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Biodiversity and agricultural landscapes: where are the gaps?

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1 Introduction

One of the many challenges in agricultural regions worldwide is how to conserve the native biodiversity of each region, given that most of the land and associated water resources in these regions are managed for food and fibre production. In some parts of the world, the opportunity has long since passed: for instance, Ireland had lost virtually all its primary tree cover by 1600 (Montgomery and Reid, 2024). In other regions where agricultural expansion is still ongoing, such as Amazonia, the challenge is to cease illegal deforestation and improve the well-being of the indigenous human population that has long co-existed with their rainforest home. This will require law enforcement and conservation financing to plan a future where the human and the natural world can coexist indefinitely (Hanusch, 2023).

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Most agricultural regions of the world exist somewhere between these two extremes, where transformation has led to the loss of a large part of the natural landscape in favour of agriculture but where varying amounts of wild nature persist in varying degrees of modification. The natural areas in such agricultural landscapes are usually much reduced in extent, fragmented and their habitat condition degraded. Such regions are in the grip of an extinction spasm (as defined by Myers, 1987), with biotic relaxation (loss of species) occurring steadily through time (Tilman et al., 1994; Blanchard and Munoz, 2023). This extinction debt is caused by earlier habitat loss, fragmentation and modification due to agricultural transformation and is exacerbated by further reduction and alteration of the native habitats that remain.

The challenge is therefore how to safeguard what remains of the native biodiversity associated with pre-agricultural landscapes in the face of extensive and sometimes almost complete transformation of land and water resources for agriculture. The 15th Conference of the Parties to the UN Convention on Biological Diversity (CBD) in Montreal in December 2022 responded with what is known as the Kunming-Montreal Global Biodiversity Framework. The framework supported by over 190 countries committed the parties to (CBD, 2022):

- cease transforming natural areas ('Reduce to near zero the loss of areas of high biodiversity importance and high ecological integrity' (Target 1 of the framework);
- restore at least 30% of degraded terrestrial, inland water and marine and coastal ecosystems by 2030 to enhance biodiversity and ecosystem functions and services, ecological integrity and habitat connectivity (Target 2); and
- conserve and manage for biodiversity conservation at least 30% of the world's lands, coastal areas and oceans by 2030 (Target 3), noting that only 17% of land and 8% of marine areas were adequately protected and managed for biodiversity globally in 2022.

Target 3 had its origins at the 74th United Nations General Assembly in September 2019, where a handful of countries announced their intention to form a coalition for nature. This group officially launched as the High Ambition Coalition for Nature and People (2024) in January 2021.

While there is some evidence that 30% represents a tipping point for the rate of extinctions once the area of remaining habitat drops below this figure (Andrén, 1994), species–area relationships are in fact a continuum. The less habitat that remains, the greater the eventual loss of species. The contribution of a particular percentage of remaining habitat managed for biodiversity outcomes is contingent on the biota and the life-history characteristics of the component species, the size and configuration of the remnant habitats, their management, threats and the ecological dynamics of the broader landscape matrix (Carroll and Noss, 2022). Targets such as 30% by 2030 are thus empirical generalisations and do not pretend to guarantee the conservation of all biodiversity into the future. Indeed, Target 3 is simply an interim goal given the 2050 Vision of the CBD (Watson et al., 2023).

However, Carroll and Noss (2022) have argued that percentage-protected targets such as 30% by 2030 can anchor comprehensive national and regional biodiversity strategies and communicate the level of ambition necessary to reverse or at least slow the current trends of biodiversity loss. They accepted that what is possible to achieve for conservation in an ecoregion with abundant remaining wild area is quite different from what can be achieved in an ecoregion dominated by intensive agriculture. Regions where restoration of degraded and denuded areas is needed will require substantial effort, funds and time to meet the 30% target. In such cases, the 2030 timeline for delivering these targets is unrealistic.

Following the lead of the High Ambition Coalition for Nature and People and the Global Biodiversity Framework, several countries have developed plans, strategies or regulations broadly embracing the 30% target by 2030. In May 2021, the US announced a locally led, voluntary, nationwide conservation goal to conserve 30% of US lands and waters by 2030 (Anon, 2021). In June 2021, the Parliament of the European Union (EU) adopted the *EU Biodiversity Strategy for 2030*, which proposed legal protection of a minimum of 30% of Europe's land (including inland waters) and sea, with at least one-third under strict protection, including all remaining primary and old-growth forests (EC, 2021; EU, 2021). In September 2022, Australia's *Threatened Species Strategy Action Plan 2022–2032* (DCCEEW, 2022b) was launched by the federal government, committing to conserve at least 30% of Australia's land mass by 2030, a commitment agreed to by the state and territory ministers in the following year (DCCEEW, 2024).

2 How to reach the 30% target for biodiversity conservation of the world's lands by 2030

In most agricultural regions across the globe, the current UN-sanctioned challenge is to achieve effective biodiversity conservation of 30% of each of the major land and habitat types, including wetlands, on a regional basis. The precise wording of Target 3 ('Conserve 30% of Land, Waters and Seas') in the Global Biodiversity Framework with respect to terrestrial ecosystems is to (CBD, 2022)

> *Ensure and enable that by 2030 at least 30 per cent of terrestrial and inland water areas … and coastal areas, especially areas of particular importance for biodiversity*

and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories, where applicable, and integrated into wider landscapes … while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities, including over their traditional territories.

The question posed in this chapter thus becomes 'How best to restore habitats in extensively transformed agricultural regions such that at least 30% of the land within these regions is managed for biodiversity conservation?' Two approaches can improve biodiversity outcomes:

- bottom-up approaches and
- top-down approaches.

Bottom-up approaches are the management actions undertaken by farmers on their properties. Many of the chapters in this book describe actions and activities that farmers can take to maintain or restore native biodiversity on their farms not only often to their material benefit but also simply because they think it is the 'right' thing to do (Klebl et al., 2024). Examples include:

- regenerative or eco-farming (Bennett et al., 2024; Squire and Hawes, 2024);
- coordinated activities of networks of farmers to address high-priority issues, such as weed control in Victoria (Australia) and conservation farming initiatives in the Chesapeake watershed (USA) (Alter et al., 2024);
- prioritising soil health through a range of farming practices (Day et al., 2024);
- taking a spatially hierarchical approach to restoring biodiversity in farmland (Lindenmayer et al., 2024; Bennett et al., 2024), given the importance of habitat heterogeneity at multiple scales, from:
  - individual structures such as peatlands (van Diggelen, 2024), farm dams, buildings and large old trees (Lindenmayer et al., 2024; Bennett et al., 2024), to
  - in-field or paddock scale, by creating semi-natural field margins (Morrison, 2024), or establishing and managing hedgerows (Montgomery and Reid, 2024) and native plantings for native biodiversity (Lindenmayer et al., 2024); and
  - whole farm and landscape (cross-tenure) scale, where different agricultural enterprises, the conservation of remnant native vegetation for wildlife habitat and habitat connectivity and coordinated threat

management are critical considerations (Bennett et al., 2024; Lindenmayer et al., 2024).

These approaches can range from activities on individual farms to large-scale collaborations by groups of farmers and others across regions or watersheds (Alter et al., 2024).

Top-down approaches are governmental statutory and policy interventions that prohibit, encourage or require farmers to undertake specified management actions on their farms. Examples of top-down approaches to maintaining or restoring native biodiversity on farms are outlined in multiple chapters in this book and include:

- government-funded extension and training programs for farmers to establish and manage hedgerows on-farm (Montgomery and Reid, 2024);
- government payments to farmers for biodiversity-positive environmental management, and the preservation or restoration of natural ecosystems on their farms (Dodsworth et al., 2024; Rausser and Zilberman, 2024; Lewis-Reddy, 2024; Jones et al., 2024);
- establishment of nature-positive markets by governments to encourage philanthropy and the private sector to incentivise farmers to conserve biodiversity on-farm (Ansell et al., 2024);
- government reversal of pest animal policies and regulations that permit the return of wild animals to agricultural regions (Smith et al., 2024; Dickman et al., 2024); and
- government purchase of farms with high potential for management and restoration of high-conservation-value species and ecosystems (Dickman et al., 2024).

Other top-down approaches include legislation that outlaws native vegetation clearance, preventing natural habitats from being converted into farmland. While cessation of habitat clearance is essential to prevent even more losses of native biodiversity in the future, command-and-control regulations are often found wanting and can provoke even greater loss of habitat than might have otherwise been the case, taking several iterations to achieve the level of control and habitat preservation desired (e.g. Bartel, 2003, 2004; Fowler, 1986; Harris, 2024). The design of new natural capital markets can also be imperfect, resulting in suboptimal outcomes and requiring adaptive finetuning over time (Chubb et al., 2022; Macintosh and Butler, 2023; Rausser and Zilberman, 2024; Ansell et al., 2024).

In addition to bottom-up and top-down approaches, third parties such as philanthropists, non-profit organisations, researchers and research institutions can play a role in helping farmers to conserve native biodiversity on their farms.

They may provide biodiversity data that enable farmers to apply for payment for biodiversity-positive management or trade in biodiversity markets (Dickman et al., 2024). Philanthropic individuals and consortia, non-profits and research institutions may also purchase and manage farms exclusively for biodiversity (e.g. Dickman et al., 2024).

However, the problem with all these approaches is that, in practice, they are unlikely to make much progress towards 30% by 2030 (Cozim-Melges et al., 2024). Either biodiversity-positive management is confined to small areas of farms (e.g. field margins or boundaries), or only a few farmers are convinced by the available incentives to adopt biodiversity-positive management or conserve and manage land for conservation, or few farms are purchased to restore native biodiversity. For instance, the private land listed under heritage agreements dating back to 2010 in New South Wales to conserve biodiversity in perpetuity is less than 0.5% of the area of the state (NSW DCCEEW, 2024), and non-profits manage only 1% of Australia for biodiversity conservation (DEECCW, 2022a).

The lack of adoption of biodiversity-positive management is due to many factors (FAO, 2019), including:

- the complexity of many biodiversity-focused practices;
- their context specificity and the need for a good understanding of the local ecosystem;
- often high short-term costs compared to benefits that only accrue in the medium to long term; and
- the joint need to both build landowner capacity to manage biodiversity assets and develop new policy frameworks.

In addition, many species cannot thrive in human-modified landscapes and need undisturbed natural areas, and sometimes large areas of native habitat, to persist in predominantly agricultural regions (Pauli et al., 2017; Dietz et al., 2020; Williams et al., 2022).

In many agricultural regions worldwide, achieving 30% of land set aside for biodiversity conservation by 2030 will therefore be difficult, if not impossible, because the extent of remaining natural areas in the most intensively farmed regions is often well under 30% and sometimes closer to 1%. South Australia is a global example of the over-zealous transformation of nature for farming. The amount of remnant native vegetation across some parts of the state (e.g. the Mount Lofty Ranges and Adelaide Plains, the lower South-East and Yorke Peninsula) in 1976 was estimated at less than 10% of the original vegetation cover, prior to the introduction of vegetation clearance controls (Fowler, 1986). Remnant native vegetation is in a similarly parlous state in many other agricultural regions across southern and eastern Australia and other parts of the world.

For regions like these, the types of initiatives described in many of the chapters in this book will be unable to bridge the gap in land managed for biodiversity conservation. While generally positive for biodiversity, the initiatives described in earlier chapters do not advocate large increases in the area of biodiverse habitat on farms or across farming regions. Rather, initiatives such as the establishment of hedgerows, biodiverse field margins, wildlife corridors and farm dams and maintenance of remnant native vegetation are likely to lead to only minor increases in biodiverse habitats on farms and across agricultural districts, and management in most cases will continue to be agriculturally focused. This is essentially a 'business as usual' approach and will not arrest much of the imminent loss of biodiversity predicted for regions that have been recently heavily cleared.

This leaves only one option in regions that have fallen well below the 30% threshold: restoration of large tracts of existing farmland to habitats managed for native biodiversity. This can be achieved by paying existing farmers to revegetate and manage land and wetlands for biodiversity. Alternatively, government or philanthropic institutions can purchase farmland, including whole farms and clusters of farms, to restore native biodiversity. The need for ecosystem restoration on a massive global scale was anticipated by the United Nations in 2019, with its declaration of the Decade on Ecosystem Restoration, 2021–2030 (https://www.decadeonrestoration.org/what-decade). The aim of this decadal program is to restore ecosystems on an immense scale of hundreds of millions of hectares globally (UNEP and FAO, 2020). The justification for the Decade on Ecosystem Restoration was to mobilise political and popular support, and technical and scientific capacity in the public and private sectors, to invest in the many hundreds of thousands of ecosystem restoration initiatives worldwide needed to address the biodiversity and climate crises and achieve the UN Sustainable Development Goals (Meli et al., 2023).

The following case study of ecosystem restoration at scale originated when the South Australian Government purchased a large area of farmland decades ago in the Adelaide – Mount (Mt) Lofty region for a new city that was not finally built. A biodiversity conservation non-profit, BioR, subsequently commenced broad-scale revegetation of woodland and mallee habitats in the region, where retention of native vegetation is currently well below the 30% threshold.

3 Case study: conserving biodiversity in agricultural landscapes – the need for a regional approach in southern Australia

The Mt Lofty region in South Australia was settled by Europeans in the 1830s and subsequently transformed into a productive agricultural region, with areas of viticulture, horticulture and extensive cropping and grazing. At the time of settlement, the region was covered in a diversity of woody habitats from coastal scrubs to heathland and a range of different eucalypt woodlands and forests (e.g. Paton et al., 2000). In the following 150 years, much of this original vegetation was cleared for agriculture and, to a much lesser extent, housing. Adelaide, the capital of South Australia, with its expanding suburbs, lies within the region.

By the early 1980s, less than 10% of the original vegetation remained. The vegetation across the lower elevations, which were more amenable for agricultural development, was disproportionately cleared. In these areas just 2% of the original vegetation remained by 1980 while, at higher elevations with steeper slopes and ridges and more skeletal soils, around 16% of the native vegetation remained (Paton et al., 2000). The loss of native vegetation has had profound impacts on the biota, with many species experiencing substantial declines in distribution and abundance and important ecological processes like pollination being disrupted (e.g. Paton, 2000; Paton et al., 2004). Although introduced honeybees can offset losses of pollination services for some of the native plants, honeybees can equally exacerbate the damage by competing with native fauna for floral resources (Paton, 1996).

The extent and pattern of vegetation clearance in the Mt Lofty region is replicated in other parts of temperate South Australia, as well as southern Australia in general. In the early and mid-1980s, the South Australian Government introduced legislation to initially reduce and ultimately prevent further large-scale clearance of native vegetation. This largely prevented further reductions in the cover of remnant native vegetation across the arable regions of South Australia, including the Mt Lofty region, but small areas continue to be cleared under permit.

Despite the extent of vegetation clearance, the Mt Lofty region along with Kangaroo Island was listed as one of 15 biodiversity hotspots across the continent by the Australian Government in 2003 (e.g. see Taylor et al., 2018). This reflects both the isolation of the woodlands in this region from other similar woodlands in south-eastern Australia, and the impending loss of biodiversity from the region. Ford and Howe (1980) were the first to point out that with just 10% of the native vegetation remaining, 35–50 of the 115 woodland bird species that originally occurred in the Mt Lofty region were likely to disappear, irrespective of how well the remnant vegetation was managed, because the amount of habitat remaining was insufficient to support all the species. The predicted losses of woodland bird species might be higher than this, given that the remaining vegetation is no longer pristine and is threatened by a range of perturbations, including incursions of weeds, excessive browsing of the understorey (e.g. Prowse et al., 2019, particularly by over-abundant Western Grey Kangaroos *Macropus fuliginosus*) and climate change.

As predicted by Ford and Howe (1980), most of the Mt Lofty region's woodland bird species have continued to decline since the early 1980s, despite there being no further vegetation clearance (Paton et al., 1994, 2004; Szabo et al., 2011; Prowse et al., 2021). Ten species are now considered regionally extinct and, for many others, regional extinction is imminent unless substantial amounts of additional woodland habitat are re-instated across the region in a timely fashion. The reason why many of the woodland bird species have not yet disappeared is because there is a time lag between the initial clearance of native vegetation and the loss of species: the disruption to demographic processes (reproduction, survival and dispersal) caused by vegetation clearance, which then leads to the disappearance of species, takes time to unfold. This lag provides a unique opportunity to reverse imminent species loss by reinstating sufficient additional habitat before it is too late. Delaying the re-instatement of habitat reduces the numbers of species that are ultimately retained.

The critical requirement is to put back substantial amounts of appropriate habitat. However, revegetation efforts within the region, although promoted as benefitting woodland birds, have been grossly inadequate. Most revegetation efforts to date have produced patches of vegetation that were too small (often less than 1 ha), linear in shape (e.g. along fence-lines and creek-lines), on poorer soils, consisting of a few plant species often planted in rows and at very high densities that were largely disconnected from other patches of vegetation (Paton et al., 2004). These revegetation efforts supported small numbers of widespread bird species and were rarely used consistently by declining species (Paton et al., 2004).

This lack of use is not surprising given that most of the declining woodland bird species have home ranges that are 3–20 ha and as much as 200 ha (Paton et al., 2010; Allan, 2016), much larger than the individual patches of revegetation. Furthermore, woodland birds require structurally and floristically diverse habitats not just to meet differing seasonal requirements for food and nesting but to meet the differing ecological requirements of diverse species (Paton et al., 2004). Future restoration efforts therefore need to reconstruct more diverse habitats at patch scales of 20–100 ha with priority given to revegetation on better quality soils. This is unlikely to be delivered by habitat reconstruction within individual farms and will likely require a proportion of existing farms, if not whole farms or districts, to be retired from agriculture and set aside for biodiversity conservation.

The critical question that arises from this is: how much additional habitat needs to be reinstated to prevent ongoing losses of woodland bird species from the Mt Lofty region? Paton (2010a) used Ford and Howe's (1980) species–area relationship model to assess woodland birds in the Mt Lofty region and estimated that increasing the area of 'native' habitat from a cover of <10% to a cover of 30% would prevent the loss of 35–40 woodland bird species. This equates to re-establishing woodland habitats across 150 000 ha of cleared land across the region. Delivering this new habitat would transform the region, require substantial changes to farming and require broad and on-going community support to deliver. This might seem like an ambitious target, but it is no more than called for in the UN Global Biodiversity Framework, that is, to effectively manage at least 30% of all land and water for biodiversity conservation (CBD, 2022). Australia was one of over 190 countries that supported this decision and, in November 2023, Australia's environment ministers agreed to protect and conserve 30% of Australia's land and oceans by 2030 (DCCEEW, 2024). This will not happen overnight, as there are many hurdles to overcome, ranging from securing funding, acquiring the land and learning how to build structurally and floristically diverse habitats for the future at ever-increasing scales.

4 Habitat restoration at scale: the role of BioR

BioR (https://www.bior.org.au/) is a not-for-profit established to reconstruct self-sustaining and resilient habitats for biodiversity outcomes. BioR is currently restoring habitat to a 550-ha farm near Monarto, on the eastern scarp of the Mt Lofty region, about 60 km east of Adelaide. The property, Frahns Farm, is crown land and was grazed by sheep until 2016, when it was set aside for habitat re-establishment. The area is in a rain shadow with low annual rainfall and is burdened with a range of environmental weeds and high densities of Western Grey and Red Kangaroos (*Osphranter rufus*).

Initial attempts to re-establish habitat on this property in 2016–2018 consisted of planting seedlings of a range of large shrubs and trees. This approach involved spot spraying to control weeds at the places where seedlings were to be planted and protecting the planted seedlings from grazing using corflute or wire mesh guards. The outcomes from these standard revegetation attempts were poor (Fig. 1h), with fewer than 10% of the seedlings establishing. A different approach was required and, in 2019, BioR changed its approach and methods.

First, an extensive area of the farm (~170 ha) was enclosed in a kangaroo-proof fence and over 100 kangaroos were removed from inside the enclosure. This approach avoids the need to individually guard each seedling and was cost-effective at this scale. The exclusion of kangaroos had other benefits in that there were immediate improvements in the condition of the small amounts of degraded remnant vegetation that remained within the fenced area, with some plants being able to recruit (reproduce and expand coverage) for the first time in decades (Fig. 1a). However, there was no recolonisation of the more extensive areas that had been cleared and managed as improved pasture for sheep.

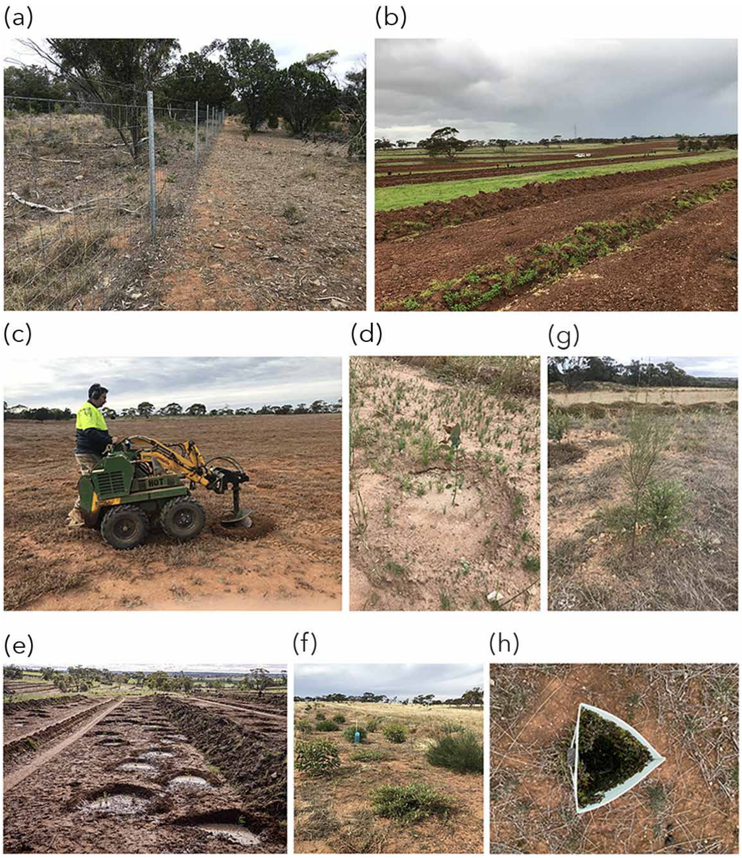

Figure 1 (a) Fencing to exclude kangaroos enables the native vegetation remnants at Frahns Farm to recover from overgrazing (left side of image) while areas where kangaroos still have access remain heavily grazed (right) (photo credits: David Paton, unless otherwise indicated). (b) Grading the top 5–10 cm of topsoil reduces the high seed densities of environmental weeds, minimising subsequent re-establishment of weeds and improving revegetation success. (c) Auguring holes in preparation for planting seedlings. (d) Native grasses have germinated from direct seeding and are establishing in the area beyond the planting bowl into which a eucalypt seedling has been planted. (e) Planting bowls capture runoff for planted seedlings (credit: Tristan Avella-O'Brien). (f) Successful establishment of various native Australian plants 28 months after they were planted as seedlings at Frahns Farm. A standard corflute guard is shown against one of the plants. Corflute guards are frequently used to protect seedlings from grazing in Australia, but these guards restrict the lateral growth of most woody species at Frahns Farm, and BioR has ceased using them. One of the many advantages of exclusion fencing and removing overabundant herbivores is that individually guarding seedlings is no longer required. (g) Complementary planting of species in a planting bowl: *Allocasuarina verticillata* (tree to 5–10 m) with *Acacia argyrophylla* (shrub to 2 m), and *Atriplex semibaccata* (low spreading shrub to 20 cm); note the galenia infestation on the mound in the middle distance. (h) A planted seedling unable to grow beyond its corflute guard due to excessive kangaroo browsing in an unfenced area of Frahns Farm prior to 2019 (credit: Fiona Paton).

Second, for these pastured areas, approximately 5 cm of topsoil was removed with a grader to reduce the extensive seed banks that had accumulated over many years by various pasture grasses and weeds (e.g. *Avena fatua*, *Galenia pubescens*; Fig. 1b). Grading also reduced any allelopathic chemicals left in the surface soil by the weeds and reduced any added nutrients left over from past farming practices. A series of holes for planting seedlings was dug across the graded area with varied density and spacing for structural diversity (i.e. to produce areas with different densities of larger plants; Fig. 1c). The graded area was then direct-seeded with a mix of native grass and herb seeds prior to planting seedlings of larger shrubs and trees in the holes (Fig. 1d). The allocation of seedlings, involving more than 100 species of plants, considered topographical and edaphic features that might influence their performance. In addition, wherever possible at least five individuals of a species were planted within 20 m of each other to improve prospects of cross-pollination (McCallum et al., 2019).

The seedlings were planted by teams of volunteers under guidance, helping to reconnect people to nature as well as hopefully building lasting ownership. An important aspect was to form a shallow planting bowl to capture local runoff from rainfall, into which each seedling was planted (Fig. 1e). This helped offset low rainfall. Once planted, the seedlings were watered in and then watered again once or twice during the drier months in their first year in the absence of rainfall. This planting technique resulted in a dramatic improvement in planting success, with more than 80% and sometimes over 90% seedling survival and establishment in the first year (Fig. 1f).

In 2019, only 6 ha and 6000 seedlings were planted. However, by 2024, BioR's capacity had grown to re-establishing plants on over 20 ha of cleared land, direct seeding these areas with a diverse mix of seeds from native grasses, herbs and small shrubs, as well as planting more than 45 000 seedlings of shrubs and trees. Over 180 native plant species are now incorporated into the planting programs. Most of these are local species with seeds generally sourced from multiple areas within a 10-km radius of the farm but also including species from more xeric (dry) locations in the region. To further improve the efficiency of the planting programs, BioR increased the diameter of the planting bowls from 10 cm in 2019 to 45 cm in 2022 and now plants seedlings of two or three complementary plants in each planting bowl. Complementary plants might include a grass, a small herb or shrub and a large shrub or tree (Fig. 1g). BioR intends to grow the areas being planted by 20% per annum for the next 25 years so that, by 2050, more than 1000 ha of cleared land will be planted per annum. Even so, more than 1000 ha of land would need to be planted annually for another 50 years before the 150 000-ha target is reached.

Given the scale of the plantings needed to prevent the losses of species across the Mt Lofty region, any plantings that are undertaken need to be self-sustaining and resilient. To be self-sustaining, the plants need to flower and set seeds, with the seeds able to germinate and establish the next generation of plants, with recruitment matching losses of plants. Resilience refers to the capacity of the new vegetation to cope with and recover from perturbations like fire and drought. Although many of the shorter-lived plants in the revegetation at Frahns Farm have already begun flowering and setting seeds, assessing whether the new plantings are self-sustaining and resilient will need to wait until the vegetation matures: woodland habitats take decades to mature, with some habitat features like tree-hollows not appearing for more than 100 years. These planting programs therefore require intergenerational ownership to be delivered.

Equally, it is premature to assess whether declining woodland birds will colonise the new habitats, at Frahns Farm. However, similar plantings at Cygnet Park on Kangaroo Island, South Australia, commenced a decade earlier, are already being used by a wide range of woodland bird species, including species that have experienced significant declines in distribution and abundance (Paton et al., 2018; Figs 2 and 3).

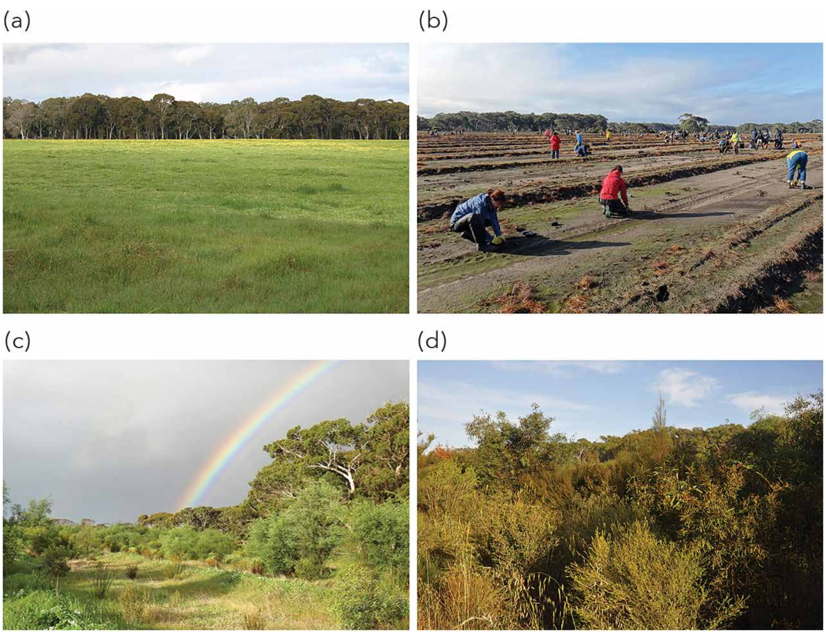

Figure 2 (a) Cygnet Park consisted of about 100 ha of riparian woodland with the surrounding 200 ha cleared and grazed by sheep and cattle until 2004. From 2008 to 2012, (b) volunteers assisted with planting seedlings of a wide diversity of native plant species; (c) 2-year-old plantings (credit: Tom Hunt); culminating in (d) the re-establishment of 170 ha of diverse native vegetation on the cleared areas of this farm (credit: Blair Wickham).

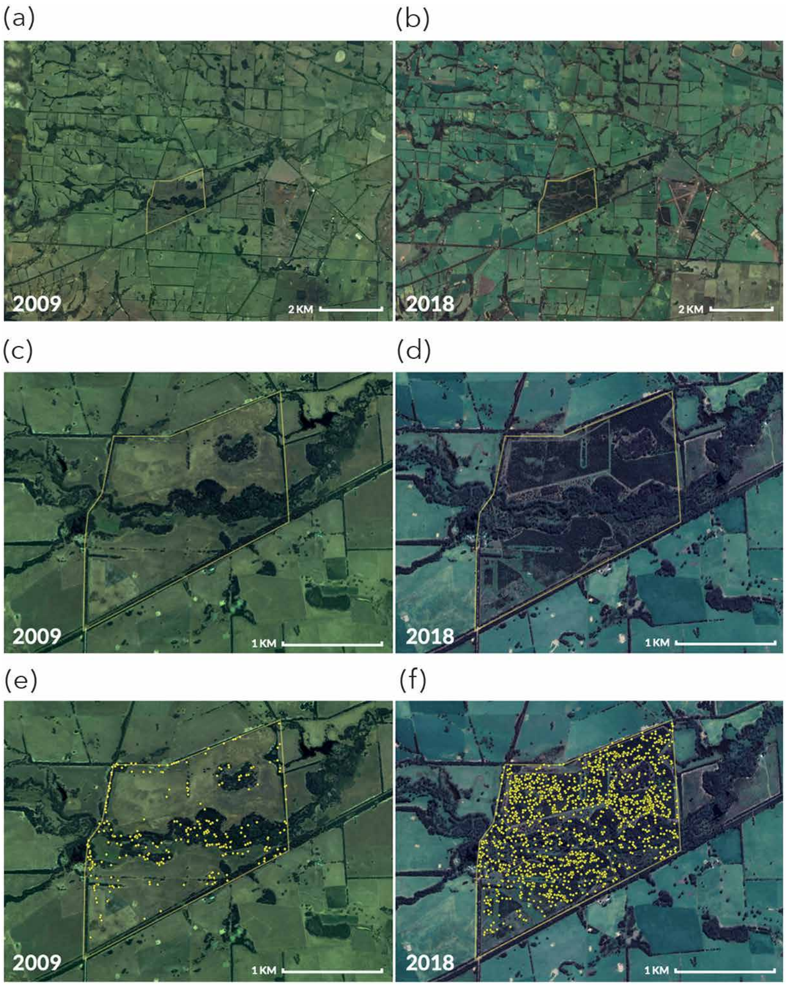

Figure 3 Aerial images of Cygnet Park (delimited by the yellow border) in (a, c, e) 2009 and (b, d, f) 2018, showing the cover of native vegetation (dark areas) pre- and post-planting at different scales and the distribution of woodland birds (shown as yellow dots) across the property in (e) spring 2009 and (f) spring 2018. Woodland birds were assessed using systematic area searches where the locations of all birds that were detected were mapped using a GPS (Paton et al., 2018).

5 Other broad-scale impacts of farming on native biodiversity: water extraction for irrigated agriculture

In addition to the almost complete transformation of terrestrial natural areas for agriculture, water extraction for irrigated agriculture can also have major impacts on the native biodiversity of rivers, their catchments, lakes and inland seas where extraction has exceeded sustainable limits. Well-known examples include:

- the de-watering of the Aral Sea for irrigation and the subsequent deterioration of a large portion of the former sea into the Aralkum Desert over the past 60 years (Micklin, 2007; Tussopova et al., 2020);
- the Colorado River (Schmidt et al., 2023);
- the Chesapeake Bay watershed (Alter et al., 2024); and
- the Murray–Darling Basin in south-eastern Australia (MDBA, 2010).

The obvious solution to over-allocation of water resources is to re-allocate sufficient quantities of water for the environment in order to sustain the native biodiversity that persists. This has been the approach in the 1 600 000-km² Murray–Darling Basin, where over-allocation of water principally for irrigated agriculture has seen a decline in biodiversity across the basin. Of the 13 000 GL of (long-term average) annual divertible flow in the basin, 11 500 GL (88%) is removed for irrigation, industrial use and domestic supply, with agricultural irrigation accounting for 95% of extractions.

The Murray–Darling Basin Plan, legislated in 2012, proposed to return 2750 GL of water to the environment. This was well below the 3000–7600 GL/year originally advised by the Murray–Darling Basin Authority (2010) prior to public consultation. After a pause in water buy-backs under the previous federal government, a reduced interim target of 2075 GL by 30 June 2024 was announced by the current government (Wheeler, 2023). In May 2023, there was still a shortfall of 49.2 GL to reach this target (MDBA, 2023). The following case study of the Murray–Darling Basin, with a focus on the ecological health of the terminal system of lakes and wetlands, explains how these current measures to return water in the basin to the environment may be insufficient to save the lakes and a Ramsar-listed wetland, the Coorong, from irreversible environmental decline (Ramsar relates to an international treaty for wetland conservation signed in the city of Ramsar in Iran in 1971).

6 Case study: over-extraction of water from the Murray–Darling Basin and consequences for biodiversity

The Murray–Darling Basin has been described as Australia’s food bowl (Davidson, 2023). The Basin covers a seventh of the Australian continent and is spread across four Australian states: Queensland, New South Wales, Victoria and South Australia. The name is taken from the two major rivers that run through the basin: the Murray and Darling Rivers. The Darling River runs across New South Wales but has tributaries that stretch into southern Queensland. It joins the Murray River at Wentworth in New South Wales. The 2500-km-long Murray River runs from the Australian Alps westwards where it forms the boundary between the states of Victoria and New South Wales, then through eastern South Australia, before discharging into Lake Alexandrina immediately upstream of the Murray Mouth and ultimately into the Southern Ocean. A series of major tributaries join the Murray before reaching South Australia. Some of these tributaries include the Murrumbidgee, Lachlan and Darling Rivers on the New South Wales side of the river, and the Ovens, Goulburn and Loddon Rivers on the Victorian side.

It is hard to understate the environmental or socio-economic significance of Australia's Murray–Darling Basin (MDBA, 2010). Some 30 000 wetlands occur across the basin, of which 16 are Ramsar-listed, providing critical habitat for 95 state and Commonwealth-listed threatened inundation-dependent fauna species. The basin contributes 39% of Australia's agricultural production and provides critical water supplies for more than three million people.

Prior to any water being extracted from the basin, around 12 500 GL flowed annually to the sea, although the volumes varied dramatically from year to year. Extraction of water for irrigation from the Murray River commenced in the late nineteenth century and, within a few decades, there were concerns about increasing marine incursions into Lake Alexandrina, particularly during autumn when river flows were lowest. This ultimately led to a series of barrages being built along the southern edge of Lake Alexandrina in the late 1930s to prevent incursions of marine water upstream. The volume of water extracted from the basin grew steadily through the twentieth century, aided by the construction of a series of locks along the Murray and by large storage dams (e.g. Hume Dam). By the turn of the century, more than 13 000 GL per annum of surface flows was being extracted on average from the basin. Water harvested and stored in dams during years of higher flows was used to supplement the volumes being taken in low-flow years. Most of the water extracted was used to irrigate pastures and various perennial (e.g. almonds, citrus and grapes) and annual (e.g. rice and cotton) crops.

This extraction of water had a dramatic influence on the volumes of water that flowed down the river and eventually reached the Murray Mouth. During the 1980s and 1990s, only 4000–5000 GL per annum, on average, flowed out to sea (e.g. Paton, 2010b). The reduced volumes and duration of flows along the river in turn reduced the frequency, duration and extent that floodplain wetlands along the Murray were inundated, leading to profound negative effects on terrestrial and aquatic vegetation, aquatic invertebrates, fish and birds (e.g. Kingsford, 2000, Kingsford et al., 2011; Paton, 2010b). Flows to the Murray Mouth reduced even further during the first decade of the twenty-first century when south-eastern Australia experienced an extended drought from 1997 to 2009 (Bureau of Meteorology, 2024). During this Millennium Drought, flows to the Murray Mouth were inadequate to keep the mouth open, requiring continuous dredging by 2002. Keeping the mouth open was important for a range of diadromous fish that spend parts of their life cycle in freshwater and other parts in marine waters (Bice et al., 2018).

An open Murray Mouth was also important to maintain a regular tidal prism in the upper reaches of the Coorong. The Coorong is a long narrow lagoon wedged between the mouth and Lake Alexandrina and stretching 100 km to the southeast behind the coastal dunes of Younghusband Peninsula that separates the Coorong from the Southern Ocean. The Coorong is an inverse estuary (where the salinity increases with distance from the mouth) and differs from the water regimes of other wetlands in the Murray–Darling Basin. Salinities increase along the length of the Coorong according to distance from the Murray Mouth: the upper reaches closest to the mouth are estuarine while salinities at the southern end are two to three times saltier than sea water. During summer, the Coorong supports large numbers of migratory Palaearctic shorebirds (Figs 4a and b). Without a tidal prism – a volume of water that enters and leaves the estuary with the tides – these shorebirds would not be able to access the productive intertidal mudflats in the estuarine areas of the Coorong.

Reductions in flows in the lower Murray and, particularly, the timing of flows have had a profound impact on the ecology and health of the Coorong, particularly the hypersaline southern end. The southern Coorong with its higher salinities supports a lower diversity of aquatic organisms than the less salty areas but is still highly productive (e.g. Paton, 2010b). A key biotic component of these hypersaline waters is an annual plant, *Ruppia tuberosa*, which grows in shallow water around the margins of the southern Coorong (Fig. 4c). These margins are ephemeral in that they are usually covered with shallow water from late autumn until late summer, allowing the plant to establish, grow and reproduce before the water recedes. Critical to preventing the water from receding prior to autumn are flows over the barrages. Prior to any extraction of water, flows to the Murray Mouth increased during winter, peaked in late spring and then gradually declined over summer. Although more than 99% of this water flows out to sea, the flows elevate water levels in the northern Coorong, such that water levels are maintained in the southern Coorong, enabling the plant to complete its life cycle.

With extraction for irrigation, however, the flows are truncated and, although still increasing over winter and into spring, they often cease in late spring before the plants have finished flowering and setting seeds. Under these changed conditions, *R. tuberosa* struggles to maintain healthy vigorous populations. This was exacerbated during the Millennium Drought when little water reached the Murray Mouth over multiple years and *R. tuberosa*, a key component in food chains, was all but eliminated from the southern Coorong (Paton, 2010b).

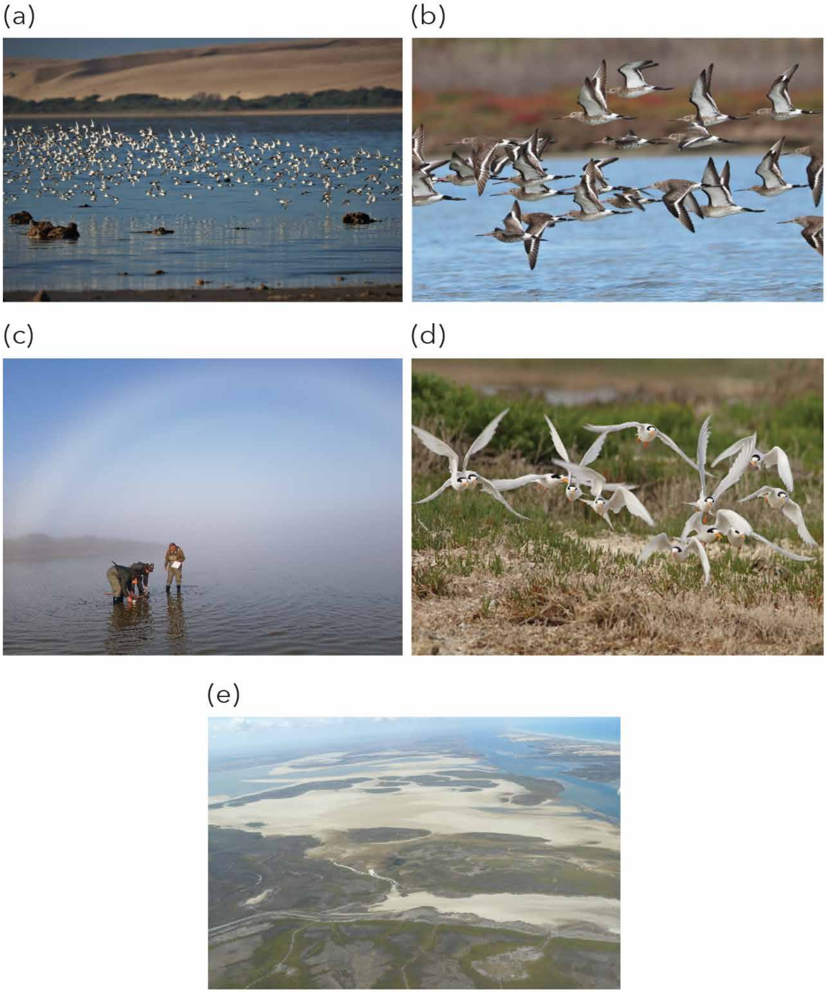

Figure 4 Images of the Coorong and Lake Alexandrina. The abundance of Palaearctic shorebirds including (a) Red-necked Stints (*Calidris ruficollis*) and (b) Black-tailed Godwits (*Limosa limosa*) have declined in the Coorong and Murray lakes in recent years (credits: Darcy Whittaker). (c) Ecologists sampling for *Ruppia tuberosa* in the southern Coorong in winter (credit: Garry Trethewey). (d) Fairy Terns are listed as endangered in South Australia. They breed in the southern Coorong but only when the salinities are not so high to exclude their fish prey (credit: Tom Hunt). (e) So little water has flowed into Lake Alexandrina in recent droughts that the water level of the Lake has fallen below sea level for extended periods, exposing large areas of bare lake bed and separating the fringing reeds from the water. This image of the Mud Islands near the Murray Mouth shows the line of barrages that separate Lake Alexandrina from the Coorong stretching southwards in the top righthand corner of the image (credit: Russell Seawright).

The lack of adequate flows during the Millennium Drought also resulted in excessively high salinities in the southern Coorong. Instead of maximum salinities two to three times those of seawater, salinities in the southern Coorong were more than five times those of seawater. These levels exceeded the salinity tolerances of two highly salt-tolerant and formerly highly abundant aquatic species in the southern Coorong: the hardyhead fish, *Atherinosoma microstoma*, and the chironomid or midge, *Tanytarsus barbitarsis*. Both disappeared from the southern Coorong but maintained populations further north in the Coorong where salinities, although also higher, remained within tolerable ranges (Paton, 2010b; Wedderburn et al., 2016). With the loss of fish from the southern Coorong, many piscivorous birds like the threatened Fairy Tern (*Sternula nereis*) vacated the southern Coorong (Paton, 2010b; Fig. 4d).

The reason for the heightened salinities relates to the saltiness of water that offsets the water that evaporates off the surface of the Coorong over summer. When there is a flow of river water over the barrages into the northern Coorong, relatively fresh water with little salt is drawn into the Coorong to offset the evaporative losses. However, when there is no flow, seawater is drawn into the Coorong to offset evaporative losses. If there is an extended period with limited river flows, as there was during the Millennium Drought, salt accumulates in the southern Coorong and salinities rise.

The other conspicuous change during the Millennium Drought was the drop in water levels in Lake Alexandrina to more than a metre below sea level, stranding the extensive reed beds around the margins of the lakes, potentially exposing acid sulphate soils, and affecting a range of freshwater biota (e.g. Kingsford et al., 2011). Clearly the available water had been overallocated and there was insufficient reduction in the volume of water extracted upstream to prevent this (Fig. 4e).

Assessments and modelling indicated that between 3000 GL and 7600 GL needed to be returned to the environment to secure the health of the basin ecosystems, the lower value giving a low probability of success and the higher value a high probability of success (MDBA, 2010). Returning water to the environment is contentious, particularly given the large volumes proposed and the potential impact on irrigators and rural communities. The Australian Government introduced new legislation, the *Water Act 2007*, to help drive water reform, and the Murray–Darling Basin Plan was legislated in 2012. The Basin Plan aimed to return 2750 GL of water to the environment by 2024, by buying back water from irrigators and introducing water efficiency measures and other engineering solutions. The Water Act stipulated that the best available science should be used to determine the environmentally sustainable level of water that could be taken, but socioeconomic and political pressures resulted in the volumes to be returned to the environment being much less than the minimum needed. The intensity of public debate led to a Royal Commission (Walker, 2019) and water reform in the Murray–Darling Basin remains challenging.

More than 10 years after the Murray–Darling Basin Plan commenced, the full 2750 GL has still not been delivered. One of the enduring challenges is convincing upstream users that their water extraction contributes to the demise of unique wetland systems a thousand or more kilometres downstream. To date the reforms have been inadequate, as the Murray Mouth still needs dredges to keep it open, and the Coorong continues to be in poor condition (e.g. Paton et al., 2022; Paton and Paton, 2022).

7 Conclusion

According to the FAO (2019), a wide range of farm management practices and approaches favourable to the sustainable use and conservation of biodiversity for food and agriculture are being increasingly applied in many countries. A much higher proportion of OECD countries report the use of biodiversity-positive practices than non-OECD countries in the FAO's (2019) survey. The chapters in this book demonstrate that many farm management practices are positive both for farmers and native biodiversity. New regulations and policy frameworks have been developed or are being introduced in many jurisdictions to stop further destruction of native habitats in agricultural regions and to change environmental decision-making by farmers to align self-interest with biodiversity conservation. While there will inevitably be missteps in the development of new laws and agri-environmental schemes, these top-down approaches will evolve and improve, and successive generations of farmers will likely be increasingly accepting.

However, in the most recently and extensively transformed agricultural regions of the world where much wild biodiversity still persists (albeit for a short time before the extinction debts fully register), broad-acre restoration of natural environments and habitats is likely to be the only option to achieve the target of 30% of land set aside and managed for biodiversity by 2030 and even more ambitious native biodiversity conservation targets for 2050 and beyond. This will have to occur either through purchase of large areas of farmland by governments and the non-profit and private sectors and their ecological restoration, or the introduction of schemes that see farmers paid to undertake the restoration. Similarly, water entitlements will have to be returned to the environment in order to reduce and hopefully reverse biodiversity declines in the most over-allocated catchments around the world.

It remains to be seen whether setting targets such as 30% by 2030 in heavily transformed regions will spur governments, industry and the non-profit and philanthropic sectors to action or will be ignored as unrealistic. New regulations and policies will be required to facilitate land acquisition and broad-acre set-asides as well as the massive amounts of ecological, habitat and biodiversity restoration required to achieve 30% of land being able to support biodiversity in the world's most intensively farmed regions. Meeting the 30% target by 2030 is highly unlikely but the legislative and policy frameworks needed to allow this to happen should be advanced quickly, as time is of the essence.

New markets in natural capital (biodiversity, carbon, ecosystem services, etc.) could help generate the funds to rapidly upscale ecosystem restoration efforts. Large investments in education and training to develop a workforce to deliver and manage 30% of lands for biodiversity will be required, both for hands-on land acquisition and restoration work, as well as for biodiversity monitoring, planning, design and procurement. We have limited long-term evidence of how biodiversity is tracking across continents, countries, jurisdictions or regions, just at the time when such information is most critical to identify the species and populations spiralling towards local, regional or global extinction and thus most in need of prioritisation. Due to the growing importance of environmental, social and governance issues in board rooms and demanded by shareholders at corporate annual general meetings, agricultural industries should be encouraged to assume proactive responsibility for the native biodiversity impacted by their activities.

It is important to highlight that agricultural regions that have undergone the most complete transformation for food and fibre production away from wild nature, or have overallocated all or most of the available fresh water, are those where native terrestrial and aquatic biodiversity has and will suffer most. The collapse of regional biotas has already occurred in parts of the world with the longest history of agriculture and is underway in the most recently developed regions. Science has identified many biodiversity-friendly strategies and practices to accommodate many terrestrial native plants and animals in farmland, as the other chapters in this book testify, but the adoption of such approaches is often less than expected or desirable from a biodiversity conservation perspective, for a plethora of reasons.

Most worrying, however, is the biodiversity conservation challenge posed by the farming regions that have been most extensively cleared in the recent past. Even interim targets adopted by the global community, such as 30% of regional lands and waters managed for biodiversity conservation by 2030, are unlikely to be achievable in such regions, given the extent of farmland that needs to be repurposed, without increased intervention by the public, private or philanthropic sectors by at least an order of magnitude. The significant opposition of farming and regional communities to even the relatively modest and inadequate amount of water buy-backs for the environment in the Murray–Darling Basin to date suggests that buying up farmland to the 30% threshold could be politically impossible in all but the most unproductive agricultural regions, let alone more ambitious biodiversity targets for 2050 and beyond.

8 Future trends in research

Typically, ecologists undertake research on biodiversity in agricultural systems whereas agricultural scientists carry out the production-focused research, and economists, political scientists and lawyers study land clearance regulations and agri-environmental schemes. The FAO (2019) argued that research on food and agricultural systems should become more multi-disciplinary and focus more on interactions between the different components of such systems, including biodiversity. Improvements for the sustainable use and conservation of biodiversity are often constrained by a lack of understanding of interactions between sectors (e.g. between the production of crops and livestock and the new environmental commodities such as carbon and biodiversity), between wild and domesticated biodiversity and between the biophysical and socio-economic components of production systems and the policy settings that influence them. Cooperation across disciplines and greater involvement of farmers and their advisers in biodiversity conservation and restoration research in agricultural systems are required to overcome these knowledge gaps.

Nisbet (2007) dubbed long-term environmental monitoring 'Cinderella' science, being unloved and poorly funded. Reasons for the neglect of environmental monitoring by scientists and governments alike include a lack of funding, lack of appreciation of the value of long-term ecological monitoring in identifying the causes of environmental change and societal fascination with new and innovative science (Lindenmayer et al., 2014a). The sad fact remains that most of the world's biodiversity remains unmeasured. Despite clarion calls over the past two decades to invest more in long-term biodiversity monitoring (e.g. Legge et al., 2018; Lindenmayer et al. 2014b, 2022; Lovett et al., 2007; Takeuchi et al., 2021), we remain ignorant of short- and long-term trends in the abundance and distribution of most species and populations of wildlife the world over. We are thus almost certainly losing populations and species without knowing it, indeed before many taxa are known to science, which means the biodiversity crisis could be unfolding more quickly than most dare to believe. This must change and the development and implementation of new technologies to identify and continuously monitor biodiversity deserves the highest priority in environmental science.

Finally, research is required about the best ways to create new markets in biodiversity and related natural capital assets, such as carbon, in order to encourage private capital investment in the ecosystem restoration of wild nature and the protection and enhancement of native biodiversity at scale (Karolyi and Tobin-de la Puente, 2023). Public finance is insufficient. The difference between what is spent on nature conservation and what is needed, if most biodiversity is to be conserved and sustainably managed for the long term (the so-called 'biodiversity financing gap'), is significant (Deutz et al., 2020). Closing the gap and mobilising private investment to maintain ecosystem integrity and biodiversity, and the services they provide, requires hundreds of billions of dollars per year. UNEP (2021) estimated that the US$133 billion spent annually on nature-based solutions will need to triple by 2030 to meet global climate change, biodiversity and land degradation targets. Yet, the development of new markets in biodiversity to attract and funnel private capital to stem and reverse the global biodiversity crisis is in its infancy. Unfortunately, there are important barriers to the development of biodiversity credit markets, given the complexity of natural ecosystems, including issues around policy objectives, biodiversity metrics and equivalence, and market transaction data and transparency (Karolyi and Tobin-de la Puente, 2023). Research is required to guide the way markets value nature, nature-based assets and natural capital, and identify innovative financing and policy mechanisms to mobilise funding to conserve nature and reform the harmful agricultural policies that result in biodiversity loss.

9 Where to look for further information

Various books provide a comprehensive introduction to biodiversity and agriculture in different parts of the world. Norton and Reid (2013) introduce the reader to the native biodiversity in Australian and New Zealand farmland and provide many case studies of farmers who have incorporated different elements of wild nature on their farms. Macdonald and Feber's (2015) multi-authored collection describes the management of lowland farms for wildlife in the UK. McNeely and Scherr (2012) provide a global perspective of 'eco-agriculture', first describing the challenge to wild nature presented by agricultural intensification and rural poverty, then describing the opportunities for integrating biodiversity in agriculture and policies for encouraging eco-agriculture.

Seminal papers about the global biodiversity crisis and its causes include Dudley and Alexander's (2017) short review of agriculture and biodiversity. They find that agriculture is the largest contributor to biodiversity loss globally and that the impacts are expanding due to changing consumption patterns and growing populations. Vanbergen et al. (2020) document how land use intensification is undermining the natural foundations on which agriculture depends. They argue that agriculture will have to change to maximise productivity, sustainability and resilience, but this will ultimately depend on people's capacity to accept new ways of operating in response to the current environmental crisis.

Readers interested in the practice of ecosystem restoration should start with the joint publication by FAO, the Society of Ecological Restoration (SER) and the IUCN, setting out the *Standards of Practice to Guide Ecosystem*

Restoration (Nelson et al., 2024), and SER's 2nd edition of their *International Principles and Standards for the Practice of Ecological Restoration* (Gann et al., 2019). The specialist journals, *Ecological Restoration*, *Restoration Ecology* and *Ecological Management and Restoration*, chart the development of the applied ecological discipline of ecosystem restoration and its continuing evolution.

10 References

Allan, J. (2016), *Habitat Reconstruction Guidelines for Woodland Birds: A Bird-Orientated Approach*, PhD thesis, University of Adelaide, Adelaide, SA., Aust.

Alter, T., Hull, L., Laddin, K. F., Reid, M. and Kleinert, H. (2024), 'Engaging local voices: farmers, rural communities, and ecological restoration'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 97–136.

Andrén, M. (1994), 'Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review', *Oikos*, 71, 355–366.

Anon. (2021), *Biden-Harris Administration Outlines 'America the Beautiful' Initiative*, The White House, Washington, DC, https://www.whitehouse.gov/ceq/news-updates/2021/05/06/biden-harris-administration-outlines-america-the-beautiful-initiative/ (accessed 8 May 2024)

Ansell, D., Macintosh, A., Butler, D. and Waschka, M. (2024), 'Developments in agri-environment schemes (AES): Australia'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 319–337.

Bartel, R. L. (2003), 'Compliance and complicity: an assessment of the success of land clearance legislation in New South Wales', *Environ. Planning Law J.*, 20, 116–141.

Bartel, R. L. (2004), 'Satellite imagery and land clearance legislation: a picture of regulatory efficacy?' *Australas. J. Nat. Res. Law Policy*, 9, 1–31.

Bennett, A. F., Haslem, A., Rainsford, F. W., Maisey, A. C. and Radford, J. Q. (2024), 'Key concepts for conserving biodiversity in agricultural landscapes'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 3–48.

Bice, C. M., Wedderburn, S. D., Hammer, M. P., Ye, Q. and Zampatti, B. P. (2018), 'Fishes of the Lower Lakes and Coorong: a summary of life history, population dynamics and management'. In L. Mosley, Q. Ye, S. Shepherd, S. Hemming and R. Fitzatrick (Eds), *Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe)*, Royal Society of South Australia, Adelaide, SA, Aust, pp. 371–399.

Blanchard, G. and Munoz, F. (2023), 'Revisiting extinction debt through the lens of multitrophic networks and meta-ecosystems', *Oikos*, e09435. https://doi.org/10.1111/oik.09435

Bureau of Meteorology (2024), Previous droughts. http://www.bom.gov.au/climate/drought/knowledge-centre/previous-droughts.shtml (accessed 19 May 2024)

Carroll, C. and Noss, R. F. (2022), 'How percentage-protected targets can support positive biodiversity outcomes', *Conserv. Biol.*, 36, e13869. https://doi.org/10.1111/cobi.13869

Chubb, I., Bennett, A., Gorring, A. and Hatfield-Dodds, S. (2022), *Independent review of ACCUs*, Department of Climate Change, Energy, the Environment and Water, Canberra, ACT, Aust. https://www.dcceew.gov.au/sites/default/files/documents/independent-review-accu-final-report.pdf (accessed 23 June 2024)

Convention on Biological Diversity (2022), Decision adopted by the conference of the parties to the convention on biological diversity 15/4. Kunming–Montreal global biodiversity framework. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf (accessed 19 May 2024)

Cozim-Melges, F., Ripoll-Bosch, R., Veen, G. F., Oggiano, P., Bianchi, F. J. J. A., van der Putten, W. H. and van Zanten, H. H. E. (2024), 'Farming practices to enhance biodiversity across biomes: a systematic review', *NPJ Biodivers.*, 3, 1. https://doi.org/10.1038/s44185-023-00034-2

Davidson, S. (2023), *Why Australia's Food Bowl, the Murray–Darling Basin, Is Making Headlines*, National Farmers Federation, Barton, ACT, Australia. https://farmers.org.au/news/why-australias-food-bowl-the-murray-darling-basin-is-making-headlines/ (accessed 19 May 2024)

Day, A., Njeru, E. M. and Johnson, D. (2024), 'Soil health and ecological restoration'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 163–196.

Department of Climate Change, Energy, the Environment and Water (2022a), Australian protected areas dashboard: terrestrial areas as at June 2022. https://www.dcceew.gov.au/environment/land/nrs/science/capad/dashboard (accessed 19 May 2024)

Department of Climate Change, Energy, the Environment and Water (2022b), *Threatened Species Strategy Action Plan 2022–2032*, Department of Climate Change, Energy, the Environment and Water, Canberra, Aust. https://www.dcceew.gov.au/environment/biodiversity/threatened/publications/action-plan-2022-2032 (accessed 19 May 2024)

Department of Climate Change, Energy, the Environment and Water (2024), Australia's strategy for nature: updates to Australia's strategy for nature. https://www.dcceew.gov.au/environment/biodiversity/conservation/strategy (accessed 10 May 2024)

Deutz, A., Heal, G. M., Niu, R., Swanson, E., Townshend, T., Li, Z., Dear, A., Meghji, A., Sethi, S. A. and Tobin-de la Puente, J. (2020), *Financing Nature: Closing the Global Biodiversity Financing Gap*, The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability, Chicago, IL, USA.

Dickman, C. R., Greenville, A. C. and Wardle, G. M. (2024), 'Animal rewilding in theory and practice: Australia and New Zealand'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 463–500.

Dietz, M. S., Belote, R. T., Gage, J. and Hahn, B. A. (2020), 'An assessment of vulnerable wildlife, their habitats, and protected areas in the contiguous United States', *Biol. Conserv.*, 248, 108646. https://doi.org/10.1016/j.biocon.2020.108646

Dodsworth, J., Lasko, R. and Little, R. (2024), 'Stick your wellies on: messy development and participation processes with England's new Environmental Land Management policy – Co-design and the Sustainable Farming Incentive in context'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 275–300.

Dudley, N. and Alexander, S. (2017), 'Agriculture and biodiversity: a review', *Biodiversity*, 18, 45–49. https://doi.org/10.1080/14888386.2017.1351892

European Commission (2021), *EU biodiversity strategy for 2030 – Bringing nature back into our lives*, Directorate-General for Environment, Publications Office of the European Union. https://data.europa.eu/doi/10.2779/677548

European Union (2021), European Parliament resolution of 9 June 2021 on the EU Biodiversity Strategy for 2030: bringing nature back into our lives. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021IP0277 (accessed 19 May 2024)

Food and Agriculture Organization of the United Nations (2019), *The State of the World's Biodiversity for Food and Agriculture*, J. Bélanger and D. Pilling (Eds), FAO Commission on Genetic Resources for Food and Agriculture Assessments, Rome, Italy. http://www.fao.org/3/CA3129EN/CA3129EN.pdf

Ford, H. A. and Howe, R. W. (1980), 'The future of birds in the Mount Lofty Ranges', *S. Aust. Ornithol.*, 27, 88–95.

Fowler, R. (1986), 'Vegetation clearance controls in South Australia – a change of course', *Environ. Planning Law J.*, 3, 48–66.

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J. G., Eisenberg, C., Guariguata, M. R., Liu, J., Hua, F., Echeverria, C., Gonzales, E. K., Shaw, N., Decleer, K. and Dixon, K. W. (2019), *International Principles and Standards for the Practice of Ecological Restoration*, Second edition, *Restoration Ecology*, S1–S46. https://www.ser.org/page/SERStandards

Harris, C. (2024), *History of Āgriculture in SA – Native Vegetation Heritage – South Australian Initiatives to Better Manage the State's Native Vegetation*, Govt of S. Aust., Dept Primary Industries and Regions, Adelaide, SA, Aust., https://www.pir.sa.gov.au/aghistory/natural_resources/native_vegetation_conservation/national_parks#toc5 (accessed 14 May 2024)

Hanusch, M. (2023), *A Balancing Act for Brazil's Amazonian States: An Economic Memorandum*, The World Bank, Washington, DC.

High Ambition Coalition for Nature and People (2024), The HAC for Nature & People story. https://www.hacfornatureandpeople.org/the-hac-for-nature-people-story/ (accessed 8 May 2024)

Jones, T. A. (2024), 'Rewilding grasslands and rangelands'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 369–418.

Karolyi, G. A. and Tobin-de la Puente, J. (2023), 'Biodiversity finance: a call for research into financing nature', *Financial Managem.*, 52, 231–251. https://doi.org/10.1111/fima.12417

Kingsford, R. T. (2000), 'Ecological impacts of dams, water diversion and river management on floodplain wetlands in Australia', *Austral Ecol.*, 25, 109–127. https://doi.org/10.1046/j.1442-9993.2000.01036x

Kingsford, R. T., Walker, K. F., Lester, R. E. et al. (2011), 'A Ramsar wetland in crisis – The Coorong, Lower Lakes and Murray Mouth, Australia', *Mar. Freshwat. Res.*, 62, 255–265. https://doi.org/10.1071/MF09315

Klebl, F., Parisi, A., Häfner, K. et al. (2024), 'How values and perceptions shape farmers' biodiversity management: insights from ten European countries,' *Biol. Conserv.*, 291, 110496. https://doi.org/10.1016/j.biocon.2024.110496

Legge, S., Lindenmayer, D. B., Robinson, N. M. et al. (2018), *Monitoring Threatened Species and Ecological Communities*, CSIRO Publishing, Clayton South, Vic., Aust.

Lewis-Reddy, L. (2024), 'Implementing sustainable land use change programmes'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 137–160.

Lindenmayer, D., Burns, E., Thurgate, N. and Lowe, A. (2014a), 'The value of long-term research and how to design effective ecological research and monitoring', In D. Lindenmayer, E. Burns, N. Thurgate and A. Lowe (Eds), *Biodiversity and Environmental Change: Monitoring, Challenges and Direction*, CSIRO Publishing, Collingwood, Vic., Aust., pp. 21–48.

Lindenmayer, D., Burns, E., Thurgate, N. and Lowe, A. (2014b), *Biodiversity and Environmental Change: Monitoring, Challenges and Direction*, CSIRO Publishing, Collingwood, Vic., Aust.

Lindenmayer, D. B., Lavery, T. and Scheele, B. C. (2022), 'Why we need to invest in large-scale, long-term monitoring programs in landscape ecology and conservation biology', *Current Landscape Ecol. Rep.*, 7, 137–146. https://doi.org/10.1007/s40823-022-00079

Lindenmayer, D., Smith, D., Florance, D., Crane, C., Lang, E., Siegrist, A., Young, M. and Scheele, B. C. (2024), 'Lessons from reforestation of agricultural landscapes in south-eastern Australia'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 419–436.

Lovett, G. M., Burns, D. A., Driscoll, C. T. et al. (2007), 'Who needs environmental monitoring?' *Front. Ecol. Environ.*, 5, 253–260.

Macdonald, R. W. and Feber, R. (2015), *Wildlife Conservation on Farmland. Volume 1. Managing for Nature on Lowland Farms*, Oxford University Press, Oxford, UK.

McCallum, K. P., Breed, M. F., Paton, D. C. and Lowe, A. J. (2019), 'Clumped planting arrangements improve seed production in a revegetated woodland', *Restor. Ecol.*, 27, 636–646. https://doi.org/10.1111/rec.12905

Mcintosh, A. and Butler, D. (2023), Chubb review of Australia's carbon credit scheme falls short – and problems will continue to fester, *The Conversation* 9 January, https://theconversation.com/chubb-review-of-australias-carbon-credit-scheme-falls-short-and-problems-will-continue-to-fester-197401 (accessed 24 June 2024)

McNeely, J. A. and Scherr, S. J. (2012), *Ecoagriculture: Strategies to Feed the World and Save Biodiversity*, Island Press, Washington, DC, USA.

Meli, P., Schweizer, D., Winowiecki, L. A., Chomba, S., Aynekulu, E. and Guariguata, M. R. (2023), 'Mapping the information landscape of the United Nations Decade on Ecosystem Restoration Strategy', *Restor. Ecol.*, 31, e13810. https://doi.org/10.1111/rec.13810

Micklin, P. (2007), 'The Aral Sea disaster', *Ann. Rev. Earth Planetary Sci.*, 35, 47–72. https://doi.org/10.1146/annurev.earth.35.031306.140120

Montgomery, I. and Reid, N. (2024), 'The impact and management of hedgerows in promoting biodiversity in agricultural landscapes'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 221–271.

Morrison, J. (2024), 'The impact and design of field margins in promoting biodiversity in agricultural landscapes'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 197–220.

Murray–Darling Basin Authority (2010), *Guide to the Proposed Basin Plan: Overview*, Murray–Darling Basin Authority, Canberra, ACT, Aust., https://cdn.environment.sa.gov.au/environment/docs/guide-to-basin-plan-vol-1-gen.pdf (accessed 21 May 2024)

Murray–Darling Basin Authority (2023), Latest Basin Plan report card – June 2023. https://www.mdba.gov.au/water-management/basin-plan/basin-plan-report-cards (accessed 15 May 2024)

Myers, M. (1987). 'The extinction spasm impending: synergisms at work', *Conserv. Biol.,* 1(1), 14–21.

Nelson, C. R., Hallett, J. G., Romero Montoya, A. E. et al. (2024), *Standards of Practice to Guide Ecosystem Restoration – A Contribution to the United Nations Decade on Ecosystem Restoration 2021-2030*, FAO, Rome, Italy, Society for Ecological Restoration, Washington, DC, USA, and IUCN CEM, Gland, Switzerland. https://doi.org/10.4060/cc9106en

New South Wales Department of Climate Change, Energy, the Environment and Water (2024), Public register of private land conservation agreements. https://www.bct.nsw.gov.au/sites/default/files/2024-05/public-register-of-conservation-agreements.xlsx (accessed 20 May 2024)

Nisbet, E. (2007), 'Cinderella science', *Nature*, 450, 789–790. https://doi.org/10.1038/450789a

Norton, D. and Reid, N. (2013), *Nature and Farming: Sustaining Native Biodiversity in Agricultural Landscapes*, CSIRO Publishing, Collingwood, Vic., Aust.

Paton, D. C. (1996), *Overview of Feral and Managed Honeybees in Australia: Distribution, Abundance, Extent of Interactions with Native Biota, Evidence of Impacts and Future Research,* Australian Nature Conservation Agency, Canberra, ACT, Aust.

Paton, D. C. (2000), 'Disruption of bird-plant pollination systems in southern Australia', *Conserv. Biol.*, 14, 1232–1234.

Paton, D. C. (2010a), 'Restoring woodlands to the Mount Lofty Ranges region'. In D. Paton and J. O'Connor (Eds), *The State of Australia's Birds 2009: Restoring Woodland Habitat for Birds, Wingspan,* 20 supplement, 22–23.

Paton, D. C. (2010b), *At the End of the River: The Coorong and Lower Lakes*, ATF Press, Adelaide, SA, Aust.

Paton, D. C., Allan, J., Rogers, D. and Northeast, P. (2010), 'Bird use of the Monarto plantations: insights from a study of home ranges'. In D. Paton and J. O'Connor (Eds), *The State of Australia's Birds 2009: Restoring Woodland Habitat for Birds*, *Wingspan*, 20 supplement, 14–15.

Paton, D. C., Carpenter, G. and Sinclair, R. G. (1994), 'A second bird atlas of the Adelaide region. Part 1. Changes in the distribution of birds: 1974–75 vs 1984–85', *S. Aust. Ornithol.*, 31, 151–193.

Paton, D. C. and Paton, F. L. (2022), 'Monitoring of *Ruppia tuberosa* in the southern Coorong, summer 2021–22', University of Adelaide, Adelaide, SA, Aust., www.mdba.gov.au/publications-and-data/publications/lower-lakes-coorong-and-murray-mouth-monitoring-reports (accessed 18 June 2024)

Paton, D. C., Paton, F. L., Whittaker, D. A. and Markos, D. G. (2022), *Condition Monitoring of the Coorong, Lower Lakes and Murray Mouth Icon Site: Waterbirds in the Coorong and Lower Lakes 2022*, University of Adelaide, Adelaide, SA, Aust. www.mdba.gov.au/publications-and-data/publications/lower-lakes-coorong-and-murray-mouth-monitoring-reports (accessed 18 June 2024)

Paton, D. C., Prescott, A. M., Davies, R. J.-P. and Heard, L. M. (2000), 'The distribution, status and threats to temperate woodlands in South Australia'. In R. J. Hobbs and C. J. Yates (Eds), *Temperate Eucalypt Woodlands in Australia. Biology, Conservation, Management and Restoration*, Surrey Beatty & Sons, Chipping Norton, NSW, Aust., pp. 57–85.

Paton, D. C., Rogers, D. J. and Harris, W. (2004), 'Birdscaping the environment: restoring the woodland system of the Mt Lofty region, South Australia'. In D. Lunney (Ed.), *Conservation of Australia's Forest Fauna* (2nd ed.), Roy. Zool. Soc. NSW, Mosman, pp. 331–358.

Paton, F. L., Paton, D. C. and Paton, P. A. (2018), 'Bird responses to large scale revegetation at Cygnet Park, Kangaroo Island using systematic area searches'. In R. Smith (Ed.), *Proceedings of Restore, Regenerate, Revegetate: A Conference on Restoring Ecological Processes, Ecosystems and Landscapes in a Changing World*, University of New England, Armidale, NSW, Aust., 67–68. https://rune.une.edu.au/web/bitstream/1959.11/22627/2/open/SOURCE01.pdf

Pauli, B. P., Spaul, R. J. and Heath, J. A. (2017), 'Forecasting disturbance effects on wildlife: tolerance does not mitigate effects of increased recreation on wildlands', *Anim. Conserv.*, 20, 251–260.https://doi.org/10.1111/acv.12308

Prowse, T. A. A., O'Connor, P. J., Collard, S. J., Peters, K. J. and Possingham, H. P. (2021), 'Optimising monitoring of trend detection after 16 years of woodland bird surveys', *J. Appl. Ecol.*, 58, 1090–1100. https://doi.org/10.1111/1365-2664.13860

Prowse, T. A. A., O'Connor, P. J., Collard, S. J. and Rogers, D. J. (2019), 'Eating away at protected areas: total grazing pressure is undermining public land conservation', *Global Ecol. Conserv.*, 20, e00754. https://doi.org/10.1016/j.gecco.2019.e00754

Rausser, G. and Zilberman, D. (2024), 'Developments in agri-environment schemes (AES): North America'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 301–318.

Schmidt, J. C., Yackulic, C. B. and Kuhn, E. (2023), 'The Colorado River water crisis: its origin and the future', *WIREs Water*, 10, e1672. https://doi.org/10.1002/wat2.1672

Smith, K. J., Gordon, I. J., Wilson, B. A. and Manning, A. D. (2024), 'The future of animal rewilding in agricultural landscapes'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 437–462.

Squire, G. R. and Hawes, C. (2024), 'Biodiversity for agriculture: the role of integrated farm management in supporting agricultural production through biodiversity'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 49–96.

Szabo, J. K., Vesk, P. A., Baxter, P. W. J. and Possingham, H. P. (2011), 'Paying the extinction debt: woodland birds in the Mount Lofty Ranges, South Australia', *Emu*, 111, 59–70.

Takeuchi, Y., Muraoka, H., Yamakita, T., et al. (2021), 'The Asia-Pacific Biodiversity Observation Network: 10-year achievements and new strategies to 2030', *Ecol. Res.*, 36, 232–257. https://doi.org/10.1111/1440-1703.12212

Taylor, G. S., Braby, M. F., Moir, M. L. et al. (2018), 'Strategic national approach for improving the conservation management of Insects and allied invertebrates in Australia', *Austral Entomol.*, 57, 124–149. https://doi.org/10.1111/aen.12343

Tilman, D., May, R. M., Lehman, C. L. and Nowak, M. A. (1994), 'Habitat destruction and the extinction debt', *Nature*, 371, 65–66.

Tussopova, K., Anchita, Hjorth, P. and Moravej, M. (2020), 'Drying lakes: a review on the applied restoration strategies and health conditions in contiguous areas', *Water*, 12, 749. https://doi.org/10.3390/w12030749

United Nations Environment Program (2021), State of Finance for Nature 2021. Nairobi, Kenya.

United Nations Environment Program (UNEP) and Food and Agricultural Organization of the United Nations (FAO) (2020), *Strategy of the United Nations Decade on Ecosystem Restoration*. https://wedocs.unep.org/bitstream/handle/20.500.11822/31813/ERDStrat.pdf?sequence=1&isAllowed=y (accessed 26 June 2024)

Vanbergen, A. J., Aizen, M. A., Cordeau, S., Garibaldi, L. A., Garratt, M. P. D., Kovács-Hostyánszki, A., Lecuyer, L., Ngo, H. T., Potts, S. G., Settele, J., Skrimizea, E. and Young, J. C. (2020), 'Transformation of agricultural landscapes in the Anthropocene: nature's contributions to people, agriculture and food security', *Adv. Ecol. Res.*, 63, 193–253. https://doi.org/10.1016/bs.aecr.2020.08.002

van Diggelen, R., Ceulemans, T., Aggenbach, C. and Emsens, W-J. (2024), 'Restoring peatlands in European landscapes'. In N. Reid and R. Smith (Eds), *Managing Biodiversity in Agricultural Landscapes: Conservation, Restoration and Rewilding Practices in Farming*, Burleigh Dodds Science Publishing Limited, Cambridge, UK, pp. 341–368.

Walker, B. (2019), *Murray-Darling Basin Royal Commission Report*. Govt S. Aust., Adelaide, SA, Aust.

Watson, J. E. M., Venegas-Li, R., Grantham, H. et al. (2023), 'Priorities for protected area expansion so nations can meet their Kunming-Montreal Global Biodiversity Framework commitments', *Integrative Conserv.*, 2, 140–155. https://doi.org/10.1002/inc3.24

Wedderburn, S. D., Bailey, C. P., Delean, S. and Paton, D. C. (2016), 'Population and osmoregulatory responses of a euryhaline fish to extreme salinity fluctuations in coastal lagoons of the Coorong, Australia', *Estuarine Coastal Shelf Sci.*, 168, 50–57.

Williams, D. R., Rondinini, C. and Tilman, D. (2022), 'Global protected areas seem insufficient to safeguard half of the world's mammals from human-induced extinction', *Proc. Nat. Acad. Sci.*, 119(24), e2200118119. https://doi.org/10.1073/pnas.2200118119

Wheeler, S. A. (2023), Water buybacks are back on the table in the Murray–Darling Basin. Here's a refresher on how they work, The Conversation 23 February, https://theconversation.com/water-buybacks-are-back-on-the-table-in-the-murray-darling-basin-heres-a-refresher-on-how-they-work-200529 (accessed 15 May 2024).