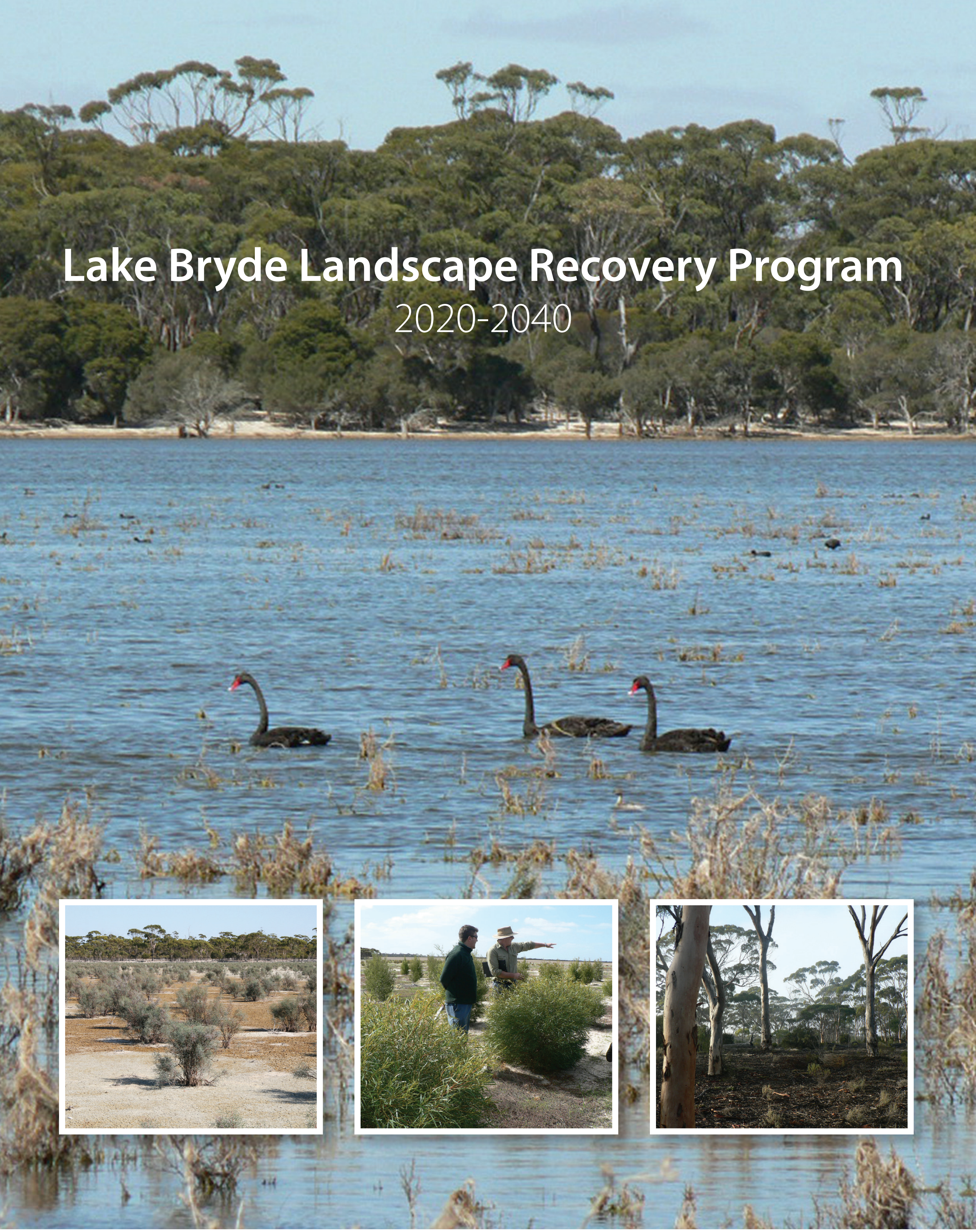
Lake Bryde Landscape Recovery Program

2020-2040



GOVERNMENT OF WESTERN AUSTRALIA

Department of Biodiversity, Conservation and Attractions

PARKS AND WILDLIFE SERVICE

Lake Bryde Landscape Recovery Program 2020–2040

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Front cover photographs

Main image Black swans on Lake Bryde. *Photo – DBCA, 2007*

Inset (l-r) Bryde TEC on East Lake Bryde playa. *Photo – Wendy Huddleston DBCA;* Inspecting revegetation near Lake Bryde. *Photo – DBCA. Salmon gum woodland. Photo –P J White.*

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Acknowledgments

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- Previous and current community members of the Lake Bryde recovery team and technical advisory group (TAG) – Terry Burges, Debbie Clarke, Ray Furphy, Leanne Grant-Williams, Ian King, Sally Phelan, Stephen Pelham, David Rosenberg, Hayley Turner and Tilwin Westrup.
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Summary

The Lake Bryde Catchment is of importance to the community of Western Australia for the values associated with the area's remarkable variety of native flora and fauna, some of which are threatened. For example, the catchment features the rare *Duma horrida* subsp. *abdita* and *Tecticornia verrucosa* Threatened Ecological Community (TEC) and the aesthetically beautiful salmon gum (*Eucalyptus salmonophloia*) woodlands and wooded yate swamps (dominated by *E. occidentalis* and *Melaleuca strobophylla*). These communities are some of the last examples of once more widespread vegetation types.

Lake Bryde Catchment was established as a Natural Diversity Recovery Catchment in 1999 under the *Western Australian Salinity Action Plan* (Government of Western Australia 1996). Since then, considerable work has been conducted to address a number of issues, particularly those relating to altered hydrology, which threatens the values people associated with the catchment's living natural resources (i.e. the biological elements). To help ameliorate hydrological issues, a waterway was constructed to improve the conveyance of rainfall runoff through the valley floor, controlling waterlogging and groundwater recharge. Most of the works were completed during 2009, with additional works proposed (Wallace *et al.* 2011). From this review, the recovery actions to date were considered successful; however, it was noted that managing hydrological issues will require an ongoing effort.

Lake Bryde Catchment encompasses a range of different land tenures (freehold, DBCA managed reserves and other Crown lands) and has a human population with a diversity of economic, social, and cultural interests and aspirations. Consequently, this generates a range of different perspectives relating to the catchment and how it should be managed. For this reason, the planning process identifies and incorporates the views of different stakeholder groups throughout the planning process. Additionally, the planning approach seeks to concentrate recovery activities to maximise the maintenance and improvement of key human values associated with the biological elements of the catchment.

Following the planning process:

1. An aspirational goal was developed to deliver three key human values: Knowledge-Heritage, Recreation and Future Options.
2. Fifteen biological elements in the catchment were identified as important in terms of the key values.
3. Several key properties (element size, total native species richness [‘native species’ being ‘naturally occurring species’], rarity, loss, visibility, and charisma) of the biological elements were identified for management to ensure the key values are maintained.
4. The values of the biological elements were rated and compared to provide important information in terms of management prioritisation.

5. Risk analyses identified key processes (hydrology, fire, problem species, temperature extremes relating to climate change and pesticide/herbicide issues relating to surrounding land use) that require management to minimise the likelihood that native species and vegetation are lost. Native species richness was used as the primary property for the management of the priority values.
6. A series of management options were identified and prioritised relative to their expected benefits per unit cost in terms of managing total native species richness.
7. An adaptive monitoring program based around limits of acceptable change in the target property (species richness) and the key threatening processes was developed to allow managers to monitor the status of the biological elements and the threatening processes over the management period to garner important management information and trigger recovery responses should they be required.

The landscape recovery program identifies that by managing the threats posed by altered hydrology, fire, problem species, climate change and surrounding land use over the next 20 years, the priority biological elements are more likely to maintain their value to people and the aspirational goals are more likely to be met.

1. Introduction

The Department of Biodiversity, Conservation and Attractions (DBCA) is responsible for managing the State's conservation reserve system, under the *Conservation and Land Management Act 1984* (CALM Act) and protecting threatened species and communities through administering the *Biodiversity Conservation Act 2016* (BC Act). The department's purpose is to promote biodiversity and conservation through sustainable management of Western Australia's species, ecosystems, lands, and the attractions in the department's care to enrich people's lives.

DBCA, through its Biodiversity and Conservation Science Directorate, maintains a high level of scientific integrity in its operational activities. Through its Parks and Wildlife Service, DBCA maintains a strong regional focus and relies on the relationships built and maintained with neighbours, visitors, volunteers, partners, individuals, organisations, and local communities to achieve its mission.

Western Australia supports many significant wetlands. Various monitoring and management programs have been implemented to ensure these important areas are understood and protected. In the past, landscape conservation programs, such as the Natural Diversity Recovery Catchment Program, have been integral in helping recover and protect significant biological communities, particularly wetlands, from altered hydrology at a catchment scale within southern agricultural areas. Recovery planning documents also identify key actions required to protect natural assets, including conservation reserves and significant wetlands. The development of this landscape recovery program aligns with the Parks and Wildlife Service's strategic direction, focusing on parks, wildlife, fire, managed use, and people.

The planning process used to develop this landscape recovery program included a series of workshops and reviews over six years involving stakeholder representatives from the community, government, and non-government groups, including the recovery team and technical advisory group (TAG). The ability to undertake the full suite of recommended actions identified in this recovery program will be dependent on allocated budgets.

In this document, recommended actions are listed in the relevant sections and summarised at the end in Section 10. To maximise the readability of this document, important terms are defined in the text, in footnotes, or in the glossary in Section 11.

The recovery program has additional information in a separate document, *Lake Bryde Landscape Recovery Program: 2020–2040 Supporting Information*. The supporting information document contains appendices that are referred to throughout this recovery program.

Monitoring and management of the Lake Bryde Catchment is undertaken within an adaptive management framework. Planning is therefore iterative and ongoing with regular review of recommended recovery actions and outputs and, with new information and techniques, may result in updated management strategies and activities over time.

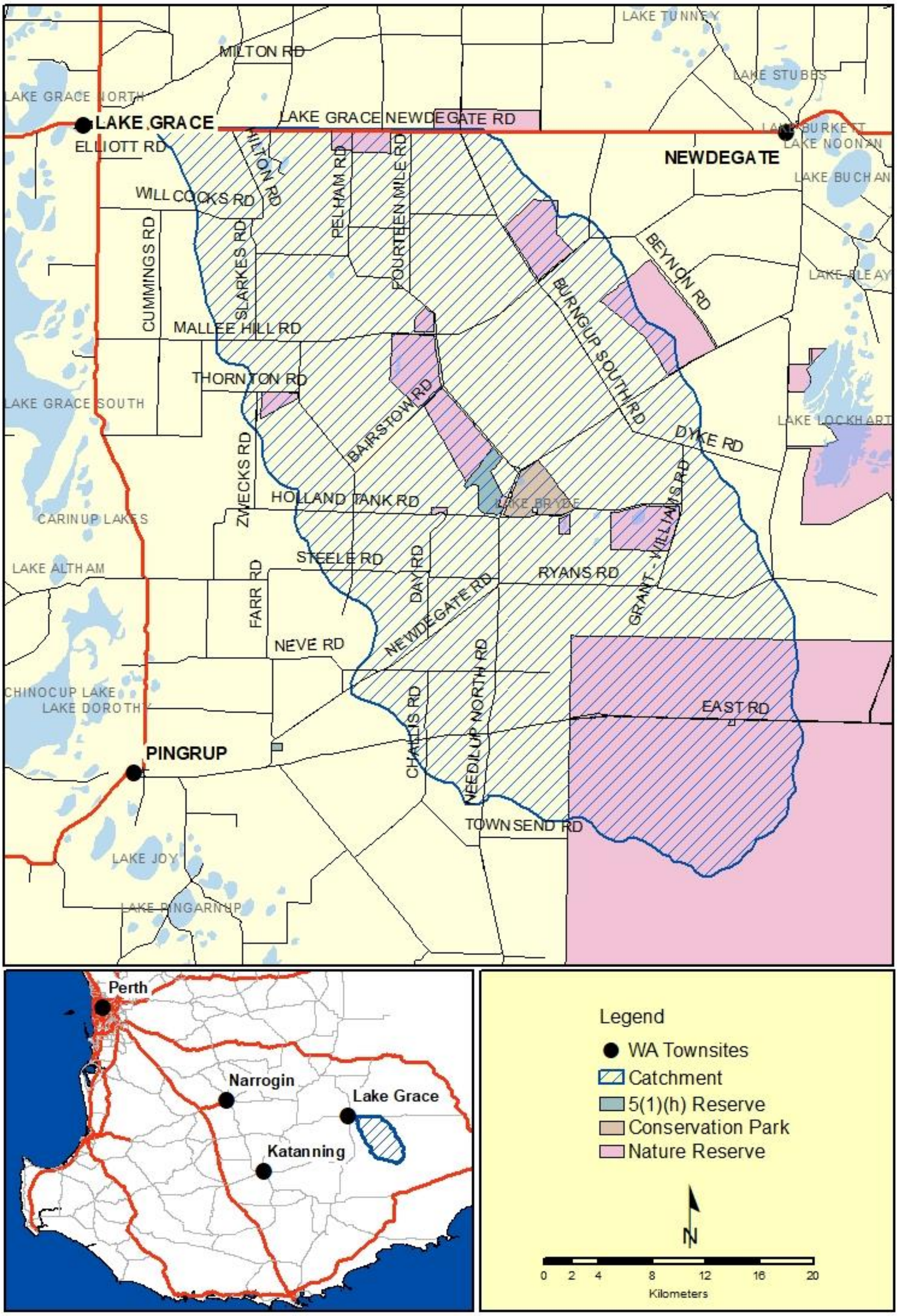


Figure 1: The location of the Lake Bryde Catchment.

2. Catchment overview

The Lake Bryde Catchment is about 350km south east of Perth in the Mallee IBRA bioregion of Western Australia. The catchment covers about 161,000 ha overlapping part of the shires of Kent and Lake Grace. The centre of the catchment is approximately equidistant from the towns of Lake Grace, Newdegate, and Pingrup. Today about 34% (55,400 ha) of the catchment's original vegetation remains.

Farming properties occupy approximately 72% (115,920 ha) of the catchment. The catchment also contains 14 reserves vested with the Conservation and Parks Commission (a statutory authority) and managed by DBCA's Parks and Wildlife Service to conserve native flora and fauna and Aboriginal culture and heritage. These cover about 23% (37,030 ha) of the catchment's area. Road reserves and other Crown lands make up the remaining 5% (8050 ha) of the catchment.

2.1. Biodiversity attributes

The Lake Bryde Catchment contains several significant biodiversity assets that are under threat from altered hydrology.

Threatened ecological communities

The Bryde Threatened Ecological Community (TEC) is listed as "Unwooded freshwater wetlands of the southern Wheatbelt of Western Australia, dominated by *Duma horrida* subsp. *abdita* and *Tecticornia verrucosa* across the lake floor" (Hamilton-Brown and Blyth 2001).

An example of the Bryde TEC on a partially inundated lakebed. *Photo – P.J. White/DBCA, 2017*

In 2001, the Bryde TEC was listed as critically endangered under criteria developed in WA in the 1990s. This listing is to be reviewed under the *Biodiversity and*

Conservation Act 2016 (BC Act) using the ranking criteria of the International Union for Conservation of Nature (IUCN) Red List of Ecosystems ranking criteria to the ecological community.

The Bryde TEC is known only from three seasonal freshwater wetlands on the valley floor within the Lake Bryde Catchment. The listing reflects the highly threatened condition of the TEC occurrences, all of which are located on the valley floor where they are threatened by hydrological changes, including altered hydroperiods, increasing salinity and rising groundwater tables.

During the development of this landscape recovery program, the ‘Eucalypt woodlands of the Western Australian Wheatbelt’ community was listed nationally as a critically endangered TEC under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This TEC was not specifically considered during this planning process, as Eucalypt woodlands meeting the TEC criteria were already represented in three of the vegetation elements (Salmon Gum Woodland, Yate Swamp and Other Woodlands) whose recovery requirements were addressed in the planning process.

Threatened, specially protected and priority fauna

Recent fauna surveys have recorded 17 native mammal, 124 bird, 34 reptile, and 10 frog species in the Lake Bryde Catchment. Six of these species are currently listed as threatened. The threatened mammal species are the red-tailed phascogale (*Phascogale calura*), the chuditch (*Dasyurus geoffroii*) and heath mouse (*Pseudomys shortridgei*). The threatened bird species include the Australasian bittern (*Botaurus poiciloptilus*), Carnaby's cockatoo (*Calyptorhynchus latirostris*) and malleefowl (*Leipoa ocellata*).

A malleefowl recorded by a remote camera near Lake Bryde. *Photo – DBCA, 2018*

Other species have been listed either as specially protected or priority fauna. (Refer Supporting Information, Appendix 10.1).

Threatened and priority flora

More than 1,000 vascular plant taxa (species, subspecies, varieties, and forms) are recorded in the Lake Bryde Catchment (Refer to Supporting Information, Appendix 10.4).

Eight of these species are listed as threatened and 84 others are assigned priority status. While most of the listed species are widely distributed, *Duma horrida* subsp. *abdita* (Endangered) and *Acacia mutabilis* subsp. *stipulifera* (Priority 3) are endemic to the catchment.

Calectasia pignattiana is one of the threatened flora found in the catchment.
Photo – D. Rasmussen/DBCA, 2014

Remnant vegetation extent

The Lake Bryde Catchment retains about 34% (55,400 ha) of its original native vegetation. Beecham (2003) reported that Wheatbelt landscapes containing such a relatively high proportion of remnant vegetation are also likely to contain:

- high species and community diversity, or to have retained large portions of their original biota (particularly birds and mammals)
- ecological processes that influence population viability at a landscape scale rather than a patch (or habitat remnant) scale
- several key threats to population viability, such as insufficient resources, salinity, and predation by introduced species, that are best managed at a landscape scale.

These attributes are enhanced by the catchment's wide and well-vegetated road reserves that link many of the larger parcels of remnant vegetation.

2.2. Human assets and attributes

Lake Bryde is a popular local recreation site. It is widely utilised by the local community for recreational activities such as water-skiing and swimming when the wetlands contain sufficient water. Nature appreciation, bushwalking and picnicking are also locally important recreational activities (Viv Read and Associates 2002).

2.3. Management activities previously undertaken

Many of the catchment's important biological elements, and the sites of locally important recreational activities, are located within the conservation reserves occupying the catchment's valley floor. As such, they are situated in the very areas most at risk from altered hydrology.

Between 1999 and 2019, action was taken to control degradation of the biological element, while medium to long-term strategies were being developed through the recovery planning processes.

Waterway project

To provide short-term relief from the effects of altered hydrology, including prolonged inundation and salinisation, surface water management projects have been implemented.

The Lake Bryde waterway looking south from the termination lakes. *Photo – DBCA, 2008*

The flatness of the catchment's valley floor and the lack of either a defined channel, or an obvious disposal point for managed water, have created considerable challenges for surface water management (Farmer *et al.* 2002). Consequently, DBCA has installed a significant waterway structure running from just below Lake Bryde into a series of degraded lakes within the Lakeland Nature Reserve north of Bairstow Road.

The waterway provides a direct intervention to the current degradation in vegetation along the western boundary (Maunsell Australia Pty Ltd 2005).

Western boundary surface water management

Surface water management structures were also installed on degraded farmland on the western boundary of Lakeland Nature Reserve. Rainfall events generated substantial runoff that flowed into and inundated the adjoining section of the reserve, causing significant impacts to the vegetation (Mudgway and Nicholson 2010).

To counter this, surface water drains were constructed to direct runoff into the waterway and convey it into the degraded wetlands in the northern section of Lakeland Nature Reserve. Weirs were installed on the newly constructed surface water drains to reduce water velocity that could damage the drains.

Projects on private property

Many of the hydrological changes that threaten the biological elements within the Lake Bryde Catchment have been caused by land clearing. These threats include unmanaged surface water flows, altered frequency and duration of inundation in low lying areas, recharge of saline groundwater tables and increased mobilisation of silt.

A revegetation team planting on private property. *Photo – DBCA, 2006*

To address these problems at their source, the department has used cost-sharing arrangements to undertake 79 projects on private property:

- Twenty two revegetation projects established 123.5 ha of biodiverse revegetation.
- A further 18 projects involved 156 ha of oil mallee revegetation.
- Twenty eight projects provided fencing for 1315 ha of remnant bushland.
- Ten of the projects involved the construction of surface water management structures and expansion of on-farm water storage facilities in the upper catchment. In total, 12 dams and nearly 13.5km of banks and drains were constructed.

Revegetation of Crown land

In 2003, the department purchased 725 ha of private property that connected Lakeland Nature Reserve with the Lake Bryde Conservation Park. This land was then converted into Reserve 47384 for the purpose of ‘Rehabilitation Trials and Demonstrations, Agriculture Flow Management and Conservation’, under Section 5(1)(h) of the CALM Act. The reserve was placed under the care, control, and management of the Conservation Commission of Western Australia (now the Conservation and Parks Commission).

A small section of the revegetation undertaken on Reserve 47384.
Photo – P.J. White/DBCA, 2018

Since 2003, about 381 ha of cleared or severely degraded land within this reserve has been rehabilitated through revegetation. Currently, only 15 ha still requires treatment.

In 2005, a 1301 ha section of the Lake Bryde water reserve 28667 was excised and set aside for the purpose of Conservation Park. This new reserve (R 48436) was placed under the care, control, and management of the Conservation Commission of Western Australia (now the Conservation and Parks Commission).

This reserve contained about 30 ha of cleared land dating to the failed settlement of the area in the 1920s. Despite being left undisturbed for nearly 90 years, it had experienced little natural regeneration of its original woodland vegetation. In 2016 the department revegetated the area using a range of local woodland species.

Endangered Carnaby’s cockatoos feeding on revegetation in the Lake Bryde Catchment.
Photo – P.J. White/DBCA 2016

2.4. Landowner initiated changes to land management

Many farmers within the Lake Bryde Catchment are supportive of land conservation initiatives and there has been widespread adoption of improved tillage and farming practices. Direct advice to landholders is provided by the Department of Primary Industries and Regional Development (DPIRD).

Through the South Lake Bryde Focus Catchment project (Department of Agriculture and Food Western Australia (now DPIRD), mid-late 1990s) and the subsequent Lake Bryde Natural Diversity Recovery Project (since 2000) many landholders have become aware of local issues and have been incorporating this awareness into the refinement of their agricultural practices and land management activities.

3. THE PLANNING FRAMEWORK

The Lake Bryde Landscape Recovery Program 2020-2040 was developed in accordance with the framework detailed in Wallace (2012) and Pourabdollah *et al.* (2014).

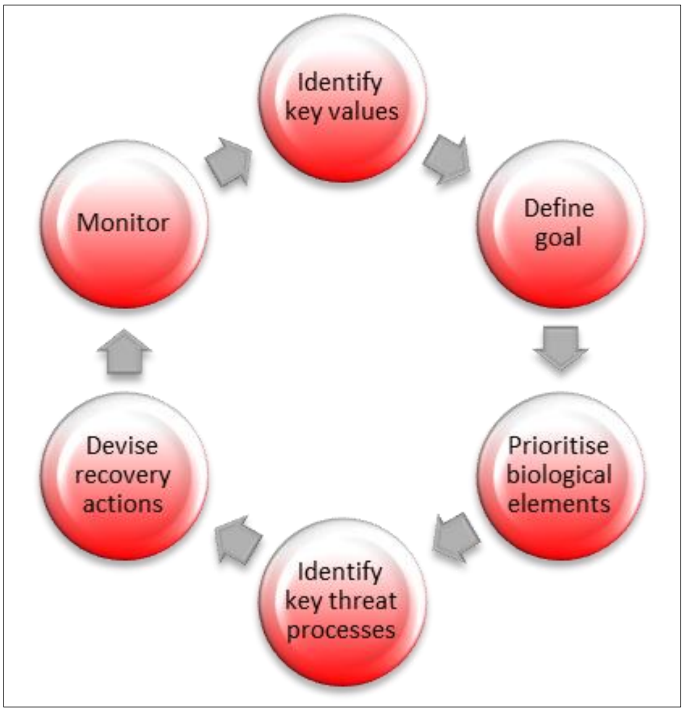


Figure 2 The recovery planning process steps used for the Lake Bryde Catchment.

This landscape recovery program incorporates input from stakeholder representatives from the community, government, and non-government groups through the Lake Bryde recovery team (see Supporting Information Appendix 8) and TAGs; also referred to as technical specialist advice). Both the recovery team and TAG are involved in the ongoing planning and implementation of recovery actions.

In consultation with the stakeholders, the planning process yielded the following outcomes:

- Three key human values were identified for the catchment: 1) Knowledge-Heritage and Education, 2) Recreation, and 3) Future Options. A goal was developed to maintain these values.
- Fifteen biological elements in the catchment were identified as important due to their effect on the three key human values. These biological elements were rated on their contribution to delivering the identified human values, which facilitated the prioritisation of management focus areas. The highest priorities were terrestrial birds, mallee shrubland, fungi, reptiles, other eucalyptus woodlands, waterbirds, and mammals.

- In this planning process, the ‘key properties’ of the biological elements were identified as species composition (richness and abundance), structure, intactness, rarity and size. These properties determine, in relative terms, the provision of human value. Properties are measured at a point in time and within specified spatial boundaries and allow us to rate the biological element.
- Through risk analyses, the key threatening processes that require management to maintain species richness were identified as: altered hydrology, problem species and inappropriate fire regimes.
- A series of possible recovery options were compared and prioritised relative to their expected benefits (in terms of human value). Altered hydrology rated the highest, followed by problem species and then inappropriate fire regimes.
- A series of recommended actions were proposed and assessed in terms of efficiency. This included further hydrological research to guide management.
- An adaptive monitoring program was developed to allow managers to monitor the status of the biological elements and the threatening processes over the management period. This program was based around limits of acceptable change for species abundance and key threatening processes. It aimed, firstly, to garner important management and recovery information and, secondly, to trigger new recovery responses should they be required.

With 72% of the catchment comprising private property landholder support for the conservation of the biological elements is critical. Recovery actions will need to take into consideration local aspirations, including the need for landholders to continue their agricultural business through economically viable, sustainable land use. Land management practices will continue to evolve over time.

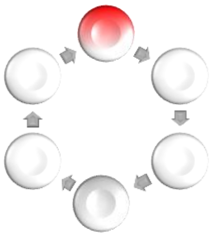
Recovery actions that meet the requirements of all partners will be those that best integrate land use and catchment recovery activities. Realising the goal to maintain or improve the values of the Lake Bryde Catchment will require consideration of a diverse set of land-use issues and collaboration with many stakeholders.

Implementation of this recovery program will give stakeholders opportunities to:

- access new knowledge relating to the management of catchment-scale hydrology
- attract funds for on-ground works identified in this landscape recovery program, to integrate sustainable agriculture with the conservation of biological elements
- contribute to identifying and implementing solutions to land degradation
- conserve native species for future generations.

In this context, management of the Lake Bryde Catchment makes an important contribution to improved land management in the south-west agricultural zone.

4. Identify key values



For effective natural resource planning and management, it is important to clarify the key human values expected from a management area's biological elements and to use those values to drive decision-making (Wallace 2006). Supporting Information Appendix 9 provides a description of the steps taken to elicit the key values arising from the catchment's biological elements.

Stakeholder representatives and technical expert groups identified a total of 15 biological elements (seven vegetation elements, seven fauna elements and a fungi element) as the basis for assessing human values (Wallace et al, 2016; Supporting Information Appendix 9). Stakeholder groups only considered the biological elements most susceptible to the impacts of altered hydrology, given the significance and catchment-wide impacts of this threatening process.

Three key values were identified. Starting with the most important, these are:

Knowledge-Heritage

The Lake Bryde Catchment is used by local school groups for education (e.g. seed collection and a Carnaby's project) and by ecologists and scientists as a research area (Craig *et al.* 1991, Halse *et al.* 2002, Timms 2009). Further, the lakes and surrounding environs are an important slice of our disappearing heritage, an example of the environment before European settlement.

The knowledge arising from continued research in the catchment is an important contribution to how these systems function, which, in turn, will contribute to our understanding of environmental change and its management throughout south-western Australia.

The Australian Shield Shrimp is a common invertebrate in freshwater wetlands.
Photo - Natalie Nicolson/DBCA, 2007

Recreation

Lake Bryde is a community focal point and the majority of landholders within the catchment utilise Lake Bryde and its surrounds for recreational activities.

A picnic site at Lake Bryde overlooking the flooded lake in 2007. *Photo - DBCA*

Future Options

The conservation of biological elements provides for a range of future opportunities in any of the human values identified by the stakeholder group (Wallace et al, 2016) and those yet to be identified. An obvious example is the genetic resource in native plants that may help to resolve health and resource issues in the future. Thus, Future Options includes the values that are not currently realised. They will include maintaining the opportunity for:

- discovery of currently unknown values in our native species
- retained opportunities to exploit currently known values at some time in the future
- future generations to make their own decisions concerning biological elements' values.

These three values guided drafting of the goal for the catchment (Section 5)

Changing value preferences

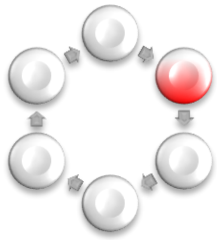
It is acknowledged that value preferences may change over time and indeed can be influenced by recovery activities. Other values may become more important as the key properties of biological elements affecting Knowledge-Heritage, Recreation and Future Option values improve due to planned recovery activities.

Delivering Knowledge-Heritage, Recreation and Future Option values will require communicating information about the biological elements, recovery activities and outcomes; developing and fostering partnerships; and engaging with stakeholders. Engagement and communication methods include a biannual newsletter and presentations at conferences and regional shows.

Community involvement in data collection will also ensure the values are upheld. A consultative approach has been devised to engage stakeholders in the monitoring and management of the Lake Bryde Catchment.

A Yate swamp in flood. *Photo - DBCA, 2007*

5. Define the goal



The goal is constrained in space to the catchment and in time to the next 20 years (2020-2040). The temporal scale for this landscape recovery program is a compromise between the long duration of some natural cycles (in some cases over 100 years) and our ability to plan with reasonable certainty.

In addition, it is expected that while positive outcomes from recovery activities may occur in the short term (less than three years), major improvements will take much longer to achieve.

Based on the values arising from the analysis of the biological elements by stakeholders and recovery team endorsement, the recovery catchment goal is:

To maintain or improve the Knowledge-Heritage, Recreation and Future Option values provided by the specified natural biological elements for the next 20 years.

Aerial view of Lake Bryde following inundation in February 2017. *Photo – M.J. Fitzgerald/DBCA*

Ancillary goals

Much of the land in the Lake Bryde Catchment is private property. Thus, landholder support for the conservation of the natural biological elements is important and recovery actions will need to take into consideration local aspirations, including the need for landholders to further their aims for economically viable, sustainable land use.

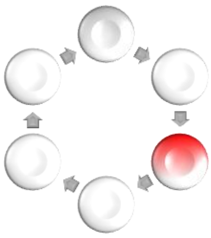
Recovery actions that meet the goals of all partners will best integrate land use and catchment recovery activities. Realising the goal for the Lake Bryde Catchment will require actions that bring together a diverse set of land-use issues and a number of stakeholders in a collaborative and focused way.

The Lake Bryde Catchment provides a unique opportunity for landholders and other stakeholders to:

- access new knowledge relating to the management of catchment-scale hydrology
- better access funds for on-ground works to integrate sustainable agriculture with the conservation of biological elements
- contribute to identifying and implementing solutions to land degradation
- participate in developing new agricultural industries that also provide a range of environmental benefits
- conserve native species for future generations.

In this context, catchment recovery activities make an important contribution to improved land management across catchments in the south-west agricultural zone.

6. Prioritising biological elements



To achieve the goal, management resources must be focused on the highest priority biological elements. Prioritisation should favour the subset of biological elements that are the most valuable in terms of the priority human values. An assumption of this approach is that, by successfully managing the highest priority biological elements, we will deliver a greater proportion of the key human values than if available funds were, for example, equally distributed across all elements.

Whilst all biological elements are valued, there are variations in why, how and to what extent they are valued. The biological elements were grouped based on their contribution to delivering the priority human values (Table 2). These groupings were derived from:

- modelling of the relationship between the properties of the biological elements (i.e. species composition, structure, intactness, rarity, and size) and the values that are derived from them (property-value modelling)
- ratings of biological elements based on their contribution to delivering the human values, as elicited from the TAG (TAG-elicited ratings).

The process of identifying and rating the biological elements and quantifying their properties is described further in Supporting Information Appendices 9 and 10.

The accuracy of the assessment process will be improved with continued dialogue amongst the interested parties (technical experts, the department, stakeholder representatives); identification and, where appropriate, inclusion of additional properties; and further quantification of native species composition, size, rarity, loss, visibility and charisma (for definitions see Supporting Information, Appendix 13.2).

Based on the property-value modelling and stakeholder-representative-elicited ratings, the biological elements have been prioritised on their expected utility:

1 Considering the stakeholder representative views and the modelling outputs, while also bearing in mind the uncertainty, the highest value biological elements are the terrestrial birds, mallee shrubland, fungi, reptiles, other woodlands, waterbirds, and mammals. Until such time that any disparity between the model and the stakeholder representative views regarding the importance of the mammals and the waterbirds is resolved (Figure 5), we include these two elements in the highest priority group.

2 Salmon gum woodland, terrestrial invertebrates, samphire shrublands, Yate swamp vegetation, melaleuca shrubland and the *Duma horrida* shrublands (Figure 5) were rated lower in their overall value when compared to the elements listed in point 1 (above).

3 The least valued elements (in terms of the priority values) were the aquatic invertebrates and the amphibians (Figure 5).

Table 1 Biological elements of the Lake Bryde Catchment[a].

Element	**Estimated size [b](ha)**	**Number of species**	**Species of conservation concern**
Fauna			
Amphibians	500 (350 to 550)	14 (2 to 15)	
Aquatic invertebrates	500 (400 to 600)	108 (50 to 150)	
Mammals	5,000 (4,500 to 5,500)	34 (25 to 40)	1 x EN; 2 x VU; 4 x P4; 2 x P5
Reptiles	8,000 (4,500 to 11,000)	62 (19 to 67)	1 x S
Terrestrial birds	10,000 (8,000 to 14,000)	108 (50 to 110)	2 x EN; 2 x VU; 1 x S; 1 x P2; 6 x P4; 1 x IA
Waterbirds	400 (360 to 440)	29 (23 to 30)	1 x EN; 2 x P4; 1 x IA
Terrestrial invertebrates	10,000 (5,000 to 15,000)	150 (50 to 500)	
Vegetation			
Duma shrubland	165 (150 to 180)	15 (10 to 20)	1 x CR (TEC) 1 x EN (Flora)
Salmon gum woodland	320 (300 to 340)	113 (30 to 120)	1 x EN; 1 x P1; 2 x P2; 3 x P3; 1 x P4
Other woodlands[c]	4,250 (4,000 to 4,500)	190 (50 to 200)	1 x CR (TEC) 1 x VU; 2 x P1; 2 x P2; 3 x P3; 3 x P4
Mallee shrublands	6,390 (6,000 to 6,780)	177 (65 to 350)	1 x VU; 2 x P2; 7 x P3; 3 x P4
Melaleuca shrublands	2,020 (1,000 to 3,000)	25 (25 to 150)	1 x P3
Samphire shrublands	1,200 (1,000 to 1,400)	15 (10 to 20)	1 x EN; 1 x P3
Yate swamp vegetation	40 (35 to 35)	21 (5 to 25)	
Fungi			
Fungi	10,000 (8,000 to 14,000)	150 (100 to 300)	

[a] The development of the species lists for the elements is an ongoing process with new information regularly arising. As a result, small changes in the richness estimates have occurred after the completion of the analyses reported in Table 1

[b] Size and species richness estimates were generated by the project team from data and the available literature. These were then amended by the TAG. The first number is the best estimate followed by an approximate range (in brackets). More detailed descriptions of each biological element are provided in Supporting Information Appendix 10.

[c] This includes Wheatbelt woodland TECs.

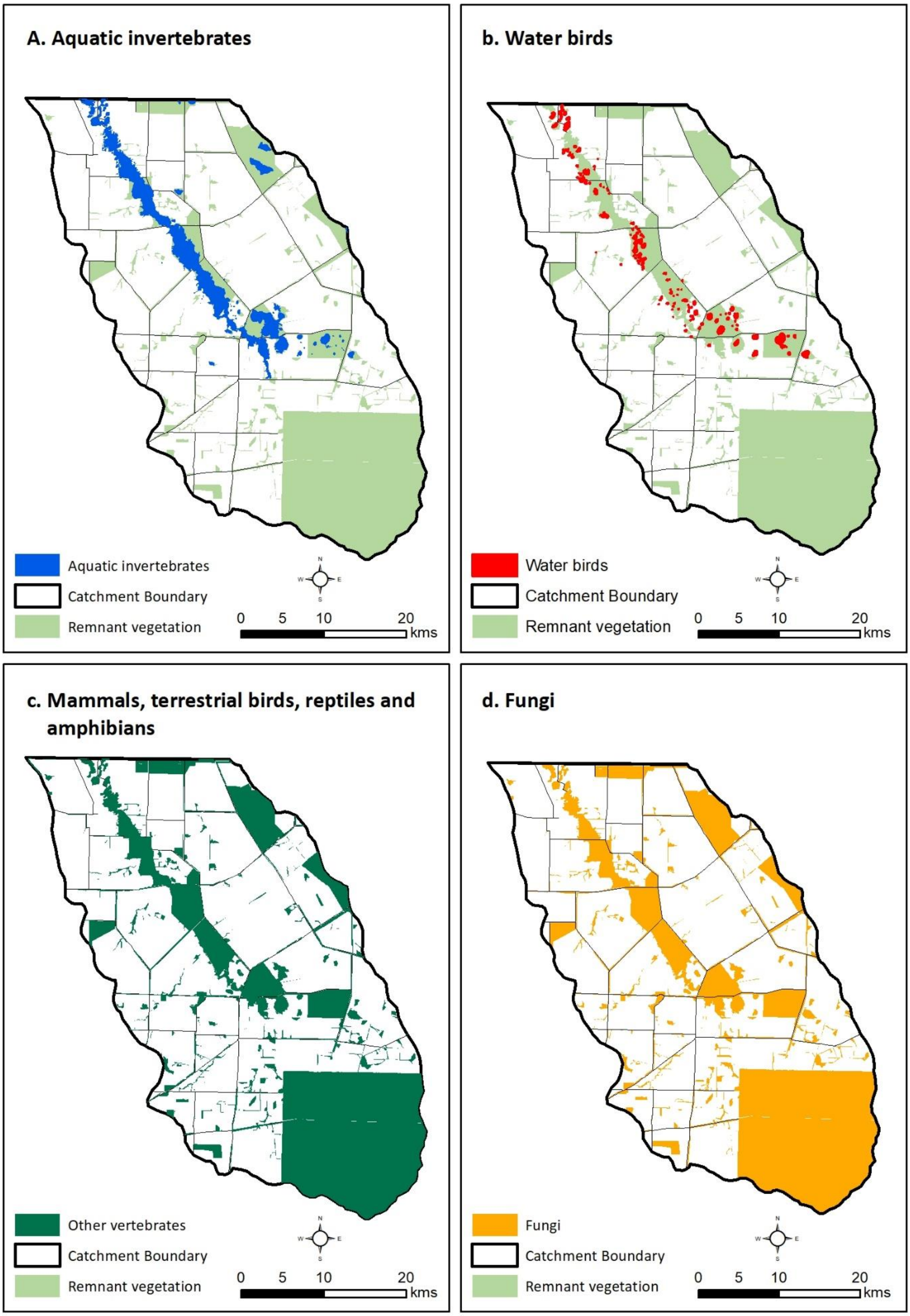


Figure 3 Fauna elements of the Lake Bryde Catchment.

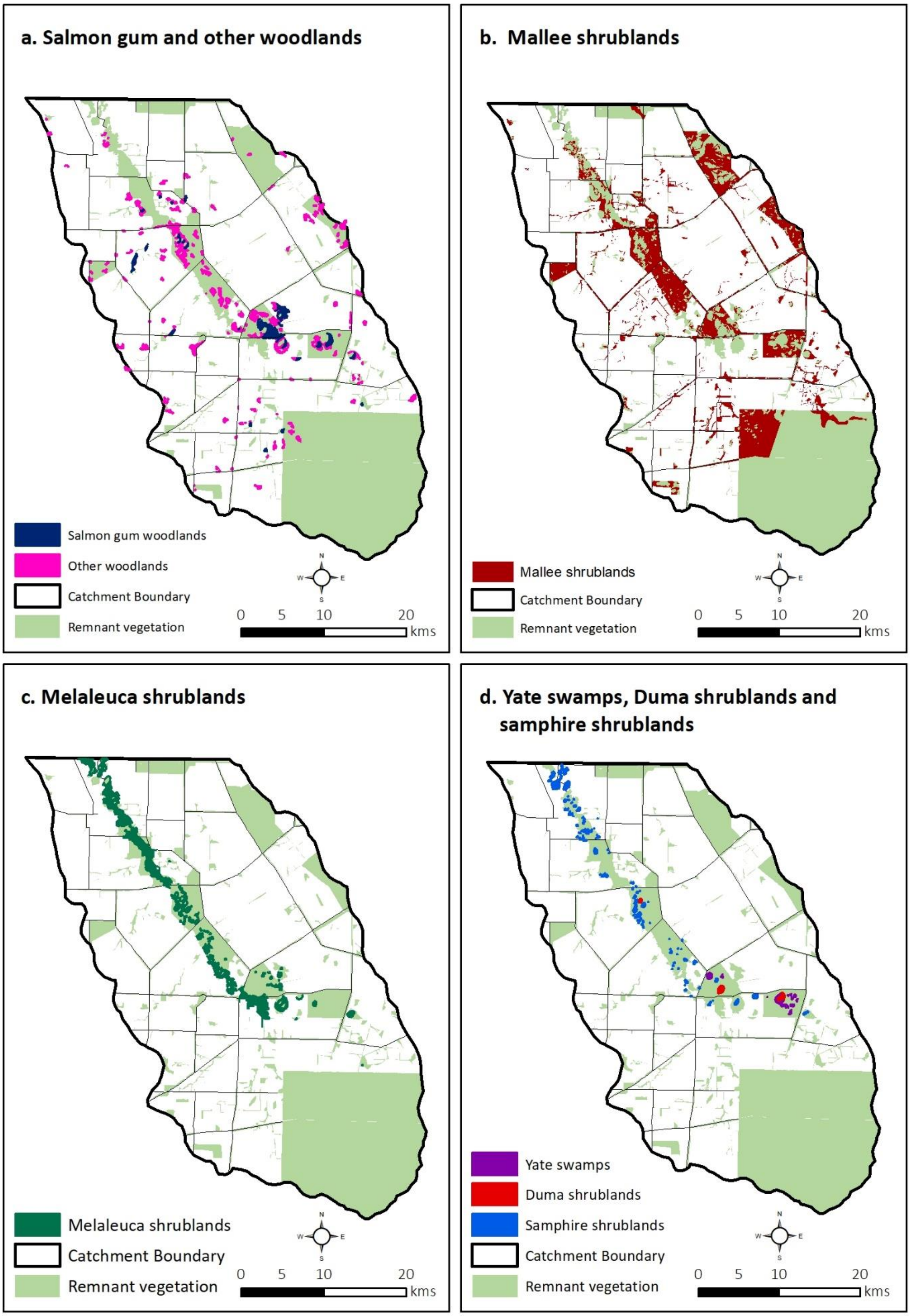


Figure 4 Vegetation elements of the Lake Bryde Catchment.

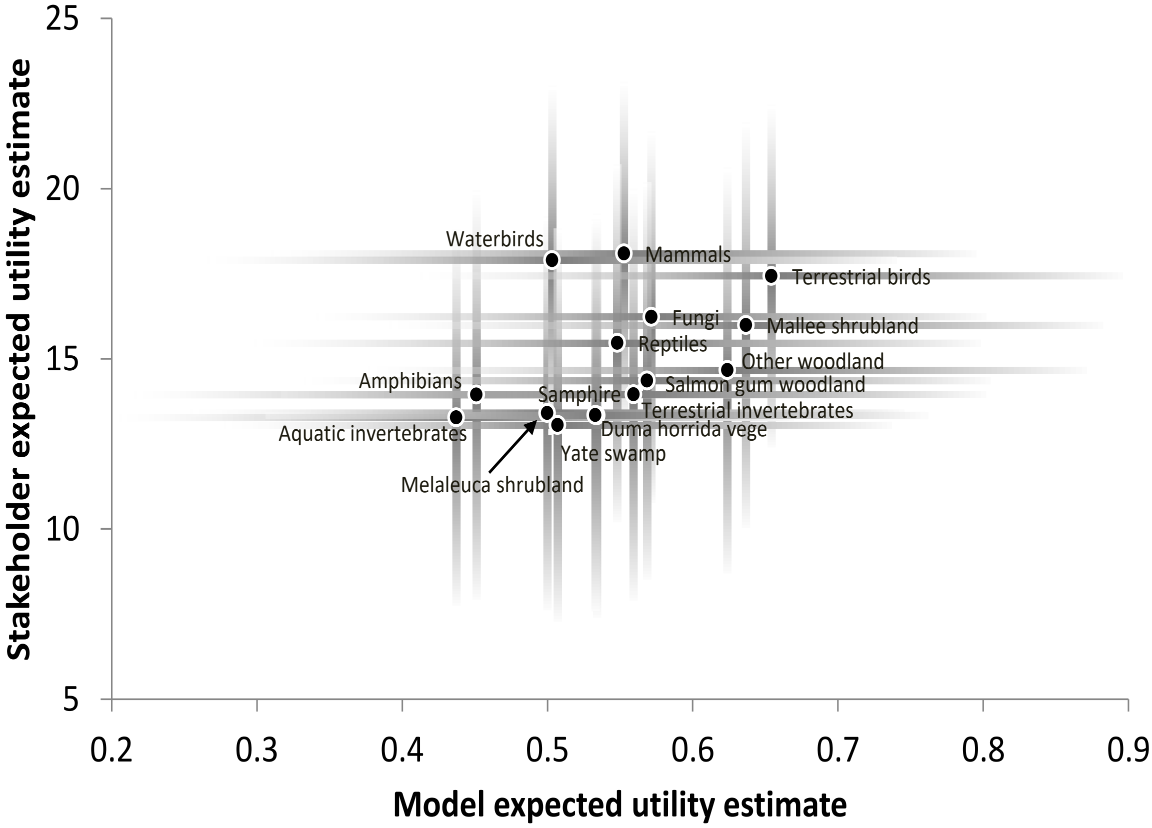


Figure 5 Expected utility (centroid estimate) for the Lake Bryde biological elements as estimated from the Fuzzy Logic System (x-axis) and the stakeholder representatives (y-axis).

Table 2 Biological element groupings for the Lake Bryde Catchment based on their contribution to the key human values.

Rating group	Values
Highest priority	Terrestrial birds, mallee shrublands, fungi, reptiles, other eucalyptus woodlands, waterbirds, and mammals. Until such time that any disparity between the model and the stakeholder representative views regarding the importance of the mammals and the waterbirds is resolved, we include these two elements in the highest priority group.
High priority	Salmon gum woodlands, terrestrial invertebrates, samphire shrublands, Yate swamps, *Melaleuca* shrublands and the *Duma* shrublands.
Low priority	Aquatic invertebrates and the amphibians

Recommended action:

1. **As part of an iterative process, continue to assess the value of biological elements through:**

    a) stakeholder representative engagement and expert consultation to identify any additional element properties and to explore their relationships with the priority values

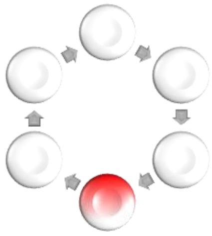
    b) surveys[d] of the native species composition and size of each biological element

    c) quantification of properties such as loss, charisma and visibility to improve the values-delivery analysis.

Importantly, by understanding the links between properties and values, we can better understand how management will influence element value and better justify management decisions.

[d] In this recovery program, surveying is defined as an initial cataloguing or quantifying of property information (e.g., composition) or process state and monitoring as ongoing (over the management period) assessment of change in the initial catalogue.

7. Key threatening processes



Many catchment processes will affect whether the aspirational goal stated in Section 5 is achievable within the specified timeframe. Identifying the key processes affecting goal achievement (i.e. a risk factor analysis) was an essential step towards describing the actions required for management success.

In this section we outline the steps used to identify the key processes affecting elements:

Step 1 Specify the aspirational goal in the form of a management target for important properties.

Step 2 Analyse the risk factors controlling the target to describe the key threatening processes.

This section also provides a summary of management targets and limits of acceptable change for priority biological elements.

7.1. Management targets

To allow for effective management targets to be set, it was necessary to conduct a risk analysis and focus on the properties of the priority biological elements that affect the way people value them. The TAG recommended that management targets focus on species composition (richness) due to its influence on key values. Importantly, this property can be used for all the priority biological elements.

Consequently, the management target is to maintain the native species composition[e] that is characteristic of the elements listed in Table 1 over the management period. Even though there should be no loss of any native species[f] that characterises an element, variation in the abundance of individual species (e.g. with ecological succession) within the limits of acceptable change[g] is acceptable.

There are two important issues to note:

- As knowledge increases, future iterations of the planning approach could include additional properties of the biological elements.
- Activities that improve element intactness and size (where appropriate) will also have positive benefits in achieving the values.

[e]Composition is the number of species (e.g. richness) and their abundances.

[f]Where there are only small numbers of individuals of a species, the loss of that species may not constitute failure to meet management targets. However, some form of population viability or expert analysis may need to be conducted to determine the likelihood of local extinction under the current management.

[g] Limits of acceptable change (LoAC) are defined in Section 9 and are set around abundance, as this ‘sub-property’ can be monitored to provide timely warning of important change in richness.

7.2. Risk analysis

To ensure consistent assessment of risk, the analysis considered the environmental factors – such as salt toxicity, grazing and drought stress – that directly affect the reproductive and survival capacity of the species characterising the priority biological elements (e.g. Metcalf and Wallace 2013). These factors are termed direct risk factors, which relate directly to broader ecosystem processes listed in Table 3.

Table 3 Direct risk factors that may cause goal failure in the Lake Bryde Catchment.

Threatening process	Direct risk factor
Physical and chemical factors (i.e. hydrology, fire)	Pesticides/herbicides
	Acidity/alkalinity
	Heavy metals
	Nitrogen toxicity
	Phosphorus toxicity
	Physical damage
	Toxins
	Groundwater salinity
	Surface water salinity
Resources	Lack of food
	Lack of oxygen
	Lack of/ too much light
	Lack of water
Problem species (i.e. disease/predation/grazing)	Disease
	Predation/grazing
Reproduction	Lack of mates
	Lack of genetic diversity
	Lack of reproduction

Risk was assessed by means of an expert analysis of the probability, under current management, that the set of direct risk factors will cause management target failure for each element (e.g. Metcalf and Wallace 2013). For the risk assessment, the spatial extent of the risk factors is considered within the mapped boundary of each element (Figures 3 and 4) and are constrained in time to the duration of the landscape recovery program (2020 to 2040).

A detailed and structured expert-driven analysis of the risk of losing species from each element was conducted and is described in detail in Smith *et al.* (2015). Of note, following the approach outlined by Metcalf and Wallace (2013), the detailed analysis of risk was conducted for factors that were assessed by the expert group to have a probability of causing goal failure in excess of 5%.

Figure 6 summarises the results of this analysis. The broader threatening processes (dark grey boxes) have been linked to each risk factor (light grey boxes). These risk factors have then been linked with the affected elements. The estimated likelihood of species loss (over the 20-year management period) for each risk factor-element combination is expressed by the thickness of the linking line (thicker the line, the greater the likelihood of management target failure). Actual likelihoods are provided in Smith *et al* (2016).

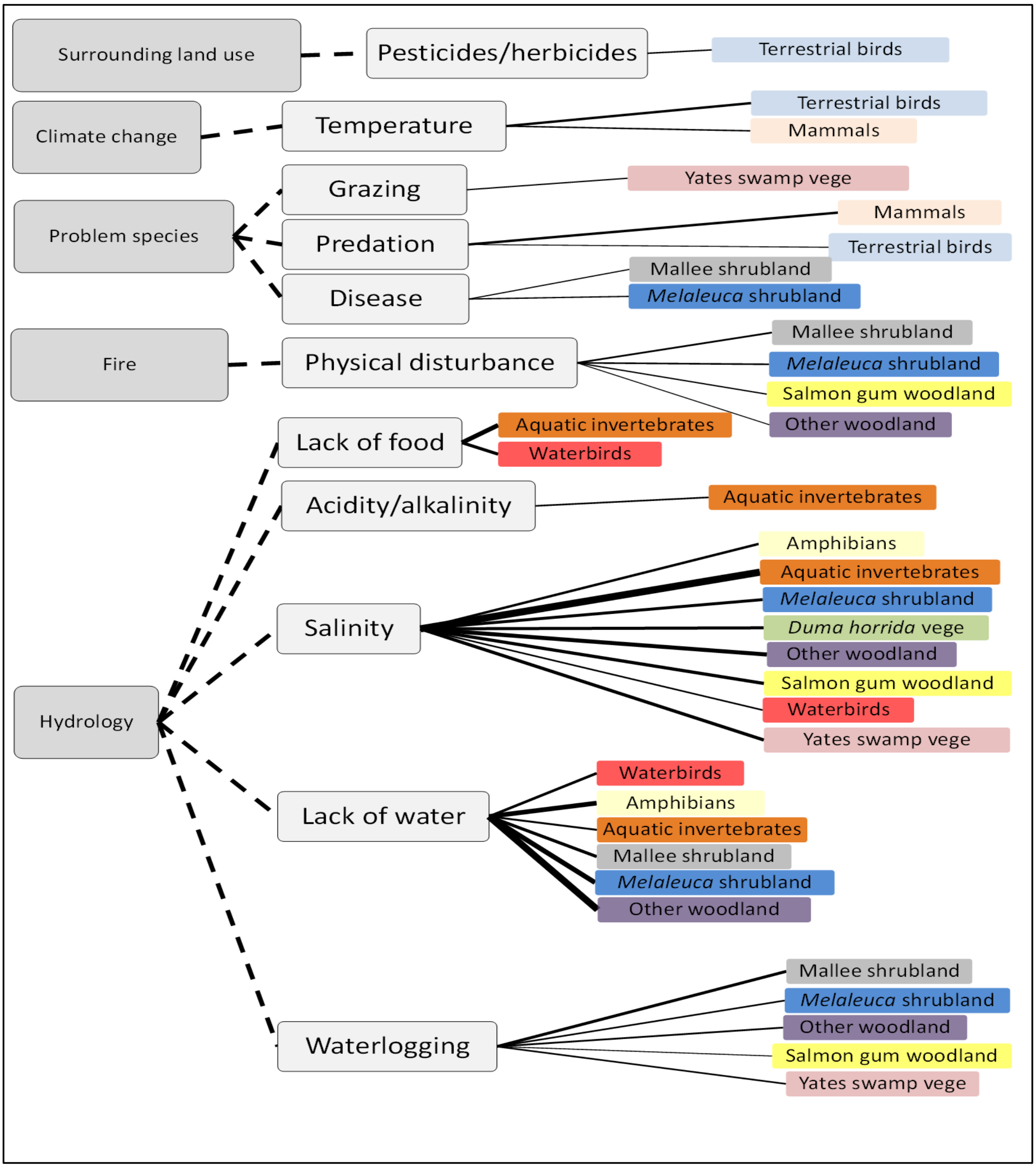


Figure 6 Logic tree for the likelihood that each important risk factor (>5%) will cause management target failure for each affected biological element. Risk-factor-element combinations with a likelihood of 5% or less of causing management target failure are not shown.

7.3. Important threatening processes

The important threatening processes emerging from the analyses of direct risk factors outlined above are:

- Altered hydrology
- Problem species (disease, grazing, predation, and weeds)
- Fire regime (physical damage)
- Surrounding land use
- Climate change

These threatening processes have been widely and well recognised in Western Australia. Consequently, there is a plethora of information available on the management of these risk factors.

Altered hydrology

Although the management of factors affecting hydrology in the Lake Bryde Catchment has contributed to stemming potentially catastrophic loss of species, significant issues still remain that require ongoing research and management (Farmer 2015). Given the likely impacts of climate change, including reduced rainfall, increasing temperatures, and increasing severity and intensity of extreme weather events (Steffen *et al.* 2017), hydrological research and management will need to be highly adaptive.

Melaleuca shrublands impacted by inundation and salinisation. *Photo – DBCA, 2008*

The hydrological problems currently being experienced in the Lake Bryde Catchment are typical of those occurring in most catchments across the Wheatbelt. These problems have been linked to the broadscale replacement of deep-rooted, perennial native vegetation with shallow-rooted, low-water-use annual crops and pastures (Froend *et al.* 1987, George *et al.* 2005, Jones *et al.* 2009).

In the Wheatbelt, this change has created a water surplus manifesting as persistent surface water runoff and groundwater recharge. For the Lake Bryde Catchment, the removal of native vegetation for agriculture has led to a reduction in annual water use by plants and increased surface water runoff and, subsequently, rising groundwater levels, mobilisation of soil-stored salt and extensive secondary salinisation.

Surface water hydrology

Surface water investigations commenced in 1979, initially as part of a State-wide study of important waterbird wetlands. These investigations determined that currently surface water processes dominate the catchment (Farmer *et al.* 2003).

Black swans cruise past alga-draped *Duma* plants emerging from a drying Lake Bryde.
Photo – DBCA, 2007

Since land clearing commenced in the 1960s, runoff thresholds had been significantly reduced leading to more frequent, more prolonged, and deeper inundation of the catchment's valley floor. This in turn has led to the ponding of water and the accumulation of salts, both of which have contributed to significant plant deaths in the vegetation communities of the valley floor and an increase in salt load for Lake Bryde.

Consequently, changes to surface water processes and conditions represent the greatest threat to the catchment's biological elements in the short to medium term (Bourke and Ferguson 2015). To meet management targets for the biological elements, infrastructure was installed to control surface water movement and collection and revegetation projects were undertaken (Supporting Information, Appendix 7.1).

Groundwater hydrology

Groundwater investigations did not commence until the 1990s, when an increasing salt load within Lake Bryde was identified as a threat to the wetlands and their biota. Since then, more than 120 groundwater observation bores have been installed.

Lake-bed vegetation on East Lake Bryde includes both samphire and *Duma* elements.
Photo - DBCA, 2014

During the initial monitoring period, groundwater levels were observed to be rising. As a result, it was thought hydraulic heads would drive groundwater movement from areas of recharge to areas of discharge, with significant impacts to biological elements.

However, the regular monitoring of groundwater between the 1990s and 2019 does not substantiate this concern. While most bores show short-term oscillations in groundwater level, the long-term trend for the vast majority of bores is for relatively static groundwater depths. Bourke and Ferguson, (2015) suggested the drying climate is a contributing factor.

Given uncertainty about the implications of climate change, rising groundwater levels are still considered to be a long-term threat to the catchment's biological elements. Revegetation, which includes the adoption of sustainable, high water-use, agricultural systems such as mallee belt farming, has been undertaken at many sites within the catchment (Supporting Information, Appendix 7.2).

Management options

Ultimately, management of hydrology (and any other threatening process) in the catchment requires:

- A conceptual model(s) that informs the application of the management options. The conceptual model(s) should be revised with new information.
- A clearly defined set of feasible and practicable management levers[h].

Preliminary limits (pending adaptive management) have been suggested for the management of hydrology-related issues and a monitoring program has been developed that is based around managing, within limits of acceptable change, water quality, periodicity, and depth of groundwater (Section 9).

By setting limits of acceptable change around a management target that links each element to the human values, a direct and adaptive link is created between management effectiveness (i.e. not losing species) and element value. In the short term, and assuming full operation of the available infrastructure, the only realistic management solutions revolve around design and installation of new hydrological management infrastructure (e.g. surface water pumps, drains, culverts, and other water conveyance infrastructure), improvements to the current infrastructure and revegetation.

Problem species

Disease

Even though the risk of the introduction of soil-borne fungal diseases such as *Phytophthora cinnamomi* is currently considered low, due to the catchment's low rainfall, the experts thought it an important risk in the context of the 20-year management period. Importantly, other species of *Phytophthora* have recently been detected in drier area of the Wheatbelt, including *P. boodjera* associated with disease in threatened *Eucalyptus steedmanii* at Forrestania, *P. inundata* at Lake Toolibin and Quairading and *P. litoralis* also at Quairading, but their impacts on native vegetation is currently poorly understood.

This is a particular concern as many of the vegetation elements are dominated by genera (e.g. *Eucalyptus, Melaleuca*, *Banksia*) that are known to be susceptible to *Phytophthora* infection.

Currently, no serious diseases are known to be affecting the native vegetation in the area. Nonetheless, all department and other agency operations should conform to:

- departmental disease policy
- good hygiene and biosecurity principles[i]
- Wheatbelt Region disease management strategies (DBCA, 2019).

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[h] By 'levers' we mean feasible and effective mechanism or tool to control salinity.

[i] https://www.environment.gov.au/system/files/resources/773abcad-39a8-469f-8d97-23e359576db6/files/arrive-clean-leave-clean.pdf

Consequently, a precautionary approach towards disease management should be adopted and coupled with continued research. Ongoing vigilance is required to prevent the spread of disease into the catchment once virulent species are identified and mapped. With this in mind and given the existence of departmental management policies and approaches for disease[j] the recovery program outlines a monitoring approach to trigger a management response. Additionally, the disease management should be updated as new information and approaches become known.

Table 4 Plant genera with species known to be affected by *Phytophthora* species[k].

Proteaceae	***Myrtaceae***	***Epacridaceae***	***Other***
*Banksia**	*Beaufortia*	*Andersonia**	*Allocasuarina*
Grevillea	*Calytrix*	*Astroloma**	*Boronia*
Hakea	*Eucalyptus*	*Leucopogon**	*Conostylis*
*Isopogon**	*Melaleuca*	*Lysinema**	*Dampiera*
*Persoonia**	*Verticordia**		*Daviesia*
*Petrophile**			*Gastrolobium*
Synaphea			*Hibbertia**
			Jacksonia
			*Lasiopetalum**

* most species in genus are susceptible to *Phytophthora*.

Grazing species

If not controlled, kangaroos and rabbits are likely to cause the loss of native species through unsustainable seedlings and mature plants mortality. It is unlikely that rabbits will be eradicated over the management period and kangaroos are native, and thus both species require ongoing density control.

The recognition of kangaroo grazing as a threatening process raises an interesting juxtaposition given the significance of the important values attributed to the mammal element. However, the objective is not to reduce the richness of the native mammals, but to manage the abundance of kangaroos.

Current departmental policies and control methodologies for in place both species:

- Rabbits are baited when monitoring detects grazing at TEC sites. Baiting is also applied, up to three times per year, at revegetation sites. Additionally, a new strain of *Calicivirus*, referred to as RHDV1 K5, has also been released.
- Kangaroo numbers are controlled as required. A key issue that remains unresolved is the maximum densities of grazers – especially in terms of appropriate limits – that are consistent with management targets. When grazers exceed a critical density, a control response should be triggered.

[j] http://www.dpaw.wa.gov.au/management/pests-diseases
[k] Taken from Dieback Working Group & Threatened Species Network (2008).

A western grey kangaroo is captured by a remote camera. *Photo – DBCA, 2018*

Predation

Predation by feral predators on terrestrial birds and mammals was seen by the expert group to be an important risk factor. Key predators in the catchment for birds, mammals, reptiles, and amphibians are the red fox and feral cat. Both have been regularly detected by remote cameras installed within the catchment.

As with the other problem species, the department has developed policies and management approaches to control feral cats and foxes, and these should be enacted once a management response has been triggered.

Naturalised animal species recently recorded in the catchment are listed in Appendix 15.

Foxes and feral cats are frequently detected by remote camera monitoring. *Photo – DBCA, 2018*

Weeds

The negative effects of weed invasion are well understood and documented (Lawes and Grice 2010). Without management, competitively superior weed species will present a threat to many of the native plant species and may cause loss of native species once they are able to establish themselves. Weed species are often introduced or quick to establish in disturbed areas and consequently, other key risk factors such as altered hydrology, excessive grazing and inappropriate fire regime may all contribute to creating a disturbance that can facilitate establishment of unwanted weed species.

Currently, weed management includes monitoring for weeds at revegetation sites and along firebreaks and tracks. Tracks and firebreaks are sprayed as required. Revegetation sites are sprayed more regularly until plants have established. Weed spraying follows departmental policy[l] and the Standard Operating Procedures (SOPs[m]) that are in place for weed management.

Given that procedures have been established for weed management, this recovery program will incorporate a focus on monitoring programs to detect the introduction and spread of weed species to trigger a management response to control or remove offending species. It will be important to use the monitoring program to determine which species are most likely to affect management targets (cause loss of native species) and require control or eradication.

Ultimately, the management of particular infestations will require case-specific approaches with case-specific control mechanisms – biological, chemical or physical. The mechanism of dispersal and establishment is an important consideration for any recovery response regarding managing a weed infestation (Sakai *et al.* 2001).

Naturalised plant species recently recorded in the catchment are listed in Appendix 15.

Sheep thistle has been controlled at two wetlands but requires long-term monitoring. *Photo – P.J. White/DBCA*

[l] The department's weed management policy can be found at http://www.dpaw.wa.gov.au/about-us/36-policies-and-legislation

[m] https://www.dpaw.wa.gov.au/plants-and-animals/plants/weeds

Fire

The catchment lies within the southwest biodiversity hotspot[n], and the biological vegetation elements support a high richness of plant species. The evolution of this diversity is a result of several factors – a geologically ancient and stable landscape, nutrient-poor soils, variable climatic conditions, highly specialised pollinators and natural fires. Natural fires have influenced the flora of the south-west for nearly 90 million years. Fire-adapted traits such as resprouting, hard-seededness, heat release of canopy-stored seed and synchronous post-fire flowering are common in the south-west flora.

Senescent *Allocasuarina* in long unburnt heathlands near East Lake Bryde.
Photo – P.J. White/DBCA

The management of fire to maintain biological diversity is a particularly complex issue (Gosper *et al.* 2013) that was initially considered a significant threat to native species , particularly in terms of physical damage. However, in a later workshop, experts noted:

- For fires that kill non-resprouting species, extinction is possible only if there is no existing seed bank in the canopy or soil.
- Fire, in combination with other processes such as grazing pressures, seed predation, weather conditions and weed invasion, may increase the extinction risk for some species.

[n] http://www.environment.gov.au/biodiversity/conservation/hotspots

- The chance of two successive fires within a 20-year period that kills two generations of non-resprouting species is low.

Different plant species vary in their response to fire according to their life history. Additionally, different frequency, timing and intensity of fires may be optimal for different plant species (Carley and Brooks 2013a, b). Too short an interval between fires can result in the loss of plant species that are susceptible to fires or for those that have not reached reproductive maturity prior to the fire. Consequently, it is generally accepted that when managing bushland, applying the same fire regime over a large area should be avoided. With this in mind, the department's Wheatbelt Region has developed the Fire Regime Optimisation Planning System (FiReOPS) to assist with the planning and scheduling of prescribed burns to improve biodiversity conservation outcomes (Beecham & Lacey 2016).

Given climate change is expected to increase the length of the fire season and the intensity of fire weather conditions (Steffen *et al.* 2017), fire management to maintain biological diversity will need to be highly adaptive.

The habitat requirements of the animal elements also need to be considered. For example, malleefowl may require areas of up to 15 to 40 years since fire to build up enough leaf litter for nest building, while they may make use of recently burnt areas to meet other life history requirements. Thus, malleefowl provide a salient example of types of specific fire requirements that fauna may have. Some plant species require fire as a cue for reproduction and regeneration. If the interval between fires is too long, the plants will senesce without reproducing, causing local extinction of that species.

A western bearded dragon (*Pogona minor minor*) waits to ambush pollinating insects. Photo - *P.J. White/DBCA*, *2018*

The relatively small areas of the reserves within the Lake Bryde Catchment, however, means the plant and animal species may be more susceptible to grazing, predation and weed competition after a fire. However, resolving how best to manage fire is complicated by a lack of understanding of how the fire response of many species and communities.

To overcome these problems, the department has developed the FiReOPS tool, which makes use of the best available information and expert opinion to set meaningful limits around the periodicity, intensity, and spatial variability of fire events. This tool incorporates the adaptive management approach, which improves our knowledge and understanding of the fire response of species and communities as we managed fire events.

Nocturnal tawny frogmouths resting during the day in Lakeland Nature Reserve
Photo - Dale Fitzgerald, DBCA/2012

Surrounding land use

The introduction of pesticides and herbicides was seen to be an important risk factor for the terrestrial bird communities. Secondary poisoning, through the consumption of insects weakened or dying from pesticides applied on farmland, has been identified as a cause of mass mortality in Australian birds (Story and Cox 2001). Ingested pesticides, even at sublethal levels, can place birds under physiological stress and alter their behaviour, making them more vulnerable to predation.

Management options are limited but include ongoing liaison with neighbouring landowners and with officers from the DPIRD, especially during times of widespread use of pesticides, such as during plague locust outbreaks.

Climate change

Recent climate studies show that, over the past 40 years, Western Australia's average annual temperature has increased by about 1°C. Depending on the level of future greenhouse gas emissions, the latest climate projections for Western Australia show the average annual temperature increasing by 0.5–1.3°C by 2030 and by 1.1-5.1°C by the end of the century (Sudmeyer *et al.* 2016).

Similarly, annual rainfall along the west coast and the far south-west over the past 60 years has declined by up to 20%, with much of this reduction occurring in winter and autumn. Again, depending on the level of future greenhouse gas emissions, annual rainfall in the south-west is projected to further decline by 5-6% by 2030 and 12-18% by the end of the century (Sudmeyer *et al.* 2016).

An emu crossing a seasonally flooded lakebed. *Photo - P.J. White/DBCA, 2016*

Additionally, the severity and intensity of extreme weather events is expected to increase (Steffen *et al.* 2017, DWER 2019). For the Lake Bryde Catchment and other areas of the Wheatbelt, this is likely to see an increase in:

- the length, intensity, and frequency of heatwaves
- the frequency and duration of extreme drought
- the length of the fire season and the intensity of fire weather conditions
- the intensity of extreme rainfall events.

Scientists often face difficulties separating anthropogenic climate change trends from cyclical events, such as droughts, bushfires, disease, extreme temperatures, and rainfall volatility (Hoffmann *et al.* 2019). While this has made it difficult to determine the full impact on native biota, some effects have been identified:

- Changes in geographic range, movement patterns, morphology, physiology, abundance, phenology, and community dynamics of Australian birds (Chambers *et al.* 2005).
- Changes in food availability, timing of hibernation, frequency and duration of torpor, rate of energy expenditure, reproduction, and development rates of juveniles in bats (Sherwin *et al.* 2012).
- Shifts in the arrival time of common brown butterflies (Kearney *et al.* 2010).
- Genetic changes in flies (Umina *et al*. 2005).
- Leaf shape changes in vegetation (Guerin & Lowe 2013).
- Press and pulse[o] events in Gondwanan forests, river red-gum forests and the arid zone (Harris *et al*. 2018).
- Drought-induced canopy dieback in forests in southwestern Australia (Allen et al. 2010; Anderegg *et al.* 2013).
- Increase frequency and severity of insect pest outbreaks resulting in *Eucalyptus* dieback (Barbosa *et al.* 2012; Björkman & Niemela 2015).
- Shift in orchid leaf emergence and flowering periods (MacGillivray *et al.* 2010; CaraDonna *et al*. 2014).
- The first mammalian extinction in a low elevation sand cay in the Torres Strait (Waller *et al*. 2017).

While this research aids our understanding of the diverse effects of anthropomorphic climate change, it is far from complete. Because of this, and the natural complexity in all ecological interactions, it is impossible to predict how the effects of anthropomorphic climate change will impact the biota of the Lake Bryde Catchment over the management period of the landscape recovery program. Additionally, we have no capacity to control increasing variability and extremities in temperature and annual rainfall in the short term.

However, integrating the results of studies into climate change impact within the catchment management strategies may help to improve the survival and resilience of species, communities, and ecosystems by:

- increasing the likelihood of successful adaptation
- decreasing vulnerability to climate change.

[o] Press disturbances are long-term disturbances (such as climate change) that have long-term impacts on ecosystems. Pulse disturbances are temporary disturbances (such as seasonal variations in rainfall or temperature) that, while influential, are usually recoverable because of the temporary nature of the problem. However, when pulse events are amplified by press disturbances, species and ecological communities can be lost or permanently altered because the press-pulse disturbance combination exceeds the limits of acceptable change for these biodiversity assets.

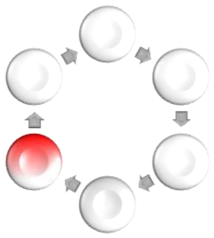
These management strategies will need to be applied at a range of management levels (Dunlop and Brown 2008, Steffen et al. 2009), including at the catchment, community and species scales.

7.4. Managing other risk factors and processes

From the above discussion and bearing in mind the results of the risk analysis, even with the maintenance of current management, there is no guarantee of goal or target success (no loss of native species). Clearly, additional management actions are required to increase the likelihood that management goals and targets are reached.

Finally, the recovery program has focused on several threatening processes thought to be the most important. However, new, or latent threats may emerge during the planning process. The monitoring approaches (described in Section 9) have been designed to provide timely warning of emerging problems.

8. Devise recovery actions



The next step is to identify and prioritise the actions required to manage the key threatening processes to maintain or, where possible, improve the status of the elements in terms of their key values. The risk analysis (Section 7.2) indicated that ongoing implementation of current management programs as well as additional management will be required to reduce the likelihood of species loss over the management period.

8.1. Benefit analysis of potential recovery actions

Methodology

To complete this step the benefits expected from managing each threatening process were assessed:

- The TAG identified a suite of recovery actions to address the key threatening processes.
- Management options were then listed, either to address individual threatening processes or to address different combinations of threatening processes. This produced a list of 31 possible management options.
- The TAG then prioritised the 31 individual management options in an assessment of the benefits (benefit analysis). This analysis considered all the currently feasible actions required to successfully manage each process.

The methodology and results of management option analysis and a description of the TAG workshops that prioritised the management options is detailed in Supporting Information, Appendix 14.

Results and implications

In general, there was considerable uncertainty surrounding each estimate of benefit, highlighting the possibility, that any option may be more or less effective (in terms of not losing species and cost) than expected. However, the inclusion of hydrology in any management option, despite its high cost, significantly increases the expected effectiveness of a management option (Figure 5).

The most effective management options are:

1. Manage all options: hydrology/fire/problem species/climate/land use.
2. Manage hydrology/fire/problem species/climate.
3. Manage hydrology/fire/problem species.

The analysis also found that undertaking no recovery actions within the catchment and walking away from the management area was the least effective option.

There is also no certainty that the current level of management resources will successfully maintain native species and thus meet the associated target and goal.

Recommended action:

2. **Where possible, continue to manage threatening processes within available budgets over the management period, and, when necessary, seek additional funding to increase management capacity and effectiveness.**

8.2. Recovery actions

Managing altered hydrology

Surface water management is currently exerted via surface water conveyance infrastructure (waterway) and through broadscale revegetation. This has generated responsibilities for ongoing management, maintenance, and future planning. Additionally, the implications of climate change, with potential reduction in rainfall but an increase in the frequency and intensity of extreme rainfall events, necessitates a commitment to the adaptive management approach, supported by rigorous hydrological monitoring and the incorporation of professional hydrological advice.

These responsibilities, along with other management activities, are essential to meet the recovery goal and management targets.

Recommended actions involving infrastructure:

3. **Maintain, modify or decommission current surface water conveyance infrastructure (waterway) based on trends in monitoring data and professional hydrological advice.**
4. **Investigate and implement new infrastructure options to improve water quality entering Lake Bryde, when justified by monitoring data and supported by professional hydrological advice.**
5. **Continue to address inundation, waterlogging, and degradation impacts along the western boundary of the Lakeland Nature Reserve through ongoing maintenance of surface water drainage infrastructure.**
6. **Manage the hydrological impacts associated with Rosenbergs Creek (Holland Tank Road sub-catchment).**

Recommended actions involving revegetation:

7. **Develop and implement a revegetation plan to provide direction for revegetation in the catchment, to address hydrological process issues and other wildlife management objectives that are related to the key values identified in Section 4.**

8. **Maintain an adequate representation and quantity of seed of local native species in the department's Wheatbelt Region seed store to meet the needs of revegetation programs and safeguard against loss of species from the catchment.**
9. **Maintain an adequate representation of local native species in the department's other seed stores to provide additional insurance against the loss of species.**
10. **Maintain areas of revegetation between Lake Bryde Conservation Park and the southern boundary of the Lakeland Nature Reserve.**
11. **Promote substantial revegetation to assist with the hydrological management of the receiving valley floor and areas that are prone to inundation in the Ryans Creek and Day Creek sub-catchments of the Lake Bryde South catchment in conjunction with key landholders.**
12. **Promote revegetation on properties contributing water to the Lakeland Nature Reserve western boundary.**
13. **Promote excess-water management in the Fourteen Mile Road sub-catchment in a bid to control impacts (mainly enhanced recharge) in the flat areas north of the Pingrup-Newdegate Road and above the Yate Swamp.**
14. **Address impediment impacts of key road crossings in conjunction with the shires of Kent and Lake Grace to reduce future salinity development and inundation impacts**

The department has undertaken land purchases to accommodate revegetation projects and surface water infrastructure. In 2003, the department purchased 724.8 ha of freehold land between Lake Bryde Nature Reserve and the southern boundary of the Lakeland Nature for these purposes. Other areas have been identified as suitable for similar projects but to date DBCA has not been successful in purchasing these areas.

Recommended actions:

15. **Identify and prioritise potential land acquisitions that are required to support important revegetation or infrastructure projects.**
16. **Pursue the acquisition of priority land purchases where appropriate and possible in terms of funding, feasibility, and effectiveness.**

Various hydrological management options must be assessed in terms of feasibility and significance with respect to meeting the management goals. Additionally, there is a clear set of steps to be taken for the management of altered hydrology and the recommended activities should be assessed and conducted within that framework (Refer Figure 7).

Recommended actions:

17. **Assess, develop, and implement proposed ground and surface water management options, with the support of professional hydrological advice.**
18. **Maintain and improve monitoring infrastructure, as necessary, and regularly analyse and report monitoring data to facilitate decision-making.**
19. **Provide ongoing hydrological support and advice to regional staff and landowners on issues relating to public land and community water management.**

A good understanding of the wetland-scale water and salt balances for Lake Bryde and East Lake Bryde would benefit decision-making in relation to management options. Unfortunately, the currently available data on several key components of the water and salt balance model are deficient. This imposes significant limitations on the accuracy and reliability of the model.

Recommended action:

20. **Where resources permit, undertake additional investigations to address data deficiencies in groundwater inflow/ outflow and overland and channel losses, the Lake Bryde outflow dynamics, spatial variability of rainfall, the flow contribution of the northern inlet (Lake Bryde), and the salinity of surface water and groundwater inflows and outflows.**

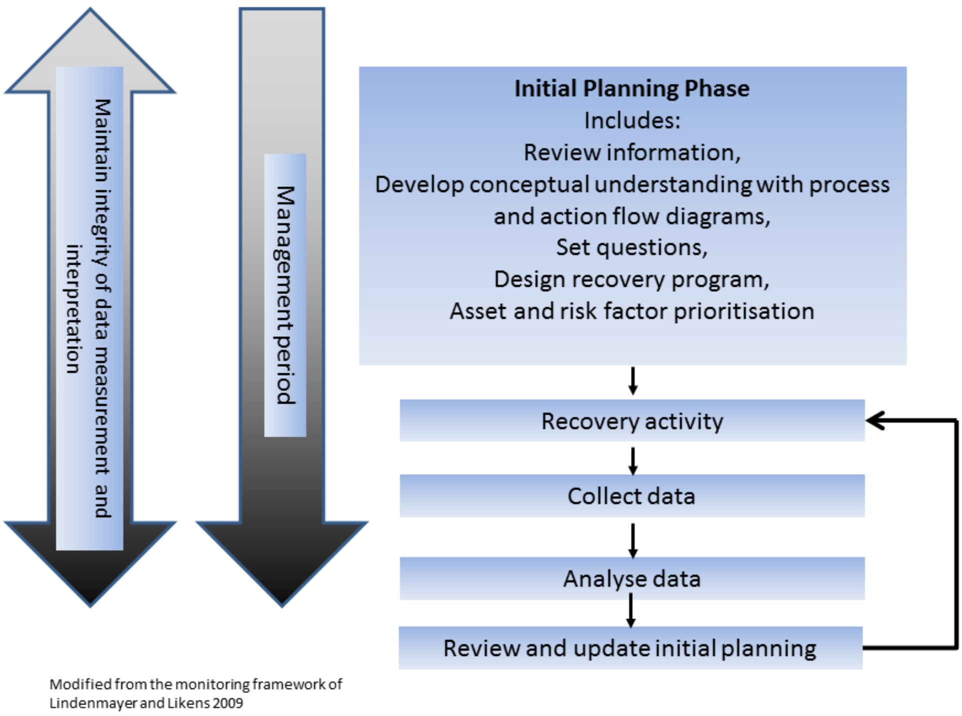


Figure 7 Intra-threat level recovery action framework.

Problem species

Disease

Currently, the risk of disease introduction into the catchment is thought to be low, due to the catchment's low rainfall. However, the 20-year management period of this recovery program, the susceptibility of the vegetation elements to disease, and uncertainties about the future climate of the catchment means the risk of introduction needs to be addressed.

Preventing introduction and spread is a key strategy in managing diseases. The department's Corporate Policy No.3[p], and existing standard operating procedure (SOP) and management guidelines direct the management of *Phytophthora*[q]. A precautionary approach towards disease management is essential, and vigilance is required through the maintenance of disease hygiene practices to prevent the introduction or spread of diseases (including rusts and cankers) in the catchment. This is reflected in two strategies employed within the catchment:

- To minimise the risk of introduction, activities that involve the movement or introduction of soil or plant material, including earthworks and revegetation, are subject to hygiene measures and checks to detect the presence of *Phytophthora* species. If detected, the response is to cancel or, where possible, to modify the activity to eliminate the risk of introduction.
- Investigations are undertaken at any sites where susceptible species are observed to have died or are in poor condition. Soil and vegetation are sampled and analysed, and the site is mapped. If analysis indicates the presence of disease, steps are taken to limit vehicular access, which may otherwise spread the disease further, and the sites is subject to ongoing monitoring and mapping.

As with other problem species, this recovery program outlines a monitoring approach to detect potential disease infestations and trigger a management response. Recommended actions for the management of disease should be updated as new information and approaches are identified. The current status of disease in the biological elements is unknown.

Recommended actions:

21. **Continue to employ hygiene management for all operations.**
22. **Continue to investigate suspected disease expression in susceptible species.**

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[p] https://www.dpaw.wa.gov.au/images/documents/about/policy/corporate_policy_statement_3_-_management_of_phytophthora_disease.pdf
[q] https://www.dpaw.wa.gov.au/management/pests-diseases/129-phytophthora-dieback

23. **Investigate, monitor, and map deaths or decline in vegetation elements that may be attributed to other diseases.**
24. **Share information with local government authorities on disease prevention strategies to minimise the spread of Phytophthora disease.**

Grazing (rabbits and potential problem native species)

A pest animal management program is in place in the Lake Bryde Catchment in accordance with the department's policy[r] and guidelines[s].

Rabbit control has been used to protect threatened flora sites, threatened ecological community sites, and at revegetation sites to protect seedlings (until seedlings are sufficiently large to survive grazing). Sites are usually monitored on foot, supported by strategic remote camera monitoring, before control measure are implemented. Control has involved chemical control methods (e.g. 1080 bait) and biological control methods, such as through the release of the RHDV-K5 *Calicivirus* strain.

Threatened flora, threatened ecological community, and revegetation sites are also monitored for grazing by native species, such as kangaroos and emus, both by direct observation and by remote cameras. While some gazing has been detected, control measures have not been warranted.

Recommended actions:

25. **Continue to control rabbits and other introduced grazing animals at vulnerable sites using best-practice methods supported by regular monitoring.**
26. **Continue to cooperate with other agencies to facilitate the release of biological control agents for introduced grazing animals, such as new strains of *Calicivirus*.**
27. **Continue to monitor potential problem grazing by native fauna at vulnerable sites and apply effective control measures when required.**

Predation (foxes and cats)

The department has developed policies and methods to monitor and control problem predator species and these approaches should be employed where appropriate.

Recommended action:

28. **Continue with the implementation of introduced predator control measures.**

[r] https://www.dpaw.wa.gov.au/images/documents/about/policy/corporate_policy_statement_12_-_management_of_pest_animals.pdf

[s] https://www.dpaw.wa.gov.au/management/pests-diseases/181-rabbits

Weeds

The current weed management program in the Lake Bryde Catchment has proven to be effective in minimising the impact of weeds on native vegetation, revegetation areas, and fire breaks, and should be continued. However, the development of a weed management strategy will assist in setting effective long-term weed management strategies to protect high priority conservation areas within the reserves.

Recommended actions:

29. **Develop and implement a weed management strategy to detect, monitor and prioritise weed management requirements.**
30. **Continue to control persistent and problematic weeds at vulnerable sites using best practice methods supported by regular monitoring.**
31. **Share information on persistent and problematic weed species with landowners and local government authorities to develop, and jointly implement, control strategies.**

Fire

It is estimated that the time since the last major bushfire in many parts of the catchment is between 40 and 50 years. This may be approaching the interval at which species dependent on fire for regeneration may be lost from bushland reserves. However, the relatively small areas of many of the reserves within the Lake Bryde Catchment means the plant and animal species may be more susceptible to grazing, predation and weed competition in the post-fire period, and there is the potential for temporary increases in water tables after a fire.

Maintaining biota is important to delivering the key human values and introducing fire in a managed way will help maintain biodiversity. Re-introducing fire will require a greater understanding of how the biological vegetation elements respond to fire, including the level of senescence, the impacts of prescribed fire. It is generally accepted that when managing bushland, application of the same fire regime over a large area should be avoided.

A long unburnt kwongan heath near East Lake Bryde showing signs of senescence.
Photo – DBCA, 2008

A fire management plan is recommended to be developed in consultation with technical specialists, and in accordance with the department's Fire Management Strategy 2017 – 2021[t]. The primary aim of the plan should be to reduce bushfire risk and loss of vegetation and infrastructure. Secondarily, fire should be introduced as required, in an informed and managed way, to maintain or improve vegetation health where it will deliver on key values and promote biodiversity. The plan should be adaptive and updated as knowledge improves.

Recommended action:

32. Develop and implement a fire management plan for the catchment to protect infrastructure and to protect and maintain biological elements.

However, there is currently not a sufficiently detailed understanding of the recent fire history of the catchment, the biological elements, or the feasibility of introducing fire management for biological diversity to set meaningful limits around the periodicity, intensity, and spatial variability of fire events.

For this reason, an adaptive decision support tool is required to consider a range of factors, including management limits (frequency, intensity, spatial variability, etc), to determine the optimal prescribed burning arrangements. If fire related disturbance is confirmed as a significant issue, this needs to be addressed.

[t] https://dpaw.sharepoint.com/Key%20documents/Parks%20and%20Wildlife%20Fire%20Management%20Strategy.pdf

Recommended action:

33. **Evaluate and, if appropriate, implement the Fire Regime Optimisation Planning System (FiReOPS) to help develop a prescribed burn program for reserves in the Lake Bryde Catchment.**

Climate change

The Lake Bryde Catchment will continue to experience rising temperatures and declining rainfall. It is therefore expected that the catchment will suffer the loss of some mammal and terrestrial bird species as populations gradually decline and disappear. These changes were flagged by the expert group.

The effects of anthropomorphic climate change on the catchment’s flora and vegetation elements are much more difficult to predict. Rare species, or those with narrow geographical ranges, may be more adversely impacted by climate change (Enquist *et al*. 2019), while those more widely distributed, especially those represented in more arid regions, may actually increase under climate change.

While it is likely that we have no capacity to control increasing variability and extremities in temperature and annual rainfall in the short term, management activities can be undertaken to limit the effects of anthropomorphic climate change.

Recommended action:

34. **Investigate the potential for climate change impacts on threatened species and communities and develop effective response strategies.**
35. **Review studies on potential climate change impact and, when necessary, update current recovery strategies at the catchment and species level.**
36. **Work with communities and other stakeholders to mitigate and adapt to climate change including through an infrastructure risk assessment to identify community assets and biological elements at risk from climate change impacts.**
37. **Continue monitoring programs for significant elements that are expected to be impacted by climate change, to aid long-term decision-making.**
38. **In conjunction with the Department of Fire and Emergency Services, LGAs, local bush fire brigades and the community, actively respond to bushfires with potential for significant expansion and/or damage to areas of remnant vegetation and important biological elements in the larger reserve network within the Lake Bryde Catchment.**

Surrounding land use

There are looming chemical resistance issues and potential restrictions on the use of some herbicides (e.g. glyphosate due to perceived health concerns) for farmers in areas that surround the elements, which may mean a shift in chemical use.

Possible management activities to minimise the likelihood that pesticides and/or herbicides will cause the loss of terrestrial bird species include changing farm management practices and purchasing land to facilitate the creation of appropriate vegetation buffers. Work to optimise the timing of application may also be of benefit, possibly requiring collaboration with DPIRD.

In general, the management of climate and surrounding land-use issues overlap significantly with the management approaches required to ameliorate issues with hydrology (e.g., land purchase, revegetation, surface water management) and thus should be important considerations when devising hydrological management activities.

Recommended action:

39. **Consider and, where justified and feasible, implement management strategies to minimise pesticide and herbicide impacts on the properties of key elements.**

8.3. Additional management activities

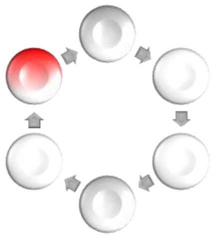
The recovery program has centred attention on the property of species richness. The other properties considered (rarity, intactness, charisma, visibility and size) and their expected relationship with the priority values means that any work to influence any of the key element properties in a positive way is likely to have concomitant benefits in terms of the human values. For example, increasing the charisma of elements, possibly through public engagement or through some form of advertisement should have positive Knowledge-Heritage and Recreation benefits. Such opportunities should be seized where possible and appropriate.

Finally, with the changes of natural resource management, we can expect general change in knowledge and technology and when new and unforeseen opportunities arise, they should be assessed.

Recommended action:

40. **Adopt appropriate new technologies and methodologies to manage the key properties (species richness, rarity, intactness, charisma, visibility, and size) and threatening processes, including research to gain new knowledge.**

9. Monitoring



To develop meaningful limits of acceptable change (LoAC) it is important to identify the main threatening process to the properties of the biological elements. This can be difficult as symptoms may be similar across threats, or a combination of threats may have caused cumulative stress and the introduction of an additional threat trigger the death of the element.

For the Lake Bryde Catchment, the LoAC has been set around species richness. The LoAC is described in terms of the abundance of detectable individuals of the native species that characterise each element[u]. As long as the LoAC are not exceeded (i.e., abundances do not change too much), detectable native species will not be lost.

Based upon this LoAC, the recommended monitoring framework for the Lake Bryde Catchment is outlined in Table 5 and, following from the previous section, focuses on monitoring native species richness (the key property) such that individual species abundance changes do not exceed LoAC.

Table 5 Recovery response framework for the Lake Bryde Catchment.

Threatening Process	**Property**	
	LoAC not exceeded	**LoAC exceeded**
LoAC not exceeded	No recovery response triggered, however, activities and LoAC can be adapted with new information.	Recovery response triggered, LoAC for process and/or property may need to be reviewed.
LoAC exceeded	Recovery response triggered, LoAC for process and/or property may need to be reviewed.	Recovery response triggered, LoAC for process and/or property may need to be reviewed. Modify control program.

To provide information to assist in the management of the elements, information relating to the threatening processes targeted by the recovery activities (identified in Section 8) should also be monitored (Table 5). Specifically, activities are undertaken to manage processes that threaten the properties that influence key values. If changing a recovery activity does not resolve a problem, management target failure (and ultimately aspirational goal failure) is a likely outcome.

[u] It is important to understand that a factor to consider in developing the monitoring program is that the number of species detected for a given monitoring approach will vary. Where resources limit monitoring to a less intensive approach, fewer species in general and fewer individuals of particular species are likely to be detected at the risk of missing important information in terms of managing elements for their human values.

In line with the recovery response model (Table 5), this section identifies the monitoring requirements for:

- the properties (of the priority biological elements)
- the threatening processes (which influence the biological elements)
- the key values (which frame the aspirational goal).

Nonetheless, the various activities outlined below should be treated as part of a larger, more integrated approach. Where appropriate, the biological monitoring should be conducted concurrently and within the same spatial context as the threatening process monitoring to maximise the concomitant benefits. That way any correlation between change in threatening process and property can be investigated, and if deemed important, used to support management decisions.

An example of adaptive monitoring and evaluation:

To provide an example of the approach, the abundance of a number of native plant species are monitored (relative to a set LoAC) at a number of sites in a vegetation element. At the same time, kangaroo management, in the same area, aiming to limit them to a particular density (e.g. no more than two kangaroos/ha, a LoAC) is also monitored.

- If the kangaroo densities exceed the LoAC, but the vegetation does not, the recovery response may be to adapt the LoAC for the kangaroo control activities (or possibly the vegetation LoAC if there is sufficient evidence that the current LoAC are too lenient).
- If the vegetation LoAC are exceeded (but not the process LoAC) and there is evidence that this is a direct response to kangaroo grazing, the control program will need to be modified (including the LoAC).
- If both the process and property LoAC are exceeded, the probable recovery response would be to modify the kangaroo control program. If the vegetation LoAC are exceeded and there is no evidence it is related to the kangaroos, other processes should be assessed.

The values of the biological elements are not currently monitored, nor have any survey or monitoring approaches been developed for the values. It is therefore assumed that, until a monitoring protocol for the values is developed, a change in a property will reflect a change in value as predicted by the modelling described in Section 8.

9.1. Monitoring species richness (the key property)

In terms of the planning approach, there are two major components with respect to data collection for properties:

- Detailed information (e.g. location, extent, species composition, condition etc) will provide a strong basis to rate the elements on their values, and as outlined previously, detailed biological information needs to be collected for each element to improve the current values and risk analyses.

- Monitoring change in properties (i.e. species richness) within the context of the management targets, LoAC, management triggers and the key risk factors is imperative, but may not require as detailed information as the values analyses.

Given the variable nature of funding and availability of management resources, an approach to monitoring the properties and processes must be developed that can be adapted to suit these constraints and can be conducted by the incumbent catchment officers. Although the focus of this section is monitoring, data can often have multiple uses and so it is noted that data collection for monitoring will also provide additional information for future values delivery analyses.

Monitoring – six vegetation elements

In Section 6, seven vegetation types were identified as high priority biological elements. These included Yate swamps, salmon gum woodlands, other woodlands, mallee shrublands, samphire communities, melaleuca shrublands and the Bryde TEC. Six of these vegetation types can be monitored using the same approach. The Bryde TEC has specific monitoring requirements because of its TEC status.

Salmon gum woodland is one of the seven high priority vegetation elements.
Photo - P.J. White/DBCA

A series of vegetation mapping projects have been commissioned to address the need for information on the location, extent, species composition and current condition of the catchment's vegetation elements. The primary focus of this work has been privately owned remnant vegetation throughout the catchment and the reserves occupying the valley floor. Vegetation mapping is scheduled to be completed in 2020.

Recommended actions:

41. Complete the vegetation mapping of the large reserves in the catchment and integrate this information with previous vegetation mapping of other sites in a format that will allow for multiple future uses.

42. Identify and assess patches of the 'Eucalypt Woodlands of the Western Australian Wheatbelt' in the catchment, and document eligible TEC occurrences under the EPBC Act.

Given the limited resources available for monitoring and the large area and significant diversity of the vegetation within the catchment, an efficient, quantitative monitoring approach is recommended. It would therefore be prudent to consider a targeted monitoring approach, such as that employed by Geyle et al. (2019). This would involve the selection and monitoring of 'indicator' species that are believed to be susceptible to a particular process, and that can be easily detected. Importantly, this may mean that different indicator species have different attributes monitored.

Detailed vegetation monitoring can be very labour intensive in terms of setting up the plots, recording plant data and analysing the complex results.
Photo – DBCA, 2011

Recommended actions:

43. **Determine the most appropriate vegetation monitoring methodology for the catchment and implement a standard operation procedure for all future vegetation monitoring.**
44. **Develop an LoAC to match the data outputs of the vegetation monitoring methodology.**
45. **Once vegetation mapping is complete and vegetation elements have been defined, establish monitoring sites to collect information on the properties and threatening processes for each vegetation element.**
46. **Ensure that the vegetation monitoring data is maintained in a format that will allow for multiple uses and provides additional information for future analyses.**

Given that the monitoring methodology has still to be resolved, it is not possible at this time to define an initial LoAC for vegetation elements.

Special purpose vegetation monitoring

Vegetation health monitoring has been conducted four times (2005, 2009, 2011 and 2013) to assess the impact of water conveyance infrastructure. The monitoring involved 17 transects varying in length between 100m and 500m and used 10m x 10m tree quadrats at intervals of every 10m, and 2m x 2m understorey quadrats at intervals of 5m.

Phillips (2011) concluded that the declining vegetation trends could not be attributed to the construction of the waterway. She also found the data collection methodology requires an excessive commitment of resources and needs to be simplified.

Recommended actions:

47. **Conduct a rationalisation of vegetation monitoring undertaken to assess the impact of the waterway.**

Monitor – Bryde TEC

The Bryde TEC is located on three different wetlands, with the first two discovered in the 1990s and the third in 2008. Two new populations of *Duma horrida* subsp. *abdita*, which is listed as threatened flora (Endangered), were discovered in 2017. However, neither currently meets the TEC criteria due to the absence of *Tecticornia verrucosa* at these sites.

Monitoring guidelines were developed specifically for the Bryde TECs (Newland *et al.* 2010). These have been applied to monitoring the TEC occurrences and the two newly discovered *Duma* populations, with randomly located quadrats installed at all sites. Data from the 72 quadrats, as well as other biological observations, have provided useful baseline information on this element.

The monitoring guidelines have proven to be difficult to implement with available resources. Some of the data collection methods have been superseded by new and more efficient techniques (e.g. low altitude drone photography). Additionally, the data prescribed by Newland *et al.* (2010) are, in some cases highly erroneous, due to improved knowledge of the biology of the TEC's key species.

Recommended actions:

48. **Develop and implement a new standard operating procedure for TEC monitoring of the Bryde TEC, which can also be used to monitor Duma populations.**
49. **Review the TEC monitoring data against the LoAC and, where necessary, adapt the management regime or the LoAC accordingly.**
50. **Review and update the Interim Recovery Plan for the Bryde TEC (Hamilton-Brown and Blyth, 2001) and incorporate the LoAC within the revised plan.**

LoAC for Bryde TEC

Factoring in the short-term effects of inundation and drought, the number of occurrences has decreased by less than 10% and the average quadrat coverage of *Duma horrida* subsp. *abdita* has decreased by less than 25% over the 20-year management period.

Waterbirds

Several waterbird surveys have been undertaken in the Lake Bryde Catchment (Jaensch *et al.* 1988; Cale 2006). They provide sufficient baseline information to allow an initial LoAC to be proposed. However, this is likely to be superseded as knowledge of waterbird dynamics grows.

Waterbirds are an important element to deliver the priority values and contribute to the ecology of the wetlands within the catchment. To permit easy comparison between observation during different phases of monitoring, it is essential that a standardised methodology be used. Halse *et al.* (2002) detailed a simple approach of using both binoculars and spotting scope, on foot and in a canoe.

While a narrow set of indicator species can be used to set the LoACs, an understanding of how the wetlands are used by waterbird species can indicate the health of the wetlands and may influence the abundance of the indicator species due to interspecies interactions (e.g. competition for resources and habitat).

Table 6 Suggested indicator waterbird species used to assess management targets.

Common name	Scientific name	Abundance range *
Australian shelduck	*Tadorna tadorniodes*	6-195
Hoary-headed grebe	*Poliocephalus poliocephalus*	37-276
Grey teal	*Anas gracilis*	102-675
Eurasian coot	*Fulica atra*	10-186

* Based on surveys: Oct. 1997, Mar. 1998, Aug. 2001, Mar. 2007, Feb. 2012.

Recommended action:

51. **Develop a new standard operating procedure for waterbird monitoring based on the methodology of Halse et al. (2000).**
52. **When conditions are conducive, monitor waterbirds abundance and breeding activity at wetlands in the management area, revising the indicator species list as knowledge of waterbird ecology grows.**
53. **Assess the LoAC in terms of the indicator waterbird species listed in Table 6 at all natural lakes and wetlands in the management area.**

Initial LoAC for waterbirds

When conditions are conducive across the natural lakes and wetlands, all indicator species are recorded as present.

Native mammal species

Historic fauna surveys undertaken in the catchment have detected 29 native mammals (Department of Parks and Wildlife 2007-2020). A remote camera survey of the reserves on the valley floor commenced in 2018 and has so far detected seven native mammals (Table 7). However, after only 12 months of camera monitoring, the data is not yet sufficiently reliable to set a LoAC based on species detection rates.

Temperature and predation have been identified as significant issues for native mammal fauna. Therefore, detailed monitoring programs and associated problem species control programs may be required. The department has standard procedures for mammal monitoring and control to refer to.

Recommendation action:

54. **Document and implement a new standard operating procedure for native mammal monitoring.**

55. Undertake native mammal monitoring for significant changes in abundance and identify the specific threatening processes accounting for the variations.

56. Assess and revise the LoAC for native mammal species once sufficient data has been collected to set reliable detection rate limits.

Table 7 Native mammal fauna detected by Lake Bryde Catchment remote camera survey.

Common name	Scientific name	Survey detection rate range*
Western grey kangaroo $^{\alpha}$	*Macropus fuliginosus*	820 - 1,322
Echidna $^{\alpha}$	*Tachyglossus aculeatus*	44 - 91
Brushtail possum $^{\alpha}$	*Trichosurus vulpecula*	26 - 51
Brush wallaby $^{\alpha}$	*Macropus irma*	2 - 24
Gilberts dunnart	*Smithopsis gilberti*	1 - 11
Mitchell's hopping mouse	*Pseudomys mitchellii*	0.0 - 9
Red-tailed phascogale	*Phascogale calura*	0.0 - 2

* Number of detections (images) per 1,000 camera days
$^{\alpha}$ Provisional indicator species

Initial LoAC for native mammals

Provisional indicator species detected by remote cameras (Table 7) are recorded as present annually.

Terrestrial birds and amphibians

No baseline information exists other than historic observations. Therefore, it will be necessary to survey terrestrial bird and frog species in a range of different habitat types within the catchment before a LoAC can be developed.

Terrestrial birds and frogs should be surveyed and monitored so that any change in species' densities can be related to issues such as pesticides/herbicides, temperature extremes and predation. These species can be surveyed and monitored using standard techniques point sampling approach (e.g. point sampling approach; Gregory *et al.* 2005) or call recording equipment may be a viable monitoring option for birds and frogs (Littlejohn 1988).

The actual survey approach employed will be determined by the resources available to collect and analyse trends in bird and frog populations and to adapt catchment management. Budgetary constraints are also a consideration. Implementation of surveys and monitoring programs are therefore only feasible after additional resources are secured for this purpose.

Recommended action:

57. Assess the feasibility of surveying terrestrial bird and frog and, if appropriate, develop and implement a monitoring program.

58. If bird and frog monitoring is to be undertaken, develop a LoAC once sufficient data has been collected to set reliable detection rate limits.

Terrestrial and aquatic invertebrates

Some baseline data exist on aquatic invertebrates (Cale *et al.* 2004; Cale 2006) but is not sufficient to establish a LoAC without additional survey work. There is very little baseline data on terrestrial invertebrates, which would require considerable research before data would be sufficient to establish a LoAC.

Invertebrates may at some point during the management period require survey and monitoring given their important role in several ecosystem processes (e.g., food availability for some waterbirds and their impact in terms of Knowledge-Heritage values). There are several accepted monitoring techniques for invertebrates that represent a trade-off between effort, precision, cost, and effectiveness (Meyer *et al.* 2011). Consequently, the actual survey approach employed will be determined to some degree by budgetary considerations and thus should not be fully developed until funding availability is known.

However, there has been previous sampling (e.g., Cale *et al.* 2004) and, where appropriate, new sampling should be consistent with previous approaches if possible (at least in terms of effort per sample). LoAC will need to be developed.

Recommended action:

59. Assess the feasibility of developing a survey and monitoring program for invertebrates and implement if appropriate.

60. If aquatic invertebrate surveys and monitoring is to be undertaken, it will be necessary to evolve a LoAC once sufficient data has been collected to set reliable detection rate.

9.2. Monitoring threatening processes

Altered hydrology

Surface and groundwater with unacceptable salinity or pH will:

- kill wetland plant and aquatic invertebrate species
- make wetlands uninhabitable for some invertebrate, waterbird and amphibian species
- reduce food availability for the waterbirds and aquatic invertebrates.

Naturally, the periodicity and duration of fill events will be linked to the level of rainfall, which is largely unmanageable. However, by using appropriate infrastructure to control the amount and quality of water that enters and leaves a wetland, hydrological impacts can be managed (e.g., *Toolibin Lake Catchment Recovery Plan*; Department of Parks and Wildlife 2015).

Many management actions, such as revegetation and the limiting of saline inflows into key wetlands, require decades to show their full impact. Therefore, it is important to maintain surface and groundwater monitoring regimes to understand how these recovery actions are achieving management targets. Consequently, considerable management resources have been used monitor the catchment's hydrology.

- Since 1995, more than 180 groundwater depth observation bores have been installed across the catchment. Until 2017, many of these bores were monitored on a monthly basis. Consequently, this monitoring generated considerable data on groundwater trends.
- Initially, between 1979 and 2004, surface water monitoring (e.g. depth, pH, and salinity) were only undertaken at Lake Bryde and East Lake Bryde sites, and then usually twice per year. Between 2004 and 2017, more than 30 sites were used to manually monitor surface water. This was complemented by surface water data collected by dataloggers installed at these and other sites in other locations.
- Four tipping-bucket rain gauges (TBRG) were installed between 2000 and 2003 for use in rainfall-runoff modelling. An automated weather station was installed in 2009 to collect complimentary climate data (temperature, wind speed and direction etc.).

Monitoring surface water at one of the termination lakes.
Photo – K. Hemmings/DBCA, 2014

Bourke and Ferguson (2015) recommended a number of changes to the surface and groundwater monitoring programs based on an interpretation of important hydrological processes across the catchment. A rationalisation of both programs was implemented in 2017 resulting in a simplified but more targeted approach.

- The groundwater rationalisation review (de Broekert 2016) noted the similarities between the data produced from closely spaced bores occupying the same landscape position. Consequently, the number of monitored groundwater bores was reduced to 92. Additionally, because of the extensive record of water levels, most of these are now monitored quarterly rather than monthly.
- The surface water rationalisation review (Hyd2o 2017) found that the surface water monitoring objectives could be achieved with six wetland or termination lakes, monitored on a quarterly basis, and six road crossing and waterway sites, monitored only after significant rainfall events only. They recommended that, when surface water is present at any of these sites, monitoring should be undertaken monthly, until dry. The review recommended against the use of a datalogging network for baseline observations, due to the complexity of maintaining a functional network and downloading and processing the data.
- The climate rationalisation review (Hyd2o 2017) found that rainfall data was only required from one site within the catchment, to inform catchment hydrological modelling. It could be captured either from a DBCA automated TBRG sited within the catchment or from rainfall data at nearby BOM sites. Data from the DBCA and BOM sites could also be used to inform the model of rainfall variability across the catchment. Consequently, rainfall within the catchment is currently collected by a single TBRG.

Collecting information on climate data will also serve to monitor for climatic temperature issues. LoAC for critical temperatures and duration of heat waves requires development.

Recommended action:

61. **Continue to implement the surface and groundwater monitoring programs and, where necessary, adapt procedure to better capture the catchment's changing hydrology.**
62. **Test a hydrological model calculating theoretical values to assess a range of factors contribution to wetland salt load.**

<u>Some considerations for setting hydrology limits</u>

The catchment wetlands are ephemeral, and, during years of normal rainfall, they hold water for less than a full year. However, they all vary naturally from fresh to saline and are generally weakly alkaline. Many of the wetlands also have different depths to groundwater and different groundwater qualities.

Given this range of characteristics, it will be necessary to define the LoAC for each monitored wetland using several different properties.

- Surface water salinity. In wetlands where the bathymetry is known, the LoAC can be expressed as a salt load[v] based on historical monitoring data. For those monitored wetlands without a bathymetric survey, it will be necessary to set their LoAC as a function of salt concentration relative to water depth, which can be defined from previously collected observations.
- Depth to groundwater. In most cases, the LoAC for depth to groundwater (mbgl) for each monitored wetland can be based on previously collected depth to groundwater data. However, in two cases new observation bores will need to be installed and the LoAC adapted as data becomes available.
- Soil salinity to 2m. The root zone, which in the management area typically ranges from the surface to within a few metres of ground level, is the critical area for subsurface management in terms of vegetation elements (Drake *et al.* 2012). However, the problematic nature of accurately measuring salinity levels within the root zone has meant there has been only limited data collection.

Recommended action:

63. Develop strategies to improve monitoring of wetlands that are data deficient, and, where necessary, develop a LoAC using available data.

<u>Proposed altered hydrology LoAC for Lake Bryde</u>

The duration of Lake Bryde inundation events were initially considered to be a significant threat to *Duma horrida* subsp. *abdita.* Hamilton-Brown and Blyth (2001) thought the species required fresh surface water conditions and that *Duma horrida* could survive prolonged inundation but needs to dry out within a year. However, Judd *et al.* (2010) found that both *Duma horrida* subsp. *abdita* and *Tecticornia verrucosa* have been able to survive past hydrological regimes, including several years of inundation, and can survive lengthy periods of drought and inundation. The duration of inundation does not therefore appear to be useful in establishing an LoAC.

Soil salinity appears to be a key factor in terms of the persistence of *Duma horrida* subsp. *abdita* (Judd *et al.* 2010) with the species growing best where soil salinities are below 500 mS/cm (Hamilton-Brown and Blyth 2001). Newland *et al.* (2010) reported that *Duma horrida* subsp. *abdita* experienced stress at soil salinity ranges above 1500 mS/m and that plant deaths occurred above 2,100 mS/m. *Tecticornia verrucosa* can tolerate more saline surface and groundwater and will replace *Duma horrida* with increasing salinities (Judd *et al.* 2010). However, regularly monitoring of soil salinity is undesirable as it would involve frequent ground disturbance within a TEC occurrence.

[v] The amount of salt contained within a wetland at a given point in time. It is usually expressed in terms of tonnes of salt.

A *Melaleuca* community severely impacted by altered hydrology.
Photo - Natalie Nicholson, DBCA 2008.

Since monitoring began in 1979 the wetland has experienced five complete and two partial fill events (Refer Supporting Information Appendix 5.4) which provided an insight into the wetland's salt load. The salt load rose from 165 tonnes in 1983 to a maximum of 1100 tonnes in 1997. The salt load then declined at the time of the 2006-08 fill event, due to an outflow that contained much of the lake's salt load. When last monitored in 2008, the Lake Bryde salt load was 680 tonnes.

As salt load has been well studied between 1979 and the present, it could be used to formulate a LoAC. However, there are uncertainties about the quality of some of the early data and the absence of data on some potentially important factors affecting salt load (i.e. soil salinity and surface water – groundwater interactions). Consequently, the salt load estimates, and the methodology used to establish them should be reassessed as part of the recovery program's five-year reviews. Ideally, these reassessments should be based on complex hydrological monitoring and modelling.

Another area of concern is the depth to groundwater. Groundwater monitoring has been undertaken since 1996. Currently many of the lakebed bores have groundwater depth only 2 mbgl. Above this depth the hypersaline groundwater may impact lakebed vegetation, which includes the Bryde TEC. Consequently, there is sufficient groundwater depth data to support the development of a LoAC.

Initial LoAC for altered hydrology at Lake Bryde

Based on hydrological monitoring data (refer Supporting Information Appendix 17.1), the initial LoAC for Lake Bryde are:

1. The salt load of the Lake Bryde wetland during any complete fill event should be less than 600 tonnes, and preferably, less than 400 tonnes.

2. Groundwater should be at a minimum of 2 mbgl when the wetland is dry.

Proposed altered hydrology LoAC for East Lake Bryde

Surface water monitoring at East Lake Bryde began in 1979 and then halted in 1984 because, unlike Lake Bryde, the wetland was very rarely inundated. Monitoring resumed in 2000 and the results again indicate that, except during exceptional rainfall events, the lake experiences only shallow fill-events (usually < 0.3m). These shallow fill-events tend to dry out before all lakebed salts enter the water column preventing the estimation of salt load.

As a result, the only salt load estimate for East Lake Bryde dates from the 2006-08 fill event (1.88m depth) when the salt load estimate was 500 tonnes. This is insufficient data on which to base a LoAC.

Recommended action:

64. **When sufficient data exists, develop an LoAC for East Lake Bryde salt load.**

Groundwater monitoring at East Lake Bryde commenced in 2003. The depth of groundwater for East Lake Bryde ranges between 2.0m and 3.0m. Consequently, there is sufficient groundwater depth data to support the development of a LoAC.

Initial LoAC for groundwater hydrology at East Lake Bryde

Groundwater should be at a minimum of 2 mbgl when the wetland is dry.

Proposed altered hydrology LoAC for Yate Swamp

For Yate Swamp, ‘healthy’ *Eucalyptus occidentalis* have been found in areas with soil salinities between 2000 mS/m and 4000 mS/m (Pepper and Craig 1986). However, soil salinity has not been routinely monitored. Therefore, a LoAC cannot be developed for soil salinity.

Surface water depth monitoring of Yate Swamp commenced in July 2005 and has been undertaken on three occasions. This is insufficient to permit the development of a sound LoAC for salt load or fill duration.

Recommended action:

65. **When sufficient data exists, develop an LoAC for Yate Swamp salt load.**

Five groundwater observation bores were installed on Yate Swamp between 2003 and 2009. Monitoring commenced in 2003 with monthly observations until 2017 and thereafter quarterly. This data is sufficient to permit the development of a LoAC for groundwater depth.

Initial LoAC for groundwater depth at Yate Swamp
Groundwater should be at a minimum of 3 mbgl when the wetland is dry.

Problem species

Weed competition

Detailed data has been collected on the distribution and density of weeds in areas disturbed during the waterway construction (Mattiske Consulting Pty Ltd 2006; Phillips 2011). Additionally, recent vegetation mapping (Rick 2017) has identified weed species occurring within the vegetation elements of nature reserves on the valley floor.

A weed monitoring program will help to determine if other weed species are likely to affect management targets (i.e. cause loss of native species) and require control or eradication. Monitoring will focus primarily on perennial weed species, as the abundance of annual weeds tends to fluctuate with prevailing season rainfall.

However, with the exception of the waterway monitoring sites, the data is not currently sufficient to define LoAC for weed competition.

Recommended actions:

66. **Develop appropriate monitoring methodologies and develop standard operation procedures for weed competition monitoring and weed control.**
67. **Monitor weeds and effectiveness of any weed control activities.**
68. **Develop LoAC using the data generated by the weed monitoring methodology.**

Grazing (rabbits and kangaroos)

A recent, remote camera fauna survey of some of the nature reserves within the Lake Bryde Catchment has yielded some data on the distribution and density of rabbits and kangaroos. However, this data is currently too sparse to permit the development of a LoAC.

A monitoring program will help to determine which species are most likely to affect management targets (i.e. cause loss of native species) and require control. Preliminary LoAC in grazer densities require development.

Recommended action:

69. Select appropriate methodologies and develop standard operation procedures for monitoring and control of gazing by problem native fauna and rabbits

70. Define a LoAC for grazing (process) by introduced gazing animals and problem native fauna based on monitoring data.

<u>Disease</u>

The lack of information and understanding concerning the number of different types of disease species (or other taxonomic units) present in the catchment's elements, their likely impact, or their distribution means that setting any realistic limits is currently impossible.

Recommended action:

71. Monitor symptoms of disease mortality in susceptible genera using the vegetation element monitoring approach and develop a LoAC based on the monitoring results.

Mortality in susceptible genera should be immediately investigated following the department's policies and protocols. If disease is confirmed, the infestation should be mapped and monitored.

<u>Predation (foxes and cats)</u>

A recent remote-camera fauna survey of some of the nature reserves within the Lake Bryde Catchment has yielded some data on the distribution and density of cats and foxes. However, this data is too currently too sparse to permit the development of a LoAC.

Feral cats were detected regularly by remote cameras.
Photo - DBCA, 2018

Department policies and methods for monitoring and controlling problem predator species should be employed where appropriate. If conducted in conjunction with the native mammal element monitoring, the effectiveness of the control programs for the problem predator species can be assessed, via LoAC in densities, which should be developed and then adapted as required.

Recommended action:

72. **Assess capacity to monitor and control problem predators and grazers in the catchment and if appropriate develop a formal program.**

Fire

The fire history of the nature reserves in the Lake Bryde Catchment indicates fire has been excluded from the reserves' vegetation since the 1970s. There is therefore considerable concern that short-lived species that are critically dependant on vegetation disturbance events, such as wildfire, for their recruitment may be lost in some vegetation elements.

If a fire management plan is developed, a monitoring program incorporating the senescence monitoring protocols should also be developed (Carley and Brooks 2013a, b; York 2020). This would include criteria for indicator species selection, monitoring protocol, thresholds (LoAC) and data analysis and interpretation. Ideally this would utilise the vegetation monitoring sites.

Recommended action until such time that a fire management plan is developed:

73. **Monitor senescence in fire sensitive plant species as part of the vegetation monitoring.**

Initial LoAC for fire sensitive plant species

Over a five-year period, there should be evidence of reproduction in senescence susceptible plant species (flowering and recruitment) in more than 25% of monitoring sites within an element, and mortality in any adult disturbance and senescence susceptible species should not be detected in more than 10% of monitoring sites

Surrounding land use

Toxic exposure to pesticides is likely to manifest as inflated mortality rates in susceptible bird species. Similarly, toxic exposure to herbicide spray drift is likely to be expressed in loss of foliage or in vegetation death.

Recommended action:

74. **Investigate the cause of unacceptable mortality rates in the terrestrial bird element (as defined by LoAC in mortality rate) and, if possible, implement an appropriate management response.**
75. **Investigate the cause of unacceptable vegetation impacts (as defined by the LoAC for vegetation loss) and, if possible, implement an appropriate management response.**

It will be challenging to identify a LoAC for bird mortality rates, given the difficulty in differentiating changes in population size caused by pesticides induced mortality, from those caused by migration, reduced recruitment, or other causes of mortality.

Research and adaption of LoAC

There is considerable scope to conduct research relating to improving the surveying and monitoring of the biological elements and the threatening processes. Additionally, LoAC should be adapted over the management period.

Recommended actions:

76. **Where appropriate, undertake research to improve surveying and monitoring of the biological elements and the associated processes (including improving the LoAC),**
77. **Undertake research to identify and address important knowledge gaps and adjusting management actions and LoACs accordingly.**

9.3. Monitoring the values

To measure the success of recovery activities, the extent to which important human values are being derived from the biological elements must also be assessed. This means quantifying who is making use of the elements in the catchment and why.

What to measure?

Wallace *et al.* (2016) and Smith *et al.* (2016) respectively have developed updated stakeholder values elicitation and property-values elicitation approaches. These approaches can be used to reassess stakeholder value preferences and to set these as a new benchmark for subsequent assessments to monitor value changes.

Knowledge-Heritage

Acceptable and measurable indicators of Knowledge-Heritage value include:

- Applicable visitation rates by individuals, educational institutes, cultural groups, interest groups. This would be measured by appropriately designed paper and online survey information.
- Production and dissemination rates of research and other information sources.

Recreation

Recreation value was rated highly by the stakeholder group (Wallace *et al.* 2016) and is an important part of the overall goals for the department[w].

Future Options:

The conservation of biological elements provides opportunities to discover values that are not currently realised. These can include:

- The biological attributes of the species, including their responses to threatening processes.
- Efficient and effective methodologies in recovery, conservation, and monitoring.

Recommended actions:

78. **Develop and implement a communication plan to improve engagement with stakeholders.**
79. **Consult with stakeholders midway through the term of the recovery program to evaluate values and management outcomes.**
80. **Monitor and assess recreational activities undertaken in DBCA reserves, including boating during fill events, to inform and support recreational management of these reserves throughout the management period of the Lake Bryde Landscape Recovery Program.**
81. **If appropriate, develop strategies to ensure recreation activities do not impact negatively upon other values or pose a threat to the biological elements.**

[w] https://www.dbca.wa.gov.au/publications/strategic-directions-2018-21

Other data collection

In general, there will always be a need for and at times opportunity to conduct more detailed research.

Recommended action:

82. **Where appropriate, undertake additional monitoring and surveys when the results are likely to support value determination and goal status monitoring.**

Management of data and statistical analysis

Appropriate collection, management and use of data are critical to effectively manage the elements and to assess target status. Data need to be properly collected, housed, and quality assured, and the amount of data collected should reflect the capacity of the organisation to manage and disseminate it. Additionally, the data must be readily available, easily accessible and accompanied by appropriate metadata. The management of data relating to the catchment's hydrology is particularly important given its cost and volume.

Monitoring the status of management targets requires timely analysis of available data to inform the need for recovery response. Data management requires appropriate training for the responsible officers and should be organised and documented to ensure consistency and allow easy handover for staffing changes over time. Staff may also need training in database development and management.

Methods for data collection and analysis must be articulated clearly and followed consistently. If consultants are engaged to conduct data collection, analysis and/or reporting, they must be given, and adhere to, clear guidelines. The time investment required for correct data collection, analysis and management is routinely underestimated, to the detriment of entire programs. When making decisions about which data to collect, the realistic cost in time and resources must be taken into consideration.

Recommended actions:

83. **Develop standard operating procedures for recovery activities to aid consistency of results, and for review and reporting on the landscape recovery program outcomes.**
84. **Continue managing all data and engage appropriate new technologies to further manage and disseminate data.**
85. **Manage historical and current records and information for planning, analyses, decision-making and reviewing, consistent with government record keeping and accountability standards.**

Reporting and review

In addition to the required departmental budget and activity reporting, reporting activities should include:

- Annual summaries of monitoring activities and results. It is important that the summaries are produced within the context of meeting the management targets.
- Annual summaries of other recovery activities relating to the recommendations. Reporting should include a description of activities and resultant benefits in terms of the management targets. Reports should include assessments of potential activities that were deemed unfeasible (both in terms of funding and capacity) or unnecessary.
- Continued reporting on TEC and threatened flora recovery activities, for the department’s annual report, and to funding bodies (where applicable) on the status of the Lake Bryde Catchment.
- Reporting to the recovery team annually.

Ultimately, the reports should provide a document that provides a clear and temporally complete record of management activities and the associated decision-making process.

Recommended actions:

86. **Continue with annual reporting to recovery team, stakeholders, and management.**
87. **Develop five-year works plans to ensure the recommended actions are implemented. This should involve a reassessment of outstanding recovery actions and the development of a five-year progress statement.**
88. **Regularly review the recovery program to improve decision-making, enhance organisational learning and document achievement of targets for biological elements, and thus progress to achieving the recovery program’s goal.**

10. Summary of recommended recovery actions

If the management actions described throughout this document are followed, it is likely that the biological elements will persist throughout the management period in such a way that the important values continue to be delivered — the main goal of this landscape recovery program. Nonetheless, the monitoring program should allow important changes to be identified and understood in a timely manner, such that appropriate management responses can be devised and enacted. Importantly, there is also considerable scope to improve the values of the biological elements over the management period and this should be an additional goal for the Lake Bryde Catchment.

General recommended actions

Recovery planning and coordination

1 As part of an iterative process, continue to assess the value of biological elements through:
- a) stakeholder representative engagement and expert consultation to identify any additional element properties and to explore their relationships with the priority values
- b) surveys of the native species composition and size of each biological element
- c) quantification of properties such as loss, charisma, and visibility to improve the values-delivery analysis.

2 Where possible, continue to manage threatening processes within available budgets over the management period, and, when necessary, seek additional funding to increase management capacity and effectiveness.

40 Adopt appropriate new technologies and methodologies to manage the key properties (species richness, rarity, intactness, charisma, visibility, and size) and threatening processes, including research to gain new knowledge.

78 Develop and implement a communication plan to improve engagement with stakeholders.

79 Consult with stakeholders midway through the term of the recovery program to evaluate values and management outcomes.

83 Develop standard operating procedures for all recovery activities to aid consistency of results, and for review and reporting on the recovery program outcomes.

84 Continue managing all data and engage appropriate new technologies to further manage and disseminate data.

85 Manage historical and current records and information for planning, analyses, decision-making and reviewing, consistent with government record keeping and accountability standards.

86 Continue with annual reporting to recovery team, stakeholders, and management.

87 Develop five-year works plans to ensure the recommended actions are implemented. This should involve a reassessment of outstanding recovery actions and the development of a five-year progress statement.

88 Regularly review the recovery program to improve decision-making, enhance organisational learning and document achievement of targets for biological elements, and thus progress to achieving the recovery program's goal.

Research and monitoring

18 Maintain and improve monitoring infrastructure, as necessary, and regularly analyse and report monitoring data to facilitate decision-making.

76 Where appropriate, undertake research to improve surveying and monitoring of the biological elements and the associated processes (including improving the LoAC),

77 Undertake research to identify and address important knowledge gaps and adjusting management actions and LoACs accordingly.

82 Where appropriate, undertake additional monitoring and surveys when the results are likely to add support value determination and goal status monitoring.

Land acquisition

15 Identify and prioritise potential land acquisitions that are required to support important revegetation or infrastructure projects.

16 Pursue the acquisition of priority land purchases where appropriate and possible, in terms of funding, feasibility, and effectiveness.

Recommended actions to address threatening processes

Altered hydrology

3 Maintain, modify, or decommission current surface water conveyance infrastructure (waterway) based on trends in monitoring data and professional hydrological advice.

4 Investigate and implement new infrastructure options to improve water quality entering Lake Bryde, when justified by monitoring data and supported by professional hydrological advice.

5 Continue to address inundation, waterlogging, and degradation impacts along the western boundary of the Lakeland Nature Reserve through ongoing maintenance of surface water drainage infrastructure.

6 Manage the hydrological impacts associated with the Rosenbergs Creek (Holland Tank Road sub-catchment).

13 Promote excess water management in the Fourteen Mile Road sub-catchment in a bid to control impacts (mainly enhanced recharge) in the flat areas north of the Pingrup-Newdegate Road and above Yate Swamp.

14 Address impediment impacts of key road crossings in conjunction with the shires of Kent and Lake Grace to reduce future salinity development and inundation impacts

17 Assess, develop, and implement proposed ground and surface water management options, with the support of professional hydrological advice.

19 Provide ongoing hydrological support and advice to regional staff and landowners on issues relating to public land and community water management.

20 Where resources permit, undertake additional investigations to address data deficiencies in groundwater inflow/outflow and overland and channel losses, the Lake Bryde outflow dynamics, spatial variability of rainfall, the flow contribution of the northern inlet (Lake Bryde), and the salinity of surface water and groundwater inflows and outflows.

61 Continue to implement the surface and groundwater monitoring programs and, where necessary, adapt procedure to better capture the catchment's changing hydrology.

62 Test a hydrological model calculating theoretical values to assess a range of factors contribution to wetland salt load.

63 Develop strategies to improve monitoring of wetlands that are data deficient, and, where necessary, develop a LoAC using available data.

64 When sufficient data exists, develop an LoAC for East Lake Bryde salt load .

65 When sufficient data exists, develop an LoAC for Yate Swamp salt load.

Revegetation (altered hydrology and other threatening processes)

7 Develop and implement a revegetation plan to provide direction for revegetation in the catchment, to address hydrological process issues and other wildlife management objectives that are related to the key values identified in Section 4.

8 Maintain an adequate representation and quantity of seed of local native species in the department's Wheatbelt Region seed store to meet the needs of revegetation programs and safeguard against loss of species from the catchment.

9 Maintain an adequate representation of local native species in the department's seed stores, to provide additional insurance against the loss of species.

10 Maintain areas of revegetation between Lake Bryde Conservation Park and the southern boundary of the Lakeland Nature Reserve.

11 Promote substantial revegetation to assist with the hydrological management of the receiving valley floor and areas that are prone to inundation in the Ryans Creek and Day Creek sub-catchments of the Lake Bryde South catchment in conjunction with key landholders.

12 Promote revegetation in properties contributing water to the Lakeland Nature Reserve western boundary.

Disease

21 Continue to employ hygiene management for all operations.

22 Continue to investigate suspected disease expression in susceptible species.

23 Investigate, monitor, and map deaths or decline in vegetation elements that may be attributed to other diseases.

24 Share information with local government authorities on disease prevention strategies to minimise the spread of *Phytophthora* disease.

71 Monitor symptoms of disease mortality in susceptible genera using the vegetation element monitoring approach and develop a LoAC from the monitoring results.

Introduced and problem fauna

25 Continue to control rabbits and other introduced grazing animals at vulnerable sites using best practice methods supported by regular monitoring.

26 Continue to cooperate with other agencies to facilitate the release of biological control agents for introduced grazing animals, such as new strains of *Calicivirus*.

27 Continue to monitor potential problem grazing by native fauna at vulnerable sites and apply effective control measures when required.

28 Continue with the implementation of introduced predator control measures.

69 Select appropriate methodologies and develop standard operation procedures for monitoring and control of gazing by problem native fauna and rabbits

70 Define a LoAC for grazing (process) by introduced gazing animals and problem native fauna based on monitoring data.

72 Assess capacity to monitor and control problem predators and grazers in the catchment and if appropriate develop a formal program.

Weeds

29 Develop and implement a weed management strategy to detect, monitor and prioritise weed management requirements.

30 Continue to control persistent and problematic weeds at vulnerable sites using best practice methods supported by regular monitoring.

31 Share information on persistent and problematic weed species with landowners and local government authorities to develop, and jointly implement, control strategies.

66 Develop appropriate monitoring methodologies and develop standard operation procedures for weed competition monitoring and weed control.

67 Monitor weeds and effectiveness of any weed control activities.

68 Develop an LoAC using the data generated by the weed monitoring methodology.

Fire

32 Develop and implement a fire management plan for the catchment to protect infrastructure and to protect and maintain biological elements.

33 Evaluate and, if appropriate, implement the Fire Regime Optimisation Planning System (FiReOPS) to help develop a prescribed burn program for reserves in the Lake Bryde Catchment.

38 In conjunction with the Department of Fire and Emergency Services, LGAs, local bush fire brigades and the community, actively respond to bushfires with potential for significant expansion and/or damage to areas of remnant vegetation and important biological elements in the larger reserve network within the Lake Bryde Catchment.

Climate change

34 Investigate the potential for climate change impacts upon threatened species and communities and develop effective response strategies.

35 Review studies on potential climate change impact and, when necessary, update current recovery strategies at the catchment and species level.

36 Work with communities and other stakeholders to mitigate and adapt to climate change including through an infrastructure risk assessment to identify community assets and biological elements at risk from climate change impacts.

37 Continue existing long-term monitoring programs for significant elements in the catchment that are expected to be impacted by climate change.

Herbicides and pesticides

39 Consider and, where justified and feasible, implement management strategies to minimise pesticide and herbicide impacts on the properties of key elements.

Recommended actions for management of biological elements

Native vegetation

41 Complete the vegetation mapping of the large reserves in the catchment and integrate this information with previous vegetation mapping of other sites in a format that will allow for multiple future uses.

43 Determine the most appropriate vegetation monitoring methodology for the catchment and implement a standard operation procedure for all future vegetation monitoring.

44 Develop an LoAC to match the data outputs of the vegetation monitoring methodology.

45 Once vegetation mapping is complete and vegetation elements have been defined, establish monitoring sites to collect information on the properties and processes for each vegetation element.

46 Ensure that the vegetation monitoring data is maintained in a format that will allow for multiple uses and provide additional information for future analyses.

47 Conduct a rationalisation of vegetation monitoring undertaken to assess the impact of the waterway.

73 Monitor senescence in fire sensitive plant species as part of the vegetation monitoring.

75 Investigate the cause of unacceptable vegetation impacts (as defined by the LoAC for vegetation loss) and, if possible, implement an appropriate management response.

Threatened ecological communities

42 Identify and assess patches of the ‘Eucalypt Woodlands of the Western Australian Wheatbelt’ in the catchment, and document eligible TEC occurrences under the EPBC Act.

48 Develop and implement a new standard operating procedure for TEC monitoring of the Bryde TEC, which can also be used to monitor *Duma* populations.

49 Review the TEC monitoring data against the LoAC, and where necessary adapt the management regime or the LoAC accordingly.

50 Review and update the Interim Recovery Plan for the Bryde TEC (Hamilton-Brown and Blyth, 2001) and incorporate the LoAC within the revised plan.

Waterbirds

51 Develop a new standard operating procedure for waterbird monitoring based on the methodology of Halse et al. (2000).

52 When conditions are conducive, monitor waterbirds abundance and breeding activity at wetlands in the management area, revising the indicator species list as knowledge of waterbird ecology grows.

53 Assess the LoAC in terms of the indicator waterbird species listed in Table 6 at all natural lakes and wetlands in the management area.

Native mammals

54 Document and implement a new standard operating procedure for native mammal monitoring, using established methods.

55 Undertake native mammal monitoring for significant changes in abundance and identify the specific threatening processes accounting for the variations.

56 Assess and revise the LoAC for native mammal species once sufficient data has been collected to set reliable detection rate limits.

Other fauna

57 Assess the feasibility of terrestrial bird and frog surveying and, if appropriate, develop and implement a monitoring program.

58 If bird and frog monitoring is to be undertaken, develop a LoAC once sufficient data has been collected to set reliable detection rate limits.

59 Assess the feasibility of developing a survey and monitoring program for invertebrates and implement if appropriate.

60 If aquatic invertebrate surveys and monitoring is to be undertaken, it will be necessary to evolve a LoAC once sufficient data has been collected to set reliable detection rate.

74 Investigate the cause of unacceptable mortality rates in the terrestrial bird element (as defined by LoAC in mortality rate) and, if possible, implement an appropriate management response.

Recommended actions for management of other elements

Recreation

80 Monitor and assess recreational activities undertaken in DBCA reserves, including boating during fill events, to inform and support recreational management of these reserves throughout the management period of the Lake Bryde Landscape Recovery Program.

81 If appropriate, develop recreation strategies to ensure activities do not impact negatively upon other values or pose a threat to the biological elements.

11. Glossary

Abiotic: Any non-living component or element of a system.

BC Act: *Biodiversity Conservation Act 2016*

Benefit analysis: A benefit analysis is a systematic process for calculating and comparing benefits of a series of recovery options (or activities).

Benefit-cost analysis: A benefit–cost analysis is a systematic process for calculating and comparing benefits and costs of a series of recovery options (or activities).

Biological element: Any group of living organisms (or an individual organism) that provides human value that is considered indigenous to the catchment.

Biotic: Any living component or element of a system.

CALM: The Department of Conservation and Land Management (1986-2006). It was responsible for catchment recovery activities until superseded by DEC.

CALM Act: *Conservation and Land Management Act 1984.*

Charisma: Applies to elements when they stimulate strong emotional attraction amongst humans. This attraction may stem from a number of sources, including that an element may be invested with significant symbolic meaning (e.g., national flora and fauna emblems), be ‘cute’ (e.g., koalas), widely admired for a particular characteristic such as beauty or strength (e.g. birds of paradise, lions), or be otherwise very famous or very popular. Such elements generally have a high public profile or are widely known.

DBCA: The Department of Biodiversity, Conservation and Attractions (2017 to date).

DEC: The Department of Environment and Conservation (2006-13). It was responsible for catchment recovery activities until superseded by DPW.

DPaW: The Department of Parks and Wildlife (2013-2017). It was responsible for catchment recovery activities until superseded by DBCA.

EPBC Act: *Environment Protection and Biodiversity Conservation Act 1999.*

Expert: An expert is taken to be someone who has skills, experiences, education, training, or knowledge concerning the issues to be discussed or resolved (adapted from Burgman 2005).

Human values: Any important state, such as health and recreation, that contributes to human wellbeing (Wallace 2012).

Intactness: The property of being sound, flawless, entire (adapted from OED). Scholes and Biggs (2005, page 45) describe their biodiversity intactness index as “an indicator of the average abundance of a large and diverse set of organisms in a given geographical area, relative to their reference population”.

Limits of acceptable change: A predetermined amount of change that can occur in a monitored property. Change that exceeds the limits of acceptable change will trigger a recovery response.

Management target: A target used to assess the risk that a process will cause goal failure. In the recovery program, the management targets are set around an unacceptable loss of a property over the 20-year management period.

Natural diversity recovery catchment: The *Natural Diversity Recovery Catchment* program was a commitment by the State Government arising from the *Western Australian Salinity Action Plan* (Government of Western Australia 1996). The objective of the program is stated as:

> The government will develop and implement a coordinated wetlands and natural diversity recovery program targeting at least six key catchments over the next 10 years to ensure that critical and regionally significant natural areas, particularly wetlands, are protected in perpetuity.

Natural living resource: Any group of living organisms (or an individual organism) that provide human value that is considered indigenous to the catchment.

Natural resource: Any biotic or abiotic element that provides human value.

Native species: Any living organism that is considered indigenous to the catchment.

Photo-point monitoring: Photo-point monitoring is a technique used to record and monitor change in the natural environment over time. It involves taking a series of images of a fixed area at regular time intervals, which can then be used to measure change at a given location.

Problem species: Any species that poses a significant threat to meeting the management targets over the 20-year management period.

Processes: The physical, chemical, and biological actions or events that link organisms and their environment.

Property-values analysis: Five step approach to classify and rate the human values expected from the biological elements.

Property: Attributes that can be used to describe biological elements (Wallace 2012).

Ramsar Convention: The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Remote camera monitoring: A specialised monitoring technique that uses purpose-built camera systems that detect animal heat and movement to capture, via photographs or video, and monitor the occupancy and abundance of animals.

Salt load: The mass of salt contained within a wetland. It is usually calculated by multiplying the salt concentration by the surface water volume of the wetland at the same point in time. The salt load is usually expressed in terms of tonnes of salt.

Species richness: The number of different types (e.g., species) of organisms that characterise a biological element.

Species composition: The types and abundances of the organisms that characterise a biological element.

Stakeholder representatives of community, government and non-government groups: A stakeholder is any person who has an interest in, is affected by, or can affect, the management of the natural living resources in the given management area (based on Reed 2008). Planning is often undertaken on behalf of an agency, which typically represents a community (a city, province, state, country) and engagement will often focus on representatives of key communities of interest as defined by Harrington *et al.* (2008). In the management of conservation lands, communities of locality (e.g., local, and regional government) and communities of practice (e.g., conservation groups and agencies, land-user groups and agencies, education bodies) will generally be important.

Structure: The three-dimensional distribution of all biological elements present (i.e., the spatial distribution of a given composition including age structure, life stages, etc). Structure includes both native and introduced species. Linkages between structure and values have been demonstrated (Nassauer 1995). Structure has proven thus far to be impracticable to find a measure that consistently linked this property to values. Thus, although an important property, the means of quantifying structure in relation to values requires further investigation before it can be applied.

TEC: Threatened Ecological Community

Threatened Ecological Community: Refer Supporting Information Appendix 11.2.

Threatened species: Refer Supporting Information Appendix 11.1.

Threatening processes: Any process that threatens the delivery of the human values by the biological elements. In the recovery program, significant processes were those thought to have a risk of more than 5% of causing the associated management target to not be met.

Value utility: An estimate of the overall human value (a combination of the priority values) predicted to be delivered by a biological element.

12. References

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