Blueprint to Repair Australia's landscapes

Actions & investment for a healthy, productive and resilient Australia in the next 30 years

Part II: Technical Review | July 2024

WENTWORTH GROUP OF CONCERNED SCIENTISTS

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ABORIGINAL AND TORRES STRAIT ISLANDER PEOPLES AND REPAIRING THE NATION'S ENVIRONMENT

"Healthy Country means healthy people"
Woodward *et al.* (2022)

The Wentworth Group of Concerned Scientists acknowledges and celebrates Aboriginal and Torres Strait Islander peoples, the Traditional Custodians of the lands and waters of Australia. We pay our respects to their elders past and present.

Aboriginal and Torres Strait Islander peoples have been stewards of Country for over 60,000 years and have continuing cultural connections to lands, waters and sky. Indigenous ownership was never ceded.

From 1788 to today, the connections and role in stewardship of Country all changed for Aboriginal and Torres Strait Islander peoples following dispossession from their lands and waters.

The state of Country was determined as poor in the 2021 Australian State of the Environment Report, which had chapters led and co-led by Indigenous authors (State of the Environment Committee, 2021). In the Indigenous chapter of the report, leading experts documented major issues affecting Australia's environment (Woodward *et al.*, 2022).

Aboriginal and Torres Strait Islander peoples now need to have leading roles in repairing and managing healthy landscapes and recovering threatened species, including to support social, economic, cultural, and spiritual values.

Together, in repairing Country with Aboriginal people and Torres Strait Islanders, Australians can advance reconciliation and improve the health of our nation's lands and waters for the benefit of all peoples.

Repairing Australia's environment is practical, feasible and affordable

Australia is home to a rich and vast natural estate. As stewards of this land and seascape, it is our responsibility to ensure that our important natural assets are preserved for their own sake, and for current and future generations. We need a national effort to repair nature and the long-term investment to achieve this goal. Without this, our environment, our wellbeing, and our productive economy will suffer.

This technical report documents the actions and investment opportunities that can substantially repair degraded natural landscapes, and puts forward evidence demonstrating the need for these actions to take place at scale across Australia.

By breaking down the work needed into pragmatic, tangible actions, and establishing the appropriate settings for these actions to take place, we show that the effort required, while substantial and urgent, will also generate benefits and income and is affordable over the next few decades. The actions do not return these assets to a past state, rather to an improved condition from which further enhancement is possible.

The accompanying synthesis report, *Blueprint to Repair Australia's Landscapes: National case for a 30 year investment in a healthy, productive & resilient Australia* summarises the actions, benefits and investment opportunities and sets out a high-level pathway for delivering a national repair effort.

These blueprint reports have been prepared to catalyse and guide a transformative effort to repair degraded landscapes in the next 30 years. If implemented together, at scale, and with planning, regulatory and governance reforms to enable these actions and prevent further degradation, these actions can help prepare Australia for the significant opportunities and pressures ahead, while contributing to our national and international ambitions for sustainable development, climate change adaptation, and biodiversity, water and soil conservation.

This assessment reflects our best understanding of the national-scale actions and investment needed. But this kind of program is never definitive and many actions are beyond the scope of our assessment. The geographical and socio-economic diversity of Australia inevitably means that these actions will need to be implemented in consideration of the regional context and refined as new knowledge, opportunities and challenges emerge.

This report is an open invitation to individuals and organisations seeking a healthier environment to use the analysis as a foundation to help expand and refine contributions to repairing Australia's landscapes, to inform the on-ground actions needed across the country, and to raise the urgently needed capital for a transformative investment in our long-term future.

Summary of the national actions and investment opportunities

Our assessment, the most comprehensive of its kind in Australia, focuses on five key components of landscapes assessed in the Wentworth Group's environmental accounts program and identified as degraded in the State of the Environment report (Sbrocchi *et al.*, 2015, Cresswell *et al.*, 2021).

1. SOILS – **Repair the productive base of agricultural soils.** We can restore the productive base of our challenged and vulnerable soils by removing intractable constraints arising from soil degradation. This will build sustained resilience to climate variability and allow soil carbon to rebuild. In addition, we can continue to build knowledge and capacity to better optimise outcomes for biodiversity and carbon within sustainable agricultural systems across Australia.
2. INLAND WATER – **Fix overallocated and fragmented river systems and rehabilitate degraded catchments.** We can restore ailing river basins by recovering surface and groundwater in overallocated systems, reconnecting floodplains and wetlands to ensure the persistence of habitat, and removing impediments to fish migration. We can restore native vegetation in gullies and along riparian corridors of rivers, lakes and wetlands through regeneration and fencing to provide habitat, reduce soil erosion and improve water quality. We can revegetate our landscapes so our catchments will be more resilient to floods, droughts and other extreme events.
3. NATIVE VEGETATION – **Restore healthy native ecosystems to a minimum 30% of their pre-1750 extent.** We can protect and restore nearly all of Australia's terrestrial ecosystems to 30% of the pre-1750 extent in a healthy condition while maintaining and even increasing productivity on prime agricultural land. Restoring native vegetation across 13 million ha would also abate almost one billion tonnes of carbon dioxide equivalent and produce an estimated AU$16 to $34 billion (2022$) in carbon offset revenue to landholders over 30 years.
4. THREATENED SPECIES – **Avoid extinctions and ensure survival of threatened species.** We can mitigate imminent extinction risk and ensure medium-term survival of most Commonwealth-listed threatened species by restoring habitat, addressing threats, undertaking interventions (i.e. breeding programs, translocation), and better incorporating Indigenous knowledge into recovery efforts.
5. COASTAL ENVIRONMENTS – **Maintain or improve the condition of estuaries.** We can improve the health of estuaries through catchment management, reconnecting freshwater and tidal flows to protect and restore tidal marshes and re-establishing seagrass meadows and shellfish reefs.

We estimate an indicative investment of $7.3 billion annually in 2022$ over 30 years to repair much of the past two centuries of landscape degradation. This aggregates to upfront funding of $218.8 billion (2022$) over 30 years. If funded on an annualised future basis, accounting for inflation and time value of money, the total investment required would be considerably greater - between $11.8 billion to $19.4 billion per annum with an average of $14.8 billion per annum.

The actions identified enable vast quantities of carbon to be stored in landscapes, contributing to the mitigation needed to reach the Paris Agreement. High-integrity carbon market revenue from native vegetation actions on private land could generate $0.5 to $1.1 billion annually (7-15% of total cost).

Large-scale restoration requires the actions to be considered as an integrated package, built into broader public policy reforms to prevent future degradation, and delivered at scale and in a way that accounts for regional context and interdependencies, dynamics and complexities in natural systems.

Actions and investment opportunities: 2025-2055		Annual expenditure* over 30 years (in 2022$)	% of GDP*
CAPITAL EXPENDITURE			
Soils	**Objective S1 Improve physical and chemical condition and productivity of agricultural soils that need remediation due to long term degradation and where that remediation is not likely to occur without direct investment.**		
	S1.1-C Apply lime to address soil acidification on agricultural soils where damage is significant, not affected by acid sulphate, and not amenable to current management.	$118 million	< 0. 01%
	S1.2-C Apply gypsum to address soil structure decline on agricultural soils with excess sodicity where amendment is likely to produce substantial improvement.	$2 million	< 0. 01%
	S1.3-C Plant salt-tolerant vegetation (e.g., saltbush) on salt-affected lands to maintain soil stability and some level of production.	$7 million	< 0. 01%
	Objective S2 Repair gully erosion hot spots across Australia to improve water quality in rivers and expand the availability of healthy land for agriculture and wildlife.		
	S2.1-C Undertake remediation works of revegetation, fencing, stick traps, and rock chutes for high-risk gullies.	$15 million	< 0. 01%
	S2.2-C Undertake remediation works of stick traps, rock chutes, fencing for low-to-medium risk gullies.	$394 million	0.02%
	Objective S3 Connect agricultural land management practices with broader national ambitions for biodiversity, climate change and agricultural productivity.		
	S3.1-C Revitalise advisory, support and extension services to provide landholders with the knowledge and capacity to better optimise outcomes including maintaining economic productivity, improving catchment health, sequestering carbon and improving biodiversity.	$42 million	< 0. 01%
	Sub-total	$578 million	0.02%
Inland water	**Objective R1 Establish and restore riparian buffer zones on all of Australia's rivers and streams to protect productive land from erosion, support biodiversity, improve water quality and enhance the productivity of fisheries and health of freshwater and marine ecosystems.**		
	R1.1-C Restore, conserve, and manage strips of healthy native riparian vegetation.	$2,396 million	0.10%
	R1.2-C Incentivise landholders to retire their farmland along the banks of Australia's major rivers, smaller rivers and streams, and major natural lakes and wetlands.	$201 million	< 0. 01%
	Objective R2 Restore overallocated river systems to sustainable levels of take.		
	R2.1-C Return overallocated river systems of the Murray-Darling Basin to environmentally sustainable levels of surface water extraction through the strategic purchase of water licences from willing sellers, on-farm investment, and other measures.	$104 million	< 0. 01%
	Objective R3 Restore lateral and longitudinal connectivity of rivers, floodplains and their wetlands.		
	R3.1-C Allow water to reach and pass safely across floodplains and wetlands in the Murray-Darling Basin by modifying infrastructure (e.g., bridges and roads), removing high-risk or unauthorised flood works, or purchasing voluntary easements on private land.	$23 million	<0. 01%
	R3.2-C Restore fish passage by removing or modifying high priority physical barriers.	$108 million	<0. 01%
	R3.3-C Install cold-water pollution control devices on priority large dams.	$20 million	<0. 01%

	R3.4-C Install fish diversion screening on all licensed irrigation pumps.	$61 million	<0. 01%
	Objective R4 Improve the efficient use and sustainability of groundwater resources		
	R4.1-C Cap remaining open artesian bores and convert remaining open bore-drains to pipes and trough systems in the Great Artesian Basin.	$4 million	<0. 01%
	R4.2-C Return groundwater extractions to sustainable levels in the Murray-Darling Basin through the strategic purchase of water licences from willing sellers.	$0.2 million	<0. 01%
	Sub-total	$2,910 million	0.12%
Native vegetation	Objective V1 Restore native vegetation cover to at least 30% of pre-1750 extent in a healthy ecological condition for each of Australia's terrestrial ecosystems		
	V1.1-C Restore 1.3 million hectares of degraded native vegetation to a healthy ecological condition within the protected area estate.	$104 million	<0. 01%
	V1.2-C Restore 11.6 million hectares of degraded native vegetation to a healthy ecological condition on non-prime agricultural land.	$895 million	0.04%
	V1.3-C Incentivise landholders to retire their non-prime agricultural land for the native vegetation conservation areas.	$624 million	0.03%
	Objective V2 Reduce the frequency and intensity of fires impacting Australia's tropical savannas		
	V2.1-C Use Indigenous fire management practices to undertake controlled low intensity fires early in the dry season in Australia's tropical savanna lands.	$79 million	<0. 01%
	Sub-total	$1,702 million	0.07%
Threatened species	Objective T1 Mitigate imminent extinction risk and ensure medium term survival of Commonwealth-listed threatened species.		
	T1.1-C Restore habitat, address threats (including some localised impacts of invasive species), and undertake population interventions such as translocation and breeding programs for species listed as Critically Endangered, Endangered and Vulnerable under Commonwealth legislation.	$1,174 million	0.05%
	Sub-total	$1,174 million	0.05%
Coastal environ-ments	Objective C1 Support coastal biodiversity, and improve coastal fisheries productivity		
	C1.1-C Maintain or improve the condition of degraded salt marsh ecosystems.	$22 million	<0. 01%
	C1.2-C Incentivise a change in management practice for salt marsh ecosystems.	$5 million	<0. 01%
	C1.3-C Re-establish locally degraded seagrass communities in priority areas.	$4 million	<0. 01%
	C1.4-C Re-establish shellfish reefs in priority locations.	$3 million	<0. 01%
	Sub-total	$34 million	<0. 01%
	Sub-total, all capital expenditure	$6,406 million	0.26%
	Transaction costs	$641 million	0.03%
	Total capital expenditure required, % of GDP	$7,047 million	0.29%

OPERATIONAL EXPENDITURE			
All assets	► Ongoing maintenance gully control measures ► Management and monitoring of new riparian plantings along major rivers ► Management and monitoring of new riparian plantings along rivers, lakes and streams ► Fishway (and other works) monitoring, operating, licensing and maintenance ► Cold-water pollution device monitoring, operating, licensing and maintenance ► Diversion screening device monitoring, operating, licensing and maintenance ► Bore system monitoring, operating, licensing and maintenance ► Monitoring and management of restored areas (fire, weeds, feral animals) ► Monitoring and management of savannas burning areas (weed monitoring and removal) ► Monitoring of existing and new seagrass areas ► Monitoring and management of existing and new shellfish reefs.	$246 million	0.01%
	Total operational expenditure required, % of GDP	$246 million	0.01%
Grand total of capital and operational investment required, % of GDP		$7,293 million	0. 30%
Carbon market revenue** from native vegetation action (V1.2-C)		-$1,118 million	-0.05%
Net investment required, incl. carbon market revenue, % of GDP		$6,175 million	0.26%

Totals may not add due to rounding.
***Assuming average carbon price of $75 per tonne CO_2e, increasing annually by inflation plus 2% (see assumptions below and CER, 2024)*

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Supplementary Material

Introduction

In the paper *Blueprint for a Healthy Environment and a Productive Economy*, the Wentworth Group put forward the case that it is possible to grow our economy and create jobs in a manner that would also lead to the long-term repair of our nation's environment (Wentworth Group, 2014). This case rests on two key premises about the economic reforms: 1) that such changes should be built into broader public policy reforms; and 2) that these reforms can be achieved without a significant call on the budget.

The Blueprint set out five major long-term institutional and economic reforms for achieving a healthy environment and a productive economy: (1) fix land and water use planning; (2) use markets; (3) conserve natural capital; (4) regionalise management; and (5) create environmental accounts (Table 1). Importantly, the full suite of reforms needs to be undertaken together to ensure long-lasting, additional, and measurable improvement in the condition of the environment.

The focus of this report is to identify the practical actions needed to achieve the third of these long-term reforms: the conservation and repair of Australia's natural capital. In this report, we identify an evidence-based suite of practical actions to substantially repair past degradation of landscapes, describe the rationale for their selection, document the methods used to determine indicative costs, and summarise the benefits of investment.

Table 1. Full suite of reforms needed for a healthy environment and a productive economy (adapted from Wentworth Group (2014)).

1. Fix land and water use planning	Regional-scale land and water use plans that address the cumulative impacts of development on the environment and the long-term costs to the economy, such as policies which prohibit broad-scale land clearing and which ensure sustainable volumes of water in river systems.
2. Use markets	Finance initiatives that pay farmers, Indigenous communities, and other landholders to transform the way we manage the Australian landscape. Establish policy incentives and leverage government funding to cultivate environmental markets and support private impact investing and other financing solutions by the public, private and philanthropic sectors (see Appendix V).
3. Conserve natural capital	Close the gaps in our national system of public and private reserves and commit resources to an effective long-term plan to conserve our threatened native plants, animals, and ecosystems.
4. Regionalise management	Embed and give prominence to natural resource management at the regional scale - a scale large enough to manage the pressures on our landscapes, yet small enough to use local knowledge to tailor solutions to suit those landscapes and address cumulative impacts.
5. Create environmental accounts	Put in place regional-scale national environmental accounts across the nation that monitor the condition of our environmental assets, guide investment and support more effective decision-making to underpin a healthy and productive Australia. This will vastly improve accessibility and transparency of data, much of which is disparate and undiscoverable across different sectors.

The national case for repairing Australia's landscapes

Australians have inherited a rich and vast natural estate. As stewards of this landscape, it is our responsibility to ensure that our important natural assets are preserved for their own sake, and for current and future generations. The case we put forward here for investing in the repair of degraded landscapes rests on seven key premises.

1. It is impossible to build a sustainable future on a degraded base

The health of our landscape matters because it affects the wellbeing of people directly, and because it underpins other things people value.

A large body of evidence exists on the important role of healthy landscapes in supporting human health, culture and wellbeing and sustaining biodiversity (Costanza *et al.*, 1997, Millennium Ecosystem Assessment, 2005, Milcu *et al.*, 2013). There are also important economic benefits – an estimated half of Australia's GDP, and more than half of the world's GDP (US$44 trillion) is dependent on a healthy environment, including a stable climate, clean air, pollination, soil security, water quality, food quality and security and natural amenity (Herweijer *et al.*, 2020, IDEEA Group, 2022).

We need a national effort to repair the capacity of our landscapes to support our ambitions, needs and values. Without this, our environment, our wellbeing, and our productive economy will suffer.

2. We can have a healthy environment and productive, net-zero economy

The Wentworth Group has long-argued that the health of our environment underpins economic prosperity (Wentworth Group, 2014). Recent studies have demonstrated that it is possible to pursue outcomes for climate, nature and economic productivity simultaneously (Hatfield-Dodds *et al.*, 2015, Henry and Thodey, 2019, Lawrence *et al.*, 2023).

The Australian Government has committed to a global agreement to ensure that at least 30 percent of land areas and sea areas are conserved (CBD, 2022). Australia has also made national commitments to enhance biodiversity (DCCEEW, 2022), reduce emissions and sequester carbon (Commonwealth of Australia, 2022, DISER, 2022), generate renewable energy (DCCEEW, 2023c), provide water security (Commonwealth Government, 2007), mitigate against risks of climate change (AWE, 2021), and address Indigenous disadvantage (PM&C, 2020). Delivering these policy goals in an integrated way has broad benefits and will leave Australians considerably better off in the future.

There are many practical actions to repair landscapes in a way that realises benefits for people, nature and the economy in the face of climate change (Bowman *et al.*, 2017). Investment in land sector carbon abatement is a clear opportunity to reduce emissions while achieving large-scale repair of degraded land and river corridors, improving condition of agricultural soil, and conserving biodiversity (see point 5. *Healthy landscapes store more carbon*). New economic opportunities such as carbon plantings, biofuels and bioenergy, and environmental plantings can help scale these landscape health outcomes (Hatfield-Dodds *et al.*, 2015).

Other practical actions include creating living shorelines to protect coasts, cultural burning practices and innovative plantings to manage fire risk, managing rivers to sustain people and ecosystems, and designing renewable energy sources to support biodiversity (Bowman *et al.*, 2017).

In agricultural systems, increases in non-food land uses can be compatible with food and fibre production (Grundy *et al.*, 2016). While food production may occupy a smaller land use footprint in Australia, with strategic land use planning and a focus on increasing agricultural productivity, this land can produce more, increasing the availability of land and water that is managed for biodiversity, carbon sequestration, energy generation and other outcomes.

3. We can unlock the potential for Aboriginal and Torres Strait Islander people as stewards of Country

European settlement in Australia has led to drastic changes in the management, value and respect for the lands and waters since 1788. For Aboriginal and Torres Strait Islander peoples, colonisation and the separation of Aboriginal and Torres Strait Islander people from their customary responsibilities of caring for Country has led to poor or misinformed land and water management decisions and consequent environmental degradation. Through Indigenous eyes, the current state of Country is far from healthy.

The health of Country is intrinsically tied to the values and identity of Aboriginal and Torres Strait Islander people. Repairing landscapes can enable Indigenous people to get back onto Country, sustain culture and reduce socio-economic disadvantage to help close the gap (Wright *et al.*, 2021, Ens and Turpin, 2022). Aboriginal and Torres Strait Islander people need leading roles in the national repair agenda, supported by long-term funding and greater ownership of land and water.

Aboriginal and Torres Strait Islander people hold generations of traditional ecological knowledge, connection, and observations for better management of natural resources and the achievement of sustainable development (Ens and Turpin, 2022). This traditional knowledge needs to be better integrated with current western scientific knowledge to better manage landscapes, for example, in the management of species (Lilleyman *et al.*, 2022) and use of fire to maintain the health of Country (McKemey *et al.*, 2019). The actions described in this report need to be applied in a way that integrates traditional ecological knowledge.

4. We can overcome constraints to agricultural productivity

Today and for the foreseeable future, agriculture accounts for more than half (55%) of land use in Australia (Figure 1) (ABARES, 2022c), reinforcing the important role of Australia's farmers in managing and repairing landscapes.

Many landholders are already undertaking actions which reduce erosion, lower input costs, improve soil biodiversity and water quality and quantity, and improve climate change resilience (CSIRO, 2016).

Nonetheless, agricultural landscapes have significantly declined in their capacity for maintaining agricultural productivity (Orton *et al.*, 2018), for supporting native systems and as a base for the growth of repaired vegetation communities (Metcalfe and Bui, 2017, Williams *et al.*, 2021).

Changing climatic conditions, water scarcity, soil degradation, salinisation, acidification and nutrient depletion are among the factors constraining the opportunities we have within our landscapes.

Clearing of native landscapes for increased agricultural production is not the solution – this practice has removed thousands of hectares of remnant vegetation (NSW DPE, 2023, Qld Government, 2023) and impacted threatened species and communities (Ward *et al.*, 2019b).

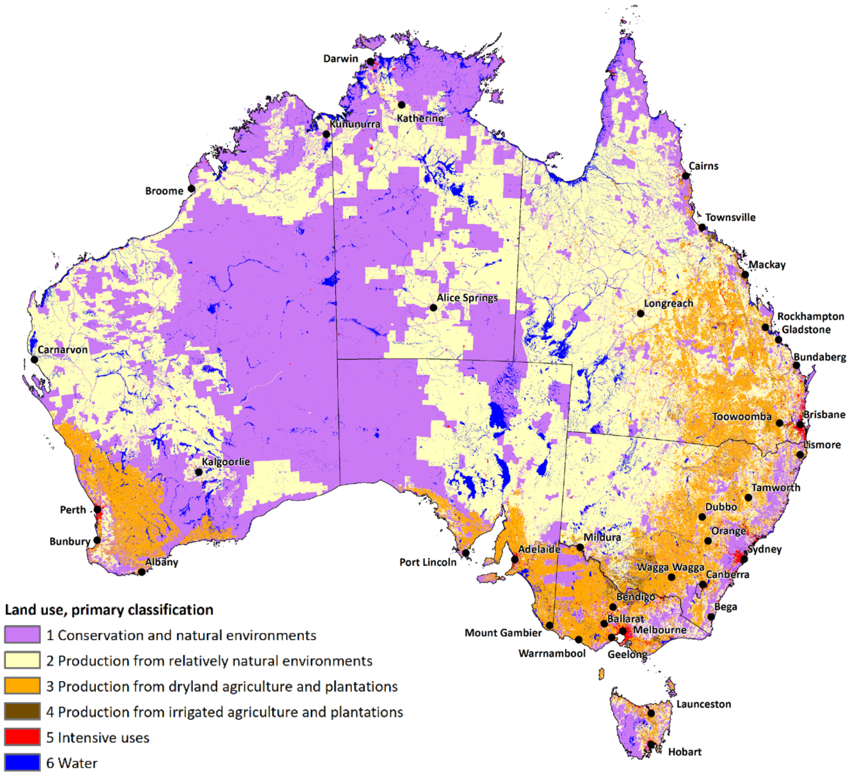

Figure 1. Land use of Australia in 2016 (ABARES, 2022a).

If we are to feed and clothe more people on smaller areas of land and unlock new economic opportunities for carbon sequestration and biodiversity within agricultural landscapes, we need to address biophysical constraints which limit the productivity of agricultural systems, broaden the adoption of farming practices which are in harmony with the natural environment and changing climate, and ensure the security of prime agricultural land (McKenzie *et al.*, 2017, Orton *et al.*, 2018).

Direct investment in repair is needed where degradation has advanced beyond the point where repair by private landholders is uneconomic, beyond the duty of care owed by private landholders, and where productivity continues to decline (e.g. areas of severe sub-soil acidification), or where there is significant off-site damage to environmental and other public assets (e.g. impacts of gully erosion in Great Barrier Reef catchments; Thorburn *et al.*, 2013b).

Efforts to boost crop and pasture yields can only be effective if they are linked with legal protection of native vegetation of high ecological value, so that food production is increased through growth in yield (intensification) and not expansion, and productivity gains will not encourage more degradation due to shifting land use.

Through these actions, landholders will have more sources of income, more rewards for verified sustainable production, better access to markets and improved yield and food quality (Thorburn *et al.*, 2013b).

5. Healthy landscapes store more carbon

It is in our nation's best interest to ensure that global greenhouse gas emissions are reduced to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC, 2015).

If Australia is to transition to a net-zero emissions economy by 2050, or preferably before, governments need to play a leading role in enabling emissions reductions with a focus on energy generation, manufacturing, agriculture, and transport.

However, while this focus is fundamental, it is nearly impossible to achieve the scale of reductions required in the necessary timeframe unless we also reduce emissions from land clearing and harness the full potential of our landscapes to remove carbon from the atmosphere and store it in vegetation and soils. Land sector sequestration will also buy us time to enable the necessary and more complex transitions in other parts of the economy.

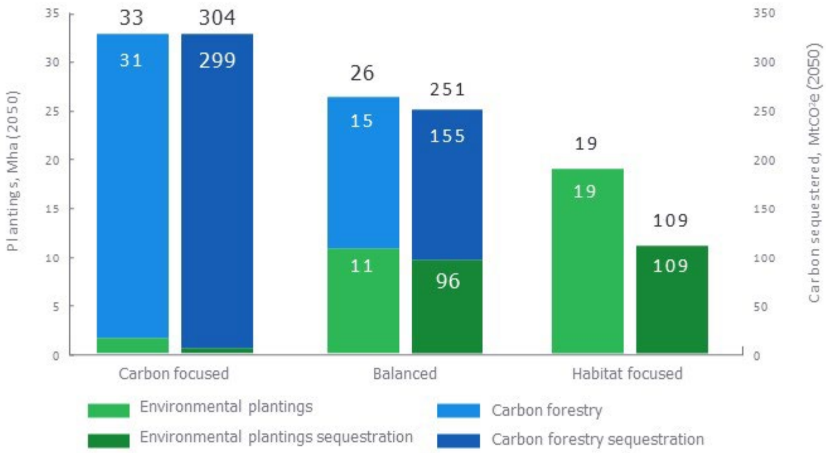

Figure 2. Environmental plantings and carbon sequestered under three scenarios to 2050, showing opportunities to optimise carbon and biodiversity benefits (CSIRO modelling commissioned by Ernst & Young; EY, 2023).

Healthy landscapes have the potential to store vast quantities of carbon (Fitch *et al.*, 2022). Harnessing the full potential of the current land sector sequestration policies presents us with a once in a generation opportunity to transform the way we manage our landscapes. CSIRO modelling commissioned by EY showed that sequestering carbon in a way that delivers biodiversity benefits can restore seven times more native habitat, can limit the extent of land use change, and the 'balanced' scenario would only sequester 20% less than an approach which maximises carbon sequestration alone (Figure 2) (EY, 2023).

6. We can reduce climate change risks and threats to national security

Only a small number of the most ambitious modelled climate change scenarios limit impacts of global warming to 1.5°C; global surface temperature has reached 1.1°C above 1850-1900 levels in 2011-2020 and there is a 66% chance of exceeding 1.5°C by 2027, causing widespread adverse impacts and related losses and damages to nature and people (IPCC, 2023, WMO, 2023). Thus, while Australia must take a leading role in addressing the causes of climate change through reducing emissions, it is also vital that we are prepared for anticipated changes, and support ecosystems to survive and adapt to these changes. Protecting and repairing the health of our landscapes is one of the most effective approaches for mitigating and adapting to climate change.

As Australia's landscapes continue to degrade, the ability of these systems to withstand, and recover from acute shocks (e.g. bushfires, floods) and chronic stresses (e.g. drought) is severely diminished, with consequences for the viability of regional economies, the agricultural sector and our national security.

The World Economic Forum has warned of the very large costs of failing to protect nature from further degradation (WEF, 2023). Risks include large-scale flooding, ill health and epidemics, lower food security, toxic water quality, climate change, destruction of coastlines, and wildfires.

A recent review by Ide (2023) found that "climate change will very likely undermine Australia's national security by disrupting critical infrastructure, by challenging the capacity of the defence force, by increasing the risk of domestic political instability in Australia's immediate region, by reducing the capabilities of partner countries in the Asia-Pacific region, and by interrupting important supply chains" (Ide, 2023).

Repairing the ecological health of Australia's environmental assets will ensure they are more resilient to harmful impacts of climate change. While the impacts of rising temperatures and climate change on some plant and animal species and ecosystems will be significant, Australia's environment overall will stand a better chance if the actions identified here are undertaken.

7. The costs of inaction are immeasurable but immense

Australia could face "long-lasting and severe consequences" unless we repair past degradation and manage current and future pressures on our environment (Cresswell *et al.*, 2021). The threats have the potential to impose significant costs because ecosystem services provided by our soils, vegetation communities, water systems and faunal communities will be impaired. We are only beginning to understand and quantify the full cost of degradation.

Failure to repair environmental damage poses major risks to Australia's economic prosperity. Global studies estimate that the cost of inaction on environmental change equates to a loss of US$479 billion per year (Roxburgh *et al.*, 2020b).

While we cannot accurately measure the true cost of environmental degradation to the environment, people and the economy, the evidence suggests these costs far outweigh the modest cost to substantially repair nature.

Approach

Principles underpinning the proposed objectives and actions

This report presents practical actions to repair landscapes, to optimise opportunities for people, nature, and the economy, and to build the capacity of landscapes to support our needs and values in the face of climate change and other pressures. Each action is linked to a specific objective (see page vii). Table 2 outlines the criteria and rationale for the selection of actions.

Table 2. Criteria for the selection of actions listed in this report.

Criteria	Description
1. Significant and measurable benefit	Actions offer significant potential for immediate and substantial remediation and subsequent measurable environmental benefit, while also supporting economic, cultural and social outcomes in the long term.
2. Systematic	Five components of Australia's interconnected landscapes were identified as needing repair: i) soils; ii) inland water; iii) native vegetation; iv) threatened species; and v) coastal environments. These were selected based on the State of the Environment report and the Wentworth Group's environmental accounts nation-wide regional trial (Sbrocchi *et al.*, 2015). Other important components, such as air quality, the marine environment and restoring nature in cities and towns, were beyond the scope of this assessment.
3. Practical	Actions are pragmatic and tangible. Minimal systemic, political or policy changes are needed, but actions also need to be undertaken within a broader reform framework.
4. Evidence-based	Actions are based on the best-available science and expert advice as to what is needed to repair each asset. We excluded actions where there was insufficient evidence of their effectiveness or cost.
5. Additional and complementary to current efforts	Actions build upon the success of existing efforts, fill gaps in existing programs or are not already being fully funded or actioned through effective mechanisms or policy/legislation commitments.
6. Nation-wide scale	Actions occur at a nation-wide scale or have national significance and are beyond the capacity of individuals or small groups to implement. Actions will need to be regionalised and implemented across management scales in an integrated way.
7. Integrated with Indigenous people and knowledge	Actions can be delivered with the involvement of Indigenous and Torres Strait Islander people, and are informed by, or have the potential to be informed by, Indigenous knowledge.

8. A reset to address long-term historical degradation	Actions improve the condition of a degraded natural asset to a baseline level from which ongoing management actions can take place. We do not propose to return the condition of assets to a past state, but rather to an improved condition from which further enhancement is possible within a modified landscape.
9. Public good outcome	Actions result in a material public benefit to the environment.
10. Supports multiple benefits	Actions support broad values and systems (i.e., food production, jobs, economy, climate change resilience and abatement) and can occur in ways that achieve multiple objectives, such as the need to restore vegetation and maintain agricultural productivity.
11. Recognises trade-offs	Actions are undertaken in a way that minimises or mitigates inherent trade-offs, having explicitly identified the nature and cost of those trade-offs. Examples include targeting restoration of native vegetation outside areas of prime agricultural land (see 'Native vegetation' section) and providing financial incentives to landholders to retire farmland along riparian buffer zones equivalent to forgone production (see 'Inland water' section).

An evidence-based approach for assessing actions and investment

We used the following approach to determine the actions and estimate the investment required. Please refer to subsequent chapters for the specific methods used for each asset.

1. Defined the natural assets in need of repair based on the United Nations System of Environmental-Economic Accounting 2012 Central Framework definition "Environmental assets are the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity" (United Nations *et al.*, 2012). They include ecosystem assets, "contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions" (United Nations, 2021).
2. Systematically identified five key environmental assets (soils, inland water, native vegetation, threatened species and coastal environments) in need of repair, based on the State of the Environment reporting and Wentworth Group environmental accounts trial (see Appendix I).
3. Defined objectives for each asset based on public policy ambitions and expert advice.
4. Identified the actions that meet objectives and satisfy the criteria in Table 2 based on published evidence and expert advice. Actions include nature-based solutions, defined as "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (Cohen-Shacham *et al.*, 2016).
5. Sourced relevant data to identify where in the landscape each action is required by (a) drawing from published national studies, (b) undertaking spatial analyses, and/or (c) making assumptions based on expert judgement.
6. Sourced relevant data to identify the capital and operational expenditure required for each action by (a) estimates based on a known unit value, (b) estimates based on case studies of similar actions in other geographic regions.

7. Determined an appropriate starting year, duration and sequence for each action within the 30-year timeframe (2025-2055).
8. Costed each action by inflating past cost estimates to 2022$, applying transaction costs, assuming inflation over 30 years then using a discount rate to determine net present value (in 2022 dollars). See Appendix II for economic assumptions used.
9. Commissioned an independent expert review of the assessment including actions, methods, assumptions and cost estimates.

Interpreting evidence in this assessment

Restoring the health of this continent's environment is a continuing and complex journey. While we have applied the best available national-scale knowledge in this assessment, this kind of program is never definitive or exhaustive. This national assessment should be used as a guide only, given the limitations and substantial number of assumptions needed. It should be refined with region-specific information and expertise. The limitations of the assessment, however, should not be used as an excuse to delay the urgent action required.

What is important in this report is that we demonstrate that the magnitude of the costs and benefits makes our mission for repairing Australia's landscapes achievable. The national assessment will need to be updated as new knowledge emerges. It will also need to be applied and refined at the regional scale, together with policy and governance reforms, accounting for the regional settings and contextual differences. The report and associated spreadsheets are publicly accessible, and we invite improvements on these initial estimates.

The following aspects should be considered when interpreting the findings of this assessment:

- **Actions need to be undertaken together, as an integrated package within and across regions.** There are practical reasons for doing so: (1) improving the health of an asset usually depends on the restoration of other assets (e.g., supporting threatened species often requires regeneration and repair of habitat, improving health of estuaries requires management of upstream impacts); (2) Undertaking actions together unlocks many complementarities including cost-savings and co-benefits for people and nature (e.g., restoring river corridors also improves water quality and biodiversity, improving soil health increases agricultural productivity); (3) Mismanagement or inaction can have broader impacts and undermine overall improvement (e.g., unsustainable land management practices contributing to poor river, groundwater, and estuary health), and poor policies and regulations which can exacerbate degradation (e.g., laws that permit broadscale clearing of native forests and woodlands).
- **Actions and investments will need to be refined in light of the regional context.** This national assessment of the necessary actions and estimated investment required broad assumptions. These need to be tested and refined as part of their implementation at a regional scale. Average national costs were used in this assessment, but in practice, costs vary by location and over time. Thus, the numbers listed in this report are estimates and will evolve in light of the geographic and socio-economic context.
- **Local actions will be required in addition to national actions identified**. The diversity of Australia inevitably means that there are additional, small-scale, local actions that may be required (e.g., rehabilitation of mine sites).
- **Natural assets beyond the scope of this assessment also require repair.** Due to resource limits, governance challenges and data gaps, the report does not include important assets that need attention, such as marine environments, air pollution, or nature in cities and towns.

- **The actions identified need to be built into broader public policy reforms.** The actions in this report are practical on-ground actions that require appropriate governance settings to enable coordination, provide integrity, transparency, and accountability, ensure additionality and avoid perverse outcomes. Effective environmental laws are needed to protect important natural assets and prevent current and future degradation due to human activity and development. Without these, repair efforts will be undermined and more costly. A regional framework is needed to ensure solutions are appropriate within the landscape context and applied at a scale which engages regional communities and integrates local expertise.
- The list does not include actions currently being funded or undertaken, such as routine management of pests, weeds, and fire (see 'Actions beyond the scope of this assessment' sections in each chapter).
- Actions and investments are a snapshot in time and will continually evolve with knowledge and practice. This assessment represents our current best understanding of available knowledge. With improvement in the knowledge base and establishment of national environmental accounts, financial estimates will also improve together with our understanding of the actions required at a national and regional scale. This assessment needs to be updated and refined over time to ensure that regional, local, state, and national organisations can add measures important to them and use the evidence to put forward a national case for investment in nature. For this reason, we are publishing the data and algorithms that form the basis of this work in a spreadsheet available under a Creative Commons Open Access licence.
- **The actions listed in this report will not fully account for, or compensate for, climate change impacts.** There is increasing recognition that traditional approaches to conservation and natural resources management need to evolve significantly if we are to meet the current and future challenges of climate change. However, the actions presented will contribute to mitigating some of the more adverse effects. More importantly, the consequences of not undertaking these actions are far worse. We recommend a future-oriented approach to implementing these actions in light of climate change and its ongoing impacts.
- **The actions do not seek to restore degraded landscapes to a pristine state but to a new state with increased capacity to support what we need and value in the face of changes ahead.** We draw on the Bowman *et al.* (2017) concept of renewal ecology, defined as "a solutions-focused discipline aimed at creating and managing ecosystems designed to maximize both biodiversity and human well-being in the face of rapid environmental change". We use the term "repair" to mean creating and managing healthy ecosystems to maximise both biodiversity and human well-being by renewing ecosystem functions and generation of services as well as conserving species as their ranges and populations adjust to a changing climate.

Limitations and assumptions

This report represents our best knowledge currently available of the actions and approximate costs to substantially repair, conserve, and manage Australia's degraded landscapes. As the first known assessment of its kind that has been undertaken in Australia, there are a range of uncertainties and necessary assumptions that underpin this work (see Appendix II for more detail). These include the accuracy of ecological health reference baselines, efficacy (success rates) of each action undertaken, existing technological and implementation capacity, delivery and contractual arrangements, political and institutional aspects, trends in technology costs, and time lags between on-ground actions and realised benefits.

Our assessment was limited to regional landscape repair actions and did not address air quality, urban settlements, or marine environments. Urban air quality trends are improving; the existing major stressors (e.g., diesel engines, wood heaters and industrial activities) are either localised and/or progressively being dealt with through emissions intensity standards and more affordable low-emissions alternatives. Conservation measures for urban environments would have required considerable value judgements to determine the key actions for this component. According to the SOE 2021, marine environments are in a good, stable condition overall, but coral reefs and temperate rocky reefs and species that inhabit these environments are in poor and deteriorating condition due to a range of factors (Cresswell *et al.*, 2021). We did not estimate the cost of repairing marine environments due to uncertainties, complexity in governance, limited data availability, and the compounding effects of climate change.

There is scope to further explore Indigenous-led repair opportunities and enhance the ways in which traditional ecological knowledge can be better integrated with western science to inform actions. There may be opportunities to use the emerging carbon and nature markets to accelerate and scale the application of Indigenous-led landscape repair methods.

As the actions are not exhaustive and the investment estimates are indicative, this assessment should not be solely relied upon to make public policy, investment, or other management decisions.

These assumptions and limitations do not detract from the value of this assessment in defining the magnitude of the response required from Australia and demonstrating that it is both affordable and practical. Nor should it be used as an excuse to delay action. Instead, this report should be used to help accelerate practical conservation actions, scale up efforts to restore our environment and refine this work through practice.

Report structure

Each of the following chapters focuses on one of five key components of Australia's landscapes requiring repair, as identified in the Wentworth Group's environmental accounts trial and State of the Environment report (Cresswell *et al.*, 2021) i) soils; ii) inland water; iii) native vegetation; iv) threatened species; and v) coastal environments. Each chapter introduces the case for why repair is needed, lists the relevant objectives and actions identified, including actions which require capital expenditure (marked -C), actions which require ongoing operational expenditure (marked – O) and actions beyond the scope of this assessment (marked -A), and presents the methods used to achieve them. Actions beyond the scope of this assessment are listed in a table at the end of each chapter.

Soils

The case for repairing degraded soils

Agriculture occurs across 55% of the Australian landscape (ABARES, 2022b) and therefore has an enormous influence on biodiversity and landscape health. About two-thirds of Australia's agricultural land continues to suffer from acidification, contamination, nutrients and organic matter depletion, and salinity (Metcalfe and Bui, 2017). This is due to the inherent vulnerability of Australia's landscapes when exposed to agricultural practices developed on other continents.

Climate change is increasing the vulnerability of Australia's soils, constraining their capacity to support productive agricultural and ecological systems, and causing soil loss and damage (Cresswell *et al.*, 2021). The interactions between land-use intensification and climate change make the prevention of soil degradation more challenging (Cresswell *et al.*, 2021).

As part of a holistic landscape repair effort, it is important to address constraints to agricultural productivity that have emerged with long-term disturbance and degradation from land management practices. Such constraints leading to degradation are increasingly recognised as material issues affecting farm profitability and future prosperity (ACCA *et al.*, 2012).

Farming practices adapted to the Australian context, such as those by leading farmers, Landcare organisations, and Indigenous landholders, demonstrate the significant opportunity for lifting constraints to agricultural productivity. Improving on-farm soil management, such as repairing degraded gully systems, also has significant co-benefits such as improving water quality in rivers, lakes, wetlands, estuaries, coasts and oceans, including for the Great Barrier Reef (Thorburn *et al.*, 2013a).

Our assessment identifies the objectives and actions required to substantially improve the condition, productivity and sustainability of Australian soils and farms. We identify on-ground actions to reduce the long-term threats of erosion, salinity, and acidification where repairing damage from these processes is beyond the year-to-year economics inherent in farm management. These actions do not replace but complement standard and continually improving farm management and allow that management to build productivity from a new base. These actions are not intended to subsidise the operation of Australia's farms; rather they are intended to return the more substantially damaged soils to a baseline from which improved farm management practices can support and maintain productivity and sustainability.

This program will involve trade-offs in our agricultural regions, many of which have already experienced declining agricultural productivity improvement in recent decades. To mitigate these trade-offs, new and diversified streams of income would be available to farmers through this national repair effort and related programs. This would allow for investment in improved and more productive agricultural systems and, where degradation is present and ameliorated, a more resilient base for improved and sustained productivity. A key focus for implementation will be to identify and address trade-offs at the regional and overall program level.

While we recognise a clear case for repair of soils and farmed lands, the approach and costing used differ significantly from approaches in subsequent chapters. Australian soils have changed substantially since European settlement mainly through the impact of clearing, change in land use, and the nature of the management imposed in establishing and continuing agricultural use (Metcalfe and Bui, 2017). Some of that change has led to soils being better suited to production agriculture through changes to the nature of ecosystem dynamics and the application of pesticides, irrigation water and nutrients (although in some cases excessive nutrients have consistently been applied without agricultural benefit, and with potential environmental cost (Wong *et al.*, 2012)).

Many soils have significantly declined in their capacity for maintaining agricultural productivity (Orton *et al.*, 2018) and for supporting native systems including repaired vegetation communities (Metcalfe and Bui, 2017, Williams *et al.*, 2021). In some cases, the pre-existing vegetation and fauna habitats no longer exist (Handreck, 1997) and there is a decline in the capacity of low-resilience soils and landscapes to support continued productivity in agricultural systems (Metcalfe and Bui, 2017, Williams *et al.*, 2021).

This decline has typically been characterised (McKenzie *et al.*, 2017) as one or more of:

- reduced soil carbon both for the multiple benefits that arise from soil carbon and as a partial index of soil biological health (Kopittke *et al.*, 2022);
- reduced levels of soil nutrients or the capacity to supply nutrients;
- reduced physical condition of soil (for example, reduced soil water holding capacity);
- toxic or unbalanced levels of soil nutrients / components (for example, the tendency of soils under agriculture to become increasingly acidic); and
- the loss of soil and soil condition through erosion.

McKenzie *et al.* (2017) assessed the variation in soil condition across Australia based on a subset of these attributes and identified priority areas for repair of Australian soils; Table 6 in their report summarised these issues and needs.

Most decline in soil condition occurs in lands managed for agriculture (Dalal *et al.*, 2021a, Dalal *et al.*, 2021b). With the exception of off-site impacts (Thorburn *et al.*, 2013a), most of the cost of this decline is borne by the land manager / owner and therefore they will also realise the benefit of repair. Australia and similar export nations have moved to substantially reduce or remove subsidies of export industries including agriculture and have moved carefully in introducing environmental improvements on agricultural lands so that these are not seen as subsidies (Pannell and Rogers, 2022). We do not recommend direct repair investment where private benefit is dominant. We do, however, recognise the need to restore the condition of Australian agricultural lands to maintain or improve productivity, an essential component of the broader use of landscapes required to recover biodiversity and to realise the benefits of land-based greenhouse gas sequestration and mitigation (Hatfield-Dodds *et al.*, 2015, Bryan *et al.*, 2016b, Grundy *et al.*, 2016).

We see two complementary pathways required to achieve this. The first is a re-invigoration of the advisory and support services based in regional bodies, in private advisory services, and to varying extents, in state government agencies. The past three decades has seen cycles of investment and de-investment in what are broadly known as extension services (Pannell and Rogers, 2022); it is essential that consistency and certainty returns so that change can occur and be maintained, and knowledge can be shared and improved.

The second recognises that direct investment in repair is needed where:

- decline has advanced beyond the point where private repair is uneconomic and productivity continues to decline (an example would be areas of severe sub-soil acidification); and
- there is significant off-site damage to environmental and other public assets (such as occurs with gully erosion in Great Barrier Reef catchments).

We cost the direct repair cases and the re-investment in support services but the estimates are only indicative; no data exist that would allow confident estimates. The implementation phase of landscape repair will require regionally-based assessments and refinement of the investment and repair needed.

Identifying actions and estimating the investment

The Wentworth Group has identified the practical actions and derived indicative estimates of the new capital and annual operational investment needed to repair the productive base of agricultural soils over 30 years. The indicative annual investment from 2025 to 2054 is $774 million including $580 million in capital costs, $58 million in transaction costs and $137 million in operational expenditure (in 2022$).

The following section describes the management objectives, the actions for repairing the health of Australia's soils and farms, the rationale for these actions, and the methods for estimating the investment.

Objectives	Actions
S1. Improve physical and chemical condition and productivity of agricultural soils that need remediation due to long-term degradation and where that remediation is not likely to occur without direct investment.	S1.1-C Apply lime to address soil acidification on agricultural soils where damage is significant, not affected by acid sulphate, and not amenable to current management.
	S1.2-C Apply gypsum to address soil structure decline on agricultural soils with excess sodicity where amendment is likely to produce substantial improvement.
	S1.3-C Plant salt-tolerant vegetation (e.g., saltbush) on salt-affected lands to maintain soil stability and some level of production.

Objective S1 - Rationale and costing methods

Soil physical and chemical properties are key indicators of soil condition and function, influencing plant and animal life, agricultural production, carbon storage and sequestration, and water quality (Bronick and Lal, 2005, Sbrocchi *et al.*, 2015). The focus of this objective is repairing key aspects of soil condition that have been impacted by past and continuing agricultural activities i.e. soil acidification and soil structure decline where sodicity is constraining productivity.

Action S1.1-C Apply lime to address soil acidification on agricultural soils where damage is significant, not affected by acid sulphate and not amenable to current management.

Rationale – About half of Australian agricultural lands are affected by acidification (NLWRA, 2001a, Baldock *et al.*, 2009, State of the Environment Committee, 2011), a problem that is becoming more severe and extensive (McKenzie *et al.*, 2017). Areas with damaging levels of acidification require amelioration. While it is clear that many farms are not fully utilising soil liming practices to reduce soil acidity and improve soil, plant, and farm health (Gazey *et al.*, 2014a, McKenzie *et al.*, 2017), the immediate concern is those areas where the damage requires high inputs over multiple years.

Having an appropriate soil pH level is necessary as it influences the availability of vital nutrients and soil organisms, and the interaction of these organisms with plants. A healthy soil biota is critical for effective water penetration and thus agricultural productivity (CCMA, 2013b).

Liming needs to be built into standard agricultural practice, but the case for additional investment lies where extensive repair is needed and costs are beyond the resources of individual farmers (Sumner and Noble, 2003).

To address soil acidification, lime (calcium carbonate) or dolomite (calcium magnesium carbonate) can be applied as an alkalizing agent to increase soil pH to the desired level (Edmeades and Ridley, 2003) and should be a regular input into agricultural systems on vulnerable soils to replace the alkalinity lost in each crop. This practice reverses short-term surface soil acidification resulting from the ongoing process of crop removal and nitrogen (ammonium) management (e.g., fertilization, legume N fixation).

The focus of the repair action is where soil acidification is intractable and remediation by an individual farmer is unaffordable. Hence, we do not suggest that this action replaces or subsidises the routine application of lime that is needed in agricultural management, but that long established and intractable acidification issues whose remediation is beyond the annual investment of farming is funded – to enable a reset and increased productivity on those lands.

The quantity of lime needed to rectify acidity issues depends on the soil type and pH profile, quality and type of the lime, agricultural land-uses, and rainfall (DPIPWE, 2014). Infertile, light textured soils have a low buffering capacity to acidification and some soils are inherently acidic and prone to become more acidic. It is also much harder to reverse the problem if the acidification has advanced deeper into the soil profile (Metcalfe and Bui, 2017).

Undertaking routine soil liming to improve soil health can produce tangible economic benefits. A study conducted on wheatbelt farms found that soil liming cost \$7-\$30/ tonne, depending on source and location, but resulted in an annual increase in yield of 10%, or approximately \$45-\$62/hectare (Gazey *et al.*, 2014b). Other estimates of the financial return of liming include: up to \$250/ha (O'Connell, 2000), up to \$13/ha (Gazey and O'Connell, 2001), up to \$60/ha (Davies *et al.*, 2009), up to \$165/ha (Leake *et al.*, 2014) and \$20 to \$60 per hectare per year (Orton *et al.*, 2018). The economic outputs of soil liming can be improved when used in combination with ripping or tillage practices, but ultimately depend on many factors relevant to individual farms (Gazey *et al.*, 2014b). Thus, it is clear that routine soil liming is both needed in many soils and is profitable. Where the extent of acidification is extreme, however, there is a case for a public investment in repair.

Costing Method – The National Land and Water Resources Audit identified that 12.3 million ha of acidic land required 11.6 million tonnes of lime to reach a critical pH level of 4.8, and 49.1 million ha of acid land required 65.6 million tonnes of lime to reach a critical pH level of 5.5 (NLWRA, 2001a, NLWRA, 2001b). McKenzie *et al.* (2017) suggest that these areas are under-estimated. In this initial costing, the audit area is used as an initial estimate of intractable acidification unlikely to be reversed without substantial reset with liming. In the implementation phase, action and funding efforts will need to be refined based on more up to date, local and precise information. The average cost of lime, including delivery and spread, is assumed to be \$43/tonne (2017\$) (AGRIC, 2017), though this can vary substantially from place-to-place and should only be applied where we can and should reset lime levels. It is assumed that lime is readily available and can come from a variety of sustainable sources across Australia.

Action S1.2-C Apply gypsum to address soil structure decline on agricultural soils with excess sodicity where amendment is likely to produce substantial improvement.

Rationale – Soil structural decline is a form of land degradation that can be caused by sodic soil conditions (i.e. where sodium in the soil reaches a concentration where it starts to affect soil structure) and other factors (NLWRA, 2001a, NLWRA, 2001b). More recent studies suggest that sodic soil conditions are more widespread and more costly to agriculture than other soil constraints (Orton *et al.*, 2018). Supplying sodic soils with a calcium source, like gypsum, can improve soil water retention, root and seedling development of plants as well as soil quality, pH, and structure (CCMA, 2013a, CCMA, 2013b).

Application of gypsum (calcium sulphate) to soil, in combination with destocking (and other actions listed here), can play a key role in managing soil structure decline, depending on the soil chemistry and the process driving the decline. Where there is an imbalance in the level of sodium attached to clay particles in soil, clay materials do not clump into stable aggregates but disperse and either erode (the main cause of tunnel erosion and gullying) or form dense layers in the soil that reduce water storage, permeability, and root penetration and spread. Many soils have naturally high sodium content and are vulnerable to poor management practices. Gypsum works by replacing sodium with calcium, freeing up the clay and allowing for improved water movement through the soil profile. The total potential annual economic benefit of addressing sodicity using gypsum has been estimated to be approximately A$1.15 billion per annum across the wheat-growing land of Australia (Orton *et al.*, 2018).

Costing Method – Studies show that 250,000 ha of land in Australia requires the application of gypsum (Madden *et al.*, 2000) at an average cost of $250/ha (2011$) (Dang *et al.*, 2011, Dang and Moody, 2016). However, the cost can vary substantially depending on soil type and management practices. It is assumed that gypsum is readily available and can come from a variety of sustainable sources across Australia where it can be trucked to the relevant site for spreading.

Action S1.3-C Plant salt-tolerant vegetation (e.g., saltbush) on salt-affected lands to maintain soil stability and some level of production.

Rationale – The National Land and Water Resources Audit (NLWRA, 2001a) projected that dryland salinity could increase from 5.7 million hectares to 17 million hectares by 2050. South-western Western Australia and Victoria have historically experienced widespread dryland salinity, and large areas of New South Wales along the Great Dividing Range and in the Murray-Darling Basin have been identified as having a high or very high salinity hazard, as well as the North Coast, Hunter Valley, Central West and Greater Sydney regions (EPA, 2018).

Planting saltbush (and other salt-tolerant native plants) in dryland areas can help to stabilise soils, while simultaneously increasing overall grazing productivity by providing feed for sheep in low-rainfall areas and providing erosion control by protecting soils from intense rainfall events and wind (Ledger and Morgan, 2007, Revell *et al.*, 2013).

Costing method – It is estimated that there are 2.5 to 5.7 million hectares already affected or with a high potential for the development of dryland salinity across Australia (Madden *et al.*, 2000, Harrington and Cook, 2014). It is assumed that the area where planting of salt-tolerant native vegetation is needed to reduce productive land lost to salinity is 845,000 ha, at a cost of $200/ha (2000$) (Madden *et al.*, 2000). It is also assumed that this extent has not changed significantly since 2000 although, in reality, the spread is likely to have increased during wetter periods. The specific sites for remediation would be based on local context, identified during the implementation phase.

Objective S2

Objectives	Actions
S2. Repair gully erosion hot spots across Australia to improve water quality in rivers and expand the availability of healthy land for agriculture and wildlife.	S2.1-C Undertake remediation works of revegetation, fencing, stick traps, and rock chutes for high-risk gullies.
	S2.2-C Undertake remediation works of stick traps, rock chutes, fencing for low-to-medium risk gullies.

Objective S2 – Rationale and costing methods

Action S2.1-C Undertake remediation works of revegetation, fencing, stick traps, and rock chutes for high-risk gullies.

Rationale – Gully erosion is an ongoing cause of loss of land, as well as sediment and nutrient run-off. There is evidence that gully remediation is able to accomplish large reductions of sediment and nutrient pollution into waterways and wetlands from catchments and riparian zones (Greening Australia *et al.*, 2021). However, the extent of gullying and the best forms of remediation are the subject of intensive research and development, so the estimates here will need to be refined.

Costing methods –Approximately 325,000km of eroded gullies have been mapped across Australia (Hughes *et al.*, 2001). We assumed 2% (6,500km) experience moderate to high rates of erosion (i.e. where gully density ≥ 1km/km^2) (Hughes *et al.*, 2001). For this action, we assumed these high-risk gullies will be treated with stick traps, revegetation, fencing, and rock chutes to effectively manage erosion (Wilkinson *et al.*, 2015, Alluvium, 2016), although in practice, appropriate solutions would need to be guided by local knowledge. The upfront average cost of these treatments is assumed to be $66,200/km (2016$) (Alluvium, 2016).

Action S2.2-C Undertake remediation works of stick traps, rock chutes, fencing for low-to-medium-risk gullies.

Rationale – As above.

Costing methods – Approximately 325,000km of eroded gullies have been mapped across Australia (Hughes *et al.*, 2001). We assumed 98% (318,500km) were low-to-medium risk gullies (i.e. where gully density < 1km/km^2) (Hughes *et al.*, 2001). We assumed these low-to-medium risk gullies would need to be treated with stick traps, rock chutes and fencing to effectively manage erosion (Wilkinson *et al.*, 2015, Alluvium, 2016), although in practice, appropriate solutions would need to be guided by local knowledge. The upfront average cost of these treatments is assumed to be $36,200/km (2016$) (Alluvium, 2016). Estimates need to be revised to account for gullying that has occurred since the original assessment.

Objective S3

Objectives	Actions
S3. Connect agricultural land management practices with broader national ambitions for biodiversity, climate change and agricultural productivity.	S3.1-C Revitalise advisory, support and extension services to provide landholders with the knowledge and capacity to better optimise outcomes including maintaining economic productivity, improving catchment health, sequestering carbon and improving biodiversity.

Objective S3 – Rationale and costing methods

Action S3.1-C Revitalise advisory, support and extension services to provide landholders with the knowledge and capacity to better optimise outcomes including maintaining economic productivity, improving catchment health, sequestering carbon and improving biodiversity.

Rationale – Australia is well placed for research excellence on agriculture and food security in a variable and changing climate, and optimising outcomes for agricultural productivity with catchment health. As an international leader in natural resource management and best practice agriculture, Australia also has opportunities to export this knowledge to countries globally that are grappling with the challenges of increasing competition over resources and food security into the future. However, there has been a stagnation in research, development and extension services by federal and state agencies over the past few decades relative to the gross value of agricultural production (Figure 3). Organisations such as CSIRO and universities need to increase their investments in field-based services capable of advancing our competitiveness and sustainability across the triple bottom line.

Agricultural advisory, support and extension services need to be expanded and coordinated across Australia to provide an integrated approach to knowledge adoption and support, and in doing so, boost economic productivity and sustainability. These services should offer assistance to land managers who seek to capture environmental benefits that underpin natural values and ecosystem services. Research programs could encompass fields such as agricultural science, farm management, ecosystems and climate change. Services could support farm-based programs with landowners to demonstrate innovations such as new crops, grazing techniques and irrigation technology. Partnership with the agri-business systems can provide mutual benefits and help raise the profile of sustainable agriculture in Australia and overseas.

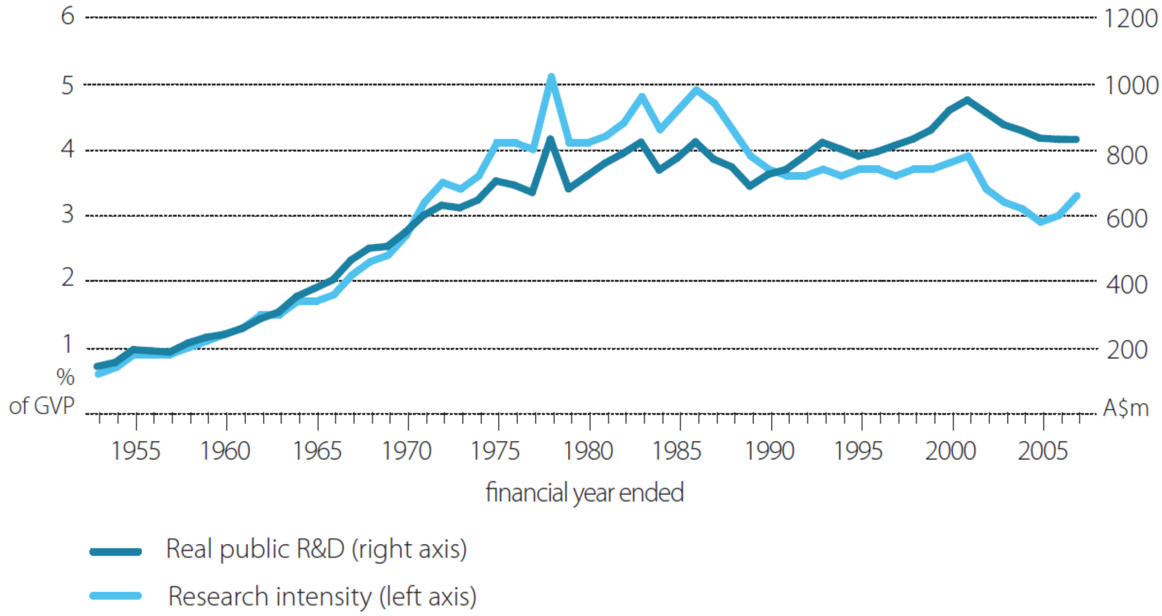

Figure 3. Real public research and development investment and research intensity (expressed as a percentage of gross value of agricultural production; GVP) in Australian agriculture, 1952-53 to 2006-07. (Sheng et al., 2011)

Costing method – Costs were calculated based on the average per hectare costs of extension services in five Great Barrier Reef (GBR) catchments where there has been concerted efforts to reinvigorate extension services (Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy, Burnett Mary; Alluvium, 2016). Extension programs in these regions have involved setting a minimum standard across cropping (sugarcane) and grazing land, based on a model where incentives are offered parallel to extension (Alluvium, 2016). Following these programs, it was reported that 62% of sugarcane farmers and 78% of graziers had improved their management practices as a result of the extension services. The method to estimate the average extension cost in the GBR was based on the integration of several datasets recognising the spatial heterogeneity between the regions, costed at a landholder level and extrapolated to a per hectare basis based on the average farm size (Alluvium, 2016). We extrapolated the costs to cropping and grazing land across Australia, based on the extent of cropping and grazing published in the latest release of the Land Management and Farming of Australia statistics (ABS, 2018).

Operational expenditure

The following are the assumed operational costs required to ensure the outcomes and benefits from the actions described above can be maintained over the 30-year period.

Action S2.1-O Ongoing management of gully control measures.

Rationale – To ensure gully repair lasts many years, gully remediation and control measures, including stick-traps, rock chutes and revegetated areas, must be monitored and managed. In addition, impacts of cyclones, intense storm events and major floods are likely to necessitate new repairs in vulnerable landscapes.

Costing Method - We have assumed a maintenance fee of 1.4% of the upfront cost of gully erosion control actions (i.e. S2.1-C and S2.2-C) (Greening Australia *et al.*, 2021).

Actions beyond the scope of this assessment

Actions in the table below have not been costed in the estimates provided above because either: (a) they are already being undertaken by the majority of landholders; (b) they require actions beyond investment such as governance or legislative changes; and/or (c) there is a lack of data or significant uncertainty regarding their effectiveness or cost.

ID	Action	Description
S1.1-A	Reducing chemical pesticide and herbicide use on farms	In some sectors (e.g., cotton and the GBR catchment industries) there have already been considerable developments in reducing chemical inputs, through increased efficiency and timeliness, gene editing to improve effectiveness of pesticides (and thus reduced need for repeat sprays), or through enhanced use of natural predators and parasitoids through management of non-cropping parts of the landscape. While we recognise this action is important, we were unable to find sufficient data for costing this action at the national level.
S1.2-A	Shifting the remaining 22% of broad-acre farming to zero-till systems	Zero-till systems has already been adopted across approximately 78% of Australia's farmland (ABS, 2018), with a number of reports suggesting that the farmers overseeing the remaining farmlands are unlikely to adopt this practice.
S1.3-A	Improving soil organic carbon	Australia needs to increase soil carbon both because clearing and cultivation have led to significant and, in some cases, continuing decline and because soil carbon and organic matter drive a number of crucial soil processes. While the need is clear, we have not included soil carbon increase in managed landscapes for several reasons. There are existing emissions reduction programs funding soil carbon restoration for climate change mitigation and active extension activities to improve land management and in the process maintain or grow soil carbon reserves in soils. There are also limited opportunities to sequester significant quantities of soil carbon in agricultural landscapes without a permanent change in land use (i.e., from crops to pasture, or pasture to trees) and in most cases these changes in land management are more complex changes than envisaged in the repair proposal.
S1.4-A	Regulations/guidelines for managing acid sulphate soils	Effective regulations and guidelines are already in place to avoid and manage disturbances to medium- to high-risk unoxidized acid sulphate soil areas. While there remains a need for remediation and drainage management of active acid sulphate soil outbreaks, the areas remain small and in most cases are managed by state and local governments.
S1.4-A	Annual cost of maintaining revegetated areas of salt-tolerant plants	Annual costs have not been included because of a lack of information on whether these are self-maintaining ecosystems, and whether the extent of salinity is being managed across these landscapes.
S1.5-A	Rehabilitate abandoned (legacy) mine sites,	There are tens of thousands of abandoned mines in Australia, many of which continue to cause environmental harm through impacts such as waterway acidification (Campbell *et al.*, 2017). However, many of these

	and mine sites that will be abandoned in the future	mines were abandoned years ago, the locations of which have been largely forgotten, and the companies responsible long gone – therefore, there is little prospect of rehabilitating these sites due to a lack of parties who might bear the burden and cost. There has been much debate as to whether state governments have secured enough finance from mining companies to cover the costs of rehabilitating mines that may be decommissioned in the future. Many commentators suggest that the current value of mine rehabilitation bonds is too low. Based on publicly available information (AECOM, 2015, EJA 2016, Mudd, 2016, Roche and Judd, 2016, West, 2016, Willacy, 2016, Campbell *et al.*, 2017) initial estimates suggest that this shortfall may be in the realm of at least $7 billion dollars. This estimate, however, has not been formally included here due to the significant uncertainty involved.
S1.7-A	Control agricultural weeds	While substantial efforts were made to estimate the investment required to control agricultural weeds, the lack of spatial information on the extent and location of agricultural weed infestations, and the lack of systematic, national-level data capture tools and incentives, makes it currently impossible to establish a credible estimate. The management of weeds is also complex, with the latest Australian Weeds Strategy 2017-2027 (IPAC, 2017), suggesting that weeds are best managed according to the stage of the spread: 1) prevention; 2) eradication; 3) containment; and 4) asset protection. While the costs of managing agricultural weeds have not been estimated here, the cost of asset protection for replanting and revegetation of native vegetation has been included.
S1.8-A	Maintain groundcover	Maintaining groundcover is important in grazing lands where rainfall is a predominant driver. This requires individuals to manage stocking rates over a sustained period. For this reason, we have included groundcover management as part of Action S3.1-C which incentivises graziers to adopt improved standards in land management for all grazing properties across Australia.
S1.9-A	Avoid future soil degradation	This assessment assumes that a once-off reset will address past degradation, allow the management of soil quality through recurring farm management and that with the actions listed above, future degradation of soils on farms will be minimised.
S1.10-A	Replant native vegetation on farms	Addressed in the 'Native Vegetation' section.
S1.11-A	An Australian Standard for Sustainable Agriculture	This standard would include whole lifecycle analyses of energy, water, land, and biodiversity inputs underpinning food and farm certification for both Australian grown and imported products. The cost of setting up and operating an Australian Standard for Sustainable Agriculture (Wentworth Group, 2015), for example, has not been accounted for in this report.

Inland water

The case for repairing degraded river systems

Healthy rivers, lakes, wetlands, and groundwater systems are vital for the wellbeing and livelihoods of people in rural, remote and urban communities across Australia. Healthy surface and groundwater systems provide clean water for drinking, sanitation and growing food and fibre. They reduce the risk of toxic algal blooms, hypoxic blackwater events, acidification, salinisation and extreme erosion, and protect catchments and downstream coastal and marine systems from storm and flood damage (Martin-Ortega *et al.*, 2015, Wentworth Group, 2017c). Healthy surface water and groundwater systems provide significant cultural and economic services to Indigenous people and benefit the broader community by supporting recreation, tourism, fishing and education as well as many aesthetic and spiritual values (Campbell *et al.*, 2021). Indigenous people share a sense of cultural and spiritual connectedness that relates to cultural responsibilities and obligations to water (Moggridge and Thompson, 2021). Healthy surface water and groundwater systems also provide critical habitat, food and life cycle cues for a wide diversity of plants and animals, as well as supporting their resilience and capacity to adapt to rapid environmental change (Capon *et al.*, 2013).

Riparian ecosystems (i.e., those which immediately fringe aquatic systems and both shape and are shaped by these systems) play a particularly important role in sustaining healthy waterways and wetlands (Riis *et al.*, 2020). Healthy riparian ecosystems buffer waterways and wetlands from both instream and upland pressures, protecting channel banks from erosion and filtering run-off. By regulating hydrological flows and the transport of sediment, pollutants and other materials, riparian ecosystems are therefore critical to the maintenance of good water and soil quality and landform stability (Capon and Pettit, 2018). Riparian ecosystems further provide critical habitat and food resources for both terrestrial and aquatic biota as well as facilitating their adaptation to climate change, e.g., by providing refuges from drought, cooler habitats and corridors for movement through the landscape (Capon *et al.*, 2013).

The health of Australia's rivers, wetlands and groundwater systems is affected by a wide range of pressures and threats including water resources development and river regulation, vegetation clearing (both in riparian zones and across catchments), landform and habitat modification (e.g., channelisation and bank armouring), fragmentation (e.g., via weirs and levee banks) and loss (e.g., draining of wetlands), pollution, and invasive species (Vörösmarty *et al.*, 2010, Davis *et al.*, 2015). Water resources development and river regulation, while having enabled floodplain settlement and irrigated agriculture in regional Australia, have come at a significant cost to the health of surface and ground water systems and the ecosystems and biodiversity which these sustain. Substantial changes to surface water flow regimes have been wrought by river regulation, including increased base flows, reduced frequency and magnitude of small to medium floods, and altered seasonality and reduced variability of flows (Maheshwari *et al.*, 1995, Kingsford, 2000), with significant implications for riverine biota. River regulation is also highly likely to have affected recharge, discharge and flow patterns of groundwater and groundwater-dependent ecosystems and biota (Nevill *et al.*, 2010, Åberg *et al.*, 2022).

Almost half of Australia's longest rivers (>1000 km) and a third of its long rivers (500-1000 km) no longer flow freely and have been impacted by physical infrastructure, both within channels and on floodplains, along with water extraction for agriculture and industry and changes in water quality and flow regimes (Opperman *et al.*, 2021). Riparian ecosystems throughout Australia have also been subjected to high levels of anthropogenic disturbance including vegetation clearing, infrastructure development and agricultural use, reducing their capacity to provide critical services and sustain the health of inland waters (ERIN, 2005, Zhang and Fryirs, 2023).

Climate change is both directly affecting river and groundwater systems, and exacerbating the pressures on these, with significant consequences for rural and urban communities, livelihoods and ecosystem health (Finlayson *et al.*, 2013, Cresswell *et al.*, 2021, Chiew *et al.*, 2023). Changes to rainfall, along with warming, are affecting runoff and streamflow with overall declines due to anthropogenic climate impacts apparent over recent decades in the Murray-Darling Basin (Prosser *et al.*, 2021) and south-west Western Australia (McFarlane *et al.*, 2020). Recent extreme events across the country, including droughts, fires and floods, have further adverse implications for the health of inland waters and their biodiversity (Alexandra and Finlayson, 2020). At the same time, demand for both surface and ground water resources can be expected to increase in response to the changing climate (Prosser *et al.*, 2021) while many ecological functions and ecosystem services provided by rivers, wetlands and their riparian ecosystems (e.g., provision of heat and drought refuge) are likely to be more important than ever (Capon *et al.*, 2013).

For over a century, successive governments have grappled with the challenge of managing water resources in Australia. Most recently, the National Water Initiative, the *Water Act 2007* and the Murray-Darling Basin Plan 2012 are nationally significant reforms aimed at bringing Australia's river and groundwater systems back into a more sustainable balance. While recent reviews of water reform in the Murray-Darling Basin show that progress has been made in some aspects of water reform, there remain major challenges and critical unfinished elements (Wentworth Group, 2017c, Walker, 2019). Riparian zones are also the focus of significant rehabilitation and revegetation activities across Australia, although the extent of these efforts at present tends to be spatially patchy and vulnerable to disturbance (Zhang and Fryirs, 2023). Climate change increases the urgency for effective adaptation of management of inland waters to protect these systems, and their biodiversity, and to maintain the essential services which they provide (Prosser *et al.*, 2021).

The actions in this assessment complement existing water reform and management. They are not yet in place or are not currently being implemented at scale. These actions focus on the need to improve riparian ecosystems and catchment health, to address over-extraction of both surface and ground water resources in overallocated systems, and to mitigate the impacts of dams, weirs and other infrastructure on flow and connectivity. We do not propose to return river systems to a past state, but rather improve their condition so that their key functions and services can be restored and sustained despite considerable, irreversible catchment modifications and the unfolding impacts of climate change.

Identifying actions and estimating the investment

The Wentworth Group has identified the practical actions and derived indicative estimates of the new capital and annual operational investment needed to repair degraded inland waterways over 30 years. The indicative annual investment from 2025 to 2054 is $3.2 billion including $2.9 billion in capital costs, $291 million in transaction costs and $78 million in operational expenditure (in 2022$).

The following section describes specific management objectives and actions for repairing the health of Australia's inland river and groundwater systems, along with a rationale for these actions and the methods for estimating the required investment.

Objective R1

Objectives	Actions
R1. Establish and restore riparian buffer zones on Australia's rivers, lakes and streams to protect productive land from erosion, support biodiversity, improve water quality and enhance the productivity of fisheries and the health of freshwater and marine ecosystems.	R1.1-C Restore, conserve and manage strips of healthy riparian vegetation along the banks of Australia's major perennial rivers, perennial lakes, minor rivers and streams.
	R1.2-C Incentivise landholders to retire their farmland along the banks of Australia's major and minor rivers and major natural lakes.

Objective R1 – Rationale and costing methods

R1.1-C Restore, conserve and manage strips of healthy riparian vegetation along the banks of Australia's major perennial rivers, perennial lakes, minor rivers and streams.

Rationale – Healthy riparian ecosystems are widely recognised as playing a critical role in the landscape, supporting the health of inland waters as well as the catchments into which they drain (Capon *et al.*, 2013, Riis *et al.*, 2020). Key riparian ecosystem functions include shading, protection of channel banks and beds, water quality regulation, provision of habitat and source of nutrients for aquatic and terrestrial biota (Capon and Pettit, 2018). In addition, riparian ecosystems provide many cultural and socio-economic benefits to people, such as protecting productive agricultural land, providing opportunities for recreation and tourism, and supporting aesthetic and spiritual values (Riis *et al.*, 2020). Healthy riparian ecosystems are also likely to facilitate adaptation to climate change for both human and ecological systems (Capon *et al.*, 2013, Capon and Bunn, 2015).

Riparian ecosystems are highly modified and degraded over much of Australia. While data concerning riparian vegetation condition at a national scale remain limited, figures suggest that almost half of Australia's major rivers have cleared riparian zones (ERIN, 2005), with many more in a poor condition. Data from the National Land and Water Resources Audit (1997-2002) reported that a quarter of 14,500 river reaches assessed were extensively modified and extremely impaired in comparison with reference reaches, with a further 50% either severely or moderately affected (Lovett and Price, 2007). Degradation of riparian ecosystems is strongly associated with many significant environmental problems such as high levels of bank erosion, water quality decline and reductions in aquatic ecosystem health (Cole *et al.*, 2020). Restoring vegetation in these cleared and degraded riparian areas can rehabilitate many critical ecological functions and generate multiple benefits at local and catchment scales including greater channel stability, reduced erosion, increased safety for cattle and stock, higher water tables, and trapping of pollution, sediments, and nutrients (Perriot, 1998, WRC, 2000, NRM North, 2018, VDEC, 2018, Cole *et al.*, 2020).

Repairing riparian buffer zones along river channels and around lake perimeters requires revegetation of these cleared and degraded areas with a suite of functional vegetation types including in-stream plants, groundcover, shrubs and trees. In grazing lands, revegetation will require fencing to exclude livestock along with the installation of associated offsite waterpoints. In riparian areas with high levels of erosion, hard engineering solutions (e.g., bank armouring, rock revetment, log jams, pile fields) may also be necessary, at least initially, to facilitate revegetation.

Alternative restoration approaches are recommended for degraded floodplains and ephemeral wetlands because these are characterised by complex spatial configurations and often lack a clearly defined perimeter. In these areas, the provision of episodic floodplain flows and the removal of barriers which impede floodplain connectivity are the key actions needed to enable regeneration of floodplain vegetation at scale (e.g., Zivec *et al.*, 2021).

Active versus passive revegetation

Important considerations in revegetating degraded riparian zones are whether active (e.g., tube-stock direct planting, seeding) and/or passive revegetation (e.g., fencing off to allow regrowth) approaches are most appropriate, as well as the extent to which on-going management and monitoring are needed. The choice of revegetation approach and ongoing management and monitoring needs will vary regionally in relation to climate, water regimes, soils, land use history and other factors.

Benefits of active riparian revegetation, using fencing along with replanting, have been demonstrated, with sediment erosion, instream sediment concentrations and/or catchment sediment losses declining after remediation by between 30% and 90% in some studies (Bartley *et al.*, 2015). On the other hand, passive revegetation and natural revegetation approaches can also be successful with the advantage of being much cheaper and suitable for implementation across much larger areas (Davis *et al.*, 2015, Zivec *et al.*, 2021, Zivec *et al.*, 2023). Riparian fencing on its own, for instance, without active revegetation, has been shown to reduce stream suspended sediment loads by about 40% (Owens *et al.*, 1996) with sediment reductions appearing to be due to decreased stream bank erosion and trapping of sediment by riparian vegetation. Depending on stream order, there can be a rapid transition from a wide, shallow stream with an unstable bed and heavily grazed and trampled banks to a stream with more stable, vegetated banks once livestock are excluded from riparian areas (Howard-Williams and Pickmere, 2010).

In much of northern Australia, including the northern Murray-Darling Basin, passively facilitating regrowth represents a viable revegetation method. In other regions, such as south-east Australia, however, long histories of intensive land management involving re-clearing, heavy grazing and fertilisation, have significantly reduced the availability of suitable plant propagules (e.g., soil seed banks) in the landscape, limiting the capacity of these landscapes to regenerate naturally (Dorrough and Moxham, 2005). In these cases, active revegetation involving fencing and planting of tube stock is likely to be needed.

Buffer zone size

Determining the optimal width of riparian buffer zones is complex and depends on numerous factors including the size of the associated waterway (e.g., stream order), topography and surrounding landscape context. Riparian buffer zones should be at least wide enough to enable full development of the vegetation canopy to maximise shade across the relevant waterway and allow the formation of a mesic (moist, humid) microclimate. Ideally, the full width of the historically inundated riparian land (excluding floodplains) should be restored—that is, the area distinguished by flow-dependent vegetation and wetland soils (Kotze *et al.*, 1996, DWAF, 2008, Pittock *et al.*, 2015). Specific assessment will be required in each case (Spackman and Hughes, 1995).

A minimum riparian buffer width of 50 m is widely reported for Australian waterways and is often used as the width for regulating vegetation clearing and development in riparian zones (e.g., in New South Wales) and reporting riparian condition (e.g., in South-east Queensland). According to Alluvium (2016: p163) in a study of Great Barrier Reef catchments, "the width of the buffer zone should be a minimum of 50 m from the top of bank in lower order rivers unless there is evidence of active channel migration." Hansen *et al.* (2010) recommend that for more temperate climates (e.g., Victoria) the width of riparian areas depends on the management objective (Table 3). Buffer effectiveness generally increases with increasing width (Castelle *et al.*, 1994). Several studies suggest larger widths, such as 200 to 500 m, are more effective for protecting fauna such as birds and reptiles, or reducing heavy metal pollution (see page 2 of Newton, 2012).

In our assessment, we have used the following buffer zone widths:

- 100 m wide strips of healthy vegetation along the banks of Australia's major perennial rivers to support multiple management objectives, assuming a low land use intensity (Table 3) Hansen *et al.* (2010);
- 200 m wide strips of healthy vegetation on the banks of Australia's major perennial lakes to support multiple management objectives, assuming a high land use intensity (Table 3) Hansen *et al.* (2010); and
- 50 m wide strips of healthy vegetation along the banks of Australia's minor rivers and streams, assuming the recommended buffer zone width for lower order streams and rivers (Alluvium, 2016).

Table 3. Summary of minimum width recommendations (metres) for riparian zones for some common management objectives under a range of landscape contexts (Hansen *et al.*, 2010).

	Landscape context				
Management objective	High Land use intensity	Moderate Land use intensity	Low Land use intensity	Wetland / lowland floodplain / off-stream water body	Steep catchments / cleared hillslopes / low order streams
Improve water quality	60	45	30	120	40
Moderate stream temperatures	95	65	35	40	35
Provide food and resources	95	65	35	40	35
Improve in-stream biodiversity	100	70	40	Variable *	40
Improve terrestrial biodiversity	200	150	100	Variable *	200

* site-specific variable width required depending on lateral extent of hydrological connectivity

Action R1.1a-C Restore, conserve, and manage 100 m wide strips of healthy riparian vegetation along the banks of Australia's major perennial rivers.

Costing method – We created a national spatial layer of riparian buffer zones based on Bureau of Meteorology watercourse data. Riparian buffer zones associated with major perennial rivers were identified from the national geospatial framework for hydrological features (Geoscience Australia, 2016). A median 100 m wide riparian buffer zone for each river bank has been adopted as the buffer zone size for watercourses classified as 'major rivers' (BOM, 2016), assuming a low land use intensity, to improve water quality, regulate stream temperatures, and improve in-stream and terrestrial biodiversity (Hansen *et al.*, 2010). Riparian buffer areas of 100 m width were then mapped for each bank of major perennial rivers.

To determine repair costs, we also estimated the extent of vegetation clearing that has occurred within these riparian buffer zones. To do this, we intersected the national riparian buffer zone layer with the Vegetation Assets, States and Transitions (VAST) framework data (Thackway and Lesslie, 2006) which classifies vegetation across Australia by degree of human modification as a series of states from intact native vegetation to total removal (see Appendix III).

Based on the VAST classification, we assumed that all cleared riparian areas (i.e., areas classified as VAST 5) require active revegetation to achieve an intact state (VAST 2). For cleared riparian zones on grazing land, as identified by Thackway and Lesslie (2006), we assumed a mean cost, based on figures in Lovett and Price (2001), adjusted for inflation, of $43,880/km (2015$) to revegetate 100 m wide riparian buffer zones on both banks, including the cost of tube stock, labour, fencing, and provision of off-site watering points for livestock. For cleared riparian areas (i.e., VAST 5) on cropping, forestry and conservation land, we assumed a mean cost of $27,900/km (2015$) for tube stock and labour to revegetate 100 m wide buffers on both banks based on figures in Bartley *et al.* (2015).

We also assumed that all degraded riparian areas (i.e., areas classified as VAST 3) require passive revegetation to achieve an intact state (i.e., VAST 2). For these degraded riparian zones on grazing land, we assumed 50% of the cost required for active restoration will be needed to passively revegetate 100 m riparian buffer strips on both banks, i.e., $21,950/km (2015$). For degraded riparian areas on cropping, forestry and conservation land, we also assumed a cost of 50% of that estimated for active restoration, i.e., $13,950/km. We did not assess repair costs for areas of native vegetation largely replaced by invasive native and/or exotic species (i.e. areas classified as VAST 4) as there are no values for this category in the VAST dataset.

Figures were converted to hectares in the investment spreadsheet and a mean cost per hectare for revegetation of $433 (2018$) was calculated to generate figures at a national scale. These estimates include buffer zones on both private and protected lands (AWE, 2016), but exclude buffer zones on land designated residential, industrial or infrastructure (BOM, 2016). We recognise that costs may be much higher where streambank engineering works are required. We further assumed that if actively replanted riparian vegetation (e.g., from tube stock) does not survive an initial three-to-five-year establishment period, replanting be covered by ongoing management costs.

Action R1.1b-C Restore, conserve, and manage 200 m wide strips of healthy riparian vegetation on the banks of Australia’s major perennial lakes.

Costing method – We identified major perennial lakes from the national geospatial framework for hydrological features (Geoscience Australia, 2016) and, as per Action R1.1a-C, intersected this spatial layer with the VAST dataset of vegetation state (Thackway and Lesslie, 2006). A median 200 m wide riparian buffer zone has been adopted as the buffer zone size for around major perennial lakes, assuming a high land use intensity, to improve water quality, regulate stream temperatures, and improve in-stream and terrestrial biodiversity (Table 3) (Hansen *et al.*, 2010).

We assumed areas of cleared riparian vegetation (i.e., VAST 5) on grazing land within these riparian buffers require active revegetation with an assumed cost of $87,760/km to revegetate a 200 m wide buffer, including tube stock, labour, fencing and provision of off-site watering points for livestock (Bartely et al., 2015). We assumed that areas of degraded riparian vegetation (i.e., VAST 3) on grazing land within these buffer zones require passive revegetation of a 200 m riparian buffer zone (Newton, 2012) with an assumed cost of 50% of the active restoration cost, i.e., $43,880/km (2015$) (Bartley *et al.*, 2015).

We assumed that cleared areas (i.e., VAST 5) on cropping, forestry, and conservation land within these riparian buffers require active revegetation with an assumed cost of $55,800 (2015$) to revegetation a 200 m riparian buffer zone, including tube stock and labour (Bartley *et al.*, 2015). We assumed that degraded areas (i.e., VAST 3) on cropping, forestry, and conservation land within these buffer zones require passive revegetation with an assumed cost of 50% of the active restoration cost, i.e., $27,900/km (2015$), to revegetate a 200 m wide riparian buffer (Bartley *et al.*, 2015).

Figures were converted to hectares in the investment spreadsheet and a mean cost per hectare for revegetation of $19,483 ($2018) was calculated to generate figures at a national scale. These estimates include both private and protected lands (AWE, 2016) but exclude land designated as residential, industrial or infrastructure. Note, costs may be much higher depending on the need for streambank engineering works.

Action R1.1c-C Restore, conserve, and manage 50 m wide strips of healthy native vegetation along the banks of Australia's minor rivers and streams.

Costing method – We identified minor rivers and streams from the national geospatial framework for hydrological features (Geoscience Australia, 2016) and, as per Actions R1.1a-C and R1.1b-C, intersected this spatial layer with the VAST dataset of vegetation state (Thackway and Lesslie, 2006). A 50 m wide riparian buffer zone has been adopted as the minimum buffer zone width required for smaller rivers and streams.

We assumed that cleared areas (i.e., VAST 5) on grazing land within this riparian buffer zone require active revegetation with an assumed mean cost of $21,940 (2015$) to revegetate a 50 m wide riparian buffer on both banks including tube stock, labour, fencing and provision of off-site watering points for stock. We assumed that degraded riparian areas (i.e., VAST 3) on grazing land require active revegetation of a 50 m riparian buffer zone on both banks with an assumed mean cost of 50% of the active restoration cost, i.e., $10,970/km (2015$) including tube stock and labour.

We assumed that cleared riparian areas (i.e., VAST 5) on cropping, forestry and conservation land require active revegetation with an assumed mean cost of $13,950/km (2015$) to revegetate a 50 m wide buffer zone on both banks including tube stock and labour. We assumed degraded riparian areas (i.e., VAST 3) require passive revegetation at a cost of 50% of the active restoration cost to revegetation a 50 m wide buffer zone on both banks, i.e., $6,975/km (2015$).

Figures were converted to hectares in the investment spreadsheet and a mean cost per hectare for revegetation of $4,420 ($2018) was calculated to generate figures at a national scale. These estimates include both private and protected lands (AWE, 2016). They do not include buffer zones on land designated as residential, industrial or infrastructure. Note, costs may be much higher depending on the need for streambank engineering works.

Action R1.2-C Incentivise landholders to retire their farmland along the banks of Australia's major and minor rivers and major natural lakes.

Rationale – This action involves providing incentives to farmers to retire grazing and cropped land from production to enable either active or passive revegetation of riparian buffer zones as described in action R1.1-C, thus repairing cleared (i.e., VAST 5) and degraded (i.e., VAST 3) riparian areas to an intact state (i.e., VAST 2). This action does not imply graziers should completely release land from grazing activity as landholders can undertake low-intensity grazing (i.e., where resource use is below carrying-capacity) under VAST 2.

Costing method – We first calculated the total riparian buffer zone area associated with major and minor rivers, both perennial and non-perennial, as well as major perennial lakes, as defined in the national riparian buffer spatial layer described in Action R1.1-C above. We then estimated the expected cost of forgoing cropping, forestry and/or grazing production within these areas using the 12-year average annual farm-cash income to capture the fluctuations in returns (2001-2013) and paid out over

20 years (ABARES, 2014). We inflated these figures to present values and thereafter at 2% per annum and capitalized in perpetuity by dividing by 5% (Baum, Mackmin and Nunnington, 2017).

This assessment was conducted for private land only (ABARES, 2016) and did not include areas designated as residential, industrial, or critical infrastructure (DCCEEW, 2023b).

Objective R2

Objectives	Actions
R2. Restore overallocated river systems to sustainable levels of take.	R2.1-C Return overallocated river systems of the Murray-Darling Basin to environmentally sustainable levels of surface water extraction through the strategic purchase of water licences from willing sellers, on-farm investment, and other measures.

Objective R2 – Rationale and costing methods

Action R2.1-C Return overallocated river systems of the Murray-Darling Basin to environmentally sustainable levels of surface water extraction through the strategic purchase of water licences from willing sellers, on-farm investment, and other measures.

Rationale – At least 10 surface water systems across Australia have been identified as being under high levels of stress and therefore likely to be at high risk of overallocation or overuse, including six within the Murray-Darling Basin (NWC, 2014). Climate change effects on hydrology and water demand are highly likely to aggravate this stress and further threaten water security in these catchments as well as others (Prosser *et al.*, 2021). The action specified here focuses on restoring over-allocated rivers of the Murray-Darling Basin to sustainable levels of take so that basic ecological functions can be supported including provision of safe drinking water, reducing salinity for viable irrigation industries, and discharging salt and sediment to the sea through an open Murray mouth. This action will also support the capacity of river systems to maintain these functions under the drier future projected (Prosser *et al.*, 2021). There are insufficient data for the other highly stressed systems for such an assessment.

The best publicly available estimate suggests that an environmentally sustainable level of water extraction from the Murray-Darling Basin requires the recovery of between 3,856 GL (high uncertainty) and 6,983 GL (low uncertainty) of surface water from consumptive use (MDBA, 2010). While this was based on the best available science at the time, it should be noted that a scientific review of the evidence which has amassed since then may suggest revised estimates. Nevertheless, it is very likely that the original surface water recovery target presented in the Basin Plan of 2,750 GL will still be below any such estimate. Additionally, this target was further reduced in 2018 to 2,075 GL following two amendments to the Basin Plan, including a provision to increase water extraction by 605 GL through offset projects proposing to deliver equivalent environmental outcomes. Our assessment, however, shows that these expected outcomes are very unlikely to be achieved (Wentworth Group, 2017d). Additionally, the Basin Plan was further amended in 2018 to increase surface water extraction limits for irrigation in the Northern Basin by 70 GL, again resulting in less water available for the environment and a reduced likelihood of achieving environmental outcomes in the Basin (Wentworth Group, 2017e).

A further water recovery target of 450 GL is also presented in the Basin Plan as necessary for achieving enhanced environmental outcomes, bringing the total to 3,200 GL. However, this still leaves 656 GL of water recovery required to reach the minimum 3,856 GL target previously established as being required to achieve an environmentally sustainable level of take (MDBA, 2010).

Failure to reach the water recovery target of 3,856 GL carries significant risks to the rivers of the Murray-Darling Basin. Modelling by the Murray-Darling Basin Authority in 2011, for example, showed that recovery of 2,400 GL "was insufficient to achieve a number of key environmental objectives for the River Murray", depriving many ecosystems, including the Ramsar-listed Riverland and the Coorong, Lower Lakes and Murray Mouth, of sufficient flows (MDBA, 2011). Under this scenario, end of system flows, which are important for exporting salt out of the Basin, will be inadequate. There will also be reduced likelihood of inundation across the large majority of floodplains and wetlands that are not served by environmental works and measures (Pittock *et al.*, 2012). Running the river system on tighter water volumes leaves less room for error and increases vulnerability to climate change as well as other pressures.

Recovery of surface water benefits water users and Basin communities through reduced costs of water extraction from aquifers/bores or transportation from other locations, improved water quality and quantity, higher productivity leading to higher quality and quantities of farming yields/outputs, access to water trading markets and improved salinity dilution and drought resistance (Crase, 2009, MDBA, 2017, Grafton and Wheeler, 2018). Modelling indicates that water recovery contributes to long-term increases in regional GDP, with a projected increase of $470 million in regional GDP between 2010-2034 from water recovery initiatives in the Murrumbidgee Irrigation Area (Dwyer *et al.*, 2017). Improved salinity dilution has created benefits worth $5 million for a variety of river stakeholders (MDBA, 2017). Water recovery and recycling can improve drought resilience and reduce negative economic impacts of drought where, over the decade between 1999-2008, approximately $461 million worth of regional output and almost 600 jobs were lost in the Murray-Darling Basin (MDBA, 2017).

A total of 2,107.4 GL/y has been recovered in the Murray-Darling Basin as of 30 June 2023 (MDBA, 2023). An additional 1,022 GL/y of water or equivalent outcomes therefore needs to be secured under the Basin Plan to reach the current Basin Plan target of 3,130GL/y (i.e., 3,200GL/y less 70GL/y from the northern Basin adjustment). While commitments have been made to achieve these targets, they fall short of the best estimates of water recovery required for an environmentally sustainable level of water extraction in the Murray-Darling Basin. Climate change will continue to exacerbate this gap.

The Guide to the Basin Plan showed that a minimum of 3,856 GL/y of water must be recovered from consumptive uses if the Murray-Darling Basin is to reach an environmentally sustainable level of surface water extraction with high uncertainty (MDBA, 2010). This figure included a simple 3% reduction in the sustainable diversion limits due to climate change. Given the current Basin Plan target is 3,130GL/y, a further 726 GL/y of water needs to be recovered in a once-off adjustment via the buy-back of water entitlements and/or the deployment of more water-efficient infrastructure to reach this target.

Costing method – We estimated the cost of recovering a further 726 GL/y of surface water to achieve the minimum target estimated under high uncertainty to achieve sustainable environmental outcomes, i.e., 3,856 GL. The average cost of water recovery using infrastructure upgrades ($5,100 per megalitre, 2017$) was more than double that of water recovery through purchase of entitlements ($2,200 per megalitre, 2018$) between 2007-08 and 2015-16 (Wentworth Group, 2017b). It is assumed that the marginal cost of securing the additional 726 GL/y is based on the higher of these two options, at $5,100/ML (2017$).

Objective R3

Objectives	Actions
R3. Restore lateral and longitudinal connectivity of rivers, floodplains and their wetlands.	R3.1-C Allow water to reach and pass safely across floodplains and wetlands in the Murray-Darling Basin by modifying infrastructure (e.g., bridges and roads), removing high-risk or unauthorised flood works, or purchasing voluntary easements on private land.
	R3.2-C Restore fish passage by removing or modifying high priority physical barriers.
	R3.3-C Install cold-water pollution control devices on priority large dams.
	R3.4-C Install fish diversion screening on all licensed irrigation pumps.

Objective R3 – Rationale and costing methods

Action R3.1-C Allow water to reach and pass safely across floodplains and wetlands in the Murray-Darling Basin by modifying infrastructure (e.g., bridges and roads), removing/remediating high-risk or unauthorised flood works, or purchasing voluntary easements on private land.

Rationale – Flow constraints comprise any physical, operational or policy barriers which impede the flow of water in river systems, both longitudinally within channels, and laterally, between rivers and their floodplains and wetlands. In the Murray-Darling Basin, flow constraints significantly limit the delivery of environmental water under the Basin Plan to the floodplains and wetlands which require watering. Key flow constraints include infrastructure (e.g., low-level bridges and river crossings), private lands, and property (e.g., fencing and irrigation pumps) which hinder people and limit the passage of environmental water in designated floodways below minor flood levels and across low-lying areas adjacent to watercourses (Wentworth Group, 2017a).

Flow constraints can be managed through a range of approaches including the modification or removal of levee banks within flow corridors, upgrades to roads, bridges, crossings and other capital works on public lands, new or upgraded infrastructure on private land, and acquisition of easements on private floodplain properties (Kahan *et al.*, 2021). Benefits of relaxing constraints include greater flexibility to deliver high-value water, improved riparian and floodplain habitat quality, increased supply of freshwater, and improved water quality (Kahan *et al.*, 2021). Constraint management will also enable greater flexibility with regards to sustainable environmental flow management under a changing climate (Prosser *et al.*, 2021, Lynch *et al.*, 2023).

The Australian Government has committed $200 million to fund constraints relaxation projects in the Murray-Darling Basin under the Water for the Environment Special Account (Murdoch, 2020). Additionally, the Gwydir constraints management project is being funded separately with a portion of the $180 million investment by the Commonwealth Government for the northern Basin toolkit (NSW DPIE, 2022). Significant funding (up to $1.3 billion) may also be available for projects addressing constraints under the sustainable diversion limit adjustment mechanism (DCCEEW, 2023d). While significant Commonwealth funding has been allocated to constraints management (Murdoch, 2020) and State governments have committed to relaxing or removing flow constraints, progress in most areas remains delayed with projected flow rates following proposed constraints management falling short of those required in some valleys (Wentworth Group, 2017a). Consequently, there is considerable uncertainty regarding constraint management in the Murray-Darling Basin which is an essential action required to deliver the environmental benefits from water recovered under the Basin Plan.

Costing method – An assessment of state government business cases by Kahan et al. (2021) provides an estimate of the cost of constraint management in five key areas of the Murray-Darling Basin, i.e., Hume to Yarrawonga, Yarrawonga to Wakool Junction, the Goulburn, the Murrumbidgee and Menindee Lakes (Lower Darling) and the Lower Murray in South Australia, with a total of $864 million (2020$). We subtracted the $200 million already committed by the Australian Government to determine a conservative shortfall to achieve this action in these key areas of the Basin.

Action R3.2-C Restore fish passage by removing or modifying high priority physical barriers.

Rationale – Freshwater biodiversity is experiencing accelerating rates of decline and loss globally (Lynch *et al.*, 2023). In Australia and elsewhere, habitat fragmentation and reduced flow connectivity have contributed to significant declines in the status of freshwater fish (Harris *et al.*, 2016). Most freshwater fish, as well as some other native aquatic fauna species such as platypus, need to move, at least to some extent, to access suitable habitats for feeding and breeding - both upstream and downstream through river systems and, for some species, laterally between rivers and their floodplains and wetlands. Artificial structures within waterways and on floodplains, however, can pose significant barriers to movement with deleterious consequences for populations and communities at catchment scales both directly, in the case of large weirs and dams, and cumulatively with respect to smaller structures such as road crossing and flood mitigation works (Harris *et al.*, 2016).

In Australia, many thousands of structures exist within river channels and on floodplains which present barriers to fish passage as well as flow connectivity (Harris, 2001, DPI, 2012, Steinfeld and Kingsford, 2013, Harris *et al.*, 2016). Often, these structures are unapproved or legally non-compliant. Removing or remediating barriers to fish passage provides significant ecological benefits, especially to native fish, by mitigating the damaging effects of habitat fragmentation and supporting adaptation of these species to climate change by enabling their movement in response to shifting climatic conditions (Harris *et al.*, 2016). Addressing barriers to fish passage also brings multiple co-benefits for the fishing industry, tourism, Indigenous communities, and recreational fishers (Makombe, 2003).

Not all barriers to fish passage will be a high priority for removal or remediation. For example, barriers in small, first order headwater streams are often considered to be a relatively low priority because these areas tend to support little significant fish habitat (Moore, 2015). A range of prioritisation processes have been developed to identify barriers for which remediation will bring the greatest ecological and socioeconomic benefits (e.g., Lawson *et al.*, 2010, Moore, 2015, Moore and McCann, 2018). These tend to identify between 2% and 6% of potential barriers to fish passage as high priorities for remediation. In the Namoi region of NSW, for example, over 6% of barriers identified across eight local government areas were deemed to be high priority barriers for remediation (NSW DPE, 2006) while Lawson *et al.* (2010) identified 104 high priority barriers, comprising approximately 2% of a total 5,136 barriers across 19,674 km of stream network in the Wet Tropics region. Similarly, around 2% of a total of 3,826 potential barriers in the Sunshine Coast local government were flagged as a high priority for remediation (Moore and McCann, 2018).

Depending on the type and position of barriers, a range of remediation approaches are available including removal of obsolete road crossings or replacement of these by bridges or culverts, or retrofitting floodgates with fish-friendly designs (Gordos *et al.*, 2007). Larger weirs and dams will require the construction of more advanced fishways. High priority barriers to fish passage for remediation include those for which ecological and socio-economic outcomes will be maximised at local and catchment scales (Gordos *et al.*, 2007, Lawson *et al.*, 2010, Marsden *et al.*, 2023). As Harris et al. (2016)

highlight, however, high dams are likely to present a near complete barrier to fish movement with impacts equivalent to the aggregate effects of many hundreds of small barriers.

Very few fishways are in place in Australia, especially in proportion to the number of barriers that exist, with fishways on fewer than 3% of Australia's 500 high dams (Harris *et al.*, 2016). Under the Sea to Hume program, 10 fishways have been established in the southern Murray-Darling Basin along 2,225 km of river network (Barrett and Mallen-Cooper, 2006) but this has yet to be matched in the northern Murray-Darling Basin where at least 42 high priority in-channel structures requiring remediation have been identified (NSW DPI, 2012). NSW also currently has a program to remediate non-compliant flood works in 100 priority areas by mid-2024 (NSW DPE, 2023). However, many more instream and floodplain structures exist both in NSW and elsewhere which require removal or modification to repair fish passage and flow connectivity.

This action concerns the removal or remediation of high priority barriers to fish movement and flow connectivity across Australia, including the installation of advanced fishways on Australia's 500 high dams.

Action R3.2a-C Remove or remediate high priority barriers to flow connectivity and fish migration.

Costing method – While national-scale estimates of fish barriers are lacking, numerous studies have mapped barriers to fish movement at regional scales. In the Wet Tropics region of Queensland, for example, 3,748 artificial barriers were identified across 18,363 km stream network (Kroon and Phillips, 2015). More than 5,000 barriers to flow connectivity and fish migration are estimated to exist in NSW (Brandis *et al.*, 2010, Steinfeld and Kingsford, 2013, Cramp *et al.*, 2021), with over 3,300 of these in coastal NSW alone (Gordos *et al.*, 2007). Baumgartner *et al.* (2014a) estimate that there are over 10,000 barriers to fish movement across the Murray-Darling Basin. Based on these regional estimates, we assumed a conservative estimate of 40,000 fish passage barriers across Australia, given that the Murray-Darling Basin occupies approximately 25% of the continent.

Based on previous regional prioritisations (e.g., NSW DPI, 2006, Lawson *et al.*, 2010, Moore and McCann, 2018), we assumed that around 5% (i.e., 2000) of all barriers to fish passage across Australia will be a high priority for removal or remediation with the potential to generate significant benefits for flow connectivity and fish passage at large scales.

Costs for remediation works of barriers to fish passage range significantly, from relatively inexpensive removal of obsolete road crossings or retrofitting of floodgates, to the construction of new bridges or culverts (Gordos *et al.*, 2007). For fishways on larger barriers (e.g., weirs), costs can range from $250,000 to $1 million (2017$) per vertical metre height depending on the type of fishway required and specific management objectives (O'Connor *et al.*, 2017).

We assumed a mean cost of $150,000 (2022$) for remediation of around 95% of high priority fish barriers, based on proportions and cost estimates in several prioritisation studies (e.g., Moore, 2015, Moore and McCann, 2018). Similarly, a mean cost of $2 million (2022$) was assumed for advanced fishways on the remaining 5% of barriers which will include high priority weirs, such as the 42 high priority structures identified within the Murray-Darling Basin in NSW (NSW DPI, 2012). We then subtracted the $56.8 million which has been committed by the Australian Government under the Fish for the Future: Reconnecting the Northern Basin project.

Action R3.2b-C Install advanced fishways on existing high-level large dams that significantly obstruct fish passage.

Costing method – This action proposes to install advanced fish ways on existing high-level large dams that significantly obstruct fish passage to restore the ability for longitudinal migration along river systems. Large dams are assumed to have a vertical height of at least 10 metres. The total height of all large dams in Australia is 17,438 metres (ANCOLD, 2022). We assume 16% of Australia's total catchment area is obstructed by large dams, based on the NSW average (Harris *et al.*, 2016). Therefore, we estimated that 2,790 vertical metres of dam wall require fishways. Existing fishways, present on 3% of dams (Harris *et al.*, 2016), are generally ineffective and require replacement by the most cost-effective and high-efficacy technologies (NSW DPI, 2012), including innovative approaches. The assumed average marginal cost of advanced fishway design (allowing both upstream and downstream movement of fish) is assumed to be $1 million (2016$) per metre (AFMF, 2016).

Action R3.3-C Install cold-water pollution control devices on priority large dams

Rationale – Water released from large dams is significantly colder than natural flows – by as much as 13°C in summer (AFMF, 2016). This 'cold-water pollution' has significant consequences for water temperature and river health which can extend for tens, or even hundreds, of kilometres downstream of dams (Lugg and Copeland, 2014). Impacts of cold-water pollution include disruption of fish spawning, larval development, metabolism, movement, growth and survival with cold-water pollution strongly implicated in the loss of native fish species, and other aquatic fauna, from Australian rivers downstream of dams and widely considered a major driver of deteriorating river health (Lugg and Copeland, 2014, Chaaya and Miller, 2022). The stress of cold-water pollution will further constrain the capacity of affected aquatic communities to cope with climate change.

A range of methods are available to mitigate cold-water pollution from large dams including retrofitting these with multi-level offtakes as well as various techniques to mix thermally stratified dammed water bodies, e.g., bubble mixers (Chaaya and Miller, 2022). This action concerns the installation of cold-water pollution devices on priority large dams throughout Australia to mitigate the impacts on fish and other freshwater species.

Costing method – A desktop study of 93 dams in NSW in 2004 identified nine dams associated with severe cold-water pollution (Preece, 2004). We therefore assumed that 75 of Australia's 500 large dams (approximately 15%) will be high priorities for cold-water pollution devices. The most appropriate technology required to achieve mitigation of cold-water pollution will depend on the context of each dam but can vary in cost from less than $1 million to $170 million (2000$, Sherman, 2000 in Chaaya and Miller, 2022). The cold-water pollution projects proposed under the Northern Basin Toolkit program comprised installation of a multi-level offtake at Pindari Dam for an estimated cost of approximately $14 million (2020$) and one at Glen Lyon Dam for $3 million (2020$; Capon *et al.*, 2020). We therefore assumed a mean cost per high priority dam of $8.5 million for initial capital works and labour.

Action R3.4-C Install fish diversion screening on all licensed irrigation pumps.

Rationale – Irrigation pumps pose a considerable threat to native fish populations with hundreds to thousands of fish a day able to be extracted by a single pump (Boys *et al.*, 2021). Once removed from rivers, these fish, if they survive, are often injured and no longer contribute to the breeding population of that species within the river system, with significant implications for native fish populations in inland rivers (Boys *et al.*, 2021). Pump diversion screens are highly effective and are both 'fish-friendly', reducing fish injury and mortality by more than 90%, and 'farm-friendly', limiting entrainment of debris and consequently reducing operational costs of pumps and increasing irrigation efficiency (Boys *et al.*, 2021, Rayner *et al.*, 2023).

This action concerns the installation of fish diversion screens on all licensed irrigation pumps across the country. Significant funds, totalling around $39.5 million (2022$) have been committed by the Australian government and States to fish screening projects in the Murray-Darling Basin in both NSW and Queensland (Rayner *et al.*, 2023). However, significant numbers of unscreened irrigation pumps remain across the country for which fish diversion screening would have significant benefits to the health of aquatic biota in inland rivers.

Costing method – There are estimated to be 4,500 licensed irrigation pumps (over 200 mm) in NSW requiring diversion screens to be installed to prevent the loss of native fish (Rayner *et al.*, 2023). From 2017 to 2020, the average annual water sourced from 'rivers, creeks or lakes' for irrigation in NSW was 843,987 ML (ABS, 2021), equating to approximately 187 ML per pump (based on 4,500 pumps). Extrapolating this ratio across Australia's average annual water sourced from 'rivers, creeks or lakes' of 2,141,578 ML (ABS, 2021) suggests there are around 11,418 pumps nationally.

Modern fish screens cost around $1,000 (2022$) per ML of pump or channel capacity (Fish Screens Australia, 2023). Based on our assumption of 187 ML per pump, this equates to around $187,000 (2022$). We have excluded from the total calculated those funds committed under existing fish screening programs (i.e., $39.5 million (2022$), Rayner *et al.*, 2023).

Objective R4

Objectives	Actions
R4. Improve the efficient use and sustainability of groundwater resources.	R4.1-C Cap remaining open artesian bores and convert remaining open bore-drains to pipes and trough systems in the Great Artesian Basin.
	R4.2-C Return groundwater extractions to sustainable levels in the Murray-Darling Basin through the strategic purchase of water licences from willing sellers.

Objective R4 – Rationale and costing methods

Action R4.1-C Cap remaining open artesian bores and convert remaining open bore-drains to pipes and trough systems in the Great Artesian Basin.

Rationale – Groundwater is a vital resource upon which many of Australia's ecosystems, plants, and animals depend (Glanville *et al.*, 2023). Groundwater is also an important source of water for communities and agricultural enterprise across Australia, especially during dry periods, representing around 30% of all water use (Barnett *et al.*, 2020, Walker *et al.*, 2021). Excessive exploitation of groundwater resources over the past century, however, has resulted in declines in aquifer pressure and a subsequent deterioration and loss of groundwater dependent ecosystems (GDEs), including iconic spring wetlands of the Great Artesian Basin (Fensham and Laffineur, 2022). Climate change increasingly demands improved management of groundwater resources which are being affected by declining precipitation in southern Australia, intrusion of sea water with rising sea levels in coastal areas and growing water scarcity, all of which are leading to deterioration of GDEs (Walker *et al.*, 2021).

One of the most effective ways to repair and improve management of groundwater systems in Australia is to cap free-flowing groundwater bores and convert inefficient high-evaporation bore drains with pipe and trough systems (Barnett *et al.*, 2020). As well as reducing water evaporation, upgrading bore drains significantly reduces operating costs and provides benefits to farmers in terms of grazing management and quality of life (Pegler *et al.*, 2002), as well as addressing ecological impacts of reduced aquifer pressure in GDEs (Fensham and Laffineur, 2022).

This action focuses on open bores and bore-drains of the Great Artesian Basin (GAB), the largest and deepest aquifer in the world, covering approximately one fifth of the Australian continent (Barnett *et al.*, 2020) and supporting a wide range of important GDEs and productive industries, contributing around $12 billion to the Australian economy each year (Frontier Economics, 2016). Significant progress has been made in addressing groundwater management in the GAB including the Great Artesian Basin Sustainability Initiative (GABSI) which ran from 1999 to 2017 with $124 million of Commonwealth funding facilitating the upgrade of more than 750 bores, decommissioning of 21,391 km of aged bore drains, and the installation of 31,547 km of new efficient bore drains, generating annual water savings of over 250 GL/year (DCCEEW, 2023a). An additional $8 million was committed between 2018 and 2020 to continue this work (DCCEEW, 2023a). The current Improving Great Artesian Basin Drought Resilience (IGABDR) program provides a further $27.6 million, to be delivered between 2019 to 2024, to fund infrastructure projects including decommissioning or rehabilitation of free-flowing bores (DCCEEW, 2023a).

In 2019, following completion of the GABSI, 431 uncapped bores remained in the GAB with 179 in Qld, 229 in NSW and 23 in SA, along with 5,136 km of open bore drains (GABCC, 2000). Rehabilitating these is expected to generate water savings of 116,261 ML/year (GABCC, 2000). Around 100 further bore rehabilitation projects appear to have been conducted, or are committed to, under interim arrangements and the current IGABDR program, as well as drain conversion for at least 576 km (DCCEEW, 2023a). This action is included because current funding still falls short of what is required to achieve sustainable management of artesian water in the GAB, a challenge which is more pressing than ever due to climate change.

Costing method – We assumed that effective groundwater management in the Great Artesian Basin requires 100% of bores be capped to ensure a reliable supply of water and to protect groundwater-dependent ecosystems. We assumed that at least 331 uncapped bores remain in the GAB, accounting for recent bore rehabilitation projects addressing 100 of the 431 open bores reported in 2019 (GABCC, 2000). The cost of bore capping ranges from $14,131 to $1.4m/bore (2018$), with an assumed average cost of $346,529/bore (2018$) (CIE, 2003, Hassall and Associates Pty Ltd, 2003).

We also assumed 4,560 km of open bore-drain remain in the GAB, accounting for the conversion of 576 km of the 5,136 km of open bore drains reported in 2019 (GABCC, 2000). The cost of converting open bore-drains to pipes and trough systems is $8,485/km (2018$) (CIE, 2003, Hassall and Associates Pty Ltd, 2003).

We have subtracted current Australian government funding commitments of $27.6 million from the total needed to achieve this action.

Action R4.2-C Return groundwater extractions to sustainable levels in the Murray-Darling Basin through the strategic purchase of water licences from willing sellers.

Rationale – The 2012 Basin Plan established sustainable diversion limits for groundwater systems in the Murray-Darling Basin, recognising over-allocation of this resource had occurred in some areas. Recovery of groundwater licenses is required to enable a sustainable level of take and protect groundwater reserves under a drying climate and increased demand.

As of June 2023, 32.5 GL of groundwater has been recovered under the Basin Plan with 3.25 GL still needing to be recovered in the Upper Condamine Alluvium to reach the proposed target of 38.45 GL (MDBA, 2023). This action concerns the purchase of groundwater licenses from willing sellers in the Upper Condamine Alluvium to bridge this gap.

Costing method – In 2018, the Australian Government purchased 35,697.40 ML of groundwater entitlements in the Upper Condamine Alluvium for $68,070,646 (2018$) through open tender (DCCEEW, 2023). Based on this, we assumed a cost for future acquisitions of $1906.90/ML (2018$)

Operational expenditure

The following are the assumed operational costs required for the above actions to be implemented effectively.

Action R1.1-O Management and monitoring of new riparian plantings along rivers, lakes and streams.

Rationale – Repair and revegetation of riparian buffer zones must be monitored and managed on an annual basis to maintain fences and mitigate negative impacts of disturbances (e.g., fire, flood drought) as well as weeds and pests.

Costing Method – We assumed a cost of managing native vegetation plantings for weeds, pests and fire of $4.7/ha (2018$), based on assumptions for non-riparian native vegetation. This is the average of the annual marginal per hectare cost spent by AWC (2016), Bush Heritage Australia (2016), the NSW Government (2006) and Queensland Government (as reported by Adams *et al.* (2011)), and other State Governments (as reported by the Legislative Council of Tasmania (2012)). We further assumed, as per Mappin et al. (2022), that revegetation under actions R1.1a-C would be carried out over a 30-year period, meaning the area requiring management and monitoring will grow accordingly over this timeframe.

Action R3.1-O Fishway (and other works) monitoring, operating, licensing and maintenance.

Rationale - Fishways and other remediation works must be monitored and maintained to ensure operating efficiencies and any leaks, for example, are fixed. This cost includes staff and licensing.

Costing Method - Operational and maintenance costs are assumed to be 1% per annum of the total upfront capital cost.

Action R3.2-O Cold-water pollution device monitoring, operating, licensing and maintenance.

Rationale – The effectiveness of cold-water pollution devices must be continually monitored and maintained to ensure operating efficiencies. This cost includes staff and licensing.

Costing Method - Operational and maintenance costs are assumed to be 2% per annum of the total upfront capital cost.

Action R3.3-O Diversion screening device monitoring, operating, licensing and maintenance.

Rationale - Diversion screening devices must be continually monitored and maintained (including cleaning) to ensure operating efficiencies. This cost includes staff and licensing.

Costing Method - Operational and maintenance costs are assumed to be 2% per annum of the total upfront capital cost.

Action R4.1-O Bore system monitoring, operating, licensing and maintenance.

Rationale - Bores must be continually monitored and maintained to ensure operating efficiencies. This cost includes staff and licensing.

Costing Method - Operational and maintenance costs are assumed to be 2% per annum of the total upfront capital cost of upgrading to bore and pipe systems. This cost includes assessing for bore failure.

Actions beyond the scope of this assessment

Actions in the table below have not been costed in the estimates provided above because either: (a) they are already being undertaken at the required scale in most catchments across Australia; (b) they require actions beyond investment such as governance or legislative changes; and/or (c) there is a lack of data or significant uncertainty regarding their effectiveness or cost.

ID	Action	Description
R1.1-A	Protect flow and flooding regimes of free-flowing rivers	Australia has more than 27,000km of free-flowing rivers, including three more than 1000km in length (Grill *et al.*, 2019). Without dams, weirs and other infrastructure, flows in these rivers can travel unimpeded along the entire length of the river system and across floodplains, supporting rich, diverse and dynamic ecosystems. Flows in these river systems are currently not well protected from flow-altering development, infrastructure and extractions. The main protected area framework in Australia is based on terrestrial areas with clearly defined spatial boundaries. These are rarely designed specifically to protect rivers which are more fluid with dynamic boundaries. Consequently, protected areas don't limit many of the threats to freshwater ecosystems. For example, the IUCN listing that covers Paroo-Darling National Park does not limit upstream threats such as water extraction, land-use modification, dam construction or pollution. Protected areas need to be established for freshwater systems that are tailored specifically to ensure that rivers flow freely, that their entire catchment is connected together without barriers, and that rivers are also connected to their floodplains.
R1.2-A	Cost of securing water in over-extracted surface water systems beyond the Murray-Darling Basin	We investigated this by reviewing Bureau of Meteorology (BOM) data and the many National Water Commission reports on water balances across Australia's rivers and catchments. Unfortunately, the data were very scarce for areas beyond the Murray-Darling Basin, and the data that exist for other rivers/catchments were judged to be either incomplete or insufficient for investment costing purposes. A 2014 National Water Commission assessment (NWC, 2014) found that water planning arrangements, including extraction limits and environmental watering arrangements, were in place for the four surface water systems with high levels of stress beyond the Murray–Darling Basin. Similarly, all 44 of the most stressed groundwater management units had water plans in place or in draft form. Beyond the Murray–Darling Basin, water recovery efforts were limited to a small number of systems where overallocation or overuse has been identified by the relevant jurisdiction. In most of these cases, pathways have been developed with substantial community input to enable a return to sustainable levels of extraction. While the timeframes for full implementation of these pathways were unclear, the National Water Commission concluded that interim arrangements such as annual allocations enabled extractions to be managed within targeted limits (NWC, 2014).

		We undertook our own preliminary analysis of the Ord, Burdekin and Daly catchments using the BOM (2016) national water account data, which indicated that none of these surface water systems are likely to be over-extracted. There is some evidence that the Swan, Barwon, Yarra, Latrobe, Hunter, and Brisbane rivers might be (or become) overallocated, particularly when the impacts of climate change are taken into account. However, there were insufficient data to justify a conclusion at time of writing.
R1.3-A	Optimise water-use efficiency on every Australian farm	As stated in Wentworth Group (2017c) "water recovered using infrastructure efficiency upgrades (e.g., lining of channels, conversion of flood irrigation to drip irrigation) may not achieve the anticipated water savings because of the reduction in return flows and groundwater recharge from existing arrangements that would have otherwise benefitted the environment". For this reason, as well as data deficiencies and difficulties in estimating how much the optimisation of water-use efficiency on farms would cost nationally, this action has not been included at this stage.
R1.4-A	Annual monitoring and maintaining flow constraints within the Murray-Darling Basin	Lack of data. The Murray-Darling Basin Authority's cost estimate for removing flow constraints in the MDB to mitigate the negative impacts of higher flows did not include an annual maintenance cost (MDBA, 2014).
R1.5-A	Removing flow constraints, other than those within the Murray-Darling Basin	Lack of data. This would require an extensive spatial, economic, and engineering analysis to determine.
R1.6-A	Threatened native fish nursery	As for other threatened species, there is likely to be a need for captive breeding to re-establish populations of many species of native fish (Baumgartner *et al.*, 2014b). Though not included here, the section of the document focused on estimating capital investment requirements to support threatened species could include provisions for establishing threatened fish nurseries where required.
R1.7-A	Effective management of aquatic pests and weeds	Invasive water-dependent species (e.g., cane toads, gambusia, redfin, perch, pigs, buffalo, oriental weatherloach, red claw crayfish, arrowhead and water hyacinth) are among the most serious threats to threatened species in Australia (Cresswell *et al.*, 2021). However, there is a lack of evidence for the efficacy of pest and weed management programs, with few highly effective management solutions demonstrated for freshwater ecosystems. National programs, including the National Carp Control Plan using the Cyprinid herpesvirus 3, are still in development. Nevertheless, there has been some success in Australia and internationally, for example, through a program in the 1980s (Motitsoe *et al.*, 2020) which used the weevil *Cyrtobagous salviniae* to successfully control *Salvina molesta*, a damaging free-floating invasive alien macrophyte native to

		South America. Given the challenges and cost of eradicating exotic species, a key focus of Australia's biosecurity has been to prevent more invasive species from arriving and establishing (Cresswell *et al.*, 2021).
R1.8-A	Cost of securing over-extracted ground water systems beyond the Great Artesian Basin and the Murray-Darling Basin.	We investigated this aspect by reviewing BOM data, academic literature, and numerous other reports on groundwater sustainable yields/ balances across Australia's groundwater resources. Unfortunately, the data were very limited. The data that do exist for other groundwater systems (aside from the Perth Aquifer) were judged to be either incomplete or unsuitable for investment costing purposes. A more comprehensive review of the data related to industrial and residential groundwater extraction was beyond the scope of this study.
R1.9-A	Addressing inter-aquifer leakage	The migration of gas and water between aquifers can be caused by natural faulting, coal seam gas activities and poorly constructed water and coal bores. Depending on the level of contaminants in this gas or water, this leakage could damage aquifers that are relied upon by groundwater-dependent ecosystems and humans, e.g., farming, drinking water. There was a lack of data underpinning the costing for addressing this challenge.
R1.10-A	Progress on national water reforms	See recommendations in the Wentworth Group's report on Water Reform in the Murray-Darling Basin 2017 (Wentworth Group, 2017c) and submission on the review of the National Water Initiative 2021 (Wentworth Group, 2021).

Native vegetation

The case for repairing degraded native vegetation

Native vegetation supports human life: it provides oxygen for breathing, maintains air and water quality by trapping particulates, regulates the climate, maintains ecosystems, supports hydrological processes and is intrinsically linked with Australian Indigenous cultural identity (Cresswell *et al.*, 2021).

Healthy native vegetation also provides many direct and indirect social and economic benefits including improved crop and pasture growth, increased livestock production, timber for firewood and fencing, forestry, reduced land and water degradation, pest control, aesthetic values that can increase property values and tourism in the region, and recreational activities (Polyakov and Pannell, 2016, Tourism Australia, 2016, Riis *et al.*, 2020).

The capacity of native vegetation to contribute these many benefits has been significantly eroded. Almost half (44%) of Australian forests and woodlands have been cleared since European settlement (Metcalfe and Bui, 2017). Land clearing accounts for 7% of Australia's annual greenhouse gas emissions (Department of Industry Science Energy and Resources, 2021). It is a major contributor to soil erosion and nutrient loss, sedimentation and pollution of waterways and coasts and is one of the biggest risks to threatened wildlife and ecosystems (Jackson *et al.*, 2017, Kearney *et al.*, 2019b). Land clearing and vegetation degradation also contribute to increasing dryland salinity (Lambers, 2003).

Climate change is affecting native vegetation through changes to temperature, rainfall and fire regimes, including increases in frequency of extreme fires, particularly in forests of southeast Australia. Other effects of climate change on biodiversity include lifecycle shifts, changing abundances, and range expansions or contractions with some loss of alpine environments already evident (Prober *et al.*, 2019, Cresswell *et al.*, 2021). The 2019-20 bushfires have increased the extinction risk of many native plant species and the risk of collapse for many ecosystems, in both cases this was largely due to broader changes to fire regimes and interactions with existing threats (Bergstrom *et al.*, 2021, Gallagher *et al.*, 2021, Keith *et al.*, 2022). While adaptation solutions are well established in the scientific literature (Heller and Zavaleta, 2009, Hughes *et al.*, 2010), actions to address impacts of climate change have not, to date, been adequately implemented in practice.

Preserving intact native vegetation and restoring cleared vegetation has a major role to play in contributing to Australia's climate change solutions. CSIRO estimates there is substantial sequestration potential across Australia's landscapes, including permanent plantings (16 Mt/yr), plantation and farm forestry (32 Mt/yr), human induced regeneration of native forest (39 Mt/yr), savanna fire management (6 Mt/yr) and soil carbon (5-29 Mt/yr) (Fitch *et al.*, 2022). This is sufficient to offset significant amounts of Australia's greenhouse gas emissions well into the future, covering the period during which the Australian economy is expected to progress to become carbon neutral.

Native vegetation restoration actions proposed below would remove about one billion tonnes of CO_2, offsetting approximately 18% of Australia's net emissions over the next thirty years. At a carbon price of between $35 and $75 per tonne of carbon dioxide equivalent increasing at a rate of 4.5% per year from 2024, the carbon market revenue from these actions could generate between $16 and $34 billion (2022$) to landholders within 30 years, covering up to 15% of the total investment required. Repairing degraded native vegetation can also increase resilience and recovery of ecosystems from the negative impacts of climate change and natural stressors, and facilitate species adaption to these changes (Owen, 2020).

Positive steps toward protecting and repairing native vegetation are already being made. At a national level, Australia has committed to protecting at least 30% of land and oceans globally by 2030 to tackle biodiversity loss, under the Kunming-Montreal Global Biodiversity Framework agreed at the 15th

Conference of the Parties to the Convention on Biological Diversity in 2022. Australia has also played a leadership role internationally as part of the 'High Ambition Coalition for Nature and People' to ensure the implementation of this ambitious target. Proposed reforms to Australia's national environment laws provide a critical opportunity to protect and restore native vegetation of national significance.

Our assessment shows it is possible to restore almost every type of native vegetation to 30% of its pre-1750 extent. This would leave our landscape in a better condition to support biodiversity in a changing climate and should be undertaken together with initiatives to protect existing vegetation, sustain and improve agricultural productivity and support jobs and livelihoods in regional Australia.

Identifying actions and estimating the investment

The Wentworth Group has identified the practical actions and derived indicative estimates of the new capital and annual operational investment needed to restore healthy native vegetation cover to 30% of pre-1750 extent over 30 years. The indicative annual investment from 2025 to 2054 is $1.9 billion including $1.7 billion in capital costs, $170 million in transaction costs and $29 million in operational expenditure (in 2022$).

The following section details the Objectives and Actions for repairing native vegetation in Australia, including the rationale, and costing methods used.

Objective V1

Objectives	Actions
V1. Restore native vegetation cover to at least 30% of pre-1750 land extent in a healthy ecological condition for each of Australia's terrestrial ecosystems.	V1.1-C Restore 1.3 million hectares of degraded native vegetation to a healthy ecological condition within the protected area estate.
	V1.2-C Restore 11.6 million hectares of degraded native vegetation to a healthy ecological condition on non-prime agricultural land.
	V1.3-C Incentivise landholders to retire their non-prime agricultural land for the native vegetation conservation areas.

Objective V1 – Rationale & Costing Methods

Across Australia, an estimated 13.2% of native vegetation has been cleared as a result of cumulative pressures from urban development, production and extractive uses over many decades (Cresswell *et al.*, 2021). Eleven major vegetation groups have lost 20% of their original extent, and some, such as Casuarina Forests and Woodlands, have lost almost half (47%) of their original extent (Cresswell *et al.*, 2021). Large areas of remaining native vegetation in Australia are degraded and fragmented (Williams *et al.*, 2020). Although cleared vegetation has regrown in many areas, this partial regrowth has reduced ecological integrity compared to its pre-cleared state (Cresswell *et al.*, 2021).

The integrity of native vegetation, that is, its community composition and ecological functions, sharply declines when the extent of native vegetation in healthy condition falls below 30% (Andrén, 1994, Banks-Leite *et al.*, 2014). While this threshold varies with landscape productivity (Maron *et al.*, 2012), we have assumed this minimum level of healthy vegetation cover is required to safeguard the persistence of species and improve their capacity to provide critical services (Newmark *et al.*, 2017).

Our assessment, published in the Journal of Applied Ecology, shows it is possible to restore 99.8% of Australia's terrestrial ecosystems to healthy native vegetation across at least 30% of their pre-1750 extent while maintaining productivity on prime agricultural land, with all the costs for the native vegetation action (V1) potentially covered by carbon farming revenue (Mappin *et al.*, 2022), reflecting 7% to 15% of the total cost of all actions.

This action involves the repairing, regrowing or replanting of 12.9 million hectares of degraded or cleared native vegetation across the continent and providing stewardship payment incentives with legal covenants equivalent to the opportunity cost of forgoing agricultural production. Ongoing management costs to manage and maintain these new conservation areas for weeds, pests and fire are estimated separately (see 'Operational expenditure' section below).

This also requires an enhanced emphasis on increasing agricultural productivity on prime agricultural land to the levels historically achieved but which have declined in recent decades (Bryan *et al.*, 2015, Hatfield-Dodds, 2015, Grundy *et al.*, 2016). Measures may include driving farming efficiency, adopting technological and other innovations and value-adding to goods and services in the supply chain.

Restoring native vegetation across 12.9 million ha could abate almost one billion tonnes of carbon dioxide equivalent and produce AU$16 billion to AU$34 billion (2022$) in carbon market revenue to landholders, based on an extrapolation of current market conditions. The carbon market revenue would provide up to 15% of the total investment required. Assurance in the delivery of this action is needed so that carbon sequestered is high-integrity abatement – that is, additional to what would have otherwise occurred, long term, and appropriate for the specific landscape (Wentworth Group, 2022).

Restoration efforts would need to be complemented by adequate funding for Australia's threatened species and by cessation of clearing of native vegetation in threatened species' ranges. Without increasing efforts toward threatened species management (Valentine *et al.*, 2014, Borrelle *et al.*, 2015) and halting further land clearing (Reside *et al.*, 2017), efforts to restore ecosystems will not have the desired effect of achieving functional and healthy life support systems.

Restoration of these most degraded ecosystems will initiate their trajectory to recover critical ecological functions and provide habitat for threatened species, assisting with Australia's commitments to the Global Biodiversity Framework and the Commonwealth's Nature Positive Plan and Threatened Species Strategy.

Overall method

We assessed the extent of native vegetation in 'healthy ecological condition' (VAST Category 2) in each terrestrial ecosystem using high resolution spatial data. This assessment has been published in Mappin *et al.* (2022).

Native vegetation condition was based on the VAST framework which classified vegetation by degree of human modification as a series of states, from intact native vegetation through to total removal (Thackway and Lesslie, 2006; see Appendix III). A "healthy ecological condition" (i.e., VAST Category 2) is where a native vegetation group's "community structure, composition and regenerative capacity [is] more or less intact" (Thackway and Lesslie, 2006).

We identified 1,285 terrestrial ecosystems based on the spatial intersection of 89 Interim Biogeographic Regions of Australia (DOE, 2012) and 26 pre-1750 Major Vegetation Groups (DOEE, 2007); aquatic vegetation excluded).

For the terrestrial ecosystems with <30% native vegetation in healthy ecological condition, we calculated the shortfall in healthy native vegetation extent. We then determined the spatial configuration and the associated costs of the restoration outside intensive agricultural and urban areas. To achieve this cost-effectively, we first determined how much could be achieved within the protected area estate where restoration was assumed to be practically feasible and cost effective. We then calculated the remaining expected costs on non-prime agricultural land, together with a stewardship payment. We defined non-prime agricultural land as the area outside the intensive agricultural land of Australia (a non-contiguous area from south-western Western Australia to eastern Queensland) using land use and vegetation data by Bryan *et al.* (2016a) and Grundy *et al.* (2016), less the land predicted to be in environmental or carbon plantings by 2050 (Connor *et al.*, 2015). We applied a spatial planning tool, Marxan (Ball *et al.*, 2009), to identify the most cost-effective solution favouring the less degraded marginal land within the ecosystem that needs repair.

We estimated the costs over a 30-year timeframe from 2025 to 2055 by assuming 1/30 of the restoration of each ecosystem would be completed each year. Repair and replanting costs were based on published estimates by Maggini *et al.* (2013) for different types of native vegetation (see **Action V1.1-C Restore 1.3 million hectares of degraded native vegetation to a healthy ecological condition within the protected area estate.**

Rationale – This action is to restore 1.3 million hectares of native vegetation to a healthy ecological condition within the protected area estate, representing approximately 10% of the total 12.9 million ha required to meet the 30% overall target. Our assessment identified that approximately 0.75 million hectares in Australia's National Reserve System was categorised as degraded (VAST Category 3) and therefore in need of some level of repair (ideally via passive regeneration, assuming a seed source was locally available) to return the vegetation to VAST 2 category. A further 0.6 million hectares in Australia's National Reserve System was categorised as being completely cleared (VAST Category 5) and therefore in need of replanting (via active regeneration, assuming there is no/limited seed source locally available) to return that vegetation to VAST 2 category.

Costing Methods – As above.

Table 4). This action does not imply graziers should completely release land from grazing activity. Under VAST 2, landholders can undertake low-intensity grazing (i.e., where resource use is below carrying-capacity). Table 8 in Appendix IV lists the regions where the 30% target was not achievable.

While we have estimated the most efficient solution, in practice, the selection of specific restoration sites would be executed through voluntary arrangements with landholders, such as environmental auctions and as such, the specific locations would vary due to local context and constraints from the legacy of past land uses (Suding, 2011). This could affect the cost estimates.

Considering climate change and current federal and state government initiatives in Australia, it is reasonable to expect that a portion of the investment can be financed by carbon market revenue. As per Mappin *et al.* (2022), this was calculated using spatial data on carbon sequestration potential produced by the former Department of Climate Change and Energy Efficiency mapping of Maximum Potential Biomass (MaxBio) across Australia. The MaxBio spatial dataset provides a conservative estimate of the maximum above-ground biomass attainable from native vegetation that has achieved a stable, mature state of growth within 25 years, which coincides with the crediting period for a Carbon Farming Initiative/Emissions Reduction Fund eligible project. Areas designated within the protected area estate were removed from these calculations as these areas are generally not eligible or are difficult to establish with respect to delivering Australia Carbon Credit Units under the *Carbon Credits (Carbon Farming Initiative) Act 2011*.

The corresponding minimum and maximum MaxBio values were averaged for each pre-1750 Major Vegetation Group, and then halved under the assumption that 50% of the dry biomass is elemental carbon which is the same value applied in the *Carbon Farming Initiative—Reforestation and Afforestation 2.0 methodology (Commonwealth of Australia, 2015)*. We assumed that the passive restoration areas will have 25% less potential carbon sequestration than the value identified by MaxBio, due to the assumption that 25% native vegetation already exists in those areas. These values of elemental carbon were multiplied by 3.67 to convert from tonnes of carbon to tonnes of carbon dioxide equivalent. We divided this by 25 to get the per year abatement over the 25-year post restoration period.

We modelled two carbon price scenarios annually from 2025 to 2054: an estimate based on extrapolating the current spot price of carbon increasing by a fixed percent, and an estimate based on extrapolating the Clean Energy Regulator's cost containment measures which reflect current policy regarding the maximum compliance costs faced by facilities under the safeguard mechanism (CER, 2024). Both scenarios are reasonably aligned with BloombergNEF's benchmark carbon offset pricing scenarios (removal and high quality scenario respectively) over the period (BloombergNEF, 2024). The scenarios are conservative compared to the interim values of emissions reductions used by the Australian Energy Market Operator from 2025 to 2050 (see Appendix A.11 in AEMC, 2024).

> Scenario 1: At the time of writing, the spot price for Australian Carbon Credit Units on the secondary market was AU$35 per tonne CO_2e (CORE Markets, 2024). We estimated income from carbon markets over 30 years by extrapolating from the current market conditions, assuming a carbon price of $35 per t$CO_2$e increasing at a rate of 2% per year plus 2.5% interest.
>
> Scenario 2: Safeguard facilities that exceed their baseline may apply to the Clean Energy Regulator to purchase the required number of carbon credits at a fixed price (CER, 2024). The price of these credits was set at $75 per tonne CO_2e in 2023-24, indexed in future financial years by the Consumer Price Index (CPI) plus an additional 2% per annum. We extrapolated from these values to provide an estimate of income over 30 years (assuming 2.5% CPI for our assessment; see Table 7).

Action V1.1-C Restore 1.3 million hectares of degraded native vegetation to a healthy ecological condition within the protected area estate.

Rationale – This action is to restore 1.3 million hectares of native vegetation to a healthy ecological condition within the protected area estate, representing approximately 10% of the total 12.9 million ha required to meet the 30% overall target. Our assessment identified that approximately 0.75 million hectares in Australia's National Reserve System was categorised as degraded (VAST Category 3) and therefore in need of some level of repair (ideally via passive regeneration, assuming a seed source was locally available) to return the vegetation to VAST 2 category. A further 0.6 million hectares in Australia's National Reserve System was categorised as being completely cleared (VAST Category 5) and therefore in need of replanting (via active regeneration, assuming there is no/limited seed source locally available) to return that vegetation to VAST 2 category.

Costing Methods – As above.

Table 4. Repair and replanting cost estimates for non-riparian native vegetation. Note: there is no VAST 4 data in the dataset.

Action	Vegetation type (reference)	Cost (2018$)
Replanting areas of cleared native vegetation (non-riparian) via active regeneration – *areas classified as VAST 5, where no seed source is assumed to exist.*	Rainforest (Maggini *et al.*, 2013)	$10,000/ha
	Forests and woodlands (Maggini *et al.*, 2013)	$5,000/ha
	Shrublands (Maggini *et al.*, 2013)	$3,000/ha
	Grasslands (Maggini *et al.*, 2013)	$2,000/ha
	Chenopods, Samphire Shrubs and Forblands (Maggini *et al.*, 2013)	$2,000/ha
Repairing areas of degraded native vegetation (non-riparian) via fencing and passive regeneration - *areas classified as VAST 3, where a seed source is assumed to exist.*	Rainforest (25% of the figure above)	$2,500/ha
	Forests and woodlands (25% of the figure above)	$1,250/ha
	Shrublands (25% of the figure above)	$750/ha
	Grasslands (25% of the figure above)	$500/ha
Annual cost of managing native vegetation plantings for weeds, pests and fire	Assumed to be $6.25/ha (2020$) – this is the average of the annual marginal per hectare cost spent by AWC (2016), Bush Heritage Australia (2016), the NSW Government (2006) and Queensland Government (as reported by Adams *et al.* (2011)), and other State Governments (as reported by the Legislative Council of Tasmania (2012)).	

Note: Costs were converted to 2020$ in Mappin *et al.* (2022), then into 2022$ for our assessment.

Action V1.2-C Restore 11.6 million hectares of degraded native vegetation to a healthy ecological condition on non-prime agricultural land.

Rationale – This action is to restore 11.6 million hectares of native vegetation to a healthy ecological condition on non-prime agricultural land. Our assessment identified that approximately 4.9 million hectares of non-prime agricultural land categorised as being degraded (VAST Category 3) and therefore in need of some level of repair (ideally via passive regeneration, assuming a seed source is locally available) to return that vegetation to VAST 2 category. A further 6.7 million hectares was categorised as being completely cleared (VAST Category 5) and in need of replanting (via active regeneration, assuming there are no/limited seed sources locally available) to return that vegetation to VAST 2 category.

Costing Methods – As above.

Action V1.3-C Incentivise landholders to retire their non-prime agricultural land for the native vegetation conservation areas.

Rationale – We included a stewardship payment equal to the opportunity cost to the landholder to retire their non-prime agricultural land from farming for conservation and encourage farmers to participate in restoration (Dorrough *et al.*, 2008).

Costing Methods – The stewardship payment was calculated as the expected cost of forgoing cropping, forestry and/or grazing production within the restoration areas using the 12-year average annual farm-cash income to capture the fluctuations in returns (2001-2013) and paid out over 20 years (ABARES, 2014). We inflated these figures to present values and thereafter at 2% per annum and capitalized in perpetuity by dividing by 5% (Baum, Mackmin and Nunnington, 2017).

Objective V2

Objectives	Actions
V2. Reduce the frequency and intensity of savanna fires.	V2.1-C Controlled low intensity fires early in the dry season in Australia's tropical savanna lands using Indigenous fire management practices.

Objective V2 – Rationale and costing methods

Action V2.1-C Controlled low intensity fires early in the dry season in Australia's tropical savanna lands using Indigenous fire management practices.

Rationale – Australia's tropical savannas extend across north Australia from around Broome on the west coast, to the Burdekin region south of Townsville on the east coast, excluding north Queensland's relatively well watered Wet Tropics (Russell-Smith and Sangha, 2018). Spanning across 190 million ha (Sangha *et al.*, 2021), the lands are sparsely populated and the major economic activity in the region is cattle pastoralism. This region experiences frequent fires, including large wildfires at the end of the dry season. The main factors contributing to degradation of savanna ecosystems are fires of high frequency and intensity, exacerbated by climate change, and ecologically inappropriate cattle grazing regimes (Douglass *et al.*, 2011).

Indigenous fire management is central to caring for Country, and Indigenous people have evolved fire practices over thousands of years as a means of managing vegetation for food, medicine and fibre (Cahir *et al.*, 2016, Cresswell *et al.*, 2021). With European colonisation, there was little recognition by the settlers of the importance or value of fire as a tool for managing native vegetation. The consequence was more destructive bushfires which have prevailed across Australia's landscapes for more than 200 years (King, 1963, Ngurra *et al.*, 2019, Bourke *et al.*, 2020). Frequent, high intensity fires in the arid savannas of northern Australia increase mortality of species and release larger amounts of carbon (Douglass *et al.*, 2011).

Indigenous fire management practices can help mitigate the adverse impacts of hot fires, reduce fuel load and decrease the likelihood of late dry season fires. Ecological benefits from savanna burning in northern Australia include increased ground cover extent, reduced threats to flora and fauna, reduced emissions from wildfires, increased landscape carbon storage, suppressed spread of invasive Gamba Grass, and protection of vulnerable biodiversity (Douglass *et al.*, 2011, Fitch *et al.*, 2022).

Opportunities to mitigate the intensity and frequency of these fires also provide social and economic benefits, including employment opportunities, expanded institutional capacity of local management organisations, and associated support for Indigenous communities. Emerging market-based, landscape-scale 'savanna burning' carbon farming projects are incentivising the delivery of ecosystem services, especially for remote Indigenous landowners (Russell-Smith and Sangha, 2018, Fitch *et al.*, 2022).

Costing Method – Roxburgh *et al.* (2020a) identified more than 80 Mha of potential land area for savanna burning projects, comprised of nine eligible fuel types within two rainfall zones in northern Australia where most project activity occurs (600-1,000 mm and >1,000 mm annual rainfall). Of this, the total eligible area for new project establishment outside existing project boundaries was estimated as 55.78 Mha. This area included land suitable for emissions avoidance and sequestration activities under the Emissions Reduction Fund (ERF) fire management methodologies. It excluded areas below 600mm annual average rainfall; a vegetation fuel class, Pindan, that will be included in a future ERF method; and the Gamba Grass exclusion zone given the high flammability of this species and the risks of adverse impacts (Fitch *et al.*, 2022). Following Roxburgh *et al.* (2020a), we assumed a total annual cost of 55 cents per hectare for the savanna fire management action based on a 25 year crediting period and a discount rate of 10% ($2020). Monitoring and management (operational) costs were estimated separately.

Operational expenditure

The following are the assumed operational costs required for the above actions to be implemented effectively.

Action V1.0-O Monitoring and management of restored conservation areas (fire, weeds, feral animals).

Rationale - Conservation areas must be monitored and/or managed on an annual/periodic basis, especially where new plantings have been established.

Costing Method - We included an annual cost of AU$6.25/ha inflated at 2% per annum to manage the native vegetation plantings for weeds, feral animals, and wildfire (Mappin *et al.*, 2022).

Action V2.0-O Monitoring and management of savanna burning areas (weed monitoring and removal).

Rationale – Savanna burning areas need to be monitored and managed on a periodic basis for weeds.

Costing Method - We included an annual cost of AU$0.05/ha (2020$) inflated at 2% per annum per annum for reporting and to monitor and manage weeds in savanna burning areas (Fitch *et al.*, 2022).

Actions beyond the scope of this assessment

Actions in the table below have not been costed in the estimates provided above because either: (a) they are already being undertaken in the vast majority of areas; (b) they require actions beyond investment such as governance or legislative changes; and/or (c) there is a lack of data or significant uncertainty regarding their effectiveness or cost.

ID	Action	Description
V1.1-A	End broadscale clearing of remnant native vegetation	Land clearing is a leading threat to native vegetation and dependent biodiversity in Australia. Reforms are needed to prohibit broadscale land-clearing and prevent other forms of degradation of native vegetation (e.g., clearing of regrowth or understorey, poorly implemented biodiversity offsetting schemes). These actions were not costed in this assessment as they require a broader suite of reforms including strengthening Commonwealth, state and territory regulations and ensuring proper implementation and compliance.
V1.2-A	Agricultural productivity improvement package	As part of a holistic repair effort, an agricultural productivity improvement package is needed to sustain the productivity of Australia's prime agricultural land. Specific actions and investment are needed to maintain an assumed growth in productivity of 2.5% on prime agricultural land (Bryan *et al.*, 2015, Hatfield-Dodds, 2015, Grundy *et al.*, 2016). Measures may include increasing farming efficiency, adopting technological and other innovations, and value-adding to goods and services in the supply chain.
V1.3-A	Eradication of myrtle rust and other existing invasive pathogens	According to the State of the Environment Report 2016, "Invasive pathogens can cause widespread mortality, habitat loss and degradation of ecosystems. Although Australia is free from many of the most damaging agricultural plant pathogens because of concerted biosecurity efforts at all levels of government, a few significant pathogens have become established or are near our borders" (Jackson *et al.*, 2017). The extent of invasive pathogens (e.g., Myrtle Rust, phytophthora) is unclear - data are very limited. Eradication is also very difficult – e.g., for myrtle rust, the Australian Government states that it is "extremely difficult to control and impossible to eradicate from natural settings." In 2017, the Invasive Species Council suggested that "Contingency planning, surveillance, and preparation for responding to future such incursions must be strengthened to avoid further failures. This must include building awareness and preparedness in the nursery industry", and that "Policies are needed to reduce the risks of disease spreading from nurseries and plant breeding sites into bushland" (ISC, 2017). As an emerging space for policy development, and given the difficulties and costliness of eradicating invasive species, we have not costed this action.

V1.4-A	Controlling and/or eradicating environmental weeds	Though difficult to quantify, environmental weeds have significant negative environmental and economic impacts, such as reducing biodiversity, cost of control, loss of ecotourism opportunities, degradation of waterways and increased risk of wildfire. While substantial efforts were made to estimate the investment required to control environmental weeds, the lack of spatial information on the extent and location of many environmental weed infestations makes it impossible to establish a credible estimate. The management of weeds is complex, with the Australian Weeds Strategy 2017-2027 suggesting that weeds be best managed according to the general invasion curve: 1) prevention; 2) eradication; 3) containment; and 4) asset protection (IPAC, 2017). While the costs of eradication and containment have not been estimated here, the cost of asset protection has been included as part of operational expenditure to mitigate threats and allow for the recovery of native vegetation communities.
V1.5-A	Technological advancements	It is expected that advancements in technology will provide a significant contribution to landscape management and facilitate cost-effective actions. For example, Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR) gene-editing technology offers some cautious hope in targeted control (and even eradication) of invasive weeds (Webber *et al.*, 2015). The application of technological advancements to landscape management is difficult (and likely impossible) to predict, and therefore its potential impact on investment estimates here has not been estimated. However, we assume technological advances will make many of the listed actions more cost-effective.

Threatened species

The case for saving threatened species

Australia is one of the most biologically diverse countries in the world, with 87% of mammals, 45% of birds, 93% of reptiles, 94% of frogs and 86% of plants found nowhere else on earth (Chapman, 2009). Yet scientific evidence demonstrates that biodiversity is undergoing systemic decline. More than 100 species (Woinarski *et al.*, 2019b) and sub-species, including 39 mammals, 22 birds, 4 frogs, 1 reptile, 1 earthworm and at least 36 plants, have become extinct since European settlement, and a further 578 animal species and 1,416 plant species are listed as threatened with extinction as of March 2024 (DCCEEW, 2024a, DCCEEW, 2024b). These figures are likely to substantially underestimate the number of species threatened with extinction (Walsh *et al.*, 2013, Woinarski *et al.*, 2019a, Alfonzetti *et al.*, 2020).

Climate change is exacerbating the existing threats facing listed species. Reduced habitat, increased disease, mass mortality of plants and animals, increased competition and predation and changes in timing of seasonal events, are among the impacts of climate change on threatened species observed to date (Hoffmann *et al.*, 2019). The status of most listed species is deteriorating, with four times as many vulnerable species declining in their threat status than improving since the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) was introduced (Simmonds *et al.*, 2020). Geyle *et al.* (2018) estimate that another seven Australian mammals and ten Australian birds will be extinct in the next two decades unless management improves. The first known global mammalian extinction due to human-induced climate change was the Bramble Cay melomys (Fulton, 2017), a rodent which inhabited a low-lying vegetated coral cay in the Torres Strait. Less than a quarter of recovery plans for Australia's terrestrial threatened species (fauna and flora) identify specific actions associated with ameliorating climate risk (Hoeppner and Hughes, 2019).

As humans, we have a moral responsibility to protect the natural world and species that inhabit it. It is also in our best interest to do so: biodiversity underpins the health and wellbeing of communities, supports tourism, agriculture and other industries, and is intrinsically linked to Indigenous culture and the identity of all Australians.

We have a significant opportunity to tackle threatened species loss at scale in Australia (Legge *et al.*, 2023). Most of the nationally listed threatened species are endemic, and hence their survival is entirely dependent on the extent and success of conservation actions taken within our borders. There are many examples of successful species recovery (Garnett *et al.*, 2018, Woinarski *et al.*, 2023). From 2000 to 2022, 29 threatened animal species have been recovered to the extent they could now be, or have been, delisted (Woinarski *et al.*, 2023), many of these because of successful conservation efforts and changed management practices.

The Australian Government's *Threatened Species Action Plan: Towards Zero Extinctions 2022-2032* sets out ambitious targets for the prevention of any new native animal or plant extinctions. Yet the $224.5 m committed to implement this plan is insufficient (Ritchie *et al.*, 2022). Australian spending on threatened species has broadly equated to around one-tenth of that spent by the United States recovery programs, and about 15% of what is considered necessary to not only avoid further extinctions, but also to recover threatened species from the brink (Wintle *et al.*, 2019).

While it is of vital importance to increase funding to target the most threatened species, focusing only on the most threatened species is expensive. Proactive conservation and threat mitigation that seeks to prevent species from becoming threatened in the first place is critical and one of the most cost-effective conservation measures available; such an approach can save tens of millions of dollars (Drechsler *et al.*, 2011). Moreover, worsening impacts of climate change are likely to lead to increased costs and decreased chances of success associated with conservation actions for threatened species

(Shoo *et al.*, 2013). While it is beyond the scope of this report, emissions reduction is likely a highly cost effective and beneficial threat reduction strategy in the long-term.

Targeted action and sufficient investment for threatened species recovery is of key importance to ensure our native plants and animal species continue to exist and flourish. In this report, we identified the actions and investments required to mitigate imminent extinction risk and ensure medium-term survival of most EPBC Act listed species. Estimates will need to be improved over time as spatially variable costs become available (Ward *et al.*, In prep)

Identifying actions and estimating the investment

The Wentworth Group has identified the practical actions and derived indicative estimates of the new capital and annual operational investment needed to mitigate extinction risk and ensure survival of most Commonwealth-listed threatened species over 30 years. The indicative annual investment from 2025 to 2054 is $1.3 billion including $1.2 million in capital and operational costs and $117 million in transaction costs (in 2022$).

The following section details the Objectives and Actions for addressing the recovery of threatened species in Australia, including the rationale, and costing methods used.

Objective T1

Objectives	Actions
T1. Mitigate imminent extinction risk and ensure medium-term survival of most Commonwealth-listed threatened species.	T1.1-C Restore habitat, address threats (including some localised impacts of invasive species), and undertake population interventions such as translocation and breeding programs for species listed as Critically Endangered, Endangered and Vulnerable under Commonwealth legislation.

Objective T1 – Rationale and costing methods

Action T1.1-C Restore habitat, address threats (including some localised impacts of invasive species), and undertake population interventions such as translocation and breeding programs for species listed as Critically Endangered, Endangered and Vulnerable under Commonwealth legislation.

Rationale – The management actions described in this chapter are additional and complementary to those described in the 'Native vegetation' chapter of this report. Management actions vary from species-to-species (Hoeppner and Hughes, 2019). Threat management actions include managing road mortality, disease prevention, invasive species management, and pesticide, herbicide and fertiliser management. Habitat restoration examples include providing coarse woody debris, restoring appropriate vegetation types within species ranges, maintaining mature hollow trees, deploying nest boxes, artificial breeding substrates and planting specific feed trees. Population management interventions include captive breeding, assisted colonisation by translocation, establishment of captive populations and reintroduction into the wild. Invasive predator and herbivore control may be undertaken in certain circumstances, noting that many of these species are difficult to eradicate or suppress to the level required to allow threatened native species to persist without predator exclusion zones (Burbidge and McKenzie, 1989, Moseby *et al.*, 2011).

Evidence from the United States suggests that money spent on threatened species has been successful in preventing extinction, stabilising species, improving species conservation status, and in some cases, recovery (Wintle *et al.*, 2019). As conservation actions vary considerably between species, so do the associated costs. It is assumed that the exact actions and investment sought for each species would be informed by the appropriate scientific studies and with local knowledge and advice. In particular, there is a need to incorporate traditional ecological knowledge about plants, animals, Country and culture in management (Woodward *et al.*, 2020), particularly in the face of the challenges of climate change and extreme weather events (Cresswell *et al.*, 2021).

Action T1.1-C Costing Method

In March 2024 when this analysis was completed, there were 1,994 taxa listed as threatened under the EPBC Act for Australia (i.e., excluding taxa listed as Extinct, Extinct in the wild or Conservation Dependent) (DCCEEW, 2024a, DCCEEW, 2024b). This number increased from 1,219 in 2000 at the average rate of 32 taxa/yr (see accompanying spreadsheet). It can be expected that this number will continue to increase as the impacts of human activity and global climate change become even more apparent, and with the assessment of new information about the status of species, including those under-represented in current listings (Walsh *et al.*, 2013, Braby, 2018, IUCN, 2022).

We assumed that the number of threatened species added to EPBC Act schedules continues at the same rate as that exhibited over recent years (32 taxa per year: 16.5 Critically Endangered, 11 Endangered, 4.5 Vulnerable). In this assessment, expenditure is considered to extend constantly from the date at which the species is listed through to 2054. This investment is expected to prevent extinction and establish the foundation for recovery (e.g. species' stabilisation, downlisting (i.e. to an improved conservation status) or delisting).

Our assessment was based on cost estimates from Wintle *et al.* (2019) derived from the U.S. species recovery expenditure figures for 2013 (Gerber, 2016). Mean annual funding allocations (within taxonomic groups) were calculated for 284 species that were assessed by Gerber (2016) as having adequate funding. Mean annual funding allocations were converted from $US2013 to $AU2022 then inflated based on economic assumptions for the 30 year period (see Table 7 in Appendix II). The resulting annual costs were then multiplied by the number of species in each EPBC Act-listed taxonomic group to provide a preliminary estimate of targeted funding required to recover Australia's listed threatened species (see Wintle *et al.* (2019) for more details; 'invertebrates' costs were assumed for EPBC Act-listed 'other animals' group). Cost-sharing among threatened species was assumed to reduce total costs to 71.5% of the full estimate (McCarthy *et al.*, 2012), that is, a 28.5% cost savings if actions for all species are undertaken together.

The investment required depends on how the actions are spread over time and the economic assumptions used. Using a discount rate of 5% and a 2.5% inflation rate (see Appendix II; Economic assumptions), the cost profile for threatened species equates to about $1.2 billion per annum in 2022 dollars over the next 30 years. On an annualised basis, estimates from 2025 to 2054 are shown in Figure 4, with an initial annual investment of $1.3 billion increasing to $4.5 billion in year 30.

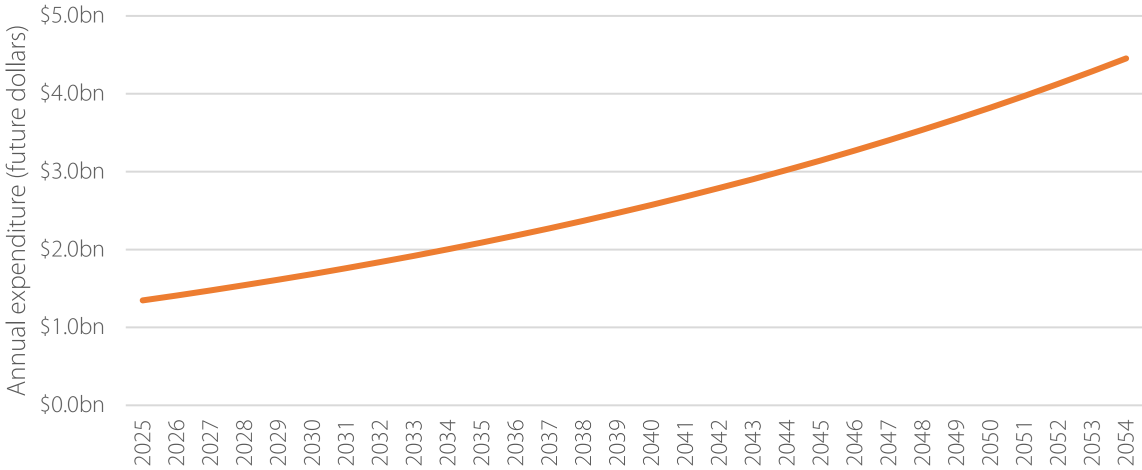

Figure 4. Estimated expenditure (in future annualised dollars) for threatened species (Action T1.1-C). Using a discount rate of 5%, this cost profile equates to $1.2 billion per annum in 2022$.

The estimate did not factor in increases in cost as species get closer to extinction nor the accelerated listing of species and increasing recovery costs under climate change. Further, the estimate did not include increases across all taxonomic groups expected in the next few years because of the Common Assessment Method process, which seeks greater harmonisation between the national list and those of states and territories (DCCEEW, 2023e). As more species tend to be listed under state legislation than under the EPBC Act, aligning the two through a common assessment of a species conservation status is likely to result in more species being formally assessed as threatened. The Commonwealth is also progressing more batch assessments of taxonomic groups through the Species Expert Assessment Panel process. This process, together with the IUCN focus areas, is also likely to contribute to increased listings in the future.

Operational expenditure

Operational expenditure for these actions is included in the above estimates. They include research, management of threats such as invasive species, disease and fire and monitoring likely to be required to prevent extinction, maintain current status or enable delisting.

Actions beyond the scope of this assessment

Actions in the table below have not been costed in the estimates provided above because either: (a) they are already being undertaken by the vast majority of landholders; (b) they require actions beyond investment such as governance or legislative changes; and/or (c) there is a lack of data or significant uncertainty regarding their effectiveness or cost.

ID	Action	Description
T1.1-A	Technological advancements	It is expected that advancements in technology will provide a significant contribution to conservation management and make undertaking some actions more cost-effective. For example, Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR) gene-editing technology offers some cautious hope in the targeted control (and even eradication) of feral pests and invasive species (Webber *et al.*, 2015), which are a major driver of species extinction. There has been some initial work on using CRISPR technologies to manage feral animal populations, such as sterilising male mice where they pose a threat to native species on islands. Other developments, such as those by an international group of scientists which has sequenced the cane toad's genome for the first time and uncovered potential viruses which could be used for biological control, provides hope that these types of technologies could play a key role in combating invasive species in the future. Likewise, advancements in drone technology, robotics and Artificial Intelligence are being applied to the control of feral cats (Slezak, 2016) and Crown of Thorn Starfish on the Great Barrier Reef. The application of technological advancements to conservation is difficult (and likely impossible) to predict, and therefore its potential impact on the investment estimates here has not been estimated. However, we assume that it will make these conservation actions more cost-effective in the future.
T1.2-A	End broadscale clearing of threatened species habitat and ecological communities	An estimated 7.7 million hectares of potential habitat for listed threatened species and ecological communities was cleared in Australia between 2000 and 2017 (Ward *et al.*, 2019a). Reforms are needed to end broadscale land-clearing and prevent other forms of degradation to threatened species habitat (e.g., clearing of regrowth or understorey, poorly implemented biodiversity offsetting schemes). These actions were not costed in this assessment as they require a broader suite of reforms including strengthening Commonwealth and state environment laws and ensuring proper implementation and compliance.
T1.3-A	Secure Threatened Ecological Communities (TECs)	There are around 100 TECs currently listed as threatened under the EPBC Act. However, there is currently limited spatial data that defines their precise distribution and extent (TSSC, 2017). Without this information, it is not possible to estimate the investment required to repair and conserve TECs. In the future, spatial data on TECs would allow us to check the overlay in extent to determine what additional investment was required.

T1.4-A	Controlling and/or eradicating invasive animals and plants	Invasive species are a primary cause of extinction (Allek *et al.*, 2018, Kearney *et al.*, 2019a, Ward *et al.*, 2021). There are 230 invasive non-native species and 37 problematic native species (207 plants, 57 animals, 3 pathogens) listed as affecting Australian threatened taxa (Kearney *et al.*, 2019a). Though difficult to quantify, invasive animals and plants have significant impacts on threatened species and have contributed to extinctions, particularly in Australia (Garnett et al., 2018; Kearney et al., 2018). Many invasive species extend over vast areas and are difficult to eradicate or suppress to enable threatened native species to persist (Burbidge and McKenzie, 1989, Moseby *et al.*, 2011). Costs for managing impacts of invasives on threatened species are very challenging to estimate, and likely to be substantially greater than the estimates provided in this assessment.
T1.-A	Eradicate invasive pathogens	There are 3 pathogens listed as affecting Australian threatened taxa (Kearney *et al.*, 2019a). According to Cresswell and Murphy (2017) "Invasive pathogens can cause widespread mortality, habitat loss and degradation of ecosystems." Although Australia is free from many of the most damaging agricultural plant pathogens because of concerted biosecurity efforts at all levels of government, a few significant pathogens have become established or are near our borders" (Jackson *et al.*, 2017). The extent of invasive pathogens is unclear - data are very limited. Eradication is also very difficult. In 2017, the Invasive Species Council suggested that "Contingency planning, surveillance, and preparation for responding to future such incursions must be strengthened to avoid further failures. This must include building awareness and preparedness in the nursery industry", and that "Policies are needed to reduce the risks of disease spreading from nurseries and plant breeding sites into bushland" (ISC, 2017). As an emerging space for policy development and given the difficulties and costliness of eradicating invasive pathogens, we have not costed this action.
T1.6-A	Program improvements	Coordinated planning across species is needed to account for the intersection of pressures and threats to native species, and optimise outcomes of investment. Scheele *et al.* (2018) identified six key areas where further program improvements are needed: 1) engagement and communication with stakeholders; 2) leadership and achievable long-term goals; 3) knowledge of target species' biology and threats; 4) setting objectives with measurable outcomes; 5) strategic monitoring to evaluate management effectiveness; and 6) greater accountability for species declines and failure to recover species. Transparency of funding and delivery, and a focus on monitoring and evaluation of the ongoing effectiveness of interventions (see Robinson *et al.* (2018)), considering current and emerging pressures, will also be important.

Coastal environments

The case for improving the health of degraded coastal environments

Over 85% of Australians live within 50 km of the coast, and almost all major population centres above 200,000 people are located adjacent to a major embayment or estuary. The Australian coastal zone is of great national significance. It is central to our nation's economy, lifestyle, and cultural identity, and home to many of our most prized ecological assets and unique wildlife. The coast plays an important role in Australia's Indigenous history and culture, with many invaluable cultural heritage sites. Coastal environments are varied and complex both in terms of form and function and in the degree to which they have been impacted since European settlement.

Extractive use of our coastal resources has resulted in extensive changes to coastal environments. Natural ecosystems in many places have been removed and degraded, with pressures increasing as the human population grows and urban settlements expand. At least 29% of estuaries in Australia have been modified, particularly those in the east, south-east and south-west of Australia (FRDC, 2013).

Large areas of tidal marsh have been lost due to urban infill of estuaries, the impacts of agricultural practices including runoff from catchments and drainage of coastal floodplains, and other activities (FRDC, 2013). Seagrass communities are under threat from nutrient inputs, increased sedimentation, dredging, anchoring and mooring of boats, habitat loss and climate change (Clark and Johnston, 2017). Australia's estuaries and bays are particularly important for fisheries as the majority of commercial fish catch, and recreational angling catch, spend part of their life cycle within estuaries.

Coastal environments are vulnerable to many aspects of climate change through the impact of extreme weather events, erosion and inundation. Sea levels are rising at a rate of 3-3.5mm per year, inundating low lying areas and magnifying the severity of storm surges (Cresswell *et al.*, 2021). Sea surface temperatures and the incidence of marine heatwaves are also increasing, and ocean waters are becoming more acidic (Cresswell *et al.*, 2021). Waycott *et al.* (2009) suggests that pressures on coastal environments are set to continue, particularly near centres of coastal development. Maintaining or improving the condition of damaged coastal habitats and addressing broader catchment pressures is critical.

In this report we identify four specific actions that can improve coastal biodiversity under current conditions. Much has been documented on these actions and the scale of investment needed at a national scale. In practice, actions and investment will vary based on factors including local and regional coastal management plans as defined by the relevant governments.

Repair of coastal environments in areas that are not intensely urbanised fall into two categories. One involves improved management of catchments that are cleared in part for agriculture or forestry. Much of what can be done in this regard is discussed and costed elsewhere in this study (e.g., riparian vegetation). The key will be to mitigate inflow of sediments and nutrients from farms, urban and industrial areas into coastal waterways as in the case of initiatives in the Great Barrier Reef catchment. The maxim must be "healthy catchments, healthy estuaries." Steps taken in other sections of this report will be relevant to securing healthy catchments.

The second category is what can be achieved within coastal wetlands and waterways and their surrounding coastal environments to improve their health and productivity. Healthy estuaries provide a range of ecosystem services such as water purification, carbon storage, fisheries production and buffering coastal assets from extreme weather (Wegscheidl *et al.*, 2015). Shellfish beds provide habitat and protection for a range of invertebrate and fish taxa (zu Ermgassen *et al.*, 2021). Studies show that seagrass can contribute around $200,000 ha/yr to fisheries productivity (Blandon and Zu Ermgassen, 2014). Increases in the extent of oyster beds can increase net fisheries production and improve water quality (Coen *et al.*, 2007). Positive progress towards repairing estuary and coastal damage has been made in areas such as fisheries management. In some states, wetlands, shellfish reefs and tidal marsh are protected and are beginning to be repaired (Wegscheidl *et al.*, 2017, Gillies *et al.*, 2018, Adame *et al.*, 2019).

Restoration of coastal environments can sequester significant amounts of carbon. A study by Hagger *et al.* (2022) found that restoring 5,046 ha of sugarcane, grazing and abandoned aquaculture land across 316 sites in Queensland's Wet Tropics has the potential to abate 221,006 Mg CO_2-e annually. The carbon market could pay for restoration across most (90%) of this area, based on a 25-year crediting period at $25 per tonne CO_2-e assumed in their report. Public funding for restoring tidal flows to seagrass, mangrove and salt marshes habitats is available under the Blue Carbon Method, one of five priority methods established in 2021 under the Emissions Reduction Fund.

Long-term persistence of species, populations, and habitats requires connectivity for gene flow and supporting adaptation to environmental change (Clark and Johnston, 2017). Improving connectivity is critical for improving the productivity of estuary fisheries (Creighton *et al.*, 2015). There are over 5,500 barriers in coastal rivers and estuaries, constricting tidal flows and restricting fish movement across Australia (Nichols and McGirr, 2005, Gordos *et al.*, 2007, Marsden, 2015, Moore, 2015). Where this issue interacts with cumulative effects of rising sea levels and other climate change impacts has not been addressed in this report and requires further investigation.

Several other major issues facing our estuaries and coasts are beyond the scope of this report. Our urbanised estuaries, including large coastal lakes, will remain under immense pressure from continued population growth, the legacy of past land contamination, ageing infrastructure, and effects of climate change. Interactive and cumulative effects arise from various sources of pollution, on-going sediment influx, invasive species, habitat modification, and climate change (Mayer-Pinto *et al.*, 2015). To a large extent, waterway health in these locations will depend on improved management of stormwater flows into coastal waters. Climate change adaptation with respect to coastal development is also needed. This needs to be carefully planned to avoid negative impacts on coastal ecosystems e.g., installation of coastal armouring such as sea walls. Appropriate coastal zoning and planned development retreat from coastlines are better solutions in the long term and complementary to the remediation actions.

There is a need to improve mechanisms of urban catchment management by local councils working with state agencies. Current governance structures for urban estuaries and coastal areas make meaningful action to address interactive and cumulative effects difficult. There is scope for a sustained national approach linking the interests of all levels of government to address these mounting issues, at a scale that can deliver the appropriate actions and associated programmatic funding, including capacity building over time (Thom, 2022).

Identifying actions and estimating the investment

The Wentworth Group has identified the practical actions and derived indicative estimates of the new capital and annual operational investment needed to support coastal biodiversity and improve coastal fisheries productivity over 30 years. The indicative annual investment from 2025 to 2054 is $37 million including $34 million in capital costs, $3 million in transaction costs and $1 million in operational expenditure (in 2022$).

The following section details the Objectives and Actions for repairing degraded coasts and estuaries in Australia, including the rationale, and costing methods used.

Objective C1

Objectives	Actions
C1. Support coastal biodiversity and improve coastal fisheries productivity.	C1.1-C Maintain or improve the health of ponded pastures and degraded tidal marsh ecosystems.
	C1.2-C Incentivise a change in management practice for ponded pastures and tidal marsh ecosystems.
	C1.3-C Re-establish locally degraded seagrass communities in priority areas.
	C1.4-C Re-establish shellfish reefs in priority locations.

Objective C1 – Rationale and costing methods

Action C1.1-C Maintain or improve the condition of degraded salt marsh ecosystems AND

Action C1.2-C Incentivise a change in management practice for salt marsh ecosystems.

Rationale – A total of 140,954 hectares of salt marsh ecosystems (ponded pastures and tidal marshes) is assumed to be unprotected, degraded and in need of remediation in Australia. This estimate is based on spatial data (Geoscience Australia, 2006) within areas classified as either "Foreshore Flats" (part of the seabed or estuarine areas, between mean high water and the line of lowest astronomical tide); "Marine Swamp" (low lying part of the backshore area of tidal waters, usually immediately behind saline coastal flat, which maintains a high salt water content, and is covered with characteristic thick grasses and reed growths); or "Saline Coastal Flat" (nearly level tract of land between mean high water and the line of the highest astronomical tide. This assessment is based on areas in active rural/agricultural areas, and on private and unprotected land only. It does not include land designated as residential/urban, industrial or as infrastructure.

Action C1.1-C Costing method – Salt marsh ecosystem remediation costs are based on the average marginal cost of the total $1.2 million (NESP, 2020) cost of rehabilitating 230 hectares of tidal marsh zone within the seasonally inundated Mungalla Wetlands, which are adjacent to the World Heritage Great Barrier Reef in Queensland (Mungalla Aboriginal Tours, 2022). Here, the marginal cost of $5,218/ha (2020$) included a range of management measures such as weed control, revegetation, and removal of an earth wall.

Action C1.2-C Costing method – The cost of forgoing agricultural production located in salt marsh ecosystems was based on the annual Farm Cash Income average 2001-2013 (spatial data which was overlayed over identified locations), paid out annually for 30 years (ABARES, 2014).

Action C1.3-C Re-establish locally degraded seagrass communities in priority areas.

Rationale – Seagrasses are flowering plants that form meadows on intertidal and subtidal sandy and muddy sediments around Australia. According to Clark and Johnston (2017) "Historical seagrass losses are extensive, and recovery times can range from months to centuries, depending on the species." It is likely that seagrass is in poor condition in more locations than are currently known (Waycott *et al.*, 2009). Clark and Johnston (2017: p84) state "some seagrass communities are stable or have increased in cover, particularly in areas away from human habitation, where water quality has improved or where land reclamation rates have decreased," however seagrass is also threatened by many factors, including "nutrient input and eutrophication, herbicides, toxicants, disease, reduced light, increased sedimentation loads and resuspension, dredging, algal blooms, boating (anchoring and mooring), and habitat loss to flooding and coastal development." Climate change and associated increases in extreme weather events are a long-term threat to seagrass communities. Waycott *et al.* (2009) suggests that pressures on seagrass are set to continue in the short term, particularly near centres of coastal development.

It is assumed that existing seagrass meadows are generally well protected under legislation, and that seagrass is capable of regenerating itself if the major pressures are mitigated. In this respect, water quality improvements through riparian replanting actions (see chapter on 'Inland water'), and through a widespread change to more sustainable farm management practices (see 'Soils' chapter), will contribute to significant seagrass regrowth in existing seagrass communities (van Katwijk *et al.*, 2016). It is also assumed that in many places, seagrass meadows need to be re-established before this regrowth can occur, and the above benefits can be realised (Tan *et al.*, 2020).

This assessment identifies the extent of seagrass that would be required to be replanted to achieve a minimum of 30% area extent at each known site, as per the historical and current extent provided by Waycott *et al.* (2009: Supplementary Table 1). Waycott *et al.* (2009) have shown that the coverage of some seagrass sites has increased over time and/or is currently assumed to be above the 30% extent threshold – at these sites, we have assumed re-establishment is not required. However, heavily degraded seagrass sites such as Cockburn Sound East (which has reportedly lost 99% of its historical extent) will require active restoration to achieve 30% area extent at each site to improve its ecological regenerative capacity to a point where it has the best chance of recovering if other pressures (e.g., poor water quality, as discussed above) are removed.

Noting the complexity of this aspect, and data limitations, the main caveat here is that the area required for seagrass rehabilitation could far exceed 1,000 hectares Australia-wide. This is particularly the case given the review by Waycott et al. (2009) focused on the temperate Southern Ocean bioregion, where data were readily available, compared to the tropical-Indo Pacific bioregion where data were relatively sparse. In the tropical and subtropical bioregions, seagrass meadows have been shown to be extensive. They are also subject to many of the same pressures as temperate ecosystems. For example, the seagrass meadows of Shark Bay in Western Australia, one of Australia's largest below-ground stores of carbon, suffered extensive defoliation due to a marine heatwave and elevated turbidity in 2011, reducing its below-ground biomass and resilience to future disturbances (Strydom *et al.*, 2020). Seagrass meadows of the Great Barrier Reef World Heritage Area, another of the largest areas of seagrass globally, have become heavily degraded (Coles *et al.*, 2015). Seagrass communities adjacent to the coral reefs in the Great Barrier Reef store approximately 11 per cent of the world's seagrass blue carbon, and provide habitat for marine species such as dugongs, turtles and fish (UNESCO, 2020).

Coles *et al.* (2015) recommend "for the effective management of seagrass at the scale of the [Great Barrier Reef World Heritage Area], more emphasis needs to be placed on the connectivity between seagrass meadow health, watersheds, and all terrestrial urban and agricultural development associated with human populations." Addressing water quality in catchments is particularly important (see chapter on 'Inland water').

Costing method – Historical and current extent data from Waycott *et al.* (2009) shows approximately 747 hectares of seagrass needs to be re-established to achieve 30% historical extent. We have rounded up to 1,000 hectares given that the Waycott et al. (2009) study was published over a decade ago, noting this may still be an underestimate given the complexity of this action and data limitations. We have assumed an average marginal cost of rehabilitating seagrass meadows of $145,405/ha (2010$)

(Bayraktarov *et al.*, 2016). This marginal cost is likely to be reduced if a large broadscale project is undertaken, as is proposed here.

Action C1.4-C Re-establish shellfish reefs in priority locations.

Rationale – Around a century ago, many of Australia's bays and estuaries were home to extensive oyster and mussel reefs which supported a range of sea life such as fish and crabs. Shellfish reefs "were once common across Australia's southern coastal waters but were lost during the mid-late 1800s and early 1900s due to a combination of destructive fishing practices, overfishing and changes to estuarine conditions" (Gillies *et al.*, 2017). Today, most (>90%) of Australia's shellfish reefs have been lost, and reefs structures and their associated communities have shown few signs of natural recovery (Gillies *et al.*, 2017). Clark and Johnston (2017: p78) states that "despite improvements, the status of coastal native oyster beds remains in a critical state following largely historical losses, especially near urban centres, because the beds are particularly sensitive to changes in water quality and overharvesting."

There have been several shellfish restoration projects in Australia which have successfully demonstrated benefits including direct and indirect jobs, including a major project in Port Phillip Bay Victoria in 2015 and a project in regional South Australia supported by Australia's National Stronger Regions Fund (TNC, 2017). The Nature Conservancy's $20 million Reef Builder Program initiated in 2021 aims to restore 60 shellfish reefs at 60 locations across Australia, creating up to 170 jobs and supporting the local economies of coastal towns (TNC, 2024).

Studies in several estuary systems worldwide have indicated that shellfish reefs provide important structural habitats for a variety of invertebrate and fish taxa, shoreline protection, improved water quality, and enhanced fisheries production (Coen *et al.*, 2007, Gillies *et al.*, 2015, McAfee *et al.*, 2020). Studies abroad have also demonstrated that increasing the area of oyster beds can increase net fisheries production, estimated to be worth US $4,123/ha/year for local fisheries (Gillies *et al.*, 2015).

Costing method – We define shellfish ecosystems as "intertidal or subtidal three-dimensional biogenic structures, formed primarily by high densities of oysters and/or mussels and their associated biological communities" (Gillies *et al.*, 2018). We base the locations in need of repair from the spatial information on historical native sites (Gillies *et al.*, 2018). Adopting the minimum 30% area extent threshold (Andrén, 1994, Banks-Leite *et al.*, 2014) and the assumption that each new site must be at least 20 hectares (to achieve a self-sustaining ecosystem), it is estimated that: the Angasi oyster *Ostrea angasi* needs to be re-established at 34 new locations (30% of the 118 sites estimated to have existed pre-1750, less the 1 existing intact site) over a total of 680 acres nationally; and the Sydney rock oyster *Saccostrea. glomerata* at 12 new locations (30% of the 60 sites estimated to have existed pre-1750, less the 6 existing intact sites), over 240 hectares nationally – a total of 46 new priority locations across Australia extending over 920 hectares in total. It is assumed that the average marginal cost of re-establishing / rebuilding shellfish ecosystems is $165,000 per hectare ($2018) (Rogers *et al.*, 2018). This marginal cost is likely to drop significantly if a large broadscale project is undertaken (see for example TNC, 2024), as is proposed here.

Operational expenditure

The following are the assumed operational costs required for the above actions to be implemented effectively.

Action C1.1-O Monitoring and management of newly conserved and rehabilitated coastal wetlands.

Rationale – Saltmarsh areas must be monitored and/or managed on an annual/periodic basis, especially where new plantings have been established.

Costing Method – The annual management cost for terrestrial native vegetation has been adopted for saltmarshes. As for native vegetation plantings, the operational costs are assumed to be $6.25/ha in 2020$ – this is the average of the annual marginal per hectare cost spent by AWC (2016), Bush Heritage Australia (2016), the NSW Government (2006) and Queensland Government (as reported by Adams *et al.* (2011)), and other State Governments (as reported by the Legislative Council of Tasmania (2012)). There is assumed to be (at least) 140,954 hectares of newly conserved and/or established saltmarsh around Australia requiring annual monitoring.

Action C1.3-O Monitoring of existing and new seagrass areas.

Rationale – Seagrass areas must be monitored and/or managed on an annual/periodic basis, especially where new plantings have been established.

Costing Method – An average marginal cost of $16/hectare (2018$) has been assumed for monitoring existing and new seagrass ecosystems, based on the Port of Townsville Annual Seagrass Monitoring survey where approximately $70,000 (Fonseca, 2016) is spent annually to survey 4,323 hectares of seagrass (Davies and Rasheed, 2016). There is assumed to be at least 34,800 hectares of existing and new seagrass meadow around Australia that should be monitored (Waycott *et al.*, 2009).

Action C1.4-O Monitoring and management of existing and new shellfish reefs.

Rationale – Shellfish reefs must be monitored and/or managed on a periodic basis, especially where reefs have been re-built.

Costing Method – After undertaking shellfish re-establishment at 46 sites and considering the 7 existing sites identified by Gillies *et al.* (2018), there is assumed to be at least 53 shellfish reef sites around Australia which will require bi-annual surveying and monitoring once established. The cost of surveying and monitoring a single site is assumed to $25,000 (2018$) per trip. Based on this, it is assumed that the annual cost of surveying and monitoring 53 shellfish sites is $662,500 (i.e., $25,000 x 53 x 0.5).

Actions beyond the scope of this assessment

Actions in the table below have not been costed in the estimates provided above because either: (a) they are already being undertaken in priority areas; (b) they require actions beyond investment such as governance or legislative changes; and/or (c) there is a lack of data or significant uncertainty regarding their effectiveness or cost. Interactions between lost connectivity from estuarine barriers, rising sea levels and other climate change impacts have not been addressed in this report and require further investigation.

ID	Action	Description
C1.1-A	Invasive species management	Invasive species are a stochastic threat to estuarine and bay ecosystems and an ongoing pressure on the aquaculture industry. There is a lack of nationally coordinated monitoring, with limited data and few management options once an invasive species takes hold.
C1.2-A	Preventing harmful algal blooms	The long-term outlook for algal blooms depends on the management of the catchment (in particular, agriculture), freshwater and estuarine conditions, and climate variability (i.e., drought periods). A primary driver of algal blooms in freshwater systems is poor water quality, often associated with drought and reduced flow, and increased organic enrichment from upstream development and agriculture. Water quality is addressed through other repair actions in this report i.e., best-practice farm management (see 'Soils') and riparian replanting (see 'Inland water').
C1.3-A	Minimising impacts of vessel activity	Localised impacts include animal strikes, oil spills, and leaching of antifouling paints. Large oil spills and use of antifouling paints are regulated. Government can work preventatively to modify routes to minimise collision. It should also be noted that vessel activities can create noise issues for marine species, but this action has been excluded at this stage due to the lack of data.
C1.4-A	Managing impacts of seawater intrusion	There are limited data on the nature of seawater intrusion into coastal systems. This issue is best addressed by managing the over-extraction of coastal surface and groundwater systems (which have been partially addressed in the 'Inland water' section).
C1.5-A	Address impacts of aquaculture	Aquaculture activities are expanding and, drawing on evidence from overseas, there is the potential for anoxia, disease etc if fish pens (for instance) become particularly widespread. Effective planning can help to avoid establishment of aquaculture in areas that are currently coastal wetlands, or areas which will be inundated by salt water in the future due to sea-level rise. Changes to regulation may be required to address impacts of existing aquaculture activities in sensitive areas. This has not currently been included in the investment costings.

C1.6-A	Mitigate impacts of dredging	There are generally highly localised impacts and limited data on dredging nationally. It should be noted that while adult fish are unlikely to experience lethal impacts during dredging activities, fish during early life history stages are at risk of lethal and sub-lethal impacts at suspended sediment concentrations and exposure durations regularly occurring during dredging operations.
C1.7-A	Establish artificial reefs	It can be difficult to weigh up the costs and benefits of artificial reefs and outcomes are localised. There is however some evidence that 'nature smart' built infrastructure can be a benefit to restoration activities. The extent to which such infrastructure could play a role (and the cost) is however unclear due to a lack of data. In the future, with more data available, this could be a worthwhile action to include.
C1.8-A	Retrofit coastal armouring	The introduction of hard engineering structures (e.g., groynes and seawalls) directly alters surf-zone processes and sediment dynamics, displaces beach habitat, imposes connectivity barriers for species and can reduce aesthetic amenity. This is potentially a major issue for marine species (e.g., crabs) and the corresponding food chain, given the total extent of coastal armouring around Australia and its likely depletion of soft substrates. Ecologically-designed seawalls, for example the Living Seawalls project, and groynes that provide habitat could progressively replace or retrofit coastal armouring (as seawalls degrade for instance). In the future, with more data available, this could be a worthwhile action to include.
C1.9-A	Reduce water turbidity	Water turbidity can be exacerbated by activities within urban, industrial and agricultural centres, with impacts on fish and other aquatic life and increasing costs of water treatment. This is addressed in part by actions in the 'Inland water' section.
C1.10-A	Protect and restore mangroves	A total of 0.3 million hectares (40%) of mangrove forests are on private land and 0.4 million hectares (43%) is on leasehold forest, public forest, conservation reserves or other crown land (ABARES, 2019). According to the National Vegetation Information System (NVIS), around 8,000 ha or 4% loss of mangrove forests has occurred since European settlement (DCCEEW, 2023b). According to Clark and Johnston (2017) most mangrove forests across Australia are in good ecological condition, although restoration may be appropriate in some areas e.g., areas next to marginal cane farming for improving catchment water quality. While in the longer-term, climate change presents a threat, mangroves are considered to be in a relatively good position (extent and condition) to deal with this threat (Clark and Johnston, 2017). The restoration of 1,000 km of mangroves destroyed by a mass-dieback event in the Gulf of Carpentaria in 2015 -16 has not been costed. The cause of this event was found to be unusually low sea levels due to large scale swings in the El Nino – Southern Oscillation events (Duke *et al.*, 2022). The restoration of ponded pastures is likely to lead to the restoration of mangroves as well as saltmarsh, which will improve the resilience of these ecosystems.

C1.11-A	Sustainable management of recreational fishing	Recreational catch for some species (e.g., trophy species such as snapper) is likely to be unsustainable, but for other species it is improving e.g., flathead. Monitoring is the most important factor however, as data are limited, and some studies suggest recreational catch could be double that of commercial catch for certain species. Surveys and licensing regimes provide two options for gathering data – these could be cost neutral if supported by licensing levies. The benefits of habitat repair may somewhat offset the impacts of recreational fishing.
C1.12-A	Removing marine coastal debris, including plastics	High concentrations of debris are found in the marine environment, with significant quantities of large/micro plastics reported in the digestive tracts of several marine animal species. Much of this debris comes from outside Australia, and growth in plastics production and use is likely. Marine debris will continue to be a major problem for marine life, and ultimately other species in the food-chain including humans. Marine debris originating from outside Australia is difficult to manage, data are limited, and therefore this action has not been costed. The cleaning up of "Ghost Nets" in the Gulf of Carpentaria, however, is a success story.
C1.13-A	Addressing coastal lighting impacts on predator-prey dynamics	Coastal lighting (e.g., streetlights on piers and on roads next to waterways) has been shown at a local scale to exert pressure on the populations of coastal/marine species. Simple solutions, such as the retrofitting of lights with red bulbs, have been shown to mitigate such pressures. At this stage, such actions have not been included.
C1.14-A	Eliminating toxins, pesticide, and herbicide pollution	Point-source toxin inputs have decreased, but diffuse sources are mixed, depending on management approach. Significant efforts aim to reduce diffuse sources in the Great Barrier Reef catchment in particular. This issue is dealt with somewhat through actions listed in the 'Soils' section.
C1.15-A	Restoring modified flow regimes	Impacts of reduced freshwater flow is associated with drought, upstream modification, and coastal development. The issue is spatially variable but of most concern in the south and east of Australia where most development is concentrated. Refer to the 'Inland water' section which addresses these concerns.
C1.16-A	Decontaminating estuaries from legacy pollution	Large variation in legacy estuary pollution exists around Australia, with waterways near urban centres most affected. Sediments in parts of some urbanised and industrialised harbours are among the most polluted in the world. Costs are likely to be significant.
C1.17-A	Managing impacts of tourism and recreational use	There is growing pressure on the coastal and marine environment from increased tourist numbers and easier access to remote locations. Though localised, the cumulative impact could be significant. Data is limited, as are the mitigation actions. This action has not been included.

C1.18-A	Cost of repairing dune systems nationally	Dunes support native vegetation, and buffer against beach erosion and saltwater intrusion. Due to a range of social, economic, and political factors, the ecological health of dune systems is considered poor and deteriorating (Clark and Johnston, 2017). Many historical attempts to repair dune systems have led to unexpected consequences, such as the proliferation of weeds. Data on the ecological health of dunes are limited, as are management options. This aspect has been excluded from our analysis – however, it is acknowledged that dunes are very important and that more robust national baseline data and management solutions are needed if we are to arrest the deterioration of this environmental asset.
C1.19-A	Addressing oil, gas, and mining impacts	National environmental legislation is intended to assess and address the impacts of major developments (including oil, gas and mining) on matters of national environmental significance. There is need to reform the *Environment Protection and Biodiversity Act 1999* to ensure that impacts are being effectively considered, and where deemed acceptable, compensated for. Further consideration is needed to identify whether state and territory planning regulations are adequately addressing the impacts of these developments on broader environmental values. Other coastal pressures arise through transport activities and infrastructure (e.g., ports and shipping) can also be managed through regulation.
C1.20-A	Addressing impacts of sea level rise on ecosystems, beaches, public and private assets.	Aside from constructing seawalls, the planning for the upland migration of saltmarsh and mangrove communities is critical with regard to sea level rise - this will require land purchases, or at least rezoning to disallow development which will have both a public and private cost. The investment requirement to do this has not been estimated, though it is likely to be substantial.

Recommendations

Fixing two centuries of landscape degradation requires a sustained effort beyond the capacity of any one group, business, institution or government. A strategic, multi-scale and multi-sector approach is needed, bringing together the resources and intellect of public and non-government sectors to work collaboratively towards common objectives.

The approach must be guided by a national vision while embedding and giving prominence to local and regional contexts and planning, to reconnect people to the land so that investment and management decisions are driven by communities and underpinned by an understanding of how landscapes function (Binning *et al.*, 2001).

If the actions in this report are to be effective with lasting outcomes, eight measures are needed:

1. A long-term nation-wide strategic plan to repair Australia's landscapes, linked to regional NRM plans.

A national strategic plan setting out the objectives, targets, actions, roles and responsibilities for repairing landscapes, and strategies to attract investment and guide expenditure. The plan should be developed together with those who have a vital role to play in the repair effort (e.g. governments, businesses, communities, NRM regions and Aboriginal and Torres Strait Islander people). The national strategic plan should be linked to NRM plans developed by NRM regions at the catchment scale.

2. A national body (e.g. a National Council) of experts and/or representatives responsible for overseeing the initiative, delivering the strategic plan and enabling policy, law and governance reforms.

The national body would report to National Cabinet, with an agreed framework, clear principles and accountability. The body would be tasked with overseeing major components of the reform, including implementing the strategic plan and advancing the necessary policy/law/institutional reforms. Membership would comprise leading experts and/or representatives across integrated landscape management including Indigenous experts.

3. Use a regional approach to planning and delivery.

Australia's 54 NRM regions have a strong track-record in delivering a wide-range of sustainability-focused NRM extension programs, management strategies, and restoration projects across the continent. NRM regions are a mix of statutory bodies and non-government organisations that deliver national priorities for natural resource management on the ground. Each region has an NRM Plan, a strategic document that identifies the important natural assets within a region, where in the landscape these assets might be maintained, restored, or enhanced, as well as agreed outcomes and management actions.

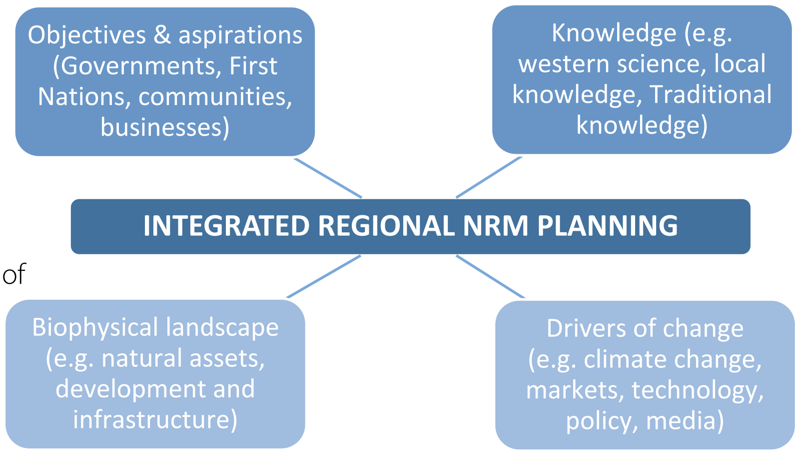

Figure 5. The integrating role of NRM planning in Australia, enabling solutions to be developed at the appropriate scale, in light of a range of priorities, local knowledge, diverse contexts and landscape dynamics.

The opportunities presented in this report build upon the successes and advances of strategic NRM planning over many decades and reinforces the vitally important integrating and delivery role that regions need to have in repairing Australia's landscapes (Figure 5). This will help to ensure actions are integrated, appropriate and strategic at the regional scale, enable coordination across sectors, and importantly, facilitate ownership and participation by regional communities.

4. Ongoing, sustainable source of finance for the repair effort.

Public investment will be an important source of funding for the repair actions critical to the health and prosperity of our nation. Increased public investment needs to be complemented by an increase in private-sector investment and philanthropic giving (individuals, corporates). Governments have a critical role in mobilising private sector investment through initiatives such as the Commonwealth's nature repair market framework, tax incentives and de-risking investment.

Governments can encourage investment in carbon projects that achieve outcomes for nature. Analysis by Herd *et al.* (2023) demonstrated that carbon and nature focused policies can deliver more than seven times more native habitat at an opportunity cost of only 20% less carbon in 2050, relative to a carbon-focused approach. This investment needs to be managed in a coordinated way across sectors and guided by the national strategic plan to drive long-term outcomes at scale across the country.

In 2023, the Australian Government established the legal framework for a national, voluntary nature repair market to enable private finance to repair and protect the environment and reward landholders for protecting biodiversity. Critical government-led enabling factors will be required to mobilise private investment in repair actions, including: a strategic investment plan; integrity standards; robust monitoring, evaluation and reporting protocols; environmental-economic accounting; incentives (e.g. tax incentives, de-risking nature investment); intermediaries and market development assistance to help structure complex conservation finance deals; technical and capacity-building assistance; and environment and planning laws that are appropriately adapted for nature restoration.

The Australian Government's sovereign green bond program launched in 2023 is designed to attract private sector investment for decarbonising the economy and supporting natural resource conservation and repair (AOFM, 2023). The Australian Office of Financial Management has commenced a global roadshow, with the first issuance to begin in 2024. Investment in landscape repair should be incorporated into the Australian Government Green Bond Framework and future roadshows.

Globally, several reviews of international and domestic finance approaches have been undertaken (Ward and Lassen, 2018, Deutz *et al.*, 2020, UNEP, 2022). The Australian Land Conservation Alliance identified at least 25 major finance approaches around the world, spanning government financing, private sector investment and philanthropic donations (see Appendix V) (Ward and Lassen, 2018). These should be considered based on their relative deployment complexity, scalability and suitability for Australia.

5. Unlock the potential for Aboriginal and Torres Strait Islander people to take leading roles in the landscape repair agenda.

This can be achieved by the recognition of inherent rights of Indigenous Peoples, increasing Indigenous ownership and management of land and water, recognising the value of traditional knowledge to repair and manage Country, establishing and expanding programs to permanently employ Aboriginal and Torres Strait Islander people to repair and manage Country, and enabling broader socio-economic benefits from the repair and stewardship of Country (see Synthesis report).

6. Support communities and businesses to drive repair actions.

We consider it imperative that there is an emphasis on supporting industries and communities to shape the repair effort and do so in a way that builds enduring community capacity and leaves people better off in the future. There are many opportunities, such as an agricultural productivity stimulus package, extension activities to promote adoption of better management practices, using emerging technologies, training the workforce to maximise the opportunities ahead, and providing financial incentives to encourage greater participation (see 'Inland water' and 'Native vegetation' actions).

We also know that a national repair effort will involve trade-offs, particularly in our agricultural regions, and that agricultural productivity improvement has declined in recent decades. There is mitigation in the new streams of income available to farmers through the actions proposed in this assessment and related initiatives. Central to this repair effort is the need to mitigate trade-offs at the regional and overall program level, having explicitly identified the nature and cost of those trade-offs. For example, we show it is possible to target restoration of native vegetation outside areas of prime agricultural land while recovering 30% of almost all native vegetation communities (see 'Native vegetation' actions).

7. Policy, law and governance reforms to prevent current and future degradation of Australia's landscapes, support restoration actions and ensure integrity and accountability.

For the repair effort to be successful, effective environment laws and regional-scale land and water use plans need to be in place to protect important natural assets and ecosystems, and prevent adverse impacts of development, human activities and other threats. This includes policies which prohibit broad-scale land clearing, address cumulative impacts of development and activities, and ensure sustainable management of river systems. Governments will also need to ensure integrity and accountability through enforceable, transparent and coherent regulatory and governance mechanisms. We must streamline and better coordinate pathways for restoration projects through the planning system, for example, through dedicated permitting processes for restoration projects (Bell-James et al., 2023).

8. A system of environmental accounts at national, regional and property scales.

We need to put in place a standard system of environmental accounts across the nation, implemented at national, regional and property scales to monitor the condition of our environmental assets, verify outcomes of investment, track progress towards our goals, identify areas in need of urgent attention, and better inform the management of landscapes. National accounts should be underpinned by robust data systems, processes and adequate resources to enable improved, systematic collection, collation and synthesis of data, and to increase data accessibility and transparency.

Appendix I: Asset Condition Indicators, State, and Objectives

Table 5. Indicators of condition of key assets based on the Wentworth Group's environmental accounts program, the current state of assets as per the 2021 Commonwealth State of the Environment report and the objectives put forward in this report to improve the state of assets.

Asset	Indicators of condition (Sbrocchi *et al.*, 2015)	Status and pressures (Cresswell *et al.*, 2021)	Objectives (Wentworth Group assessment)
Soils	• Salinity • Soil organic carbon • Soil acidification • Water erosion • Wind erosion • Nutrients • Physical condition • Biophysical condition	• Overall soil health (i.e. condition) – Poor • Soil health in intensive land-use zone – Very Poor • Pressures that degrade natural capital – High Impact • Management of natural capital assets and pressures – Partially Effective • Management of soils – Partially effective	S1 Improve physical and chemical condition and productivity of agricultural soils that need remediation due to long term degradation and where that remediation is not likely to occur without direct investment. S2 Repair gully erosion hot spots across Australia to improve water quality in rivers and expand the availability of healthy land for agriculture and wildlife. S3 Connect agricultural land management practices with broader national ambitions for biodiversity, climate change and agricultural productivity.
Inland Water	• Flow and flooding regimes • Physical form • Water quality (physical/chemical parameters) • Riparian vegetation • Aquatic biota (e.g. waterbirds, fish) • Ecosystem processes • Freshwater ecosystems	• Water supplies -Poor • Condition of water-dependent ecosystems and heritage – Poor • Geographic social and cultural inequities in water supply – Poor • Water use and restrictions – Low impact • Water management – Partially effective	R1 Establish and restore riparian buffer zones on all of Australia's rivers and streams to protect productive land from erosion, support biodiversity, improve water quality and enhance the productivity of fisheries and health of freshwater and marine ecosystems. R2 Restore overallocated river systems to sustainable levels of take. R3 Restore lateral and longitudinal connectivity of rivers, floodplains and their wetlands. R4 Improve the efficient use and sustainability of groundwater resources.

Native vegetation	• Extent • Composition • Configuration • Structure	• Native vegetation extent and condition – Poor • Status of native and threatened plants – Poor	V1 Restore native vegetation cover to at least 30% of pre-1750 extent in a healthy ecological condition for each of Australia's terrestrial ecosystems. V2 Reduce the frequency and intensity of fires impacting Australia's tropical savannas.
Threatened species	• Population • Habitat extent • Distribution	• Status of native and threatened animals – Poor • Pressures from human population – Very high impact • Pressures from industry – Very high impact • Pressures from invasive species – Very high impact • Effective management of biodiversity – Partially effective	T1 Mitigate imminent extinction risk and ensure medium term survival of most Commonwealth-listed threatened species.
Coastal Environments	• Physical/Chemical indicators • Biological indicators • Foreshore vegetation	• Condition of beaches and shorelines - Poor • Condition of coastal waterways – Poor • Condition of coastal ecosystems and habitats – Poor • Condition of coastal species – Poor • Pressures from climate change and extreme weather – High impact	C1. Support coastal biodiversity and improve coastal fisheries productivity.

Appendix II: Assumptions

Table 6. General Assumptions

Aspects	Key assumptions
Impacts of climate change	It is assumed that best efforts to meet the Paris target of "well below 2 degrees Celsius" will be met. The impact of climate change on ecological systems has generally not been modelled in this assessment. The broad assumption is, however, that if an environmental asset is returned to a healthy ecological condition, and there are adequate and representative population numbers, this will ensure these assets stand the best chance of rebounding from, and being resilient to, the impacts of climate change. It is acknowledged that this will not fully compensate for climate change impacts but will mitigate some of the most adverse impacts. In this respect, it is acknowledged that the restoration of environmental assets (where they are returned to their pre-1750 type/condition) may not be possible. Therefore, climate adaptation planning and adaptive management must be undertaken in light of climate change projections (e.g., where possible, planning the location of terrestrial conservation areas should ideally allow flexibility over time).
Future environmental degradation	Not taken into account. We have assumed "no net loss" for assets including native vegetation and soil into the future – in this respect, it is assumed that stronger environmental laws and incentives will be enacted at all levels of government in Australia, and that development will be undertaken in a way that does not contribute to further degradation.
Systems approach	The conservation and repair actions proposed here should be considered as a landscape "package" of measures and executed together and in full to maximise benefits at the ecosystem scale. However, it is also recognised that undertaking actions simultaneously may not be practical – these measures should be progressively rolled-out between 2025 and 2055, as budgets and resources allow. The earlier they are implemented, the better outcomes will be overall (e.g. build climate resilience early to mitigate/minimise future losses).
Data	The best available national, sub-national and (where possible) spatial data and information have been used to inform these estimates. Information has been used from a broad range of data sources and from consultations with experts who represent a range of scientific and economic disciplines. Where possible, spatial data, empirical studies and other sources of evidence were used. In some cases, experts contributed directly to estimates. In other cases, workshops were held to gather data and information, discuss issues and elicit expert opinions. Evidence and assumptions are made explicit in the costing section for each action.
Australian External Territories	Australian External Territories, such as Heard and Norfolk Islands, have not currently been included in this assessment.

Table 7. Economic Assumptions

Variable	Key assumptions
$	All investment estimates quoted are in 2022 Australian dollars. Pre-2022 costings were converted to 2022$ using the Inflation rate (see below).
GDP	Gross Domestic Product (GDP) for FY22-23 was calculated to be $2,406,800,000,000 based on seasonally adjusted chain volume measures (ABS, 2023). This is applied when annual investment estimates are described as a percentage of GDP.
Farm opportunity cost	Land "stewardship payments" have been determined using the Average Profits Method approach to valuing agricultural goodwill via 12-year average farm-cash income (2001-2013) paid out annually for 20 years (ABARES, 2014).
Native vegetation replanting, repair, and management costs	See 'Native vegetation' for more detail.
Riparian replanting, repair, and management costs	See 'Inland water' for more detail.
Estuarine and coastal ecosystem repair and management costs	See 'Coastal environments' for more detail.
2050 land use change and food production scenarios	The average of two sets of scenario modelling results from *Australian National Outlook* (ANO) Land Use Trade-Offs (LUTO) model were used to exclude potential areas of "prime agricultural land" in 2050 from where native vegetation might be restored and conserved across Australia. The core assumptions behind these two scenarios ('S341_M2_MPI-ESM-LR_M_Bio_2x_C'; and 'S342_M2_MPI_ESM-LR_H_Bio_2x_C') are: Agricultural Productivity Growth Rates (1.5% versus 3.0%); 'Biodiversity focused carbon payments', 'strong global GHG mitigation scenario', with '2x agricultural profit hurdle' required to adopt trees; maximum 100,000 ha of trees can be planted per annum. The average Agricultural Productivity Growth Rate is therefore 2.25% (Bryan *et al.*, 2015, Hatfield-Dodds, 2015, Grundy *et al.*, 2016).

Transaction costs	Given the significant economies of scale concerned here, transaction costs (e.g., legal costs of land tenure transfer) are assumed to be 10%, on average, of the upfront capital cost for each repair and conservation project. Transaction costs also include the additional costs that the landholder or government incurs collecting their own information (including opportunity costs associated with the time spent on such activities), and time in extension and regulatory compliance activities. Regulatory compliance is another additional cost incurred by the landholder in complying with regulation, above and beyond the direct and indirect costs already identified (Alluvium, 2016).
Climate policy, carbon credit integrity and carbon price	It is assumed that a strong 'safeguard mechanism' will create sufficient demand for carbon credits over time. A \$35/tCO2e carbon spot price scenario and \$75/tCO2e cost containment scenario were considered in this analysis, rising at 4.5% per year (see 'Native vegetation' chapter for details). It is assumed that the Australian Carbon Credit Units (ACCUs) available on the market are high-integrity, following the Federal Government's commitment to implement the recommendations of the Independent Review of ACCUs (Chubb *et al.*, 2022) and of the Climate Change Authority's review of the ACCU scheme (CCA, 2023).
Economic and social benefits, aside from carbon revenue and farm productivity	This report describes some economic benefits from terrestrial carbon sequestration (in vegetation and soils). However, there are other economic benefits arising from natural capital repair, conservation, and management e.g., the net increase in land value due to more native vegetation creating greater landscape amenity. These benefits have not been accounted for because estimation methodologies vary widely across different environmental asset types, and/or because the institutional arrangements are not available. Despite their importance, this study does not provide a cost-benefit analysis in this regard. Unaccounted for economic benefits include (for example): avoided soil salinification and avoided agricultural losses; economic benefits gained through greater water security; and increased commercial and recreational fishing production as a consequence of restoring estuarine and coastal ecosystems.
Inflation rate	Actual averaged annual inflation rates used until 2022, as published by the Reserve Bank of Australia (RBA, 2023b).

Investment period, discount rates and present value	The investment period is assumed to be 30 years from 2025 to 2054. Over this time period, different actions are assumed to have different start and finish dates and require different project financing durations. This is highlighted in the respective table for each environmental asset class (see accompanying spreadsheet). The different start and finish times impact the overall cost of each action when considered in 2022 dollars due to inflation and the weighted-average cost of capital increasing over-time. By adjusting for these changes, it is possible to compare the relative cost of each action in today's dollars. A discount rate of 5% per annum has been used to provide a present value of all future costs in 2022$. An inflation rate of 2.5% per annum was used to account for the increase in the price of actions. These assumptions are in line with the Australian Government's Intergenerational Report 2023, Department of Finance Factsheet 30 June 2023 and the Reserve Bank of Australia's longer term projection of inflation (Australian Department of Finance, 2023, Australian Government, 2023, RBA, 2023a).
Economies of scale	In the case of landscape-scale repair (e.g., replanting riparian buffer zones), the lowest cost of repairing and conserving the land has been adopted, as it is assumed costs will be driven down over time, given the significant economies of scale concerned and future technologies, and through, for example, the use of market mechanisms and reverse tender processes.

Appendix III: VAST framework

Figure 6. Vegetation, Assets States and Transitions (VAST) framework, and the threshold at which native vegetation is considered to be in a healthy ecological condition (Thackway and Lesslie, 2006).

INCREASING ECOLOGICAL HEALTH

Code	Category	Description
0	Naturally bare	Areas where native vegetation does not naturally persist and recently naturally disturbed areas where native vegetation has been entirely removed (i.e. subject to primary succession).
1	Residual	Native vegetation community structure and composition, with regenerative capacity intact – no significant perturbation from land use/land management practices.
2	Modified	Native vegetation community structure, composition and regenerative capacity more or less intact, perturbed by land use/land management practices such as intermittent low intensity grazing.
3	Transformed	Native vegetation partly removed but community structure, composition and regenerative capacity has been significantly altered by land use/land management practices.
4	Largely replace and degraded	Native vegetation largely replaced by invasive native and/or exotic plant species (commonly areas abandoned or burnt).
5	Replaced and managed for intensive production	Native vegetation completely removed and replaced with intensive agriculture: rain-fed broad-acre crops, feed lots, horticulture, irrigation agriculture and long or short rotation forestry. Various types are recognised in the vegetation classification.
6	Replaced with man-made structures	Settlements and cultural features – e.g. buildings, roads, water reservoirs; gardens, parks and amenity plantings.

VAST 2 is the assumed threshold for "healthy native vegetation" i.e. where it can repair itself via passive regeneration

Going from VAST 3 classified native veg to VAST 2 requires active "**repair**" (<50% of area

Going from VAST 5 classified native vegetation to VAST 2 requires "**replanting**" (50% or more replanted)

Appendix IV: Where is the 30% target not achievable?

The table below provides a list of bioregional groups for which the 30% of pre-1750 native vegetation extent could not be achieved, to maintain prime farmlands for agriculture, or because the area has been settled as an urban zone. The table also shows the shortfall in area (ha and %) to meet that target. For example, the Eucalypt Open Woodlands of the Geraldton Sandplains fell short by just 0.5%.

Table 8. Native vegetation biogeographical groups where the 30% target cannot be met through restoration in protected areas and on non-prime agricultural land (Mappin et al., 2022).

Bioregion/Major Vegetation Type	Total Region Area (ha)	Max area able to be repaired and/ or conserved (ha)	Progress to target (30% is max)
Geraldton Sandplains_Eucalypt Open Woodlands	2,029	599	29.5%
Desert Uplands_Casuarina Forests and Woodlands	1,642	482	29.4%
Southern Volcanic Plain_Other Shrublands	54,547	15,849	29.1%
Tasmanian Southern Ranges_Eucalypt Woodlands	27,872	7,914	28.4%
Central Mackay Coast_Melaleuca Forests and Woodlands	78,255	22,043	28.2%
Tasmanian Northern Midlands_Mallee Open Woodlands and Sparse Mallee Shrublands	8,919	2,438	27.3%
NSW South Western Slopes_Mallee Open Woodlands and Sparse Mallee Shrublands	37,196	9,798	26.3%
Southern Volcanic Plain_Mallee Open Woodlands and Sparse Mallee Shrublands	52	12	23.9%
Kanmantoo_Other Grasslands, Herblands, Sedgelands and Rushlands	2,290	540	23.6%
Darling Riverine Plains_Mallee Woodlands and Shrublands	13,538	3,044	22.5%
Sydney Basin_Acacia Forests and Woodlands	5	1	20.0%
Naracoorte Coastal Plain_Melaleuca Forests and Woodlands	46,865	9,227	19.7%
Great Victoria Desert_Other Grasslands, Herblands, Sedgelands and Rushlands	95	18	19.1%
South East Coastal Plain_Eucalypt Open Woodlands	6,879	1,284	18.7%
South Eastern Highlands_Other Grasslands, Herblands, Sedgelands and Rushlands	50,852	8,053	15.8%
Nandewar_Other Grasslands, Herblands, Sedgelands and Rushlands	214	27	12.4%
Eyre Yorke Block_Eucalypt Open Woodlands	33,399	3,893	11.7%
Tasmanian Central Highlands_Chenopod Shrublands, Samphire Shrublands and Forblands	9	1	11.1%
Cobar Peneplain_Acacia Open Woodlands	21	2	10.1%
South East Coastal Plain_Mallee Open Woodlands and Sparse Mallee Shrublands	4,266	268	6.3%
Victorian Midlands_Casuarina Forests and Woodlands	379	-	0.0%
Mallee_Tussock Grasslands	24	-	0.0%
New England Tablelands_Other Forests and Woodlands	21	-	0.0%
NSW South Western Slopes_Chenopod Shrublands, Samphire Shrublands and Forblands	20	-	0.0%
Darling Riverine Plains_Hummock Grasslands	57	-	0.0%

Appendix V: Overview of conservation finance sources

Table 9. Overview of conservation finance sources and approaches, adapted from the Australian Land Conservation Alliance report (Ward and Lassen, 2018).

Source	Conservation Financing Approach	Description
Government funding *No financial returns expected. Industry development, management of public goods, catalysing of private finance expected.*	Grants	An arrangement for the provision of non-repayable financial assistance gifted by one party to another.
	Environmental levies	A tax/charge levied against a good or service with the proceeds to be used to fund environmental outcomes.
	Favourable tax incentives	An offset or deduction that reduces the taxes owed by a person or entity.
	Environmental trust funds	An investment special purpose vehicle (and legal entity) setup to mobilize, blend, allocate, and manage funding for environmental purposes
	Ballot measures	Voter initiated referenda and direct democracy instruments that voters can use to shape public policy at the voting booth. Common in the US.
Private investment *Financial returns and conservation outcomes expected.*	Bridge financing	A temporary loan to fill a finance gap between the availability of permanent funding and the immediate need to purchase an asset, used in public/private sectors.
	Revolving land funds	Funds used to purchase, protect and sell conservation land – proceeds are used for subsequent land purchases.
	Seller (vendor) financing	Where a seller accepts a portion of the sales price upfront, and future periodic payments/interest for the remainder.
	Program-related investment	Where a privately-run foundation provides a loan/equity on more favourable terms than commercial markets.
	Environmental credit markets	Putting a value on the benefits of an ecosystem service via monetising these benefits as "credits", which may then be sold or traded on a voluntary or compliance market (e.g. Nature Repair Act 2023).
	Green bonds	A bond where proceeds are utilised for financing environmentally friendly projects or activities.
	Outcome-based models	Pay-for-success contracting where a government limits the contractor's losses in case projects are unsuccessful.
	Green product and service certification	Using a standardised framework to verify the environmental outcomes of a good or service.
	Impact investing in real assets	Real asset investments (e.g. real estate, water rights) that are managed using sustainability practices.
Philanthropic giving *No financial return expected. Conservation outcomes expected*	Individual donations	A monetary gift to a cause or project by a donor, with no financial return/repayment expected.
	Voluntary surcharges	Places an added charge onto a retail, hospitality or lodging customer's bill on an opt-in or opt-out basis.
	Crowdfunding	The practice of funding a project by raising small amounts of money from many people.
	Transfer fees	An additional fee paid into a stewardship account, as part of a covenant transaction with a land trust.
	Corporate Social Responsibility	A voluntary effort by a corporation to take responsibility for its environmental and/or social impacts.
	Corporate-cause marketing	Where a for-profit entity agrees to donate a percentage of its sales or profits to a cause.

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