allow nature to adjust and adapt to new climatic conditions in ways that improve the likelihood of persistence of biodiversity and ecosystems.

3. The state of play, gaps in existing work and barriers to managing for adaptation

In preparing the Plan, the contracted project team reviewed the relevant information on management and knowledge in order to identify gaps. The following analysis is primarily based on information gathered from stakeholder interviews, workshops and survey responses (Appendix 3), together with a limited desktop review of existing work (Appendix 5). In this section we summarise the current state of play and analyse gaps and barriers. The recommendations made in the Plan arose from this analysis.

3.1 The state of play

3.1.1 Progress toward adaptation

The science of climate change adaptation is relatively new, and while the body of knowledge is growing rapidly, there is limited experience in developing, implementing and evaluating adaptation options. As a result, there are few examples of adaptation that comprehensively deal with the complexity of multiple interactive and cumulative changes in natural systems or incorporate the uncertainty of climate change.

Research effort has so far largely focused on the impacts of climate change on biodiversity and ecosystems (Section 2) and the likely response of species and ecosystems to those impacts (Appendix 2). This research includes modelling future scenarios of species' distributions and identification of suitable climate spaces. New approaches being considered for managing biodiversity and ecosystems under climate change include landscape-based and ecosystem process-based approaches and the proposition of new conservation frameworks (Appendix 5). Support for facilitating adaptation includes frameworks for developing decision-support tools and vulnerability assessments specific to the unique challenges of managing biodiversity and ecosystems.

A small number of cases in Queensland are researching and testing on-ground interventions. These include trials of physical interventions (e.g. moving turtle nesting sites) and restoration (e.g. coral translocation experiments). During the Plan's development, stakeholders shared their experiences of developing terrestrial projects including developing insurance populations of threatened species, feral animal exclusions, and investing in habitat restoration and developing connectivity. Appendix 5 provides a more detailed description of developing knowledge and action in the sector.

At both the regional and local scales there are examples of adaptation planning underway or completed. NRM groups across Australia incorporated adaptation into regional NRM plans under the Australian Government's National Resource Management (NRM) Planning for Climate Change Program (2013–16). Local governments also apply local planning instruments and acquisition programs to protect habitats, which is expected to increase adaptive opportunity for biodiversity and ecosystems.

Private conservation organisations also play important roles in Queensland's biodiversity and ecosystem matrix. Private conservation organisations own several significant properties in Queensland and have invested in reducing threats and improving landscape condition on these properties. These groups are generally highly engaged in climate change adaptation through research, planning and on-ground trials and interventions. Private landholders may also manage for the adaptation of biodiversity and ecosystems independently and by engaging with programs such as Land for Wildlife, local Landcare and other groups.

3.1.2 Current policy

Queensland policy is informed at international and national levels. Policy relating to climate change and biodiversity and ecosystem adaptation is complex and highly dynamic, making it difficult to capture a neat snapshot of the full influence over the sector. Appendix 5 outlines key policy and legislative instruments.

International activity informs Australia's policies and obligations with respect to both climate change (e.g. emissions targets associated with the 2015 Paris Agreement, adaptation investment and activities) and biodiversity (e.g. World Heritage and Ramsar management obligations).

The Australian Government's *Environment Protection and Biodiversity Conservation Act*

1999 provides a legal framework for protecting nationally and internationally important flora, fauna, ecological communities and heritage places. This legislation applies to species and systems in Queensland that are listed as being of national significance.

The Queensland Climate Change Response involves twin strategies released by the Queensland Government – the *Queensland Climate Transition Strategy* (QCTS) and the Q-CAS.

In addition, the State Planning Policy guidelines now include climate change, in particular sea level rise. Queensland legislative controls that relate specifically to biodiversity and ecosystems include instruments that establish protected areas (both terrestrial and marine), control extraction that includes or impacts on environmental values (e.g. tree clearing controls, water extraction controls), and control planning impacts on biodiversity and ecosystems (see Appendix 5 for a complete list of relevant legislation).

Legislation is supported by policies and programs that include support for putting protections into practice and monitoring and reporting ecosystem condition (Appendix 5).

3.2 Identified gaps in existing work

Gaps identified primarily through stakeholder engagement are organised here under the four management domains identified earlier (Section 1.3). We note these management functions are not mutually exclusive in practice, but proved useful for framing the gaps analysis.

3.2.1 Research and knowledge building

Management needs to be informed by robust information and data. The body of research and knowledge is growing rapidly, although many gaps remain. Several key gaps were highlighted by stakeholders and are listed below. Cooperative research topics associated with key knowledge gaps (listed in Appendix 6) include the need for:

- knowledge about ecological processes and ecosystem functions
- better understanding of the responses of biodiversity and ecosystems to multiple stressors
- guidance on applying adaptation management objectives e.g. protection of ecosystem function
- statewide data layers identifying current distributions of species and ecosystems to support modelling, decision-making and assessing change
- improved long-term monitoring to inform current and future decision-making
- models of species distribution that can be applied to on-ground and regional or local planning
- models of future species distribution that can integrate interactions with climate and other factors (e.g. scenarios of weed distributions, stocking rates and microclimate)
- guidance for adaptation planning and decision-making appropriate to managing complex natural systems
- a review of operational tools and understanding their usefulness in managing for the adaptation of biodiversity and ecosystems to climate change
- experimentation to support the radical and transformational management interventions
- greater geographical spread of information, e.g. there is already considerable research effort related to the Wet Tropics and Great Barrier Reef
- an improved understanding of the role of micro-refugia.

3.2.2 Policy, legislation and planning

Current legislation and policy relating to biodiversity and ecosystems in Queensland (summarised in Appendix 5) primarily focuses on protected areas and threatened species and ecosystems. In addition, new policies, investment programs and legislation are looking to respond to climate change and sea level rise.

Highlighted gaps in policy, legislation and planning include:

- the lack of legislative mechanisms to protect or incentivise protective management of climate refugia or other habitats with the potential to support autonomous adaptation of Queensland's biodiversity and ecosystems in the future
- limited supportive legislation that includes adaptation measures in local planning
- inadequate recognition of ecological processes, functions and services provided to society by ecosystems and biodiversity
- inadequate or ineffective legislative recognition of the roles of biodiversity and ecosystems in facilitating adaptation in other sectors.

3.2.3 On-ground operations and implementation

Few on-ground operations specifically target adaptation. Instead, management tends to focus on current threats (e.g. invasive species, disturbance regimes, fragmentation, pollution, extraction), often with the view to increase ecosystem resilience. This focus may provide adaptive opportunities. Examples of on-ground management specifically designed for climate adaptation include re-profiling beach sand on Raine Island to protect sea turtle nesting sites from rising seas, and selecting plant species or seed sources from hotter areas for revegetation planting stock.

The limited examples of implementation reflects the fact that many climate change impacts are yet to be fully realised. However, stakeholders identified gaps in knowledge (see section 3.2.1) and barriers to undertaking adaptation and these include:

- unrealistic expectations of the role of landscape connectivity (e.g. corridors, land bridges) in increasing opportunities for autonomous adaptation
- limited case studies, experimental trials and monitoring of more radical interventions
- the lack of guidance on incorporating future priorities into current operations.

3.2.4 Engagement and advocacy

Gaining community, political and sector-wide engagement is important to support successful adaptation. To date, most messaging has been around understanding climate change impacts and the need to reduce emissions. Identified gaps in engagement and advocacy include:

- a lack of communication and engagement on the topic of climate adaptation across the diverse audiences in the Queensland community, including the role of biodiversity and ecosystems in facilitating adaptation
- the need for more effective communication of the values of biodiversity and ecosystems to human society and the economy, and the consequences for Queenslanders of climate change impacts on natural systems
- a lack of dialogue around what management of biodiversity and ecosystems for adaptation to climate change could realistically achieve, including some of the more difficult decisions about potential species loss, ecosystem transformations or radical interventions
- limited guidance on the most effective ways to engage with stakeholders to support adaptation planning and decision-making.

3.3 Key challenges to adapting work in the biodiversity and ecosystems sector

Despite considerable knowledge, experience, insight and willingness to act, the sector faces several barriers and challenges to managing for the adaptation of biodiversity and ecosystems to climate change. The following challenges for the Queensland situation were distilled from stakeholder engagement and a literature review.

3.3.1 Uncertainty and complexity

While there is consensus that the climate is changing and that this has consequences for biodiversity and ecosystems, there is inherent uncertainty around the scale, rate and nature of these changes. Knowledge will continue to build, but as for many other types of risks, we will likely continue to face a

range of plausible futures, rather than a single, predictable one. Current planning approaches struggle with this level of uncertainty, which can result in deferred or maladaptive management decisions.

3.3.2 Knowledge gaps

Formal research is the predominant way we develop knowledge, but it tends to be slow, short-term and focused on specific questions. Research has so far delivered a range of useful concepts and high-level principles, as well as information to guide planning, policy and operational decisions. This can be difficult to put into practice, particularly when research results are not translated into the type of information or level of detail required by planners and on-ground managers. Legislation and policy can also thwart findings being implemented when they do not enable the recommended action (e.g. climate refugia are not included in the *Vegetation Management Act 1999* (Qld)). There are gaps in locally relevant information (e.g. there is little information about many species and ecosystems in western Queensland) and about the practical implications for current on-ground management interventions (how to decide what, if anything, should be done differently).

3.3.3 Lack of coordination across the sector and with other sectors

A diverse range of individuals and organisations from the four management domains identified in the Plan make management decisions that relate to, or have incidental impacts, on biodiversity and ecosystems. Decisions made in isolation can have conflicting and even perverse outcomes. For example, constructing a seawall to protect houses from sea level rise has the potential to increase erosion in adjacent areas and affect dune habitats. Climate change impacts and adaptation are also often conceived in separate planning and decision-making processes rather than being embedded within all plans with implications for biodiversity and ecosystems. Further, a lack of coordination has made it difficult to understand the role of non-climate stressors at the landscape scale and in climate change. A lack of coordination has also resulted in duplicated effort and missed opportunities to share knowledge and skills.

3.3.4 Lack of collaboration with Aboriginal and Torres Strait Islander Peoples

Aboriginal and Torres Strait Islander Peoples hold knowledge informed by lived experience of past periods of climate change, as well as Traditional Knowledge developed over many generations of adaptive management of biodiversity and ecosystems. In addition to specific ecological information, Aboriginal and Torres Strait Islander knowledge and management systems complement those based on western science in being holistic and long-term (e.g. the Wujal Wujal Aboriginal Shire Council's premise that decisions need to be good for three generations). Importantly, Aboriginal and Torres Strait Islander knowledge systems have enabled management and decision-making in a changing, uncertain environment and without reference to a historical baseline – a decision-making environment relevant to the current context. A lack of equitable partnership with Aboriginal and Torres Strait Islander Peoples in the management of biodiversity and ecosystems has largely marginalised Traditional Knowledge from decision-making. This has resulted in sub-optimal outcomes for both natural systems and for Aboriginal and Torres Strait Islander Peoples.

3.3.5 Lack of high level leadership and guidance

The sector is ready and willing to adjust management approaches to support the adaptation of biodiversity and ecosystems to climate change, but feels that a lack of strong leadership, guidance and support from both the Australian and state governments has stunted progress. Stable and strong government policy at national and state levels could inspire institutional confidence across the sector, enabling the management decisions needed at local and regional scales. Despite underpinning many economic industries and sectors, the environment in general, and climate change in particular, are beholden to ideological shifts that accompany changes in political power. At times, even the discussion of climate change adaptation has been prohibitively difficult. The sector has experienced a steady de-prioritisation, with concomitant reductions in legislative support, community buy-in and funding.⁴¹ The sector strongly supports the Queensland Government taking a lead role in coordinating and driving priority actions, especially in the perceived absence of strong national leadership.

3.3.6 Institutional barriers

Existing frameworks for protecting biodiversity and ecosystems are beneficial for values of state and

national significance. However, their focus on current values and particular geographic areas presents barriers to management for the adaptation of biodiversity and ecosystems to climate change. For example, using regional ecosystem classification forms static boundaries around changing systems. Furthermore, implementing new or direct-intervention management options for adaptation to climate change involves onerous and cumbersome approvals.²⁸

3.3.7 Inertia in management approaches

The focus of management, legislation, planning, operational works, monitoring and evaluation is to resist changes in natural systems that shift them away from what we recognise as 'natural' (usually defined in terms of our understanding of their historical, 'pre-European' distribution, composition and structure). This focus has been embodied in notions of preservation, conservation and protection. This approach makes sense in relatively stable climatic conditions, but climate change means there will be an unavoidable, unprecedented and unpredictable 'new natural'. In addition, managing to facilitate change will be more likely to achieve the higher level aim of minimising biodiversity loss and maintaining ecosystem function than management that resists change.^{13, 34} Generally speaking there is an appetite across the sector for developing adaptive management objectives and approaches, but the conversation has not yet been brokered at the scales required.

3.3.8 Limited options and tools to manage natural systems

Managers of biodiversity and ecosystems have at their disposal only a limited suite of tools. Planning instruments can either regulate to prevent removal or damage of habitats (e.g. vegetation protection legislation, zoning to limit commercial activities in certain areas) or provide incentives to discourage their removal or damage (e.g. development offsets, tax concessions for water quality improvement works). The operational domain of management tends to focus on minimising key threats (e.g. controlling invasive and introduced species, implementing controlled burning, reducing erosion and run-off and restoring lost or damaged habitats). For adaptation to climate change, a suite of 'new' approaches, previously considered too ethically challenging, are being put forward (e.g. assisted migration and assisted gene flow).

3.3.9 Social and political context

Government investment is driven by real or perceived community priorities. If a government feels it lacks the community support to invest in biodiversity and ecosystems or to manage for adaptation to climate change, it is unlikely to prioritise these actions over priorities such as housing, infrastructure and industry. Stakeholders identified that the measures we are taking are clearly not enough to maintain biodiversity and ecosystems in Queensland. There is a strong sense that this is because natural systems are not perceived as a high priority by the general Queensland community, and hence by governments. The sector strongly expressed an important aspiration to improve community understanding of the importance of natural systems and of the threats facing them.

3.3.10 Cumulative and interacting impacts of climate change with existing stressors

Queensland's biodiversity and ecosystems are already under pressure from existing stressors (e.g. land clearing and modification, habitat fragmentation, pollution, runoff, overharvesting, extraction, invasive plants and animals, diseases and pathogens, and inappropriate fire regimes). Climate change will exacerbate many of these and create new impacts (e.g. changing distribution of suitable climate space, more frequent and intense disturbance from climate events). Most existing research, planning and policy does not integrate the myriad of interacting impacts. The risk is that actions directed to reduce an impact may be undermined by other stressors, or may have unintended, maladaptive consequences.

3.3.11 Large spatial and temporal scales

Management to facilitate adaptation to climate change requires planning across large spatial scales (including across government and other jurisdictions) and over long time frames. It also means accommodating considerable uncertainty, multiple plausible future scenarios, and considering how current decisions affect the potential to make future decisions (i.e. path dependencies). Applying new planning approaches with long time frames and multiple futures (e.g. adaptation pathways planning)

are being developed for natural systems.²² Short-term project funding cycles and higher level planning frameworks compound the intellectual difficulties of applying new planning approaches to management decisions.

3.3.12 Insufficient finance and resourcing

Organisations (both public and private) often have limited financial, technical and human resources to dedicate to planning for and collaborating around a complex issue like climate change. In addition, many competing and immediate issues are likely to take priority. The scale of the funding shortfall in the biodiversity and ecosystems sector is such that many members of the sector already feel overwhelmed by their workload and by the ongoing decline in natural systems. This has created a sense that there is no time and possibly no point in considering the implications of climate change for current management. In addition, there is concern across management domains that expertise and experience are at risk of being lost. For example, there appears to be a dramatic decline in available qualified operational workers at the same time as management for adaptation to climate change demands are increasing the expectations of on-ground managers. Increased investment is required in areas such as monitoring, surveillance, innovation in management techniques, and identifying and interpreting indicators of management success.

3.3.13 Failure to communicate effectively

Successful adaptation will require strong and positive community and stakeholder engagement. Some sectoral members propose that communication around climate change and natural systems has been dominated by sensationalist, doom-and-gloom messages. They argue that this closes the audience to underlying messages about the values that are at risk and options for managing these risks. There is also a strong sense in the sector that it is important to be realistic and pragmatic (e.g. we face the real risk of losing the GBR as we know it). Work around changing attitudes suggests that communication framed around the intended audience's sense of what is important (e.g. land productivity, economic returns, iconic species) will have more success than communication based on the sector's values (e.g. biodiversity and ecosystems have inherent value and existence rights).

4. The Plan

The Plan makes recommendations for work in the sector (Section 4.3) based on high-level principles (Section 4.2) that reflect the priorities of the biodiversity and ecosystem sector.

4.1 What is the Plan designed to achieve?

It is clear from stakeholder engagement and review of the evidence that we are at a point in time when as a society we must decide how important biodiversity is to us and prioritise it accordingly. There is a clear need to raise the priority of biodiversity to prevent massive losses in coming decades. Even with increased prioritisation of biodiversity and ecosystems in decision-making, we are likely to see more climate-change-induced extinctions adding to extinctions due to other pressures. For example, the Bramble Cay melomys, *Melomys rubicola*, is considered Queensland's first known case of mammal extinction caused by human-induced climate change. These consequences can be minimised by mitigating greenhouse gas emissions and managing for adaptation, but action in this sector needs to happen quickly. The Plan is intended to inform immediate and strategic action.

The high-level outcome that the sector is seeking to achieve might be expressed as 'minimising the loss of biodiversity and maintaining viable ecosystems through management for adaptation to climate change'. The Plan recognises that people make decisions and those decisions are informed by what they consider to be important (i.e. their values). It is anticipated that application of the principles set out below (Section 4.2) will minimise the loss of biodiversity and maintain viable ecosystems.

4.2 Principles for managing biodiversity and ecosystems for adaptation to climate change

Research and information and the development of management approaches and tools (e.g. decision-support frameworks) has considered what we need to do to manage for adaptation to climate change. Review of key existing work (Appendix 5, Table A.8) and stakeholder engagement identified a range of additional ways that management could be adjusted to promote adaptation. From this, we identified seven broad adaptation principles to underpin the Plan (described in detail in Appendix 4). These principles are not necessarily intended to replace current principles, but to provide an adaptation lens to our management of biodiversity and ecosystems. Facilitating the adaptation of biodiversity and ecosystems under climate change will be guided by the following seven principles:

1. Use dynamic, evidence-based and transparent strategies to facilitate autonomous adaptation of biodiversity and ecosystems.
2. Prioritise the maintenance of viable ecological processes and functions.
3. Consider longer timeframes and larger spatial scales in planning.
4. Use flexible and adaptive evidence-based decision-making processes and practices to help account for uncertainty.
5. Collaborate across sectors and jurisdictions to maximise co-benefits and minimise maladaptive outcomes for biodiversity and ecosystems.
6. Collaborate within the biodiversity and ecosystem sector to improve the exchange and co-production of knowledge, including through equitable governance and management partnerships with Aboriginal and Torres Strait Islander Peoples.
7. Recognise that adaptation planning does not diminish the urgent need to reduce greenhouse gas emissions.

The adaptation actions recommended in the Plan are intended to be consistent with achieving these principles.

4.3 Recommended actions for managing biodiversity and ecosystems for adaptation

Priority adaptation actions have been developed by engaging with the sector and analysing current actions and gaps (Section 3 of the Plan) and organised into five action areas listed below.

1. Develop the sector's capacity to incorporate climate change adaptation into management decisions

and practices (Section 4.3.1).

2. Develop decision-making and adaptation planning systems that work across all sectors to support the persistence of biodiversity and ecosystems (Section 4.3.2).
3. Invest in building landscape resilience (Section 4.3.3).
4. Implement a statewide response to provide leadership and support to local and regional responses (Section 4.3.4).
5. Improve knowledge and understanding through collaboration and partnership (Section 4.3.5).

The Plan identifies key actionable steps associated with the 19 actions that are set out under these five action areas. These actionable steps are aimed at achieving each action, together with potential roles of stakeholders. Note that these are indicative rather than exhaustive sets of steps. We have suggested a broad timeframe and difficulty-ranking for each of the actions as listed below.

Timeframe:

- **immediate** – start within next 12 months, potentially complete within 1–2 years
- **intermediate** – start and potentially complete within next 1–5 years
- **discrete** – expect to be completed within 1–3 years of commencement
- **ongoing** – likely to require continued progress or development over next 10 years.

Difficulty:

- **low** – few barriers to implementation, could potentially be implemented through existing mechanisms, broad stakeholder agreement
- **moderate** – some barriers to implementation, could require new mechanisms and/or resources, some disagreement among stakeholders
- **high** – several barriers to implementation, requires considerable investment of effort, new knowledge and/or resources, likely to see considerable divergence among stakeholders.

The project team developed these rankings based on discussion with stakeholders and analysis conducted as part of developing the Plan, and they are intended to be indicative only. Note some actions may attract more than one ranking.

There is a pre-existing shortfall in investment in the sector, and implementing priority adaptation actions will require serious, additional funding. Much work in the sector depends on government funding, but we consider how some of the priority adaptation actions may be funded from other sources in Section 5.3.

Action Area 1: Develop the sector's capacity to incorporate climate change adaptation into management decisions and practices

The sector has good awareness and knowledge and a clear willingness to manage for adaptation. Many management decisions will need to be made at a local scale. It needs to develop a clear understanding of evidence-based practice and decision-support tools that can be used across the sector (and potentially in other sectors). It is clear from stakeholders that they are looking for practical ways to access the large body of information already available, further develop the knowledge base and value existing expertise.

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
1.1	Develop a central, authoritative source of guidance and tools for managing Queensland's biodiversity and ecosystems under climate change (e.g. a toolbox; see description in Box 1).	<p>Assemble and curate existing information into an authoritative and accessible source.</p> <p>Develop simple guidance to help users navigate and apply the information e.g. the merits and risks of species reintroductions and translocations.</p> <p>Establish options for documenting case studies, sharing information and online discussion forums.</p> <p>Update as new information is developed.</p>	<p>State government:</p> <ul style="list-style-type: none"> • lead and resource development of toolbox or similar. <p>All stakeholders:</p> <ul style="list-style-type: none"> • contribute information • engage in development. 	Immediate Ongoing	Low

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
1.2	Develop an understanding of adaptation options for Queensland that are likely to be important in the future under different plausible scenarios of climate change.	<p>Expand knowledge of adaptation options, including options derived from Aboriginal and Torres Strait Islander management systems e.g. firestick ecology, management in a time of change.</p> <p>Develop and apply multiple risk-assessment frameworks and trial implementation and cost-benefit analysis of interventionist adaptation options e.g. captive breeding, insurance populations for species at risk, assisted gene flow, relocation of symbiotic species.</p> <p>Evaluate current options for developing a system of gene banking and germplasm storage for at-risk species or populations e.g. Myrtaceae under threat from myrtle rust.</p> <p>Continue existing applied research, experimentation and evaluation of adaptation options (e.g. work by GBR Marine Park Authority and Australian Institute of Marine Science).</p> <p>Develop knowledge and guidance about 'minimal regrets' approaches, i.e. actions that address other threats at the same time as increasing adaptive opportunity.</p> <p>Assemble existing information and new information to feed back to the sector under Action 1.1.</p> <p>Investigate new and innovative funding mechanisms to resource options.</p>	<p>State government:</p> <ul style="list-style-type: none"> • invest in research • revise and adjust relevant legislation and approval processes to support options. <p>All stakeholders:</p> <ul style="list-style-type: none"> • invest in research • support partnerships between research and on-ground management • invest in engagement and communication of risks, costs and benefits of options. 	Intermediate Ongoing	Moderate

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
1.3	Invest in retaining and sharing existing knowledge as well as co-developing new knowledge to support on-ground management practices for adaptation.	<p>Prioritise organisational investment in and retention of skilled and experienced on-ground staff and managers, including Indigenous Land and Sea managers.</p> <p>Ensure plans, policies and programs are informed by on-ground knowledge and experience so that they are practical.</p> <p>Invest in professional development to support managing biodiversity and ecosystems for adaptation.</p> <p>Develop mechanisms to share experience and knowledge (e.g. Actions 1.1, 5.1).</p> <p>Develop mechanisms to share and co-develop information between Aboriginal and Torres Strait Islander managers and non-Indigenous managers.</p>	<p>State government:</p> <ul style="list-style-type: none"> • lead engagement and exchange with Aboriginal and Torres Strait Islander knowledge holders. <p>All stakeholders:</p> <ul style="list-style-type: none"> • adopt and prioritise this action in recruitment and HR practices • contribute to development of community of practice (Action 5.1) and sharing of knowledge. 	Immediate Ongoing	Low

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
1.4	Increase investment in the collecting baseline information and data and develop strategic, long-term monitoring programs to track change and to help understand ecological limits, thresholds and tipping points.	<p>Develop coordinated data collection, handling and analysis processes and sharing protocols.</p> <p>Support existing integrated long-term monitoring and data storage systems (e.g. Terrestrial Ecosystem Research Network 'TERN').</p> <p>Co-develop applied understanding of how to track change across the state, monitor ecosystem function, and to assess the effectiveness of management interventions over multiple years and decades.</p> <p>Link with emerging frameworks (e.g. environmental accounts⁵³) modified to apply locally and regionally.</p> <p>Incorporate monitoring data into feedback loops to support adaptive management and 'living' planning processes.</p>	<p>Federal, state and local governments:</p> <ul style="list-style-type: none"> • develop guidelines for data collection and processing • support long-term monitoring and data storage systems. <p>All stakeholders:</p> <ul style="list-style-type: none"> • develop adaptive planning approaches that incorporate monitoring. 	Immediate Ongoing	Moderate

Box 1: A toolbox for adaptation (see Action 1.1)

Climate change presents new and complex challenges for protecting and managing natural areas. Planning and decisions are being made by numerous people and organisations in multiple locations. Developing a 'toolbox' that brings together information and guidance will promote understanding of adaptation Planning processes, adaptation options and potential issues as well as facilitating sharing of experience and knowledge. The toolbox could assemble existing resources and expertise into a single accessible place. Stakeholders told us they are looking for guidance on:

- downscaled climate projections and scenarios
- drivers of change for different regions
- decision-making processes and planning tools to deal with uncertainty
- identifying refugia and improving functional connectivity in the landscape
- identifying limits, thresholds and triggers
- how ecosystem types and species might respond to changes in climate
- implementing adaptive management
- monitoring and evaluation
- 'low-regrets' actions that can be implemented now (i.e. actions that address other threats as well as increasing opportunities for adaptation)
- costs and benefits of adaptation options
- good practice principles.

The toolbox would ideally include guidelines, checklists, and technical information, as well as being a forum to share case studies. There are some adaptation guidelines already available such as those available on AdaptNRM (adaptnrm.csiro.au). NCCARF developed a toolbox for adaptation in the coastal zone, CoastAdapt (coastadapt.com.au), which could be a useful model for a similar exercise for the biodiversity and ecosystems sector.

Action Area 2: Develop decision-making and adaptation planning systems that work across all sectors to support the persistence of biodiversity and ecosystems

Decision-support frameworks are important tools in planning for adaptation. They can help examine potential options, incorporate uncertainty and unpredictability, and evaluate complex changes in benefits, costs, trade-offs, likelihood of success and feasibility of different options. Decision-support frameworks can help to identify alternative pathways and avoid foreclosing future adaptation options as a result of current decisions.

All sectors of the community are affected by climate change and will need to take action to adapt. Decisions in different sectors affect natural systems and these may be positive (e.g. conversion to agricultural production systems that require less water extraction from waterways) or negative (e.g. landward development of housing and infrastructure that prevents landward retreat by coastal ecosystems). Likewise, management for the adaptation of biodiversity and ecosystems can have impacts on other sectors, especially because natural systems provide beneficial services to people and industries (e.g. food, pollinating insects, support fisheries). Establishing collaborative connections across sectors may help avoid unintended impacts, develop efficiencies and build biodiversity and ecosystem benefits into the adaptation efforts of other sectors.

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
2.1	Develop dynamic management objectives that support adaptation of biodiversity and ecosystems at the various scales of planning and implementation needed.	<p>Review management objectives and strategic plans to test if they will remain suitable under climate change. Shift focus if needed (e.g. resilience, ecosystem function, connectivity in place of static preservation) (Box 2).</p> <p>Incorporate an understanding of plausible, acceptable and/or preferred future state(s) of biodiversity and ecosystems into planning and decision-making (e.g. dominate species likely to change).</p> <p>Build knowledge of how to optimise ecosystem function, maintain ecological processes and preserve ecosystem services through management.</p> <p>Use long-term planning that considers multiple divergent futures and when decisions about different options may need to be taken. Avoid decisions that might lock management in to a particular strategy or foreclose future options (e.g. adaptation pathways approach; Appendix 4 Box A.1).</p> <p>Develop and implement flexible monitoring and evaluation-reporting processes to match dynamic objectives and adaptive management.</p> <p>Develop integrated regional targets and agreed action, for example through regional NRM plans.</p>	<p>State government:</p> <ul style="list-style-type: none"> • review legal and policy frameworks, monitoring and evaluation processes to ensure suitability for new management objectives. <p>All stakeholders:</p> <ul style="list-style-type: none"> • integrate dynamic objectives into planning • invest in research and knowledge-building to understand implications of new management objectives • contribute to review of legislative frameworks. 	Intermediate Ongoing	Moderate– High

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
2.2	Build planning, legislation and decision-making mechanisms that prioritise management of Queensland's biodiversity and ecosystems for adaptation and promote engagement across all sectors.	<p>Review existing policy and legislation and revise to recognise and protect the adaptation services provided by ecosystems and biodiversity.</p> <p>Review adaptation options likely to arise for other sectors in terms of the implications for biodiversity and ecosystems. Work with other sectors to improve outcomes for biodiversity and ecosystems.</p> <p>Incorporate assessment of the consequences of adaptation action for biodiversity and ecosystems into State Ministerial review process, and other development and planning processes. Include decisions within the biodiversity and ecosystems sector itself.</p> <p>Develop and apply a framework for assessing biodiversity and ecosystems benefits in existing programs e.g. Carbon Farming Initiative, Land Restoration Fund.</p> <p>Assign responsibility for monitoring impacts and benefits for biodiversity and ecosystems in development approval processes.</p>	<p>State government:</p> <ul style="list-style-type: none"> • review legislation, policy and decision-making mechanisms. <p>Local government:</p> <ul style="list-style-type: none"> • consider implications in planning and development approvals processes. <p>All stakeholders:</p> <p>communicate the longer term benefits to other sectors of prioritising biodiversity and ecosystems in decision-making.</p>	Intermediate Discrete	Moderate
2.3	Develop and support decision-making mechanisms that provide realistic opportunities for engagement with the breadth of stakeholders across the sector.	<p>Develop guidelines for, and applied examples of, the use of participatory planning processes to establish priorities for adaptation of biodiversity and ecosystem management. Make available to sector (e.g. Action 1.1).</p> <p>Apply planning and decision-making processes that explicitly draw out values, including cultural values, and consider them in management decisions.</p> <p>Work equitably and collaboratively with Australian Aboriginal and Torres Strait Islander Peoples to develop and implement adaptation plans.</p>	<p>All stakeholders:</p> <ul style="list-style-type: none"> • contribute to guideline and case study examples • adopt participatory planning processes • collaborate with knowledge holders and stakeholders impacted by decisions. 	Immediate Discrete and Ongoing	Low

2.4	Promote community understanding of the values of biodiversity and ecosystems and the threat of climate change to these values.	<p>Develop a quantitative understanding of the ecosystem and adaptation services provided by biodiversity.</p> <p>Develop and promote an understanding of the roles of biodiversity and ecosystems as 'natural infrastructure' in the adaptation of other sectors to climate change (e.g. storm protection to coastal development by coastline vegetation) and likewise, for the maintenance of viable ecosystems.</p> <p>Include identification of potential co-benefits and maladaptive consequences of adaptation actions in other sectors for the biodiversity and ecosystem sector.</p> <p>Use a range of techniques to engage the wider community in understanding our common future e.g. virtual images, networking technologies, place-based experiences, interactive mapping.</p> <p>Secure political buy-in to support and promote adaptation for biodiversity and ecosystems.</p> <p>Prepare a cross-sectoral education and communication program to:</p> <ul style="list-style-type: none"> • improve understanding of the values of biodiversity and ecosystems to health, tourism, farming, social, cultural and environmental wellbeing • discuss the potential loss of iconic and other species, likely changes in local character, potential positive changes • build realistic, pragmatic and empowering messages that are tailored to the diversity of sectors and the Queensland community (Box 3) • increase community understanding of likely trade-offs for biodiversity and ecosystems resulting from decisions • support individual action. 	<p>State government:</p> <ul style="list-style-type: none"> • promote the importance of biodiversity and ecosystems through <i>State</i> programs, legislative and policy mechanisms, resourcing and support • build communication into other portfolios e.g. infrastructure, transport, tourism. <p>All stakeholders:</p> <ul style="list-style-type: none"> • undertake and support research and knowledge-building • develop collaborative partnerships for adaptation planning and implementation • <i>engage and advocate to</i> support actions. 	Immediate Ongoing	Moderate
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Box 2: How might management objectives address the climate change challenge? (Action 2.1)

Many management objectives will continue to be relevant under climate change. For example, it is likely we will wish to conserve known species, maintain regional character and uniqueness, and have a protected area system that is comprehensive, adequate and representative. But climate change will alter the practicality of some management objectives and run the risk, for others, of producing undesirable outcomes for natural systems (i.e. maladaptation). And so, we will need to consider adjusting management objectives to be more realistic and more successful. The importance of this will increase over time as the impacts of climate change become greater.

Biodiversity management has predominantly focused on preserving or restoring species assemblages thought to 'belong' to a place (based on current or historical knowledge of assemblage composition). The logic follows that by doing this we have a good chance of retaining or restoring habitats that are needed by, and useful to, the biodiversity natural to an area. There is general agreement that under climate change, it will be difficult to feel confident about the most appropriate species, assemblages or even ecosystems to conserve. One of the main outcomes of thinking around this has been to step back from objectives that are defined by species composition. Some examples of principles or objectives for climate adapted management are listed below.

Natural resource management principles

Susan Prober and colleagues, in guidelines developed for the natural resource management sector³⁵ suggested the following principles:

- Optimise ecological processes to maximise species survival and benefits to human society.
- Maintain the evolutionary character of the Australian biota by maintain its unique flora and fauna.
- Maintain unique regional character to promote reassembly of communities from nearby species.
- Minimise species loss nationally through support of the underlying principle of the Comprehensive, Adequate and Representative reserve system including management and conservation both on- and off-reserve.
- Promote cross-sectoral adaptation Planning to ensure biodiversity is considered in the decisions of other sectors.

These are largely consistent with the principles identified in the Plan.

Landscape design approaches

Under the landscape design approach, areas to be managed and/or restored for biodiversity are planned in very specific locations over relatively large scales. The aim is to have large populations spread over multiple patches of native ecosystems in the landscape and intermingled with other necessary land uses.¹² Because we can't predict exactly what future landscapes will be like, this approach needs to identify landscape designs that have a good chance of benefiting native species. In a modelling analysis of landscape scale approaches, Doerr and colleagues found that 30% of native vegetation cover was the minimum needed to allow for multiple future scenarios.¹²

Ecosystem function

The ecosystem function approach advocates protecting ecosystem function rather than species or species assemblages and ecosystem structure. So for example, if we consider a coral reef, its function as substrate for fish and other tropical marine organisms may be maintained even if the coral species vary from historical assemblages.

Box 3: Getting the message right (Action 2.4)

During adaptation Planning and implementation, managers and policymakers will need to engage with internal and external stakeholders about the climate risks and the management responses Planned or being undertaken. This may mean providing information about future climate scenarios, the range of possible impacts on biodiversity and ecosystems, and implications for other sectors. It is important that messages are framed to be informative and realistic and that encourage meaningful engagement. Insights collated from stakeholder engagement include the following.

- Messages should be framed in terms of audience worldviews — their values, beliefs, perceptions and knowledge. For example, talk to farmers about production benefits of biodiversity.
- Frame risks to biodiversity and ecosystems as a shared problem. Take advantage of the pervasive nature of climate change (i.e. it affects everyone).
- Communicate what is at stake in realistic terms (e.g. we have to accept some loss of species, decreasing chances of species survival), but don't allow messages to be characterised by doom and gloom, which elicit helplessness and hopelessness.
- Use relatable, acceptable language and appropriate timing to engage (e.g. avoid harvest times for crop farmers).
- Use a mix of strategies e.g. multi-stakeholder forums, kitchen-table conversations.
- Link with trusted information e.g. existing management principles and extension programs.

In addition to promoting the values of biodiversity and ecosystems, and the threats to these, communication could include information about how to get involved in action to address threats, for example:

- discussion with local councillor and Member of Parliament about their position on biodiversity and ecosystems and climate change
- engagement in public discussion
- involvement with NRM groups, Landcare and catchment management groups
- participation in local council nursery/revegetation/Bushcare and Coastcare/Land for Wildlife programs
- entering into a voluntary conservation agreement with local council or nature refuge with state government
- visiting conservation reserves and national parks.

Action Area 3: Invest in building landscape resilience

Landscape resilience relates to maintaining ecological function, landscape processes and the evolutionary process.^{35, 55} This is a shift away from focusing on maintaining species composition as a primary objective of biodiversity and ecosystem management. It is based on the premise that by investing in maintaining resilience, particularly at large scales, we optimise the chances for species to adapt to new climate conditions and keep open options for future management.

There is already inadequate habitat to protect much of Queensland's biodiversity and ecosystems from pre-existing threats, that is, landscape resilience is not preserved under the current regime. Climate change exacerbates these threats and creates new ones, so considerably more habitat and sympathetically managed areas will be needed for nature to take advantage of adaptive opportunities under climate change.

No.	Adaptation actions	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
3.1	Build a practical understanding of ecosystem resilience in the context of adaptation of biodiversity and ecosystems. Provide guidance on implementation.	<p>Develop and share an agreed definition of ecosystem resilience that allows for expected changes and autonomous adaptation under climate change.</p> <p>Develop an understanding of adaptive change including transition paths, ecological limits, thresholds and tipping points e.g. dynamic ecosystem modelling.^d</p> <p>Develop principles for evaluating changing species distributions or assemblage composition to determine desirability of that change e.g. adaptive change <i>versus</i> opportunistic invasion.</p> <p>Identify practical opportunities to reduce barriers to and increase opportunities for autonomous adaptation.</p>	<p>State government:</p> <ul style="list-style-type: none"> • support development of ecosystem resilience research and thinking • adopt agreed definition of ecosystem resilience. <p>All stakeholders:</p> <ul style="list-style-type: none"> • invest in building operational understanding • monitor and review management to promote ecosystem resilience • contribute to research and knowledge-building. 	Immediate Ongoing	Low

^d <https://research.csiro.au/biodiversity-knowledge/projects/models-framework/>

No.	Adaptation actions	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
3.2	Revise and adjust legislation, policies, plans and programmatic efforts to allow adequate space for nature to respond adaptively to climate change.	<p>Review planning and legislation to include emphasis on the functional and other dimensions of 'resilience'. Avoid implicit objectives involving return to previous system states.</p> <p>Review options for the using incentives (e.g. subsidies) and disincentives (e.g. regulation) for increasing the space available for nature.</p> <p>Deliver and implement recommendations for legislative protection and restoration of important terrestrial, aquatic and marine habitats, including potential refugia (see Actions 2.1, 3.3 and 4.3).</p> <p>Develop a vulnerability and transition path framework for Regional Ecosystems to support legislative protection of vegetation.</p> <p>Ensure climate change resilience is incorporated into existing initiatives e.g. Voluntary Conservation Agreements, nature refuges, Queensland Protected Areas, Land Restoration Fund, <i>National Reserve Strategy</i>, National Landcare Program.</p> <p>Expand and focus support for integrated management of off-reserve areas, including retention and buffering of existing habitats and informed management of invasive species, fire to develop landscape scale resilience.</p>	<p>State government:</p> <ul style="list-style-type: none"> • review and adjust associated legislative frameworks; review the role of incentives for off-reserve ecosystem management. <p>All stakeholders:</p> <ul style="list-style-type: none"> • contribute to research and knowledge-building • develop resilience objectives into planning and management. 	Intermediate Ongoing	Moderate

No.	Adaptation actions	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
3.3	Resource the continued development of fine-scale spatial mapping of potential climate refugia and key habitat areas across Queensland with the view to prioritising protection and restoration action.	<p>Develop and apply knowledge about species distribution shifts e.g. characteristics of leading-edge and frontline populations and systems; evidence from the paleo-record.</p> <p>Invest in developing models that integrate reliable projections for all dimensions of climate change to develop scenarios of potential refugia and other priority habitats (including micro-refugia) across Queensland, where this has not already been done.</p> <p>Assess and understand functional connectivity over the range of temporal and spatial scales required by organisms, accounting for:</p> <ul style="list-style-type: none"> • variation throughout their life cycles • the range of levels of mobility • dependency on other species or processes for movement (e.g. seed dispersal in plants). <p>Feed information into a review of the adequacy of current systems for reserve selection (see Action 4.1) and regional planning.</p> <p>Develop guidelines for developing functional connectivity in landscape planning.</p> <p>Develop guidelines for buffering key habitats against impacts from adjoining areas.</p>	<p>State government:</p> <ul style="list-style-type: none"> • feed information into statewide response (Action 4.0) • disseminate information through community of practice (Action 1.1). <p>All stakeholders:</p> <ul style="list-style-type: none"> • invest in development of models and scenarios • invest in cooperative research • develop on-ground experimentation to inform guidelines and planning. 	Ongoing	Low–Moderate

No.	Adaptation actions	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
3.4	Include future values, future risks and new evidence-based approaches in strategic interventions for managing existing threats to biodiversity and ecosystems.	<p>Develop and integrate knowledge about likely future climate suitability and patterns of disturbance (e.g. fire, flood, cyclone) to prioritise investment in invasive species control. Include potential sleeper species.</p> <p>Develop an understanding of potential changes in fire-proneness.</p> <p>Expand the current threatened species framework to include climate change as a threatening process.</p> <p>Re-evaluate 'degraded' areas in terms of their potential to provide adaptive opportunities.</p>	<p>State government:</p> <ul style="list-style-type: none"> • review legislation and policy to incorporate climate change as a threatening process • feed information into statewide response (Action 4). <p>All stakeholders:</p> <ul style="list-style-type: none"> • invest in cooperative research • prioritise on-ground management of existing threats in response to new knowledge. 	Ongoing	Moderate

Action Area 4: Implement a statewide response to provide leadership and support to local and regional responses

Many decisions will be made at local and regional scales about managing biodiversity and ecosystems, and about managing adaptation in other sectors. Informed leadership by the Queensland Government is therefore critical. Developing a coordinated, multi-jurisdictional action framework for the sector will have several benefits. It will guide the translation of principles for management of biodiversity and ecosystems for adaptation and provide a platform for developing supportive legislation, policy and investment. It will also help to align work across regional Queensland in different management domains towards the same objectives.

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
4.1	Demonstrate a statewide action-focused response to the recommendations of the Plan that aligns action at regional and local scales.	Cooperatively develop agreed specific roles, objectives, funding responsibilities and evaluation frameworks for recommended actions of the Plan. Develop a process for ongoing, iterative review and improvement of the Plan, including timing and resourcing.	State government: • lead development of implementation and review process.	Immediate Ongoing	Low

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
4.2	Review and adjust Queensland's natural resources and planning policy and legislation to include recognition of climate change as a fundamental threat to natural systems.	<p>Review Queensland's key policy and legislation in relation to biodiversity and ecosystems for barriers and enablers of adaptation. Include consideration of planning systems.</p> <p>Assess and action development of a new section in the <i>Nature Conservation Act (1992)</i> that incorporates climate change as a threatening process into Queensland legislative system.</p> <p>Advocate for stronger leadership by the Australian Government on climate change, environmental protection and biodiversity conservation.</p> <p>Consider options for sub-national action e.g. the Global Partnership on Local and Sub-national Action for Biodiversity.</p>	<p>State government:</p> <ul style="list-style-type: none"> • lead review of legislation and policy • amend legislation and policy as appropriate. 	Immediate Discrete	Moderate

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
4.3	Support the integration of climate change adaptation into regional management planning processes for biodiversity and ecosystems, including for protected areas and surrounding landscapes and seascapes.	<p>Review natural areas (i.e. national parks, state forests, nature reserves, private holdings) to identify priority regions for adaptation action planning based on climate vulnerability assessment e.g. likely to experience the greatest change soonest.</p> <p>Act on adaptation planning in WHAs as a matter of priority to apply principles and test the regional implementation of recommended actions from the Plan (Box 4).</p> <p>Support ongoing work by NRM groups to integrate climate change adaptation into regional planning.</p>	<p>State government:</p> <ul style="list-style-type: none"> • ongoing investment into vegetation mapping and monitoring • support WHA committees to undertake adaptation planning and action • engage with other managers to support this action. <p>WHA management committees:</p> <ul style="list-style-type: none"> • undertake adaptation planning (if not yet underway) and implementation. 	Ongoing	Moderate

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
4.4	In leading whole-of-government action to reduce net greenhouse gas emissions, prioritise adaptation options with that align with a zero emissions future.	<p>Recognise and quantify the climate change mitigation dimension of maintaining natural systems e.g. improved long-term protection and restoration of carbon stocks in natural ecosystems reduces emissions from land use, and maintains or increases sequestration. Incorporate this into mitigation targets.</p> <p>Establish a process for systematically assessing the balance of lifetime emissions and/or sequestration benefits of adaptation action.</p>	<p>State government:</p> <ul style="list-style-type: none"> • adopt methods to assess mitigation benefits of adaptation actions. <p>All stakeholders:</p> <ul style="list-style-type: none"> • contribute to developing methods that quantify mitigation benefits of adaptation actions. 	Ongoing	Moderate

Box 4. Queensland's international obligations (Action 4.3)

Queensland co-manages many properties that receive international recognition and protection. World Heritage properties are areas of 'Outstanding Universal Value' (OUV) that are committed to protect and present their natural and cultural values. Queensland also has five Ramsar-listed wetlands within its jurisdiction. Under the Ramsar treaty, member countries must maintain the ecological character of their Wetlands of International Importance, and to Plan for the 'wise use', or sustainable use of all the wetlands in their territories.

In 2017, UNESCO's World Heritage Committee acknowledged the worldwide threat of climate change to all World Heritage properties (<http://whc.unesco.org/archive/2017/whc17-41com-7-en.pdf>) and has now developed a *Strategy for Action on Climate Change* (<http://unesdoc.unesco.org/images/0025/002592/259255e.pdf>) to guide managers in meeting their obligation to enact best practice adaptive management to protect against the threat of climate change.

Palaeoclimatic studies have revealed that some of Australia's World Heritage properties have undergone periods of considerable change through a series of glacial cycles. These studies provide a clear indication that the World Heritage values of these properties tell a story of climate change adaptation and survival in response to 'natural' or non-anthropogenic climate change processes. However, the capacity of World Heritage properties to adapt and maintain their OUV in the face of current rapid changes in climate is not known.

To protect the properties it will be important to understand potential climate change impacts on OUV in the World Heritage areas and ecological character in Ramsar-listed areas, and to respond to those risks effectively. These properties, especially the WHAs, have relatively well-resourced management and governance and as a result are well placed to start the process of responding to climate change.

The Plan provides statewide guidance on priority activities to progress adaptation in the sector. One of the critical actions will be to commence adaptation planning at regional and local levels. For Queensland's World Heritage and Ramsar-listed areas, it will be important that property-level adaptation plans are developed and implemented. In some cases this has already begun or is well underway (e.g. for the GBRWHA and Wet Tropics WHA). In addition to protecting natural values, these areas typically have high cultural values for Aboriginal Traditional Owners, as well as significant socioeconomic value in terms of tourism income, recreational, health and wellbeing benefits.

While work has been done on climate change in relation to WHAs, this work has largely been opportunistic and not distributed evenly across properties. Adaptation action plans for Queensland's WHAs could build on this useful groundwork and feed into property based plans. World Heritage property based plans could then:

- understand and summarise the likely specific impacts on World Heritage OUV resulting from a changing climate
- identify planned and sustained actions to manage OUV in response to widespread, unavoidable and substantial ecological change
- identify the work of management agencies, research and partners in response to climate change
- advance collaborative work to understand and address specific potential impacts of a changing climate on World Heritage values
- support funding bids to advance on-ground actions to protect the integrity and OUV of WHAs.

Action Area 5: Improve knowledge and understanding through collaboration and partnership

Climate change presents future scenarios that are beyond anything we have experienced in the past. Our current and past management options may not provide the outcomes in managing biodiversity and ecosystems that we seek. We are likely to have to consider new, innovative and, in some cases, unpalatable options. Working collaboratively across the biodiversity and ecosystem sector will support the exchange and co-production of new knowledge, help coordinate monitoring and enable sharing of data to inform the implementation of good adaptation practice, and foster confidence and a culture of innovation in the sector. Ongoing collaboration across all domains of biodiversity and ecosystems management will help to develop knowledge and tools that are more readily translated into decision-making. Collaboration will also help form policy, plans and legislation that are based on evidence and support on-ground works, and to frame ideas and communicate across and beyond the sector. For example, co-developed strategies and plans will be more practical if they consider the actual management interventions that are used and the relevant legislation and policy from the outset. This should improve uptake of evidence-based actions.

In an environment where decisions must be made based on multiple scenarios of the future, access to considerable information and expertise is necessary. While we cannot expect to have perfect knowledge, we can target knowledge needs that will improve confidence in decisions and that will build relationships among stakeholders.

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
5.1	Develop and support a community of practice across the sector to share knowledge and experience, implement cooperative research, and align work relating to adaptation.	<p>Establish mechanisms that support a community of practice to promote linkages and to share and co-develop information, knowledge, expertise and experience among:</p> <ul style="list-style-type: none"> • NRM groups • Indigenous land and sea management networks • WHA scientific/community advisory committees • research networks • government, industry, and private and non-governmental organisations • Queensland Government. <p>Support existing networks (e.g. NRM networks) that facilitate interaction across the sector, especially between domains of management.</p> <p>Consider developing new means of connection (e.g. a sector-based adaptation network or hub).</p> <p>Provide dedicated resourcing to support a community of practice e.g. knowledge broker/co-ordinator and opportunities for physical or virtual gatherings (e.g. conferences, conference sessions, newsletters, online forums).</p> <p>Review case studies of existing successful collaborations at scale, co-management and enduring governance.</p>	<p>State government:</p> <ul style="list-style-type: none"> • facilitate community of practice through resourcing or kick-off events. <p>All stakeholders:</p> <ul style="list-style-type: none"> • look for existing opportunities to incorporate knowledge sharing • contribute case studies to community of practice (e.g. Action 1.1) • build collaborative partnerships. 	Immediate Ongoing	Low

No.	Adaptation action	Actionable steps/tasks	Indicative responsibilities	Time frame	Difficulty
5.2	Foster equitable and meaningful partnership with and leadership by Aboriginal and Torres Strait Islander Peoples in adaptation planning, decision-making and action.	<p>Promote Indigenous led and run processes and/or shared governance arrangements.</p> <p>Support processes that include culturally appropriate engagement with knowledge holders.</p> <p>Develop understanding of culturally appropriate protocols in relation to knowledge sharing.</p> <p>Adequately resource management leadership, partnerships and engagement with Traditional Owners.</p> <p>Respect Aboriginal and Torres Strait Islander knowledge systems.</p>	<p>State government:</p> <ul style="list-style-type: none"> • allow for appropriate, meaningful and resourced engagement in the Plan implementation and review process • provide leadership in this action. <p>All stakeholders:</p> <ul style="list-style-type: none"> • review partnership and management arrangements to meet this action. 	Intermediate Ongoing	Moderate
5.3	Support cooperative research.	<p>Prioritise research needs (e.g. Appendix 6) and develop co-investment and research partnerships to undertake projects.</p> <p>Develop data access and sharing agreements.</p> <p>Develop culturally appropriate co-research and knowledge partnerships with Aboriginal and Torres Strait Islander Peoples.</p>	<p>All stakeholders:</p> <ul style="list-style-type: none"> • invest and engage in priority cooperative research projects. 	Ongoing	Low

5. Delivering the Plan

5.1 Early initiatives

Developing the Plan has not involved systematically prioritising across the 19 adaptation actions; this would logically be done subsequent to implementation planning. However, in this section we highlight those ready for immediate action and which will in turn assist with implementing other actions. Their implementation would also maintain and build on momentum generated during development of the Plan. The highlighted actions are presented as readily achievable, standalone projects.

Action 1.1 Develop a central, authoritative source of guidance and tools for managing Queensland's biodiversity and ecosystems under climate change

Constructing a toolbox or information portal early will develop its reputation as an authoritative and accessible source. Once established, new information and resources can be added to the tool as they become available. Investment in user testing and simple user guidelines will improve the value of the tool above existing repositories.

Action 4.1 Demonstrate a statewide action focused response to the recommendations of the Plan that aligns action at regional and local scales

We anticipate that the Queensland Government would respond to the Plan by formulating its next steps. The government is in the best position to identify what can be done given existing resources and work programs and what additional resources can be leveraged. This might be done as part of an integrated response to the eight Q-CAS sector adaptation plans. Implementing key actions from the Plan will flag the government's commitment to supporting and building on the momentum initiated in developing the Plan.

Action 4.3 Support the integration of climate change adaptation into regional management planning processes for biodiversity and ecosystems, including for protected areas and surrounding landscapes and seascapes

While this action will be ongoing and will require more information and additional support, it was identified in developing the Plan that Queensland's WHAs are well placed to undertake adaptation planning processes and could serve as useful test cases, exemplars and leaders for adaptation planning to other priority regions. In some cases, planning is already underway (e.g. the GBR and Wet Tropics). The WHAs have well established governance frameworks, resources and knowledge and we would expect rapid progress.

Action 5.1 Develop and support a community of practice across the sector to share knowledge and experience, implement cooperative research, and align work relating to adaptation

A community of practice (COP) will often develop organically as members of the sector share ideas, exchange knowledge and develop collaborations (e.g. NRM communications network). There was a clear appetite among stakeholders engaged in the developing the Plan to create opportunities for such exchanges, and build on momentum of working on the Plan. However, experience has shown that despite strong desire for collaboration, this rarely eventuates or continues without dedicated and resourced coordination or facilitation. Developing formal coordination for a biodiversity and ecosystem adaptation community of practice (e.g. a network or a hub) will require time, but some activities could be contemplated in the short-term that would support a future COP. For example, a one day kick-off forum could bring together stakeholders in research, policy and practice, to share current work and thinking and develop planning for further developing the COP. Regional NRM groups have extensive networks across the sector and have already brokered collaboration for integrating climate adaptation into regional plans. This capacity could be used to bring together regional expertise in research, policy and planning, on-ground implementation and engagement, and advocacy to advance implementation planning around actions identified in the Plan.

5.2 Capitalise on existing opportunities

Existing work in the sector and the legislative, policy and planning context for work in the sector is summarised in Appendix 5. There is already considerable planning, research and on-ground action in Queensland. A number of the actions recommended in the Plan could build on existing work with some adjustment or expansion. These include the following suggestions.

Action 1.4 Increase investment in collecting baseline information and data and develop strategic, long-term monitoring programs to track change and to help understand ecological limits, thresholds and tipping points

Integrated long-term monitoring and data storage systems already exist (e.g. TERN) that could be supported to collect and manage data. This action could also build on the existing capacity in many on-ground operations to collect and manage field data (e.g. Indigenous land and sea ranger groups using technology such as iTracker).

Action 1.2 Develop an understanding of adaptation options for Queensland that are likely to be important in the future under plausible scenarios of climate change

Applied research is already evaluating direct intervention options (e.g. coral translocation). Bringing the results of that work into the toolbox (Action 1.1) as examples or case studies will help develop knowledge, experience and evaluation of adaptation options.

Action 2.2 Build planning, legislation and decision-making mechanisms that prioritise management of Queensland's biodiversity and ecosystems for adaptation and promote engagement across all sectors

Linking with actions arising from other sector adaptation plans, such as ecosystem-based adaptation in the emergency management sector (e.g. integrating ecological and cultural burning practice into hazard reduction burning), could provide adaptive opportunities for biodiversity and ecosystems. Cross-sectoral collaboration may be facilitated within an existing arrangement (e.g. existing governance bodies).

Action 3.3 Resource the continued development of fine scale spatial mapping of potential climate refugia and key habitat areas across Queensland to enable prioritisation for protection and restoration

Revising existing vegetation mapping could capture more information such as high-value regrowth areas. There could be an opportunity to work with the Commonwealth Government on their Common Assessment Method^e and climate-relevant approaches to categorising the level of threat to biodiversity and ecosystems.

Action 5.1 Develop and support a community of practice across the sector to share knowledge and experience, implement cooperative research, and align work on adaptation

Interaction to support the community of practice recommended in the Plan may be incorporated into existing networks within the sector (e.g. facilitated with support by NRM groups).

Action 5.3 Support cooperative research

Cooperative research is the focus of existing Commonwealth Government funded work through the National Environmental Science Program (NESP) and research-industry knowledge building partnerships are becoming more common. The Queensland Government also forms partnerships to deliver research. Continuing to support collaborative work and looking for new opportunities to implement cooperative research that engages members from all management domains will help deliver practical and rigorous outcomes.

5.3 Consider innovative funding mechanisms

One of the great challenges for the biodiversity and ecosystems sector is that the significant investment needed for adaptation is not reflected in a direct financial return the way it is in other sectors (e.g. costs to research developing climate-ready crop varieties may be recovered by increased farm productivity). This is despite the clear understanding that the monetary logic would be obvious if the economic values of ecosystem and adaptation services (and underpinning biodiversity) were quantified (e.g. clean air and water, safe food, human health and wellbeing, inputs to industry). As a result, the sector is heavily dependent on government funding. Private funding is increasingly

^e <http://www.environment.gov.au/biodiversity/threatened/cam>

supporting important work in the sector, but is typically gained using well-resourced marketing strategies.

While there is a valid argument for investment in biodiversity and ecosystems as part of our moral obligation of stewardship, public investment has been preferentially directed toward sectors with direct links to economic and social outcomes (e.g. farming, housing). In order to adequately fund adaptation action in the sector, substantially increased funding may come from a range of possible sources, including the following potential sources which have been successfully used elsewhere:

- specific levies (e.g. entry fees to national parks or other reserve areas, stewardship programs, climate adaptation fund)
- existing funds (e.g. from offsets) to establish a 'market' for investment in priority work
- increased opportunities within the Queensland carbon farming industry for ecological revegetation (as opposed to purely commercial revegetation)
- funding from industries that emit large amounts of greenhouse gases (e.g. oil industry, aviation, transport)
- corporate social responsibility initiatives managed to achieve strategic outcomes (e.g. Aboriginal Carbon Fund *Core Benefit Standards*)
- public-private partnerships.

Ecosystem-based adaptation in other sectors has the potential to highlight the value of services provided by natural systems to humans, while also providing opportunities to benefit biodiversity and ecosystems. Market mechanisms and incentives (e.g. offsets, carbon farming) have the potential to contribute to biodiversity and ecosystems management for adaptation, but care must be taken to ensure appropriate outcomes are achieved and that the damage permitted by these schemes does not reduce important current or future opportunities for biodiversity and ecosystems to persist.

5.4 Consider the social context and risks

In implementing the Plan, it is important to recognise the social context and risks and to consider the potential for management for adaptation to affect people experiencing social vulnerability. In general, it is more likely that the failure of biodiversity and ecosystems to adapt appropriately to climate change will bring significant risks to society, including socially vulnerable people. This is because of the links between biodiversity and ecosystems and human health (e.g. food and clean air), culture (e.g. sense of place, aesthetic values, cultural and spiritual values) and economics (e.g. tourism, primary production). However, adaptation decisions intended to benefit biodiversity and ecosystems may disadvantage some people. For example, the sense of urgency and the high stakes involved in helping natural systems autonomously adapt to climate change may mean that some people are unintentionally left out of decision-making processes. There is valid concern that Aboriginal and Torres Strait Islander Peoples risk alienation from their cultural practices and heritage, as well as from meaningful participation in governance and employment opportunities, including on their own country. Meaningful, equitable engagement will be needed to avoid unintended outcomes.

Building strong ties with other sectors will also be critical to building mutual efficiencies in adaptation, looking for opportunities to incorporate biodiversity and ecosystem outcomes in adaptation options in other sectors and to avoid maladaptive outcomes for biodiversity and ecosystems. To date Q-CAS sector adaptation plans have been developed for the tourism, health, emergency management, built environment, and agriculture sectors. All have identified either working with the biodiversity and ecosystem sector to implement adaptation measures or including biodiversity as an important priority. The effective implementation of the sector adaptation plans is an opportunity to build cross-sector collaboration and knowledge exchange.

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Appendix 1. Stakeholder identification and engagement

A1.1 Stakeholder identification

In identifying stakeholders, we recognised the wide range of organisations with a stake in biodiversity and ecosystems, including people and organisations who either:

1. **influence** decisions about the adaptation of biodiversity and ecosystems to climate change (Table A.1), or
2. **are affected by** the outcomes of decisions about the adaptation of biodiversity and ecosystems to climate change (Table A.2).

We focused engagement for the Plan on people and organisations managing natural systems (i.e. those with the potential to influence adaptive opportunities for biodiversity and ecosystems; Table A.1).

Table A.1 Examples of stakeholders likely to influence management of biodiversity and ecosystems

Sphere of influence	Mechanism examples	Stakeholder examples
Evidence and knowledge	Research Traditional Ecological Knowledge	Universities, CSIRO Traditional Owners Private conservation organisations Partnerships with state government
Policy and Planning	Protected area network Climate adaptation plans Regional NRM plans Disbursement of funds	State Government World Heritage management Local governments Aboriginal shire councils Land Council Aboriginal corporations NRM bodies Consultants Industry groups Australian Government
On-ground operations	Protected area operations Traditional Owner land management Carbon offsets projects	National parks rangers Indigenous rangers Local governments Aboriginal shire councils Private conservation organisations Landcare; Catchment management groups Community groups Carbon fund managers and participants Land management businesses
Engagement and	Special interest groups	Conservation NGOs

advocacy	Communication and education material	Private conservation organisations NRM bodies; Landcare Local government partnerships programs Industry groups, including competing interests
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Table A.2 Examples of stakeholders potentially affected by decisions about biodiversity and ecosystems management in the context of climate change.

Type of effect	Mechanism examples	Stakeholder examples
Nature of and ability to undertake on-ground work	Funded programs or projects	National Parks Rangers Indigenous Rangers Public and private land owners or lessees Community groups
Community wellbeing and resilience	Health of Country Ecosystem services Adaptive capacity (green infrastructure etc.) Existence value Social service provision	Traditional Owners Whole-of-community QCOSS and service providers Emergency management Health
Ability to maintain (or need to change) cultural or other practices (e.g. collection or harvesting)	Regulation Condition and availability of natural resources	Primary producers Wild-catch fishers Native forestry Indigenous peoples Industry groups (e.g. utilities, land developers)

A1.2 Methods of engagement

The project team held semi-structured interviews and discussions which targeted people (24 interviewees) doing key research, developing relevant reports or applying adaptation principles in management (Table A.3). We used notes from interviews and a review of existing work to develop an initial set of adaptation principles used in the Discussion Paper and workshop testing and discussion.

The Discussion Paper for Queensland's Biodiversity and Ecosystems Climate Adaptation Plan was released in May 2018, along with an online survey that was open for three weeks. The Discussion Paper and survey link were emailed to over 330 people, many of whom forwarded these within their organisations or member groups. We had 61 responses to the survey from across the sector and Queensland.

The project team held two face-to-face workshops in Cairns (7 June 2018) and in Brisbane (13 June 2018). We also facilitated two online workshops later in June in an effort to engage with more remotely located members of the sector. The workshops aimed to:

- catalogue approaches to managing natural systems under climate change
- review a strategic framework for the direction of future work in the sector

- discuss potential recommendations for the Plan.

Invitations were emailed to over 400 people. In total 102 people participated in the face-to-face and online workshops.

In total, 189 people engaged in the consultation process of developing the Plan, representing a broad range of organisations including all levels of government, research, conservation organisations, community groups and individuals (Table A.3). Survey respondents represented all aspects of biodiversity and ecosystem management: policy (43 per cent), management planning (39.7 per cent), on-ground NRM (36.2 per cent), advocacy (32.8 per cent) and research (29.3 per cent), and represented all regions of Queensland (many respondents identified with more than one management domain).

The project team made substantial effort during the short project to engage with people from all spheres of influence and representing as many stakeholder examples as possible (Table A.1). The stakeholders who engaged in the work through the Steering Committee, workshops and interviews are listed in Table A.3. Note that some stakeholders who contributed preferred to have their name and/or organisation identity kept private, or did not provide these details. Survey responses were confidential, so we have only provided information about respondents' organisational type (Figure A.1).

Table A.3 List of Steering Committee members and stakeholders consulted during the development of the Plan

Engagement mechanism	Name	Affiliation
Steering Committee	Catie Dunbar/David Putland	Department of Environment and Science, Queensland, Climate Change Policy; Environmental Policy and Planning
	Moir Rice	Department of Environment and Science, Queensland, Climate Change Policy; Environmental Policy and Planning
	Stacey Maddock-Armstrong/Ilza Brieze	Department of Environment and Science, Queensland, Strategy and Policy Services; Protected Area Innovation, Engagement and Policy
	Robert Hughes/Narelle Sutherland/Steven Howell	Department of Environment and Science, Queensland, Conservation and Biodiversity Strategy; Conservation and Biodiversity Services
	Bob Speirs	Natural Resource Management Regions Queensland (NRMQR)
	Luke Reade	Queensland Council of Social Service
	Kamil Shah	Queensland Council of Social Service
Semi-structured interviews	Scott Buchanan	Wet Tropics Management Authority
	Terry Carmichael	Wet Tropics Management Authority
	Lisa Cliff	Queensland Conservation Council
	Paul Donatiu	Healthy Land and Water
	Michael Dunlop	CSIRO
	James Fitzsimons	The Nature Conservancy

Engagement mechanism	Name	Affiliation
	Rowan Foley	Aboriginal Carbon Fund
	Iain Gordon	James Cook University; Wet Tropics
	Ro Hill	CSIRO
	Craig James	CSIRO
	Peter Johnson	Department of Environment and Science, Queensland
	Melinda Laidlaw	Department of Environment and Science, Queensland
	Linda Lee	Department of Environment and Science, Queensland
	Tim Low	Consultant
	Revel Pointon	Environmental Defenders Office
	Nick Reid	University of New England; Gondwana Rainforests
	April Reside	University of Queensland
	Mike Ronan	Department of Environment and Science, Queensland
	Tim Seelig	Queensland Conservation Council
	Leslie Shirreffs	Wet Tropics Management Authority
	Stephen Trent	Department of Environment and Science, Queensland
	David Wachenfeld	Great Barrier Reef Management Authority
	Tricia Waters	Gondwana Rainforests; NSW Office Environment & Heritage
	Kristen Williams	CSIRO
	Tim Wong	Wet Tropics Management Authority
	Colleague	Pew Charitable Trusts
Workshops	Sandra Abell	Wet Tropics Management Authority
	Rebecca Bretton	
	Terry Carmichael	Wet Tropics Management Authority
	Catherine Cleary	Brisbane City Council
	Lisa Cliff	Queensland Conservation Council
	Jelenko Dragisic	Greening Australia
	Andrew Drysdale	NRM Regions Queensland
	Doreen Erhart	Local Government Association of Queensland

Engagement mechanism	Name	Affiliation
	Edward Fensom	
	Emma Finney	Cairns Regional Council
	Gudju Gudju Fourmile	Abriculture and Gimy Walubara Yidinji Traditional Owner
	Tess Galvin	Department of Communities, Disability Services and Seniors
	Mark Gasson	RCBC Fund
	Steve Goosem	previously Wet Tropics Management Authority
	Simon Goudkamp	Department of Environment and Science, Queensland
	Paul Hales	Bush Heritage Australia
	Scott Hanna	Roberschan Environmental
	Dale Hansen	Brisbane City Council
	Pippa Kern	Bush Heritage
	Lene Knudsen	Growcom
	Jenny Lynch	Abriculture
	Ramona Maggini	Queensland University of Technology
	Laura McCallum	Verterra Ecological Engineering
	Andrew McCarthy	Condamine Alliance
	Oliver Mitchell	Losee Consulting
	Liz Murphy-Forrever	
	Mitchell Neto	Department of Environment, Land, Water and Planning, Victoria
	James Newman	QPES
	Conor Neville	Noosa Shire Council
	Emma O'Neill	SEQ Water
	Rebecca Paine	Department of Agriculture and Forestry
	Kayler Plant	Southern Gulf NRM
	Revel Pointon	Environmental Defenders Office
	Luke Preece	The Nature Conservancy
	David Putland	Department of Environment and Science, Queensland
	John Rainbird	Torres Strait Regional Authority

Engagement mechanism	Name	Affiliation
	April Reside	University of Queensland
	Moiria Rice	Department of Environment and Science, Queensland
	Mike Ronan	Department of Environment and Science, Queensland
	Penny Scott	Terrain NRM
	Tim Shields	Ipswich City Council
	Luke Shoo	University of Queensland
	John Sinclair	
	Bob Speirs	Natural Resource Management Regions Queensland
	Gillian Smith	Sunshine Coast Regional Council
	Anne Sutherland	
	Lin Sutherland	
	Travis Sydes	Far North Queensland Regional Organisation of Councils
	Jozef Syktus	University of Queensland
	Sherri Tanner-McAllister	Department of Environment and Science, Queensland
	Matt Thompson	Queensland Fire and Emergency Services
	Ralph Trancoso	Department of Environment and Science, Queensland
	Steve Turton	Central Queensland University
	Paul McAnty	Moreton Bay Council
	David Wachenfeld	Great Barrier Reef Management Authority
	Roz Walden	Cairns and Far North Environment Centre
	Tim Wong	Wet Tropics Management Authority
	Virginia Young	Australian Rainforest Conservation Society

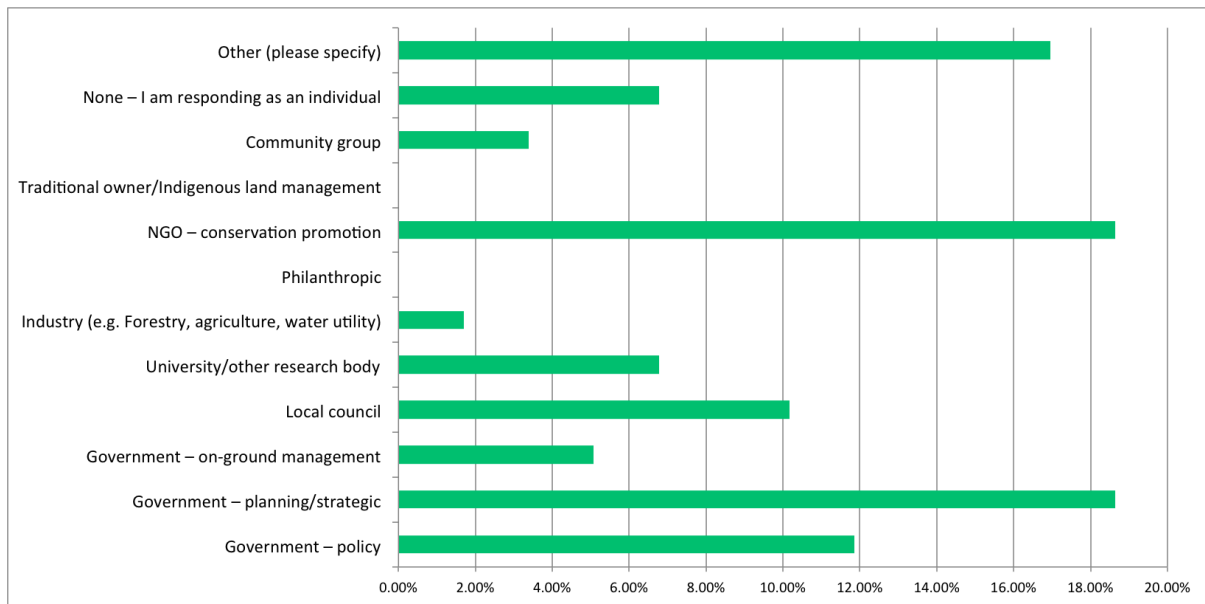


Figure A.1 Percentage of survey respondents in each organisation type

Appendix 2. Climate change projections and consequences for biodiversity and ecosystems

A2.1 Climate change projections

Table A.4 presents a general overview of recent climate change and projected changes for Australia and Queensland.

Table A.4 presents a high level summary of recently observed and projected future climate trends out to 2100.^{2, 8, 54} Considerable detail (including regional information) is available on the Climate Change in Australia website and technical reports: www.climatechangeinaustralia.gov.au

The recent past	The future
Air temperature	
<p>The Australian average surface air temperature has risen by 0.9°C since 1910. Over the past 50 years Queensland air temperatures have increased, with parts of the state (e.g. south-western areas) warming at the fastest rate in Australia. There has been a shift to more extremely warm days and fewer extremely cool nights.</p>	<p>There is very high confidence that, if greenhouse gas emissions continue under a business-as-usual scenario (Representative Concentration Pathways 'RCP' 8.5) projected changes will include the following.</p> <p>Australia's temperatures are projected to increase by between 2.8 and 5.1°C above 1910 temperatures by the year 2100.</p> <p>We will experience progressively fewer frosts.</p> <p>Very hot days will occur more frequently, and warm spells will last longer. For example, some models project that by 2090 Cairns might experience around 100 days over 35°C in an average year, while Windorah could experience around 140 days per year hotter than 40°C.</p>
Rainfall, precipitation and run-off	
<p>Since the mid-1990s, there have been substantial long-term changes in rainfall over Australia. In Queensland we have seen below-average rainfall from April–October and above average rainfall from October–April for much of the state. Since the 1970s, there has been increased rainfall across northern Australia.</p>	<p>The direction of change in rainfall is uncertain for most of Australia. Natural variability is expected to dominate Queensland's rainfall patterns in the next two decades. Beyond that time, models project both substantial increases and decreases. It is likely that rainfall will be less predictable, including seasonal patterns. The intensity of extreme rainfall events (wettest day of the year and wettest day in 20 years) is projected to increase, likely leading to more extensive and prolonged flooding. Drought will continue to be a feature of Queensland's climate, though it is not clear whether or how the intensity or frequency of drought will change.</p>
Sea level rise	
<p>Globally averaged sea levels have risen by over 20 cm since the late 19th century. The largest rises in Australia over the past 25 years have happened along northern Australia's coast, including Queensland's Cape York.</p>	<p>There is very high confidence that Australian sea levels will continue to rise. The rate will be faster during the 21st century than experienced over the past four decades. Sea-level projections for the Australian coastline by 2090 are projected to be as high as between 45 and 82 cm. Some sea-level rise researchers have suggested that these projections may be conservative (e.g. https://sealevel.nasa.gov/understanding-sea-level/projections/empirical-projections) because they do not account for the possible impact of melting or displacing major terrestrial ice sheets. A risk-</p>

The recent past	The future
	management approach would involve consideration of projections that include higher sea level rises.
Ocean temperature and acidification	
<p>Australia's oceans have experienced substantial warming with sea-surface temperatures warming almost 1°C since 2010.</p> <p>Since around 1850, the oceans have absorbed between one-third and one-half of the CO₂ emitted to the atmosphere. As a result, the average pH of ocean surface waters has fallen by about 0.1 units, from 8.2 to 8.1. Because pH is measured on a logarithmic scale, one whole pH unit indicates a tenfold change in ocean alkalinity/acidity (a pH of 7 is neutral).</p>	<p>There is very high confidence that sea-surface temperatures around Australia will rise, with near coastal sea-surface temperatures around Australia expected to rise by between around 0.4 and 1.0°C by 2030, and by 2 to 4°C by 2090 under RCP 8.5 compared to current (1986–2005).</p> <p>Australian oceans will become less alkaline with a projected increase in acidity of 0.4 by 2100.</p>
Changes in atmospheric greenhouse gas concentration	
<p>Global average annual CO₂ levels are steadily increasing and reached 405 parts per million (ppm) in 2017. Prior to the Industrial Revolution levels were around 180 ppm.</p>	<p>Future levels of anthropogenic greenhouse gases and aerosols depend on trends that are hard to predict. These include technological developments and transfer, political will and social factors. In a high-emissions scenario, it is projected that the Earth's atmosphere might reach 1370 ppm of carbon by 2100.</p>
Evaporation and evapotranspiration	
<p>No clear changes have been observed in pan evaporation across Australia in data available since 1970.</p> <p>There is a broadscale pattern of decreases in pan evaporation across northern Australia in regions that have seen recent increases in monsoonal rainfall.</p>	<p>Increased warming and radiation (if cloudiness decreases) will increase potential evapotranspiration and evaporation.</p>
Tropical cyclones	
<p>The number of tropical cyclones each year has decreased. No trend in intensity can be discerned.</p>	<p>Tropical cyclones are projected to become less frequent but more likely to be high-intensity storms (stronger winds and greater rainfall). There is some chance that more cyclones will track further south (e.g. 25 degrees latitude).</p>
Fire weather	
<p>There has been an increase in the high (90th percentile) Forest Fire Danger Index (FFDI) since 1974 across Australia, especially in southern and eastern Australia, and the fire season has lengthened. Increasing temperatures and drying contributed to the observed upward trend in FFDI.</p>	<p>For southern Queensland, it is expected that there will be more fire weather. While modelling suggests little change in the risk for tropical and monsoonal northern Australia, the length of the fire season has increased significantly in these areas. Confident projections about fire risk are difficult because of the important role of fuel loads. These are driven by rainfall and future patterns for them are unclear.</p>

A2.2 Consequences of projected climate changes for biodiversity and ecosystems

As climate changes, conditions in an area may become more or less suitable for a species with some advantaged and many more likely to be disadvantaged. The responses of individual native species, as well as introduced species and invasive pests, to climate change will be determined by their inherent adaptive capacity and external factors. Taken collectively, these responses will change ecosystems. For most species we have a very limited understanding of this potential adaptive capacity.³⁰

Table A.5 Summary of consequences of climate change for biodiversity and ecosystems

Changes in distribution and abundance
<p>Species distribution can be closely matched to climate conditions ('climate space', usually defined by temperature and rainfall), although apparently suitable climate space can be unoccupied for a range of reasons, including habitat type, fire regime, interactions with other species, and enduring effects of historical climate change on species distributions.^{25, 57} Changing patterns of climatic conditions are expected to lead to substantial, multi-directional shifts in climate spaces, including poleward, west to east and altitudinal shifts.⁵²</p> <p>The climate record suggests that there are four possible responses of biodiversity to substantial climate change:</p> <ol style="list-style-type: none"> 1. persistence throughout current distributional range – likely to be because of a wide physiological tolerance to climatic variation, the ability to modify behaviours, or phenotypic plasticity. 2. persistence in areas of the range that remain climatically suitable (internal refugia) but disappearance from other parts of the current distribution (range contraction) 3. a shift in distribution to areas of suitable climate that are outside the current distribution (external refugia, range shift) 4. extinction – either because there are no remaining climatically suitable areas or because it's not possible for individuals to (i) survive in or (ii) colonise the remaining areas with suitable climate conditions. <p>The responses of individual species and populations will depend on several factors that are related to specific traits, such as motility, mobility, dispersal life cycle, niche breadth, and degree of habitat specificity.^{44, 47} For example, some organisms may be able to persist through climatic extremes by changing their behaviour (e.g. being active during cool periods), by using fine-scale 'micro-refugia' (e.g. rocks, boulders, logs, crevices), or because of topographical features (e.g. aspect, proximity to watercourses and altitude) that provide protection from climate shifts for some time into the future.²⁵ Populations with the potential to colonise new areas (leading-edge or frontline populations) are likely to be disproportionately important in range shifts and research shows that individuals in leading-edge populations can have distinct behavioural and physiological traits.</p> <p>The two obvious differences between past and current periods of climate instability are first the rate of current anthropogenic climate change and second, the suite of other pressures on biodiversity. The first of these may exceed the inherent adaptive capacity of species, and the second may diminish or improve a species' adaptive capacity. For example, the persistence of species and populations is also limited by other threats, as evidenced by the already large number of species in decline, independent of a changing climate. If these threats affect the availability of adaptation options (e.g. heavy weed infestation preventing recruitment of a plant species in the remaining areas of suitable climate space), then this will reduce adaptive opportunity for this species.</p>
Changes in individual biology
<p>Potential biological responses to climate change include changes in growth and rates of photosynthesis in plants and algae, changes in metabolic rates, altered phenological patterns, and changes in behaviour, morphology and physiology. These changes will be driven not only directly by changes in the climate, but also indirectly by secondary environmental effects such as increased salinity, higher atmospheric CO₂, increased ocean acidity, changes in disturbance regimes and so on. The outcomes for individual species are difficult to predict. For example, warmer temperatures and greater CO₂ availability may have a positive effect on the growth of certain types of plants, although not if moisture is limiting.²⁹</p>

Changes in biotic interactions

Most species interact with other species in some way, either directly (e.g. pollination, predation) or indirectly (e.g. decomposition and the plants that make use of soil nutrients). These interactions mean that impacts on one species have the potential for flow-on consequences for other species (e.g. increased numbers of insect-eating vertebrates reduces herbivory on plants). Where (directly or indirectly) interacting species have different responses to climate change, we can expect 'decoupling' of interactions. In addition to affecting habitat suitability for interacting species, these changes may affect ecological processes that depend on these interactions (e.g. seed dispersal, nutrient cycling and pollination). These in turn underpin ecosystem functions.³⁰ There is likely to be some level of functional redundancy in many interactions (i.e. one species can perform the role of another), meaning that ecosystem processes may be maintained, albeit with fewer or new species. However, there are also likely to be cases where altered abundance of a particular species will have cascading effects for ecosystem function, especially if change in the co-occurrence of species in ecosystems (see below) reduces functional overlap in assemblages.

Changes in ecosystem assemblages

As species distributions contract or shift, and as increases and decreases in abundance (including extinctions) occur, the composition of ecosystems will also be likely to change. Resultant ecosystems may retain similar species composition, but those species may occur in different relative abundances, potentially with a shift in dominance. The general character and function (e.g. rainforest, coral reef) of such systems may be retained, or changing species distributions and interactions may result in novel ecosystems that comprise very different assemblages or communities of species from those we currently recognise.¹ These transitions may be most likely in cases where extreme weather precipitates disturbance events that transform ecosystems from one state to another, for example where repeated coral bleaching, crown of thorns starfish and cyclone impacts transform a coral reef system to an algae-dominated system,¹¹ or where extreme fire weather, coupled with invasion by flammable weed species allow intense wildfires to convert closed to open forest.¹⁷ More intense extreme weather will mean that such transformative events are more likely than they are now, and shorter return periods (i.e. their increased frequency) may prevent the return of some systems to their previous state. Generalised Dissimilarity Modelling has been used to understand the scale of potential change in Queensland's vascular plant communities, with results suggesting that much of the state could conceivably experience a shift in climatic suitability for up to 50 per cent of plant species by 2070.¹⁴ This work identified Plant assemblages associated with climate spaces that are at risk of disappearing, as well as areas expected to support novel Plant assemblages because of the extent of projected climatic change. The slow growth and reproduction of trees, and their often limited dispersal, means that the scale of plant species turnover is likely to be considerably less than projected in these types of models. It is likely that large climatic change will result in depauperate vegetation assemblages over time as existing individuals fail to recruit.

Interaction with existing stressors

Changes to the climate are likely to interact with existing disturbances including land-use changes and other agents of change, typically amplifying impacts on biodiversity and ecosystems. For example, increases in water stress from climate change-induced drought, higher temperatures and evapotranspiration, combined with high grazing pressure would be likely to result in reduced ground cover (i.e. shrubs, forbs and cyanobacteria), increasing soil temperatures and a self-reinforcing cycle of vegetation degradation. The response of invasive species to climate change is of concern (e.g. novel agricultural pests, weed species and pathogens). Invasive species are expected to respond to climate change in different ways. There is a general expectation that tropical and subtropical weed species will move towards the poles, although complex interactions with other species and the environment will provide exceptions to this trend. Increased risk of disturbance events may also provide opportunities for species to colonise new climate space as it becomes available, since weed species are often characterised by high dispersal ability and expanding populations. There is also the potential of an increasing threat from introduced species that are not yet invasive ('sleeping species'); native species may also have impacts that resemble those of introduced invasive species as they respond favourably to changing conditions (e.g. the barrens-forming sea urchin colonising southern locations in temperate south-eastern Australia²⁴). Some pathogens and diseases may also change in their prevalence, extent

or impact under changed climate conditions. For example, there is considerable concern that myrtle rust, *Austropuccinia psidii*, may benefit from changing climate conditions, with potentially devastating consequences for plants in the Myrtaceae family (e.g. eucalypts, paperbark, bottlebrush, tea tree, lilly pilly).

Habitat fragmentation is a pre-existing threat to biodiversity that will interact with pressures from climate change. For example, if the usefulness of remaining habitat declines (e.g. if it no longer provides enough protection during more extreme weather), the area of remaining effective habitat will be reduced and further fragmented.

Impacts on ecosystem services

Biodiversity and ecosystems provide services on which humans depend for survival (e.g. clean air, fresh water, productive soil), as well as for materials (e.g. food, timber) and for their commercial value (e.g. ecotourism, agriculture, mineral resources, fisheries). In many Australian Indigenous and other remote communities, terrestrial, freshwater and marine habitats yield critical resources, particularly fish and other seafood, bushfoods and medicines. Changes in biodiversity and ecosystems will impact on ecosystem services, although it may be possible that ecosystem services could be maintained in a situation where biodiversity was not (e.g. protection from soil or dune erosion may be provided by a range of plant species, including introduced species, whereas nectar and fruit-feeding animals depend on resources provided by suites of species).

Ecosystems also deliver a range of benefits to humans referred to as adaptation services, for example by providing protection or buffering against the impacts of climate change, and by retaining adaptation options for the future. Greater diversity can provide redundancy and mean that ecosystem services are maintained, although there are examples of individual species, or small suites of species, that perform specific functions (e.g. keystone predators) and their removal from a system can impact ecosystem services.

Appendix 3. Analysis of stakeholder engagement

The project team developed the Plan through considerable stakeholder engagement that included targeted conversations with individuals or work groups, a discussion paper and online survey and a series of regional workshops. We attempted to obtain representation from across the domains of biodiversity and ecosystem management and Queensland.

A3.1 Summary of key issues identified by the sector

Respondents identified most climate impacts as a risk to biodiversity and ecosystems, but in particular changes in rainfall and extreme events (Figure A.2). All impacts were identified as being relevant to organisations (Figure A.3).

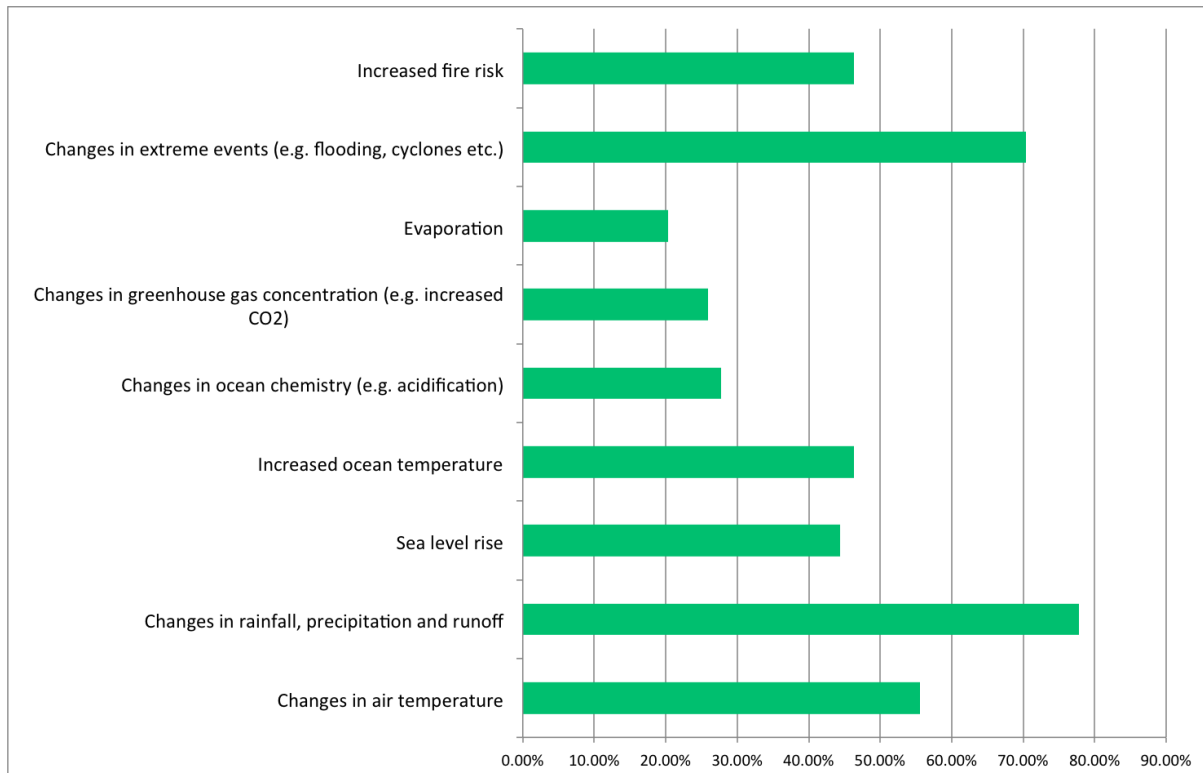


Figure A.2 Percentage of survey respondents who considered particular climate changes as the greatest risk to biodiversity and ecosystems (n = 61)

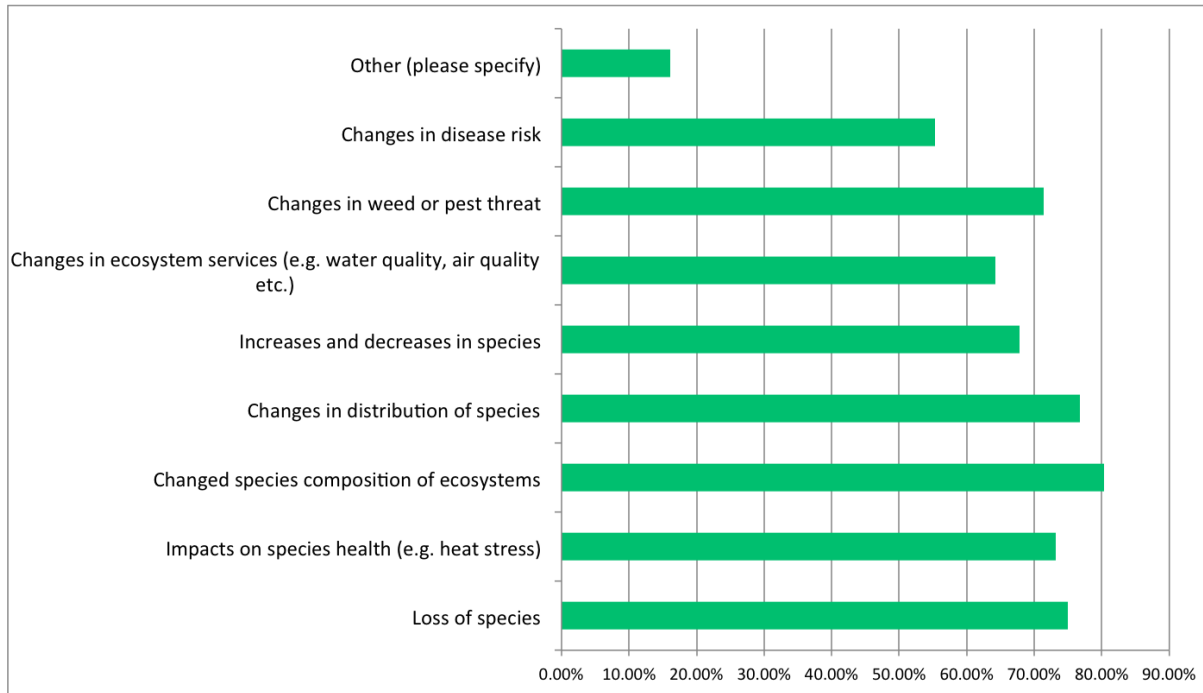


Figure A.3 Percentage of survey respondents who identified that particular climate change impacts were relevant to their organisation (n = 61). Respondents could tick more than one impact.

We asked stakeholders what key issues the Plan should address. A number of key themes were common in discussions and survey responses are listed in Table A.6 below.

Table A.6 Summary of potential issues stakeholders considered the Plan could address

Issue to address	Role of Plan in adaptation
Reduce species extinction	Prevent overall loss of biodiversity and ecosystem functions Prevent local extinctions
Develop resilience of ecosystems and habitat	Maintain outstanding universal biodiversity and ecosystem values which stakeholders administer and manage Reduce barriers to autonomous adaptation Improve maintenance of community structure, biodiversity and ecosystem function Maintain ecosystem health
Develop landscape-based strategies to provide statewide resilience	Protect areas that will protect species during future climate scenarios Prioritise spending (triaging conservation dollars), prioritise areas that have best chance of being preserved/maintained/enhanced to ensure ecosystem services Prioritise regionally, that is, 'Regional specificity – within each region identity the highest priorities. This will make the Plan useable and relevant for managers'. Plan for long-term outcomes (forward planning) Create appropriate movement/range corridors, focus on connectivity

Issue to address	Role of Plan in adaptation
	<p>Include/create urban 'forests'</p> <p>Inform planning processes</p> <p>Manage matrix land to make less hostile to species movement</p> <p>Create minimum standard (x quantity of a Regional Ecosystem) benchmarks for each region</p> <p>Develop statewide/consistent biodiversity and conservation metrics for local governments</p> <p>Provide space</p> <p>Maintain realistic objectives under different climate scenarios (e.g. we may be able to save coral under RCP 2.6 but not RCP 8.5)</p> <p>Change legislation</p> <p>Provide genuine incentives</p>
Improve knowledge	<p>Complete baseline studies (know what we have, benchmark)</p> <p>Provide reliable and contemporary knowledge</p> <p>Map those areas that will be most affected</p> <p>Develop knowledge on susceptible species</p> <p>Collate scientific evidence</p> <p>Provide guidance for decision-making around innovative approaches</p> <p>Provide guidance on management response to various risks (e.g. temperature sensitivity and moisture sensitivity)</p>
Transition to adaptive management	<p>Shift focus to broader system functionality beyond maintenance of current systems – anticipate impacts and novel conservation measures</p> <p>Carry out specific climate adaptation actions (acknowledge some impacts faster than ability to autonomously adapt)</p> <p>Outline management options for different environments</p> <p>Manage fire appropriately</p> <p>Identify and clearly define actions including tipping points, thresholds; associate timescales and resource implications</p> <p>Link monitoring to climate scenarios</p> <p>Understand pros and cons of options</p> <p>Take a pathways approach</p> <p>Integrate with socio-economic narrative</p> <p>What 'no regrets' actions can be adopted now</p>
Improve awareness and social values	<p>Raise awareness of potential impacts, improve buy-in</p> <p>Develop and promote shared vision</p> <p>Communicate the values</p> <p>Building a sense of urgency</p>

Issue to address	Role of Plan in adaptation
Increase ability to work across sectors and departments	Develop biodiversity outcomes into other forms of adaptation Facilitate consistent approaches to incorporating climate change into management and planning Avoid maladaptive outcomes Accountability Consider how sectors interact Increase integration into existing planning frameworks
Reduce existing stressors	Respond to linked stressors Reverse damage already underway
Provide adequate funding	Dedicated budgets Provide appropriate investment in conservation activities to improve resilience

A3.2 Summary of existing work in the sector

Over 80 per cent of survey respondents indicated that they were already engaged in some kind of climate adaptation or mitigation activities. It was clear at the workshops that this was likely to be similar for attendees. Activities included:

- working to mitigate greenhouse emissions
- assessing impacts and risks
- planning (including fire management, refugia identification, etc.)
- education, communication and awareness raising
- monitoring
- land acquisition and habitat protection.

Appendix 4. Explanation of adaptation principles

The seven adaptation principles identified by reviewing existing information (Appendix 5, Table A.8), targeted interviews, and workshops are as follows.

1. Use dynamic, evidence-based and transparent strategies to facilitate autonomous adaptation of biodiversity and ecosystems

Ecosystems and biodiversity change in response to new conditions, and the extent to which they can do this influences their capacity to adapt. People change ecosystems through their management interventions. New, unprecedented climatic conditions will likely require different approaches. While overall objectives for management would not be likely to change (e.g. retain the Great Barrier Reef [GBR] as a coral reef system), finer-scale objectives may require revision. For example, a focus on optimising ecosystem function, ecological processes and ecosystem services may have better adaptation outcomes than traditional management which preserves current species composition, distribution and assemblages and predominantly assume a relatively stable climate. In the GBR example, this could involve the deliberately introducing coral species that tolerate warmer conditions, but that are not currently found in the region. In a stable climate, it makes sense to use historical reference points of ecosystem condition (e.g. the pre-clearing or pre-European composition of vegetation systems).¹ However, because of new and changing climate conditions, substantial ecological change is to be expected. Therefore, our knowledge of past states may help to understand rate of change rather than being the desired objective or goal of conservation. New management objectives may, as a result, focus on maintaining ecological function, landscape processes⁵⁵ and evolutionary process.³⁵

While decoupling management objectives from species or assemblage composition may be appropriate, there are concerns about the potential for unintended consequences, and questions about how to apply this to on-ground management. Current frameworks for the legal protection of natural systems are based on species and ecosystems. Furthermore, there are concerns that 'whole-of-ecosystem' or ecological process-based approaches may fail to protect vulnerable species. Finally, it is difficult to apply the concept of 'maintaining ecological processes' to many aspects of on-ground management, which typically incorporate species occurrence, abundance and behaviours as decision cues for management. It may be possible to formulate objectives that are based on more tangible characteristics, such as structural or functional diversity or species richness, without specifying species.¹³

2. Maintain viable ecological processes and functions

There are two key reasons why adaptation includes a focus on maintaining viable ecological processes and functions. First is to maximise species survival. Our natural areas already experience a number of pressures and stressors that impact on the ability of species to survive and thrive. Climate change is likely to amplify some of those stressors. By investing in maintaining condition, we optimise the chance for species to adapt to new climate conditions.

Second is to lay the groundwork for future management decisions. Future options for adaptation and management will be limited if ecosystems are already compromised by other stressors or pressures. By investing in building the condition of ecosystems now, we retain options for future management.

3. Consider longer time frames and larger spatial scales

Climate change is affecting all regions and all organisms at once, albeit in different ways. The impacts of climate change will persist for a long time (many decades or several centuries). In acting to minimise the climate risks to biodiversity and ecosystems and to maximise adaptive opportunities for biodiversity and ecosystems in the future, it is necessary to consider a trajectory of change over a period of decades and a spatial scale of several regions to statewide. Landscape-based approaches¹² to planning recognise the large spatial scale of climate responses and have the potential to transcend usual jurisdictional boundaries (e.g. state borders). They have potential to be useful as climate change adaptation strategies, but they may be challenging to implement.

4. Use flexible and adaptive evidence-based decision-making processes and practices to help account for uncertainty

Management and planning will need to contemplate a range of options and must be relevant and feasible under a range of future plausible scenarios. While models can provide scenarios of the future

largely based on climate envelopes, they can't capture the complexity of interactions and factors that determine the fate of a species. This complexity, added to the larger time and spatial scales involved, demands more nimble and flexible approaches to managing biodiversity and ecosystems, including providing as much opportunity as possible for adaptive change. Adaptation pathways approaches (Box A.1) are one method of long-term planning that can incorporate multiple divergent futures, identify when decisions about different options may need to be taken, and avoid decisions that might lock management into a particular strategy (e.g. path-dependency) or foreclose future options. Long-term monitoring of the responses of biodiversity and ecosystems to climate change and to adaptation interventions will become important to inform adaptive decision-making and management.

5. Collaborate across sectors and jurisdictions to maximise co-benefits and minimise maladaptive outcomes for biodiversity and ecosystems

Competing land uses and demands for resources already have large impacts on natural systems and their management. Climate change will mean that some of these conflicts are amplified or become more complicated (e.g. more restricted availability of fresh water in semi-arid and arid parts of Queensland, leading to reduced ecological flows and increased demand from industry). Cross-sectoral impacts and opportunities need coordination. Regional NRM groups typically maintain diverse stakeholder networks and could effectively coordinate engagement across sectors.

6. Collaborate within the biodiversity and ecosystem sector to improve the exchange and co-production of knowledge including through equitable governance and management partnerships with Aboriginal and Torres Strait Islander peoples

For managers of biodiversity and ecosystems, climate change means identifying and adopting new management objectives and adaptation options in a complex and uncertain decision-making environment. Although the scale of the problem is cast in terms of longer time scales and larger geographical spaces, it is likely that management decisions will be made at the local scale, drawing in part on local knowledge, experience and desired outcomes.

Collaboration within the sector across all domains of management will deliver efficiencies from economies of scale and the sharing of data, expertise and decision-making tools.

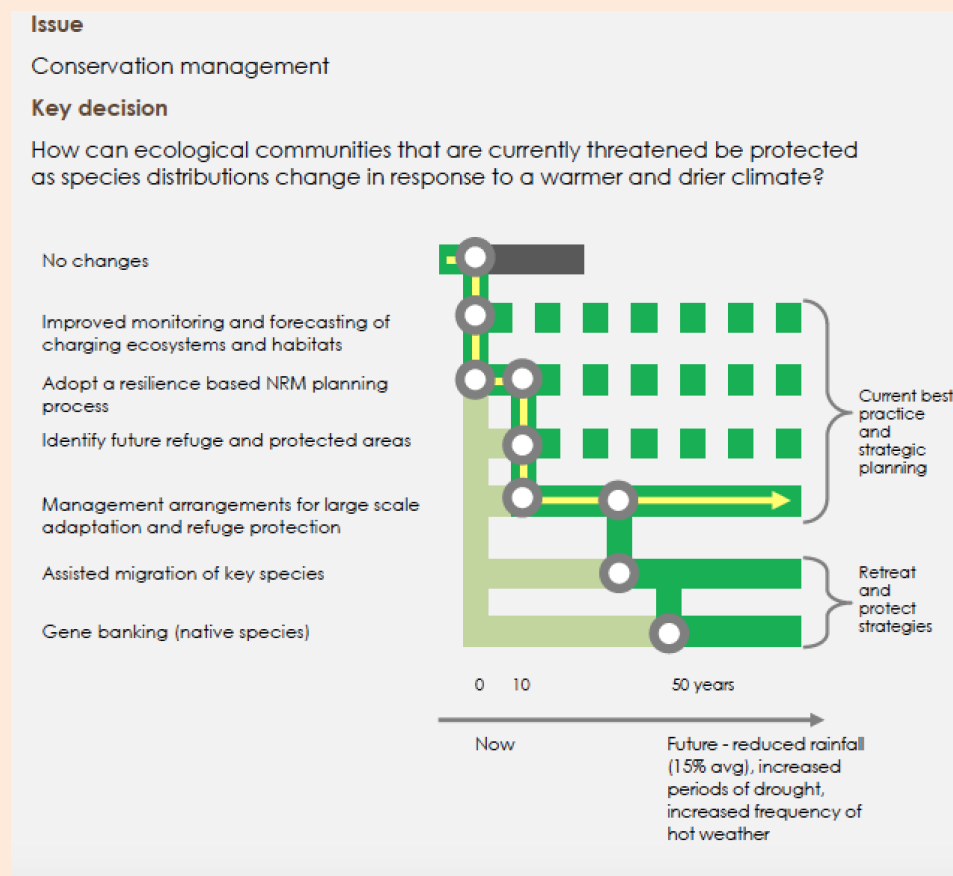
7. Recognise that adaptation action does not diminish the urgent need to reduce greenhouse gas emissions

Without substantial mitigation, opportunities for adaptation in natural systems will be extremely limited because change will be too large and too fast for most species and systems. It's important to recognise that maintaining healthy biodiversity and ecosystems contributes to mitigation, by maintaining (or improving) carbon sequestration. It also keeps open adaptation options for other sectors.

Box A.1 The pathways approach for biodiversity and ecosystems

'Pathways' in adaptation is an approach designed to support strategic, flexible and structured decision-making. It helps identify those decisions that need to be taken now and those that may be taken in the future. It seeks to avoid being locked-out of options in the future. Decision-makers plan for, prioritise and stagger investment in adaptation options. Trigger points and thresholds help them identify when to revisit decisions or act. Decisions can be represented in visual aids such as route maps which help with consultation and engagement.

The pathways approach enables managers to consider a range of options (including those that would normally not be considered) and what actions are needed now to prepare for the future.



Example of an adaptation pathways route map developed by the Eyre Peninsula Climate Change Agreement Committee to explore options for how ecological communities that are threatened could be protected under climate change.⁴⁹

Appendix 5. Current research, knowledge, legislation, and programs relevant to the Plan

This section provides an overview of work across the sector about managing biodiversity and ecosystems for climate change adaptation in Queensland. The review covers the dominant directions of current work across the sector, rather than comprehensively catalogue every activity. The content is based primarily on information provided during interviews, workshops and in survey responses, together with a limited review of published work. This section is organised under the four domains of biodiversity and ecosystems management used in this project to subdivide work in the sector: i. research and knowledge building; ii. policy, planning and legislation; iii. on-ground operations and implementation; iv. engagement and advocacy.

A5.1 Research and knowledge building

The science of climate change adaptation is relatively new and while the body of knowledge is growing, we are still at the stage where there is limited experience of developing, implementing and evaluating adaptation options. As a result there are few examples of adaptation that address the complexity of multiple interactive and cumulative changes in natural systems or that incorporate the uncertainty associated with climate change adaptation. There are, however, emerging concepts that can guide how we think about adaptation. A number of reports synthesised research findings.^{e.g. 4, 19, 39, 55, 59} An annotated list of key reports on climate change and biodiversity and ecosystems in Queensland is included in Table A.7. Research work most relevant to managing Queensland's biodiversity and ecosystems for adaptation, has principally focused on informing the planning and policy element of management. In Table A.8 we summarise key research and knowledge building work.

Table A.7 Summary of research and knowledge building work to manage for adaptation of biodiversity and ecosystems to climate change impacts

Area of research	Summary
Baseline information and monitoring data	<p>Queensland has a comprehensive mapping and monitoring program for vegetation and the Great Barrier Reef (GBR) has had extensive baseline surveys. The Atlas of Living Australia https://www.ala.org.au/ provides an accessible, central collection of information about the occurrence of species; numerous research projects have looked at individual species and ecosystems, including responses to various stressors and threats. WetlandInfo https://wetlandinfo.ehp.qld.gov.au/wetlands/ is an online portal that provides mapping and other information relevant to the state's wetlands including creeks, rivers, estuaries, mangroves and marshes. Some work has been done to collect data targeted at detecting changes resulting from climate change.⁵⁷</p> <p>Establishing long-term monitoring programs to build on existing baseline datasets is an important part of knowledge building to inform management of biodiversity and ecosystems for adaptation and is done through a range of research projects (e.g. Terrestrial Ecosystem Research Network http://www.tern.org.au/). Monitoring has been integrated into on-ground operations, for example in private conservation organisations (e.g. Australian Wildlife Conservancy, Bush Heritage Australia) and many national parks and Indigenous ranger programs.</p>
Scenarios of species distribution	<p>Modelling is being used to develop scenarios of changes in species distributions under climate change. Most techniques focus primarily on the known climate envelope that characterises the current distribution of a species or assemblage. Several research projects have used species distribution modelling or niche modelling to determine the likely climate spaces that might support species into the future (including 'refugia'^{27, 37, 38, 46} Box A.2), and which could be prioritised for protection or restoration. Indeed, the Queensland Government has used modelling of potential refugia to acquire additional properties for the protected area network. Species distribution modelling has also been used to identify species for which suitable climate space is projected to vanish⁵⁷ and which may be candidates for assisted translocation or captive breeding. Generalised dissimilarity modelling has been used to project the extent to which species assemblages could be expected to</p>

	change under different emissions scenarios. ^{14, 56} Potential climate space for weed species has also been modelled ⁴⁵ and may help prioritise weed species for control.
Identifying refugia	As previously described, species modelling has been used to provide scenarios of future refugia (Box A.2). There is little information for arid zones, particularly western Queensland where low relief may mean the availability of aquatic refugia is very limited. ⁵⁵ Further, rapidly increasing temperatures and evapotranspiration may cause the precipitous loss and further fragmentation of aquatic habitats, leaving few potential refugia.
Management objectives	There is a growing body of knowledge around adapting the very fundamental objectives of biodiversity and ecosystem management to the changes presented by climate change. ^{13, 34, 35} In essence, this involves a shift from aiming to preserve species and ecosystems as and where they are to maintaining ecological processes and ecosystem functions, and allowing change in species composition and ecosystems.
Planning frameworks and decision support	There is research relating to developing risk-assessment and planning frameworks for adaptation, ^{10, 13, 42, 48, 58} including participatory systems for Indigenous-driven adaptation. ¹⁸ Reside et al. ⁴⁰ provide guidance on key components of spatial conservation planning to favour approaches that protect and restore biodiversity conservation. Options for managing for adaptation to climate change in protected areas within the Gondwana Rainforests World Heritage Area (WHA) have been evaluated. ⁵¹ A framework for vulnerability assessment with respect to climate change has been developed. ⁵⁸
Ecosystem and adaptation services	There is emerging work on the ecosystem and adaptation services provided by ecosystems and their biodiversity (summarised by Williams et al. ⁵⁵). This may help quantify how human's value natural systems.
Practical implications	<p>There is growing research into how on-ground interventions may be able to facilitate the adaptation of biodiversity and ecosystems to climate change, for example practicalities of coral restoration through experimental larval re-seeding⁹, issues associated with assisted colonisation²⁰ and potential approaches to assisted gene flow.²⁶</p> <p>Dynamic ecosystem modelling is helping to understand likely trajectories of change in ecosystems https://research.csiro.au/biodiversity-knowledge/projects/models-framework/</p> <p>Research is also looking at how restoration can be adapted to climate change, for example, by integrating short-range seasonal weather forecasting into timing of revegetation.¹⁶</p>

Box A.2 Modelling climate space to identify refugia, vanishing climate space and novel climates

There is evidence in past climate change (over geological time) that populations of species survived, evolved and subsequently recolonised areas by relying on refugia. Interest in the idea as potential safe havens for species under contemporary climate change has led to not only a diverse array of technical definitions of the term, but also to an interest in understanding where future refugia may exist in the landscape.

'Climate change refugia' are specific locations in which climate conditions will be fairly well buffered from contemporary climate changes. Biodiversity (often as relics of past populations) can persist in these areas, potentially expanding from them if conditions in surrounding areas become more suitable again in the future. Refugia generally occur in places of unique local conditions (e.g. favourable aspect or topography). To perform as refugia, areas will need to:

- be large enough to support viable populations or meta-populations
- support the range of habitat requirements of species, including symbiotic interactions.

Refugia are different from micro-climate refuges more commonly termed micro-refugia that provide smaller scale, usually temporary refuge from exposure or disturbance³² (e.g. protection from high temperatures in boulder piles).

In relation to climate change, climate refugia is typically applied using 'climate space' mapping. This involves defining the climatic characteristics of the areas where a species currently occurs to determine their climatic 'envelope', then mapping the spatial distribution of these conditions as their climate space.

Modelling can then be used to map future projected distributions of the species' climate space, representing the projected distribution of climatically suitable areas for that species. Some areas that are currently suitable may remain so, while other areas that are currently unsuitable may become suitable.

Both areas are considered to be climate refugia, although the usefulness of the second type would depend on the ability of the species to disperse to and colonise areas beyond its current range (unlikely for many species; Box A.3). Information about refugia can be used to prioritise areas for protection or restoration and to identify refugia potential (e.g. artificial water bodies).

Climate refugia modelling has also been used to identify species and assemblages that are at risk of disappearing. That is, areas that are currently suitable become unsuitable and there are either no other areas expected to support suitable climate (i.e. vanishing climate space), or there is small chance that they would be able to colonise and survive in remaining/new suitable climate space.

Climate space modelling can also identify where previously unknown climatic conditions are expected to occur (no-analogue climates).

Climate refugia modelling does not deliver predictive maps of species distributions. It does offer potential scenarios based on a range of assumptions and can indicate the size and direction of change managers can expect to face.

Table A.8 Annotated list of key information sources relating to the adaptation of biodiversity and ecosystem management to climate change

Information source	Description
<p><i>Queensland's biodiversity under climate change: impacts and adaptation 2011–2012</i></p> <p>(Synthesis report and five technical reports developed by CSIRO)</p>	<p>In 2011–2012, the Queensland Government commissioned a synthesis of climate change impacts and adaptation options for terrestrial, freshwater aquatic, coastal and marine biodiversity, its ecosystems and the services they provide. The resulting reports and overview synthesis remain an important source of information, modelling and analysis to support decision-making and policy development.</p>
<p><i>Climate Change and Terrestrial Biodiversity in Queensland</i></p> <p>T. Low. 2011</p>	<p>An independent report commissioned by (the then) Department of Environment and Natural Resource Management (Queensland) from author and consultant Tim Low. The report reviewed existing information and evidence relating to the impacts of climate change on terrestrial biodiversity and the author has provided his own analysis of evidence to develop regional scenarios of potential impacts.</p>
<p>WetlandInfo</p> <p>wetlandinfo.ehp.qld.gov.au/wetlands/</p>	<p>The Queensland Government's WetlandInfo web page is a comprehensive repository of information about ecosystems that are 'wet for a period of time' and covers rivers, creeks, estuaries and coral reefs. The site includes:</p> <ul style="list-style-type: none"> • maps and information for local wetlands ecosystems • summaries • management guidelines • case studies • relevant legislation.
<p><i>The Long Paddock</i></p> <p>www.longpaddock.qld.gov.au</p>	<p>The Long Paddock website is a Queensland Government initiative (established in 1995) that provides climate information. Specifically developed for the grazing industry, it nonetheless provides high-resolution climate projections for Queensland.</p>
<p><i>Climate Change in Australia</i></p> <p>www.climatechangeinaustralia.gov.au</p>	<p>Developed by the CSIRO and Australia's Bureau of Meteorology, the Climate Change in Australia website provides reliable climate projections for all regions of Australia. The information is available for NRM bioregions and so provides climate projections at a regional scale for Queensland.</p>
<p>Climate Change in Queensland</p> <p>http://qgsp.maps.arcgis.com/apps/MapJournal/index.html?appid=1f3c05235c6a44dcb1a6faebad4683fc</p>	<p>Developed under the <i>Queensland Climate Adaptation Strategy</i>, the Climate Change in Queensland map application presents regionally specific climate projection information for 13 Queensland regions.</p>
<p>Queensland Regional climate change impact summaries</p> <p>https://www.qld.gov.au/environment/climate/resources</p>	<p>These resources provide basic information on climate change projections for the years 2030 and 2070 at a statewide level and for 13 Queensland regions.</p>
<p>Queensland high resolution climate projection data</p>	<p>High resolution climate change projections for Queensland (approx. <10 km grid) using dynamical downscaling of CMIP5 global climate models.</p> <p>Datasets are available for download via the Terrestrial Ecosystem Research Network (TERN) spatial data catalogue.</p> <p>A user-friendly interface for these projections is due for release in 2019.</p>

A5.2 Policy, planning and legislation

Management of biodiversity and ecosystems is influenced and regulated by several layers of policy, planning and legislation including key global and national frameworks as well as those at state, regional and local levels. Here we highlight key policy, legislation, programs and actions from all levels.

Global frameworks

- The Paris Agreement is a global agreement to limit global warming to well below 2°C above pre-industrial times (as close to 1.5°C as possible). Also defines a global goal to enhance adaptive capacity and resilience and to reduce vulnerability through adaptation.
- The *Strategic Plan for Biodiversity 2011–2020* sets the global framework for priority actions on biodiversity through its Aichi Biodiversity Targets which have been adopted under the international Convention on Biological Diversity.
- 2030 Agenda for Sustainable Development (2030 Agenda) includes biodiversity and ecosystems across many of its Sustainable Development Goals and associated targets.
- Intergovernmental Panel on Biodiversity and Ecosystem Services provides policymakers with objective scientific assessments about the state of knowledge about the planet's biodiversity and ecosystems, and how they contribute to human wellbeing. A global review is expected to consider ways to mitigate climate change as well as future scenarios, possible pathways and policy options.
- UNESCO World Heritage Committee has developed a *Strategy for Action on Climate Change* (<http://unesdoc.unesco.org/images/0025/002592/259255e.pdf>). Development of a Climate Vulnerability Index is a current proposal for facilitating responses to climate change in all WHAs.

National context

- The *Environmental Protection and Biodiversity Conservation Act (1999)* is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places — defined in the Act as matters of national environmental significance.
- Emissions Reduction Fund is the centrepiece of Australia's current climate change policies and supports new practices and technologies to reduce Australia's greenhouse gas emissions.
- The *National Climate Resilience and Adaptation Strategy* is a set of principles to guide adaptation practice and resilience to climate change.
- Reef 2050 Long-Term Sustainability Plan provides an overarching strategy for managing the GBR, including climate change impacts.
- Australia's *Strategy for Nature 2018–2030: Australia's biodiversity conservation strategy and action inventory* is a joint, cross-jurisdictional strategy intended to drive change in biodiversity management priorities, and provide better alignment with Australia's international biodiversity commitments. It is in review following public comment. The Queensland Government is contributing to the cross-government working group considering submissions.

State level frameworks

Two key state level strategies specifically respond to climate change:

- *Queensland Climate Transition Strategy (QCTS)* outlines how Queensland will transition to a zero net emissions future by 2050, while supporting jobs, industries, communities and the environment.
- *Queensland Climate Adaptation Strategy (Q-CAS)* outlines how Queensland will manage current and future impacts of a changing climate by reducing risk and increasing resilience.

The QCTS focuses on cutting greenhouse gas emissions in line with Australia's and Queensland's international commitments, while transitioning Queensland's economy to allow for, and capitalise on, global economic decarbonisation and related economic trends. The two strategies are designed to complement each other. Under the Q-CAS, the work to develop sector adaptation plans for eight sectors is of obvious key relevance to the Plan in terms of cross-sectoral overlaps. Sector adaptation

plans for certain sectors are more relevant than others, for example the tourism, and health and wellbeing sectors. Also under the Q-CAS, the Queensland Government is taking the lead by developing a Government Adaptation Action Plan (GAAP). The GAAP is clearly relevant to the Plan with its focus on Queensland's natural assets and systems.

In addition to these specific policy instruments, the State Planning Policy guidelines consider climate change, in particular sea level rise.

Queensland biodiversity and ecosystems management is subject to a number of Acts and Regulations, including those listed below.

- The *Nature Conservation Act 1992* provides for the gazettal of important ecological areas as protected areas. It also has a number of associated regulations and conservation plans for specific species.
- The *Marine Parks Act 2004* and the *Fisheries Act 1994* protect important marine and estuarine areas as marine parks and fish habitat areas.
- The *Vegetation Management Act 1999* controls clearing of native vegetation in Queensland. Under recent revision, it provides a level of protection to high-value regrowth and remnant vegetation.
- The *Water Act 2000* regulates water extraction from wetlands.
- The *Environmental Protection Act 1994* was established to protect Queensland's environment while allowing ecologically sustainable development.
- The *Biosecurity Act 2014* and *Biosecurity Regulation 2016* ensures a consistent, modern and risk-based approach to providing biosecurity measures that safeguard our communities, economy, agriculture, tourism and environment from pests, weeds, diseases and contaminants.
- The *Biodiscovery Act 2004* regulates and defines biodiscovery activities such that they are managed in a manner consistent with Australia's international obligations under the Convention on Biological Diversity.
- The *Planning Act 2016* and State Planning Policy establish a planning system that includes identifying state interests around biodiversity, healthy waters, coastal environments and heritage and provides for local government planning schemes to identify and protect from any potential significant adverse environmental impacts on matters of local, state and national significance.
- *Environmental Offsets Act (2014)* and associated Strategic Environmental Offset Implementation Tool seek ways to achieve conservation outcomes and identify opportunities for achieving additional co-benefits including social, cultural and economic enhancement. Currently under review.

The legislative setting is complemented by a number of relevant policies, plans and strategies, including those listed below.

- The *State Planning Policy 2017* together with regional plans set out state and regional planning matters to be preserved and protected. These now include climate change adaptation and mitigation, as well as fuller consideration of biodiversity.
- The *Sustainable Fisheries Strategy 2017–2027* intends to pave the way for Queensland to have a world-class fisheries management system. It aims to ensure healthy fish stocks and support for jobs.
- The *Draft Reef 2050 Water Quality Improvement Plan 2017–2022* is designed to address all land-based sources of water pollution including run-off from urban, industrial and public lands; while recognising that most pollution comes from agricultural activities. The Plan establishes water quality targets for the catchments adjacent to the GBR.
- The Basin Plan is aimed at managing the Murray Darling Basin's water for the benefit of all its users and the environment.

In addition, it is worth noting a number of programs and tools that are underway in Queensland that are important initiatives for the biodiversity and ecosystem sector, including the following list.

- The Land Restoration Fund is a \$500 million investment to promote carbon farming initiatives that deliver co-benefits <https://www.qld.gov.au/environment/climate/climate-change/land-restoration-fund>.

- The Back on Track species prioritisation framework considers both level of threat and aspects of species' roles (under review).
- Nature refuge agreements provide the framework for a voluntary conservation covenanting program.
- Biodiversity Planning Assessments (BPA) identify the terrestrial ecological values in a region, or bioregion, according to their conservation significance. Governments, members of the community and landholders use BPAs to make Planning decisions about appropriate land use.
- Aquatic Conservation Assessments are used to identify the conservation value of wetlands.
- The Queensland Government, in collaboration with the National Environmental Science Program (NESP) Northern Australia Hub, is mapping threat-sensitivity for a subset of Queensland's threatened species and threats (e.g. grazing, pest plants and animals) to identify where threat mitigation activities (such as pest control) would achieve the greatest conservation outcome by benefiting the most species. The NESP Threatened Species Hub is also developing tools and methods for improving threatened species decision-making, such as an ASX-like index, to provide reliable and robust measures of changes in the relative abundance of Australia's threatened and near-threatened species.

Regional and local activities

Regional and local actions are important for managing biodiversity and ecosystems and in responding to climate change. Initiatives under QCAS (e.g. Climate Resilient Councils program^f and QCoast2100) are building the capacity of local governments to plan for climate change adaptation. Some local governments are using local planning and acquisition programs to protect habitat beyond those areas protected by higher level legislative mechanisms

NRM bodies recently undertook climate adaptation planning at a regional level supported by the Australian Government's NRM planning for Climate Change Fund.^g Planning approaches varied among NRM clusters, but included work to prioritise adaptation management strategies for biodiversity, synthesise Indigenous knowledge of climate change, decision-making and planning tools and capacity building.^h

There are also examples of property-level actions in Queensland. Those highlighted by stakeholders include those listed below:

- The notion of shifting species distributions has intersected quickly with the 'conduit' notion of landscape connectivity, with large-scale regional connectivity incorporated into some Planning projects. Although there may be limited support for this as a climate response (Box A.3), considering functional connectivity in landscape Planning is supported as important to biodiversity and ecosystems management.
- Queensland Parks and Wildlife Service is developing a Values Based Park Management Framework to Plan for protected areas.ⁱ This process begins by assessing the values of national parks, then identifies the actions required to manage for identified values and includes threats from climate change.
- Conservation focused, not-for-profit organisations incorporate climate change adaptation in their Planning for individual reserves.
- NRM groups, industry bodies and other regional organisations are working to integrate climate change into property planning (e.g. Cape York NRM).

^f <http://qcrc.lgaq.asn.au>

^g <http://www.environment.gov.au/climate-change/adaptation/planning-climate-change-nrm>

^h <https://www.terranova.org.au/>

ⁱ <https://www.npsr.qld.gov.au/managing/framework/>

With the exception of the GBR⁷, the WHAs do not yet have integrated climate adaptation plans. These properties are likely to be important climate refugia in Queensland and climate change has been identified as a potential threat to the Outstanding Universal Value for which they are listed as WHAs. UNESCO has noted that the continued preservation of WHAs means understanding and addressing this threat⁶ and has now developed a *Strategy for Action on Climate Change* to guide properties in meeting this obligation.^j At the time of writing, the Wet Tropics had started climate adaptation Planning and preliminary work had begun for the Queensland section of the Gondwana Rainforests WHA.

On-ground operations and implementation

For terrestrial and freshwater systems, there appears to be relatively few examples of adaptation in operations as a specific response to climate change. In many cases, managing current threats (e.g. invasive species, disturbance regimes, fragmentation, pollution, extraction) is seen as a measure that increases the ability of natural systems to adapt to climate change, because reducing threats is considered to promote resilience. Adaptation of on-ground management in response to climate-driven changes has been incorporated into the location of restoration works. For example, a cleared area identified as a likely climate refuge for a range of high-altitude mammals in the Wet Tropics of North Queensland has been purchased and replanted using funds from the charitable South Endeavour Trust.^k Elsewhere, climate adaptation has been incorporated into operational restoration works. For example, selecting species or seeds from warmer and drier regions may help 'pre-adapt' revegetation to projected changes in climate.

In contrast, marine systems provide several examples of the adaptation of on-ground operational management to climate change. For example, managers of green turtles, *Chelonia mydas*, on Raine Island off northern Cape York Peninsula have reshaped the profile of the beach in an attempt to restore nesting habitat impacted by high-tide inundation from increasing sea levels. Other examples include installing artificial reefs to protect coastlines in southern Queensland and to also facilitate colonisation by southward-shifting reef organisms.

Engagement and advocacy

Mitigating greenhouse gas emissions has been the major focus of advocacy and engagement, with most effort directed towards promoting understanding of the scale of risks posed by climate change. A common concern across the sector is that this has led to negative messaging that may overwhelmed or alienated other sectors and the general community. There are opportunities to adjust approaches to engagement and advocacy by reframing information about climate change based on the values of target audiences.

The Environmental Defenders Office has worked to communicate to the sector and wider Queensland community the implications for climate adaptation of planning law changes.

As part of the NRM Planning for Climate Change Program, information was synthesised into fact sheets that were co-developed by scientists, media, communication and NRM staff to help NRM stakeholders understand high-level impacts of climate change on biodiversity.^l

There are many and ongoing efforts to communicate the value of biodiversity and ecosystems to Queensland communities. Understanding the links between the state of natural systems and human health and multiple dimensions of wellbeing is effectively communicated through the Healthy Country Healthy People initiative. While this is currently applied to Aboriginal and Torres Strait Islander Peoples, it may have potential for communicating with the wider Queensland community.

^j <http://unesdoc.unesco.org/images/0025/002592/259255e.pdf>

^k http://www.southendeavour.com.au/lemuroid_leap.html

^l <https://terranova.org.au/repository/wet-tropics-nrm-collection/climate-change-impacts-and-adaptation-opportunities-1>

Box A.3 Regional landscape connectivity and the colonising of refugia

Investing in 'connectivity' in the landscape is not new, but there has been increased focus in recent years to ensure 'functional connectivity' rather than just structural connections (often referred to as 'corridors') between habitats. Functional connectivity considers an organism's ability to move over different timescales (daily, seasonally, following disturbances, and at different stages in its life cycle) to access resources and disperse. It may or may not be necessary or adequate to improve an organism's ability to move.

One potential approach to climate change adaptation for biodiversity and ecosystem is investing in improving landscape connectivity to allow organisms to occupy suitable 'climate space' potentially outside their current distribution or range. Colonising new areas could be possible if:

- individuals are motivated to disperse to new areas
- there is adequate functional connectivity for individuals to be able to cross the landscape and encounter the suitable climate space (the focus of connectivity adaptation work)
- there are opportunities to recruit or establish in climate change refugia
- they can survive and reproduce in their new habitat (which will depend on factors such as predation and competition).

However, work on leading-edge or frontline populations suggests that individuals involved in such colonisation may have particular characteristics. This means that the option of colonising habitat outside of species' current ranges may be restricted to species and populations with these characteristics. There is limited evidence in the paleo-record of species colonising new areas in response to climate change, especially in Australia. In reality, instead of shifting distributions being caused by individuals moving to new areas, it is more likely that recruitment and survivorship will decline in some areas as climate suitability deteriorates and be maintained or increase in areas with suitable climatic conditions.

Appendix 6. Key cooperative research topics

The following topics for cooperative research were identified through the stakeholder engagement process as key knowledge gaps associated with priority actions.

1. Refine understanding of the ways biodiversity and ecosystems might adapt (in the context of understanding past climate change, as well as population dynamics and other processes) and how management may increase adaptive opportunities and avoid maladaptive outcomes.
2. Develop appropriate measures or indicators of success for Planning/policy and on-ground management relating to agreed principles.
3. Quantify the potential roles of, and trade-offs between, various spatial Planning strategies (including refugia, functional connectivity, restoration) in facilitating the adaptation of biodiversity and ecosystems to climate change, considering current and future values.
4. Incorporate additional climate change information (e.g. flood events, cyclones, sea-level rise, drought) into understanding of future spatial Planning, legislative and on-ground intervention priorities for biodiversity and ecosystems.
5. Develop applied best-practice guidelines for prioritising adaptation action.
6. Synthesise understanding of the options for on-ground management and monitoring of ecological functions, together with implications for Planning.
7. Develop practical understanding of how to manage for ecological function rather than composition, and how this relates to tangible characteristics such as structural or functional diversity, as well as ecosystem processes.
8. Develop understanding of ecosystem 'health', resilience and integrity (link to Planning and on-ground management).
9. Develop understanding of ecological function, species' functional roles, redundancy and relationships between species and functional diversity.
10. Build understanding of warning signals and decision triggers in relation to desired future states, ecological limits, transitions, thresholds and tipping points.
11. Develop understanding of 'species threatened by climate change' in relation to the current 'threatened species' framework and assess implications for Planning, legislation and on-ground interventions.
12. Synthesise information on quantifying ecosystem services, including adaptation services and blue carbon, as well as likely impacts of climate change and the potential influence of Planning, policy and legislation.
13. Develop understanding of Planning approaches (e.g. modified pathways Planning) to allow for decision-making amongst the complexities and uncertainties inherent in the management of social–ecological systems.
14. Develop understanding of trade-offs (spatial, economic, social, cultural) between current and future biodiversity and ecosystem priorities.
15. Develop understanding of a suite of potential implications of climate change for fire and burning practice in the context of cultural and ecological values and dynamic objectives.
16. Prioritise knowledge building in under-studied systems and regions (e.g. groundwater-dependent systems, mycorrhizal assemblages, arid zone systems) in the context of potential climate change impacts and associated advice for Planning, policy, and on-ground interventions.
17. Develop understanding of the likely impacts of seawater intrusion and conversion from fresh to brackish systems.

Glossary

Adaptation – see Climate change adaptation.

Adaptation services – The benefits natural systems can provide to help sectors adapt. For example, protecting mangroves can help protect coastal properties from storm surge.

Adaptive capacity – The inherent ability of organisms to adjust to changing climate, either by taking advantage of opportunities, or by avoiding negative consequences. Adaptive capacity varies depending on characteristics of the organism (e.g. mobility, reproductive rate, behavioural traits, physiology, age, sex) and the impact(s) being considered.

Adaptive change – Response to new climatic conditions that enables persistence. Note that not all responses to changed conditions will necessarily be adaptive (i.e. some may result in failure to survive or reproduce).

Adaptive management – A general management approach involving iteratively planning, implementing and modifying strategies for managing resources in the face of uncertainty and change. In adaptive management, strategies are adjusted in response to their observed effect and to changes in the system brought on by feedback effects and other variables.

Adaptive opportunity – For natural systems, this is about keeping options open and enabling alternative possibilities for organisms to change as needed to persist through climate change (e.g. sheltering during more intense extreme events; foraging in more/different areas in response to changed patterns of flowering; increased seedling recruitment in current marginal parts of a Plant's range).

Assisted migration – Deliberate and controlled movement of individual organisms by humans to areas within or beyond their current range (e.g. to internal or external refugia, respectively) to bolster existing or establish new populations.

Assisted gene flow – Intentionally introducing genetic material (through assisted migration or under captive conditions) from individuals with genetic traits that are more suited to expected future climate conditions. Can involve the same or different species. For example, introducing a population of individuals from another part of the species natural range that is warmer and drier.

Autonomous adaptation – Adaptation in response to experienced climate and its effects, without planning explicitly or consciously on addressing climate change. Also referred to as spontaneous adaptation. Likely to be the dominant form of adaptation for natural systems, in contrast to adaptation in sectors such as built infrastructure, where adaptation will be controlled and deliberate. While managing biodiversity and ecosystems may have the intention of increasing opportunities for the adaptation of natural systems, we lack the capacity to directly control whether or not biodiversity and ecosystems actually make adaptive changes.

Biodiversity – The variety of all life forms on Earth including the Plants, animals and micro-organisms and the ecosystems of which they are a part. This diversity exists at different scales: regional diversity, ecosystem diversity, species diversity and genetic diversity.

Buffer or buffer zone – A zone or area that is intended to provide protection to natural habitat by minimising the impacts of surrounding human uses or activities.

Climate change adaptation – The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment.

Climate change mitigation – Actions to limit the extent of long-term climate change caused by human emissions of greenhouse gases.

Climate transition – Shifts in the economy in response to the way the global economy is changing, and will continue to change, in response to an increasingly carbon-constrained environment.

Co-benefits – Positive secondary benefits for a sector arising from action taken primarily for another reason (e.g. reduce greenhouse gases). For example, re-instatement of Aboriginal burning regimes reduces carbon emissions, but can also have positive environmental, social and cultural benefits.

Decision-support framework – A system that can integrate and analyse the multiple factors and variables involved in making complex decisions.

Ecological process – An ambiguous term, but used in the Plan to describe dynamics arising from interactions between living organisms and/or chemical or physical components of natural systems (e.g. seed dispersal, decomposition, Plant recruitment). Related to *Ecosystem function*.

Ecosystem – A biological community of interacting organisms and their physical environment.

Ecosystem-based adaptation – Involves the conservation, sustainable management and restoration of ecosystems to help people adapt to the impacts of climate change. It is related to adaptation services. Considered to be of particular relevance to developing nations.

Ecosystem function – An ambiguous term, but in the Plan used to refer to the emergent fluxes of energy and matter that result from complex interactions in ecosystems (e.g. nutrient and water cycles). Related to *Ecological process*.

Ecosystem resilience – The capacity for a system to regain structure, composition and function following a stress or perturbation. It can imply return to a previous state, but may be used more to emphasise similar regained function.

Ecosystem service – The benefits provided to humans through the transformations of land, water, vegetation or atmosphere into a flow of goods and services. Examples include clean air, soil, water, food and timber, as well as psychological wellbeing benefits of experiencing nature.

Evolutionary process – The process by which organisms change over time as a result of changes in heritable physical or behavioural traits.

Functional connectivity – Measure of actual ecological connections and interactions. Includes species-specific connectivity. For example, while a physical connection exists (i.e. structural connectivity), species-specific behaviour may prevent them from using that connection. Alternatively, habitats may be functionally connected (i.e. organisms can move between them) even if they are not structurally connected.

Functional redundancy – A species new to the ecosystem can perform the role of another that has been lost and therefore the ecosystem function continues with this new species.

Genotype – The genetic make-up of an individual organism.

Greenhouse gases – Greenhouse gases are gases that trap heat in the Earth's atmosphere, having the same effect as a greenhouse for Plants. The main greenhouse gases in Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone. Carbon dioxide stays in the atmosphere for a long time and is the major greenhouse gas responsible for current climate change. Carbon dioxide is released into the atmosphere when coal, oil and natural gas are burned, forests are cut down or burned and from certain chemical processes (e.g. cement manufacture).

Integrated management – Management that considers multiple factors affecting the species, ecosystem or natural area under consideration.

Landscape processes – Dynamics that derive from the features of a landscape and may include water flows or may be defined in terms of organisms (e.g. the functional connectivity of the landscape arising from the amount, composition and configuration of habitat).

Leading-edge populations – Those populations that are the first to colonise new habitats as part of a shifting species distribution in response to changing conditions.

Limits to adaptation – A barrier to adaptation that cannot be overcome.

Maladaptation – An action that may lead to adverse climate-related outcomes, increased vulnerability to climate change or diminished welfare, now or in the future. It can arise from action taken to avoid or reduce vulnerability to climate change in one sector that (inadvertently) impacts adversely on or increases the vulnerability of other sectors.

Management of biodiversity and ecosystems for adaptation – Management that is intended to facilitate nature's own adjustment and adaptation to new climate conditions in ways that improve the chances of persistence of biodiversity and ecosystems. Recognises that adaptation by biodiversity and ecosystems to climate change will largely depend on the inherent capacity of individuals, populations, species and ecosystems to respond in ways that enable their persistence under different climatic conditions (i.e. their adaptive capacity). See also *Autonomous adaptation*.

Micro-refugia – Relatively fine-scale features that enable persistence of individuals or populations

through climate change e.g. caves, burrows, gullies, boulder piles, tree hollows, rock fissures, deep cracks in soil.

Mitigation – See Climate change mitigation.

Morphology – The form, shape or structure of an organism.

Nature-based solutions – Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges, simultaneously providing human wellbeing and biodiversity benefits. Ecosystem-based adaptation is an example of this.

Path dependency – When an early decision may constrain future decisions

Phenotype – The set of observable characteristics of an individual.

Phenology – Describes how the timing and other aspects of periodic events (e.g. flowering, breeding, migration) are affected by climate and other environmental factors.

Physiology – The way in which a living organisms functions.

Plasticity – The adaptability of an organism to changes in its environment or differences between various habitats. **Phenotypic plasticity** – the ability of one genotype to produce more than one phenotype when exposed to different environments. **Behavioural plasticity** – change in an organism's behaviour in response to changing environmental conditions.

Range shift – A change in the natural distribution of a species arising from increased or decreased survival in a given location(s), or from colonising new areas.

Refuge – Micro-habitat features that provide temporal and/or spatial protection from disturbances, predation, competition, climatic extremes etc.

Refugia – Areas of limited spatial extent where special environmental conditions enable a species, population or a community to survive despite extinction in surrounding areas due to climatic change. (Refugium is the singular form of this term). Internal refugia – are located within a species' current distributional range; External refugia – are located outside of a species' current distributional range.

Regional ecosystem – Vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil.

Representative Concentration Pathways (RCP) – Based on selected scenarios from four modelling teams/models working on integrated assessment modelling, climate modelling and modelling and analysis of impacts. They are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modelling.

Resilience – The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance by responding or reorganising the ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation.

Return period – Also known as 'recurrence interval' and is the estimated time between repeats of an event (e.g. high sea-level event, major river flood).

Sector – In the Plan, 'the sector' refers to the groups of organisations and individuals that influence the management of biodiversity and ecosystems.

Sleeper species/weeds – Plants that appear benign for many years, but which may suddenly spread rapidly following certain natural events such as flood, fire, drought, climate change or change in land or water management.

Structural connectivity – Indicates the part of the landscape that is physically connected e.g. corridors, land bridges. Compare to Functional connectivity.

Threshold – The condition under which an asset or process is no longer able to achieve its desired objectives because of changing environmental conditions.

Tipping point – A level of change in system properties beyond which a system reorganises, often abruptly, and does not return to the initial state even if the drivers of the change abate. Usually biophysical thresholds where the magnitude of change means the current management strategies will

no longer meet their intended goal. An example is permanent inundation of a salt marsh or mangrove.

Traditional Ecological Knowledge – In this case referring to the knowledge systems and specific understanding held by Aboriginal and Torres Strait Islander Peoples in relation to land, waters and sea, plants and animals, and their management. It is often related to the sustainability of local resources.

Transformational adaptations – Adaptation actions that result in a significant change to community goals and expectations, or how they are met and potentially disrupt those communities and their values.

Translocation – A deliberate change in the location of an individual or species. See also Assisted migration.

Uncertainty – A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. In the case of adaptation for biodiversity and ecosystems it includes: uncertainty around how greenhouse gas emissions might change, an incomplete understanding of the Earth as a system, the difficulty anticipating species/population-specific responses to projected climate change, and a lack of detailed understanding of the effects of management interventions for many taxa.



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