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REVIEW

The Dingo Barrier Fence: Presenting the case to decommission the world's longest environmental barrier in the United Nations Decade on Ecosystem Restoration 2021–2030

Justine Philip[1]

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Abstract
The longest environmental barrier in the world is Australia's 5614 km Dingo Barrier Fence. The structure was completed in the 1950s, designed to facilitate the eradication of the country's apex predator and cultural keystone species the dingo (*Canis dingo*) from sheep (*Ovis aries*) grazing areas to the south-east of the continent. The fence and its support systems now present an immense obstacle to ecological restoration in Australia's arid zone, preventing traditional management practices, and are hazardous to all terrestrial wildlife in the immediate vicinity. The barrier presents a worst-case scenario for animal-generated seed dispersal patterns over the wider region and limits genetic transfer. Plummeting biodiversity inside the fence line and increasing pressures of climate change have left this region highly vulnerable to ecological collapse. Concurrently, sheep numbers have contracted over 75% in the arid zone since 1991, due to market forces and climate change, while demand for ethically produced goods such as predator-friendly meat production and organic produce is increasing. Decommissioning the Dingo Barrier Fence, moving the stock protection zone south and diversifying land use would not impact significantly on the current livestock production. It offers a sound economic alternative for the region, with the potential for regeneration of 82 million hectares of land, a scale encouraged for inclusion in the global initiative the United Nations Decade for Ecosystem Restoration (2021–2030). This would restore connectivity across the region, including vital access to the waters of the Murray Darling Basin. This would provide mitigation for the effects of climate change, new markets in organic and sustainable industries, and support ecological and cultural renewal.

Keywords Dingo Barrier Fence · Ecosystem restoration · Animal welfare · Biodiversity · Sheep · Aboriginal culture

Introduction

The United Nations Decade of Ecosystem Reconstruction 2021–2030 aims to foster large-scale restoration programmes, addressing the degraded, damaged and destroyed lands that have triggered a biodiversity crisis worldwide (Besseau et al. 2018). Poor management of land and water resources has depleted many of the world's natural resources, threatening food security, biodiversity and health. Regaining ecosystem functionality is the goal, supporting transformational, mosaic restoration projects that connect water sources and protected areas, with areas for sustainable human and agricultural use. This would aid restoration of biodiversity and provide mitigation and adaption to climate change on a broad scale (Aronson et al. 2020).

This report examines 82 million hectares of marginal grazing lands in south-east Australia, linking human–wildlife conflicts in the region with the severe land degradation and biodiversity loss in the region. Drought is the predominant state for the region, yet prior to colonisation the land supported many people and highly specialised plant and animal communities adapted to thrive in the extreme climate. These have been largely displaced by agricultural operations since the 1850s (Lunney 2001). The data for this research are collated from archival and scientific sources, scientific journals, government records, reports and legal documentation.

✉ Justine Philip
justineph2018@gmail.com

[1] Pont Melvez, Bretagne, France

Arid zone ecology

Dry lands (arid and semi-arid zones) cover 41.3% of the earth's land surface (Davis et al. 2013). The Food and Agricultural Organisation of the United Nations (FOA) describe dry lands as vital to the stability of earth's environment, playing a key role in the balance of atmospheric elements, and in the reflection and absorption of solar radiation. Dry lands support a wide range of human communities and unique biodiversity, with sustainable management of these regions considered essential to ensuring food security, biodiversity and conservation of biomass as we adjust to a rapidly changing climate (UNEP 2017).

Australia's marginal sheep grazing lands is a sparsely populated region, subject to irregular rainfall and episodic weather, high temperatures and large flood plains (Fig. 1). Local ecology is highly specialised with many species' endemic to the region and extremely vulnerable to disruption. Flora and fauna evolved strategies to cope with the climactic pressures including explosive breeding, migratory patterns, physiological adaptations and aestivation (Letnic 2000a, b). In the dry years, many animals die, aestivate or migrate out of the region, while vegetation dies back to perennial cover. Since European occupation in the mid-1800s, 24 of the 61 native mammal species recorded in the New South Wales (NSW) Western Division—the central region of the marginal grazing lands—have become extinct and another 17 endangered.

Heightened mobility and the ability to locate remote water sources above and below ground are essential to the survival of terrestrial wildlife in arid lands. Intentionally obstructing movement and preventing water access place insurmountable pressures on native flora and fauna. In order to avoid complete ecosystem collapse, a three-step approach of awareness, anticipation and action is recommended for this region, following the model of Bergstrom et al. (2021) (Fig. 1).

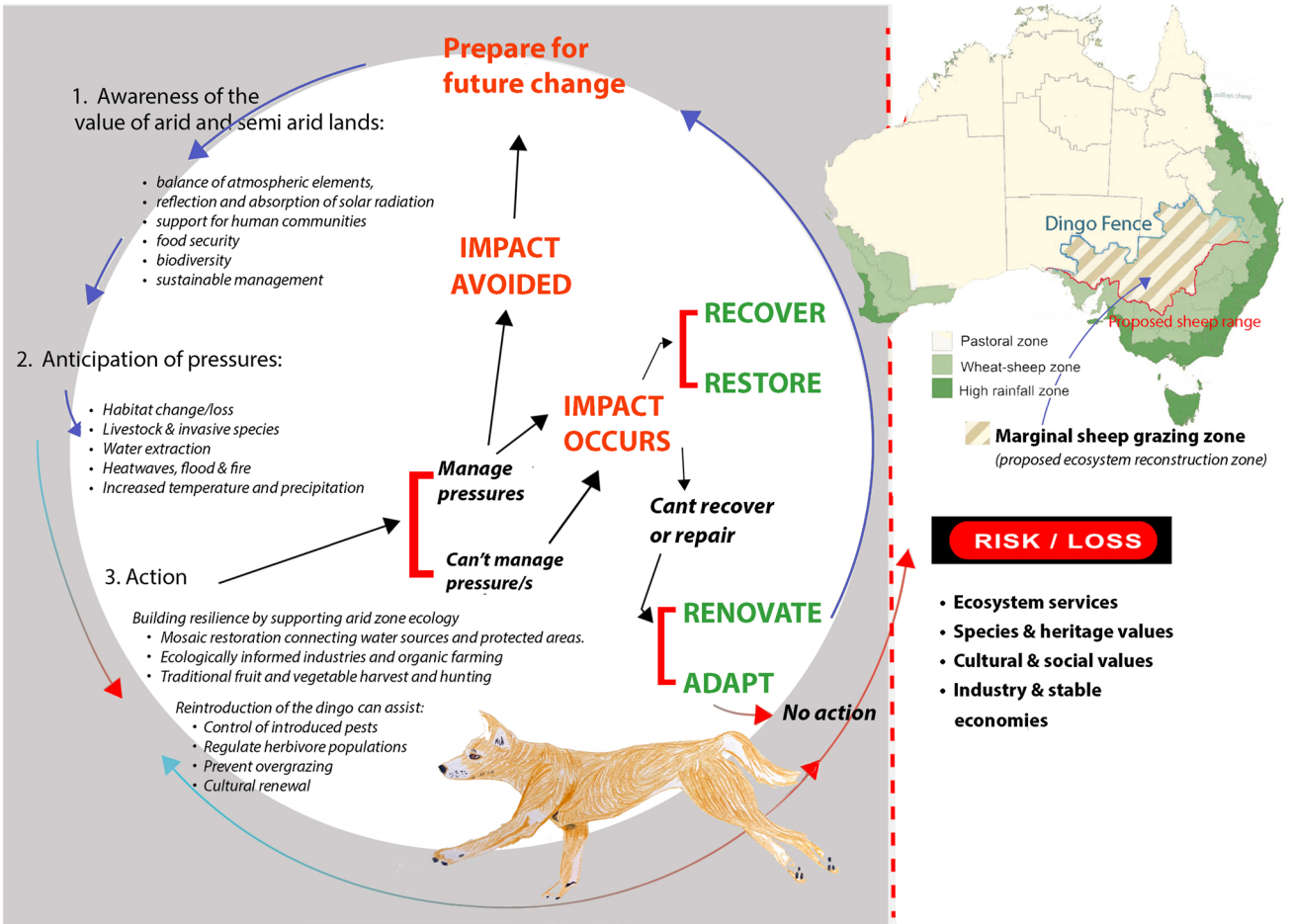

Fig. 1 Three pathways to combat ecosystem collapse following Bergstrom et al. (2021) model of Awareness, Anticipation and Action, as applied to in the marginal grazing lands of south-east Australia

Awareness

The ecosystem reconstruction zone or marginal grazing lands highlighted in Fig. 1 represent 82 million hectares of land running between the Dingo Barrier Fence to the north, and the higher rainfall sheep–wheat belt to the south. The Dingo Barrier Fence is the longest environmental barrier in the world, running ≈5614 km across the heart of Australia (Woodford 2003). The Dingo Barrier Fence project started in 1946 and was completed in the 1950s, connecting older isolated border and boundary fences across the south-east Australian arid zone to form one cohesive environmental barrier (Olsen 1998). The goal was to completely eradicate the country's top order predator, the dingo, from grazing areas to the south-east of the continent. This was to protect sheep from predation and reduce the need for prohibitively expensive livestock surveillance.

While the fence does not actually kill dingoes, it does provide a clearly defined physical and legally sanctioned "kill zone" along the 5614 km trajectory and has been operating as such for ≈70 years (Philip 2017). The wire mesh and pole structure stands around 1.7 m high, sufficient to obstruct the movement of most medium to large terrestrial wildlife. Dingoes are quite capable of scaling a structure of that height (Reading and Macintosh 1954). However, the animals that reach the barrier tend to run the fence looking for a gap, so the area is managed with regular ground baiting and steel padded-jaw traps lined with strychnine poison along the base (PIRSA 2016–2020). This is designed to kill the animals running its course and prevent a breach of the barrier. The dingo fence as such is a strategic management tool. This is distinct from exclusion fencing—the latter acts as a non-lethal barrier but requires a greater level of engineering, effective for smaller areas and predator-free enclosures such as in the Sturt National Park reintroduction programme (NSW National Parks and Wildlife Service 2021) (Fig. 2).

A nil tenure approach or "zero tolerance" to dingoes is applied across public and private lands inside the Dingo Barrier Fence, with extermination of dingoes' mandatory—this is different from culling animals, where the goal is to contain population levels within a band of sustainable density levels (Singleton 2007b). The goal has always been extermination for the dingo, the fact that this has not been achieved is entirely unintentional.

The marginal grazing land/potential ecosystem reconstruction zone covers 11% of the Australian continent. It carries 6% of the Australian sheep flock, or 4.5 million sheep, compared to 48.5 million sheep south of the red line in Fig. 1, in the higher rainfall areas (AWI 2020). The stocking rates in this region contracted 52% between 2012 and 2020 in response to rising temperatures, market forces and animal welfare concerns. Since 1990, the National sheep industry has similarly contracted from 180 million to 62.5 million following worldwide trends (ABS 2021) (Fig. 3).

The history of the Dingo Barrier Fence

The path of the Dingo Barrier Fence starts in Queensland and follows the northern reaches of the Murray Darling Basin, rupturing connectivity between the central desert and 77,000 km of interconnected waterways to the south-east of the continent. At the NSW border, the fence follows the oldest path of the original corner fence that was

Fig. 2 Agility tests and Police training in 1946 found the dingo agile and unimpeded by barriers over two metres in height. Courtesy of Mitchell Library, State Library of New South Wales, and ACP Magazines Ltd

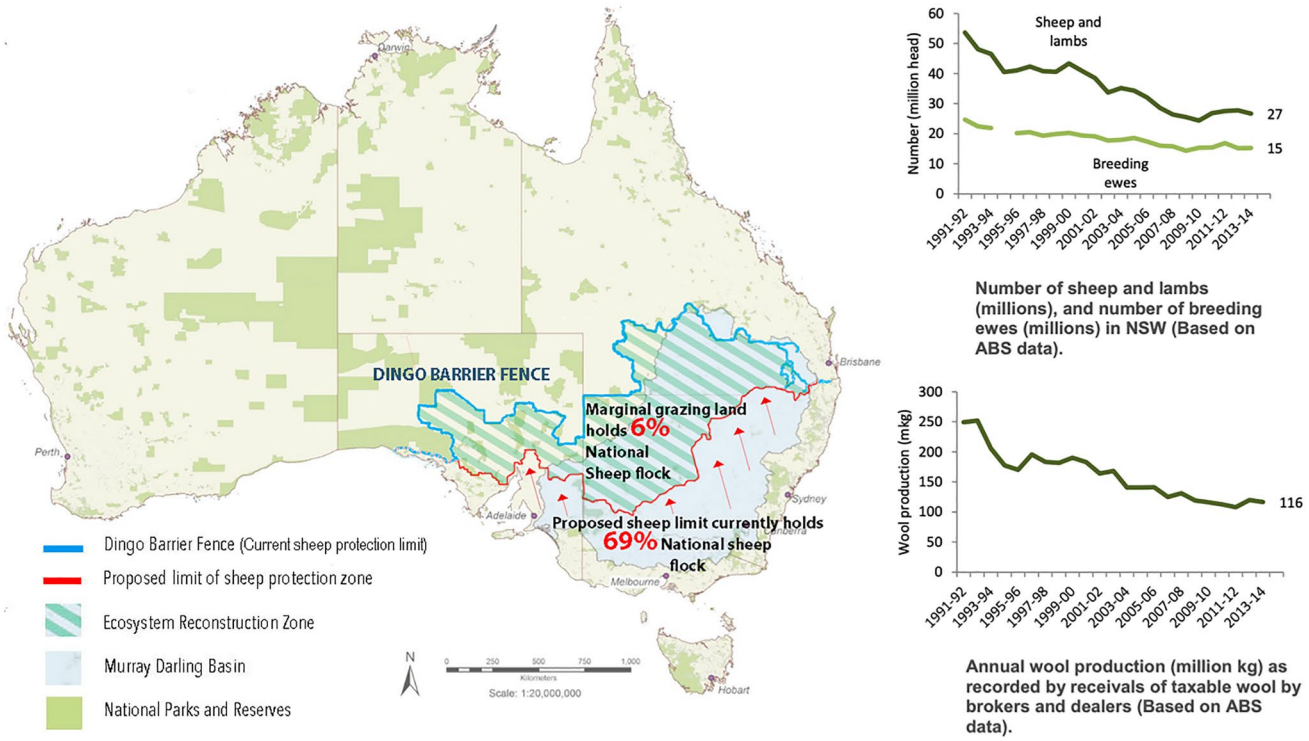

Fig. 3 The marginal grazing lands cover 82 million hectares of land and carry 4.5 million sheep, in comparison to 48.5 million sheep south of the arid zone. The sheep industry has been in rapid contraction since 1991, the graphs detail NSW, data source Pattinson et al. (2015)

completed in 1890—joining the South Australian border to the Queensland/NSW border fence. This section was originally built to keep European rabbits *Oryctolagus cuniculus* out of South Australia. However, by the time the structure was completed rabbit populations were well established at both sides of the barrier (Woodford 2003). Sturt National Park and the Western Division are inside the NSW central dingo eradication zone.

Reaching South Australia, the fence line takes a jagged path around the external boundaries of South Australia's largest sheep stations, before reaching the coast at the South Australian Bight. Four of the outback stations on the South Australian boundary belonged to the architect of the barrier project, pastoralist Byron McLachlan. Described as the *Pioneer of Useless Land* (Financial Review 1992), MacLachlan successfully lobbied government to construct the fence and then to facilitate its maintenance supported by a fence tax imposed on pastoralists throughout the region. MacLachlan established a sheep empire that parallels the Scottish Highland Clearances, displacing Aboriginal communities and clearing the land of native wildlife to make way for a highly volatile grazing industry (Adamson 2007). MacLauchlan owned seventeen sheep stations (over 3.5 million hectares) by the time he passed away in 1992, by then one of the richest men in Australia (Van Dissel 2014).

The fence weaves its way across five deserts, three inland salt lakes, the Maralinga nuclear site, Woomera rocket range, gas and uranium mine sites (Woodford 2003). It crosses three states and over traditional lands that belonged to at least 23 different Aboriginal language groups pre-colonisation—thirteen now extinct and six critically endangered (National Indigenous Language Survey (NILS) 2014).

Fencing remote regions early in Australian colonial history served a clearly defined legal as well as practical functionality, following the pathway of colonial expansion. As historian Michael Cathcart details in The Water Dreamers (2009), Imperial Property Law required occupation of land, so the movement of settlers into the rangelands was a legal requirement of the British land claim in Australia. *Terra Nullas* (land ungoverned by recognised law) could—theoretically—have been taken by any invading nation if left unoccupied. There was great confidence that the hydro-engineering technology of the 1890s would transform the arid region into productive farmlands (Cathcart 2009; Philip 2019); however, the projects proved an overwhelming failure. The Federation drought of 1895 to 1903 brought an end the expansion of sheep grazing in the south-east Australian arid lands. The first influx of sheep to the region in the late 1800s was recorded as turning the formerly dense vegetation of dwarf saltbush, grasses and herbaceous plants on the planes into scantly covered and almost bare country (Bennett

1891). Stocking rates of the Western Division in 1860 were around 350,000 sheep, climbing to ≈13.6 million sheep by 1891 (Quinn 1997).

By 1901, the marginal grazing lands were a region overwhelmed by financial ruin, littered with bank foreclosures and abandoned properties—farmers walked off an estimated 5 million hectares of Crown leases in the Western Division (National Museum of Australia 2021). The widespread, severe environmental degradation caused calamitous' sandstorms across the south-east of the continent. The decline in available water resulted in contamination and poor sanitation, followed by outbreaks of illness and epidemics—typhoid, diphtheria, enteric fever, influenza, dysentery, malnutrition and heatstroke (Garden 2011). Many people died and an estimated two-thirds of the sheep flock starved or died of dehydration, as prices for livestock were reduced to "virtually nothing" (Fig. 4).

Formal establishment of the Dingo Barrier Fence in the 1950s gave increased control to the police and pastoralists along the outer edges of the south-east grazing lands. This was frontier land for the sheep empires (Letnic 2000a, b), fencing in the best waterholes and severing traditional *mura* or ancestral pathways between water sources and Aboriginal camp sites and hunting grounds across the remote region (Jack and Jeans 1996; Adamson 2007). Laws were imposed with gaol terms of 3 months for leaving a crossing gate open and 6 months for damage or removal of part of the structure—these penalties have remained active and unamended since 1946 (Dog Fence Act 1946: Sections 43:1 & 43:2). Movement of Aboriginal people was already seriously impeded, with most communities along the fence region voluntarily or forcibly removed off their traditional lands onto government reserves hundreds of kilometres away prior to the 1950s. The new laws further limited access, with movement and hunting too hazardous for Aboriginal people due to the frequent applications of poisons and use of concealed steel padded-jaw traps along the fence line. The Woomera and Maralinga tracks of the fence line were further contaminated with dangerous levels of radioactive waste following British weapon and nuclear tests through the 1950s (Jack and Jeans 1996). The wire structure in 2021 is accompanied on both sides by a clearing for a four-wheel drive maintenance track and remains entirely out of bounds to the public though the fence line can be traversed at various intersection points (Woodford 2003).

Fig. 4 The dingo fence traverses the remote South Australia arid lands, with sections of the fence built over 150 years old. Aerial view of the fence illustrates the extreme nature of this environment, north of Lake Torrens. PHOTO: Justine Philip, July 2021

The NSW Western Division is almost entirely Crown land and managed as grazing leases, with land fees assessed on an average carrying capacity of 0.366DSE (dry sheep equivalent) per hectare (LLS 2021). This area currently carries just over two million sheep (ABS 2020), performing at ≈25% expectation of the Crown Land figures. It is the region already described as one most at risk of ecological collapse in Australia (Bergstrom et al. 2021). Of the 24 mammals extinct in the Western Division, 14 were sighted for the last time before 1881. Causal factors for the extinctions are attributed directly to the impact of sheep grazing (Lunney 2001). The regular use of poisons to control native wildlife since the nineteenth century suggests the catalyst also has an ecotoxic legacy (Philip 2019), alongside the impact of introduced species such as feral cat, *Felis catus*, European red fox, *Vulpes vulpes*, and rabbits.

The Dingo Sink

To fortify the Dingo Barrier Fence as a kill zone, regular baiting programmes operate throughout south-east Australia, extending into a buffer zone to the north of the structure. In South Australia, this operational area outside the fence is called the Dingo Sink. Represented by the yellow area in Fig. 5, the dingo sink covers 40,000km^2 of land along a 1000 km front, traversing 15 cattle properties and 240 target waters that are usually baited twice a year (SA Government 2020, p. 18). The raw meat baits are injected with sodium fluoroacetate (1080) a broad-spectrum poison banned in most countries, apart from New Zealand and Australia (Philip 2019). It is classified as inhumane by the Royal Society for the Prevention of Cruelty to Animals (RSPCA 2021a, b) and it has no antidote; however, use is permissible failing any financially viable alternative to livestock protection in monocultural holdings. Inside the fence line, there are regular ground and aerial baiting programmes involving hundreds of thousands of meat baits designed to kill dingoes that have managed to breech the fence line.

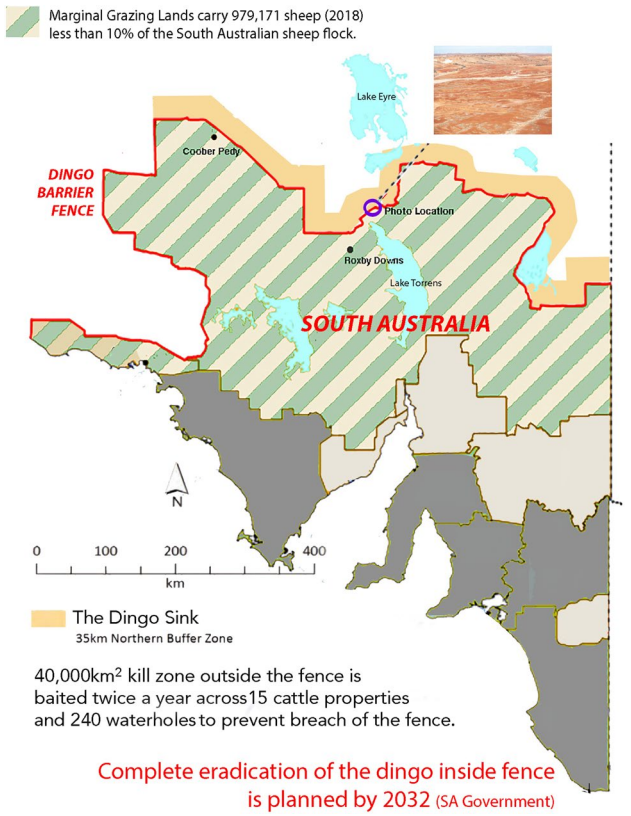

Fig. 5 The dingo sink (in yellow) represents a 35 km deep buffer zone to the north of the dingo Barrier Fence in South Australia. Data source: PISRA, South Australian Government 2020

From 2019 to 2022, the South Australian Government allocated A$25 million towards the rebuild and reinforcement of their 2150 km of the Dingo Barrier Fence, with the aim of 100% eradication of all dingoes south of the fence within 10 years (Kingsford et al. 2021; PIRSA 2019).

The success of grazing operations in the Australian arid zone has always been a question of scale—described as a marginal enterprise, over its 170-year history the industry has returned great economic dividends for the largest operators. At the same time, it caused excessive land degradation, a biodiversity crisis and financial ruin for many (Mabbutt 1973). Farms are getting larger to remain viable, as the human population in the regions is declining. Throughout NSW, there were 68% fewer farms in 2011 compared to 1981, and the industry is supporting an ageing population (Pattinson et al. 2015). The average age of an Australian farmer is 59, with a drop of 75% in farmers under 35 years of age since 1981.

Undeterred, the NSW Department of Primary Industries describes the Western Division of NSW as an economic powerhouse (LLS 2021), and they are currently extending the Dingo Barrier Fence along the entire north and west boundaries of the NSW Western Division adding 732 km to the existing structure (Fig. 6). The A$37.5 million taxpayer funded project aims rejuvenate stocking rates in an area that is already exhausted, to supply a market that is in serious decline (Fig. 7). The aim is to complete the construction in 2022.

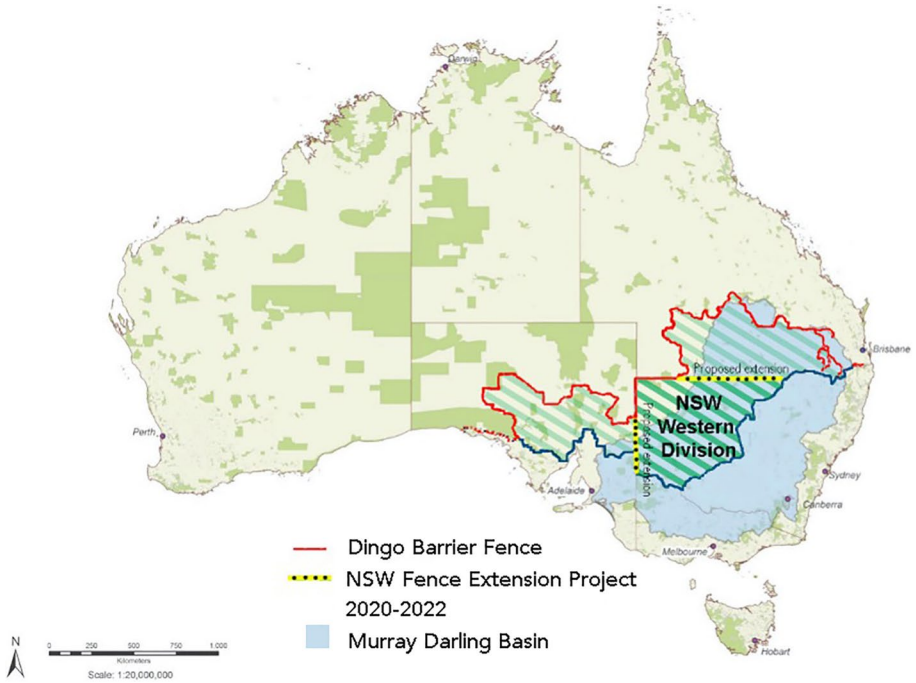

Fig. 6 NSW is currently spending A$37.5 million in public funds to extend the range of the Dingo Barrier Fence around the north and western borders of the NSW Western Division

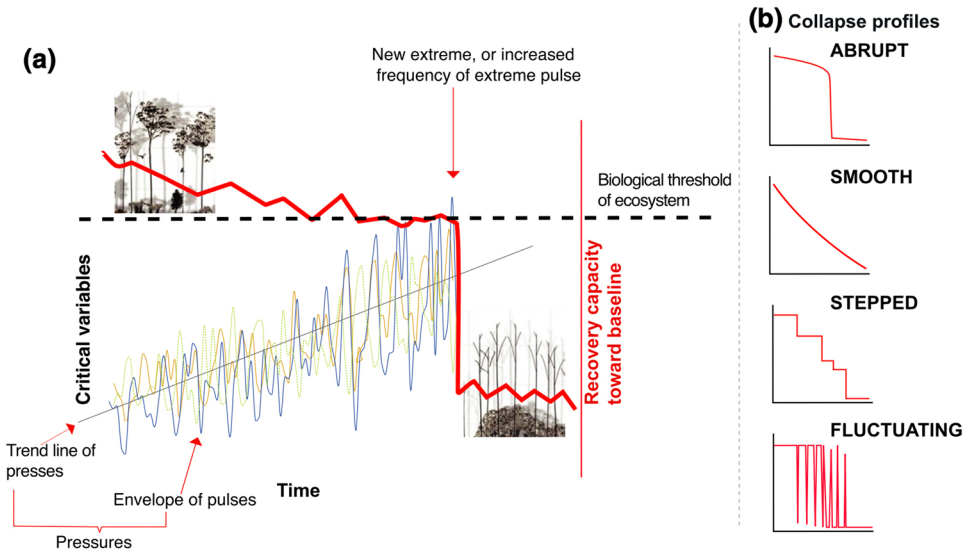

Fig. 7 Bergstrom et al. (2021) illustrate the pathways towards ecosystem collapse in response to environmental variables and reaching a biological threshold where recovery is no longer possible

Anticipation

A report on the impact of the Dingo Barrier Fence found that the wire mesh structure presents an environmental hazard to all terrestrial wildlife in its vicinity (Michniewicz 2020). It interrupts ancient semi-migratory pathways across the continent (Nield et al. 2020) and has created two separate ecological universes each side of the wire (Newsome et al. 2001). As such, the fence presents an obstacle to ecological reconstruction and prevents traditional land management practices such as firestick farming (cool burning) essential to the maintenance of arid zone vegetation.

The NSW Western Division is often referred to in literature and scientific reports as a dustbowl or conservation wastelands (Lunney 1994; Dickman et al. 2009). This area is identified as the region most at risk of total ecosystem collapse in Australia due to abrupt, smooth, stepped and fluctuating impacts and influences (Fig. 7), equal only in scale to the dying Gulf of Carpentaria mangrove forests (Bergstrom et al. 2021). Multiple threats are identified including increasing pressures of climate change—temperature, precipitation, heatwaves, flood and fire. Damaging human influences include livestock, invasive species, water extraction, habitat loss, run-off and pollution.

From biodiverse food systems to monoculture

Prior to British occupation, the Western Division was described as well-maintained parklands (Lunney 1997). The entire marginal grazing zone was an extreme but biodiverse region that supported many Aboriginal communities. Mobility was key to survival, and the fragile landscape benefitted from regular cool burning fire management and free movement of people and wildlife. Harvests included a wide range of traditional foods: perennial wild tomatoes *Solanum phlomoides*, dry season wild onions *Cyperus bulbosus*, bush potatoes *Solanum ellipticum*, wild orange *Capparis mitchelli*, bush lemon *Canthium oleifolium*, gruie apple *Owenia acidula* bush banana *Leichhardtia australis*, quandong *Santilum acuminatum* and an indispensable plant that stored water in its root system called *Tjunkul-tjunkul*, (Harding 2016; Low 1989; Smith et al. 1994). Other nutritional sources included the wood duck *Chenonetta jubata*, mallefowl *Leipoa ocellata*, red kangaroo *Osphranter rufus*, Emu *Dromaius novaehollandiae*, Witchetty grub *Endoxyla leucomochla* and blue-tongued lizard *Tiliqua scincoides*.

The first explorers described the region as diverse with dense grasslands, supporting large stands of large eucalyptus pines in the vicinity of the Darling River, and inhabited by thousands of waterbirds, kangaroo, emu, numerous species of rodents, snakes, dingoes, bats and nocturnal raptors (Lunney 2001). There were extensive stands of banksia (now locally extinct) growing on the sandhills, stabilising the soils and supporting nectivorous birds that have not been seen in the area since the nineteenth century (Smith et al. 1994). This biodiversity has largely been displaced by sheep grazing. However, the region presents a great opportunity and potential for cultural, ecological and economic reconstruction.

The ecological role of the dingo

The Australian dingo is a medium-size canine, ≈ 15.7 kilo body weight (Breckwoldt 1988). A generalist species, they inhabit arid, tropical and alpine landscapes and function as apex terrestrial predators on the Australian mainland (Newsome et al. 2001; Letnic and Koch 2010; Letnic et al. 2012;

Morrant et al. 2017). They are a cultural keystone species to the Aboriginal people and were fully integrated into Aboriginal cultural life and kinship systems (Philip 2017; Smith and Litchfield 2009). Genetic studies suggest they arrived by boat in a human assisted migration from east Asia between 4,000 and 10,000 years, and/or possibly by land bridge from Papua New Guinea (Cairns and Wilton 2016; Mattias et al. 2011). They remained geographically isolated from other canine species until the arrival of the British in 1788. As semi-wild companions, they contributed to Aboriginal society as hunting assistants, waterfinders and guardians (Philip 2020). Despite this long association they retained their independence, remaining true to the description of wild living canines (Cairns et al. 2021), not reliant on human society for food or water, and exerting influence as apex predator on local flora and fauna (Fig. 8).

All wild canine populations in Australia are predominantly of dingo heritage (see "The myth of wild dogs in Australia: are there any out there?" Cairns et al. 2021). Genetic testing indicates dingo populations in central Australia, and to the north and west of the continent, are largely free from introgression with domestic dogs. Conditions are too extreme for a feral or domestic dog to survive without human assistance in these regions. The term wild dog is used commonly within agricultural discourse, having less cultural associations than the distinctly Australian dingo. Hence, the Dingo Barrier Fence is also referred to as the Dog Fence, under the management of various wild dog destruction boards, etc. As such, the ecological and cultural significance of the dingo is largely unrecognised and their classification as vermin unchallenged by the status quo (van Eeden et al. 2020a).

Ecosystem restoration on landscape scale requires high functioning apex predators to support long-term environmental resilience and non-interventionist management goals (Colman et al. 2014). Rees et al. (2019) describe the dingo as functionally extinct inside the Dingo Barrier Fence, attributing their absence to the decline in biodiversity in the region.

Dingo populations have proved beneficial to the Australian biota by controlling herbivores in the medium to large weight range, easing grazing pressure on vegetation communities and aiding ecosystem stability and regeneration in the arid zone (Letnic and Koch 2010) Ecological studies comparing mammalian assemblages reveal stark differences on either side of the Dingo Barrier Fence, with populations of small mammals < 7 kg thriving in areas where dingoes are present (Letnic et al. 2009).

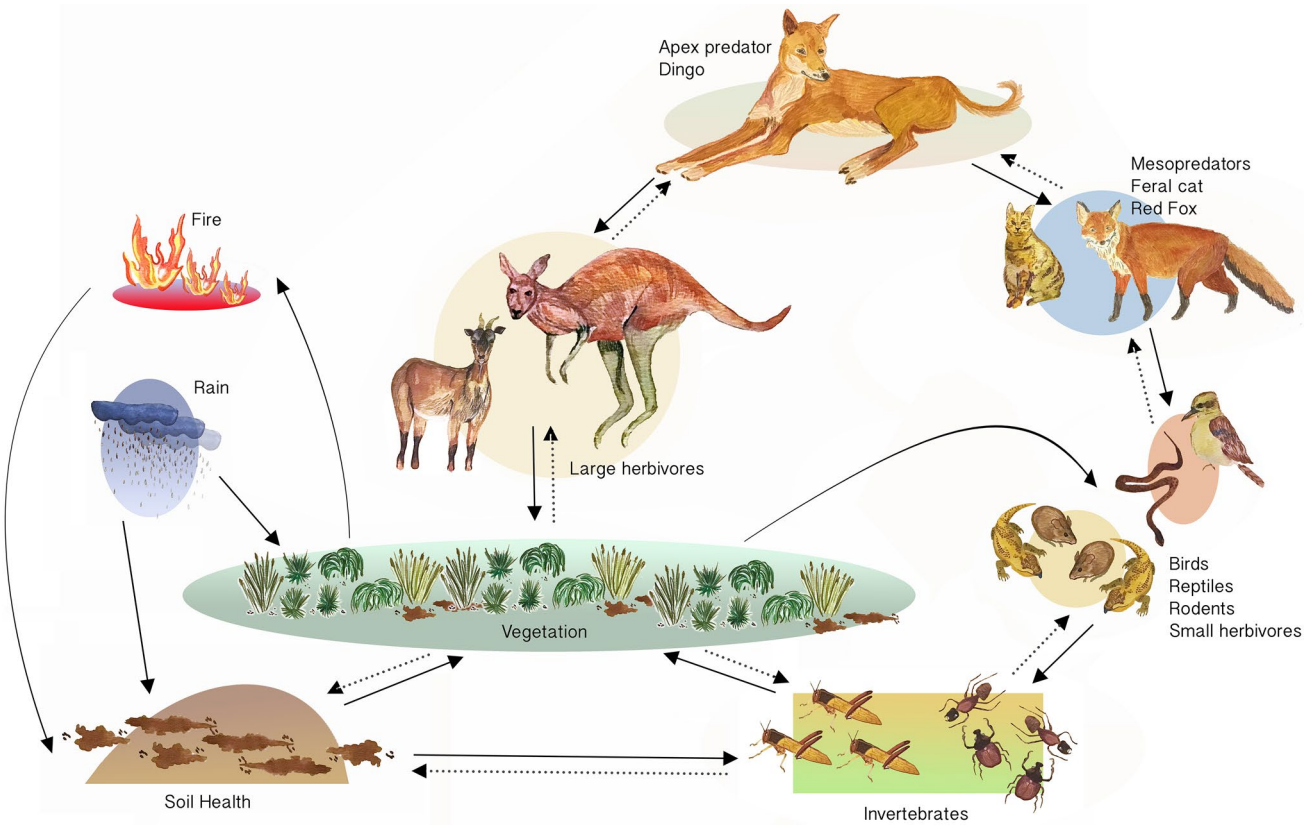

Fig. 8 The dingo's role as apex terrestrial predator in the Australian environment influences the health and fitness of all levels of biota above and below ground. Flow chart based on observations in Sturt National Park (Newsome et al. 2015) Artist: Joni Philip 2020

The regulation of herbivore populations is essential to the health of flora communities and is an animal welfare issue. The overabundance of herbivores leads to loss of vegetation cover essential in providing energy, habitat, carbon sequestration, water retention, improved soil health, support for insect populations (Newsome et al 2015). Vegetation cover is essential for boosting populations of small prey species and insectivores through providing habitat and food.

A 2021 study of the Dingo Barrier Fence analysed satellite imagery recorded over a 32-year period and identified changes in vegetation cover dynamics each side the fence line (Fisher et al. 2021). The changes were attributed to overgrazing of livestock and explosions in herbivore populations on the inside of the fence line in response to rainfall patterns. The absence of the top order predator and loss of traditional range of movement range was identified as the causal factor, proving detrimental to the health of soil, plant and animal communities.

A study by Pople et al. (2000) examined fluctuations in population densities of red kangaroos and emu inside of the Dingo Barrier Fence compared to relatively stable populations on the outside, concluding that dingoes do not just limit the numbers of herbivore populations but regulated them. Dingoes also ease competition on smaller herbivorous communities by suppressing mesopredator populations—predominantly feral cat and fox, two abundant introduced species considered to be key drivers of the current biodiversity crisis in Australia, alongside land clearing and changed fire regimes (EPBC Act 1999; Woinarski et al. 2015).

Maps from the Commonwealth Government's National Land & Water Resources Audit (2008) (Fig. 9) show a direct correlation between dingo absence and abundant fox and cat populations inside the dingo exclusion zone.

Ecologists suggest that reintroduction of dingoes to the Western Division could provide a cost effect method of reducing fox and cat populations; this could benefit around 90% of threatened vertebrates in the region (Dickman et al. 2009). The abundant feral goat and pig populations could also decline, allowing native trees and scrubs to regenerate. Facilitating reintroduction by removing the Dingo Barrier Fence would allow emu and kangaroo to disperse, and their movements and populations to be regulated by the dingo populations. This would improve vegetation cover, animal welfare outcomes and the dispersal of genetic material (Emmott 2020).

Dickman et al. (2009) presented a succinct argument estimating that 70 to 80 vertebrates on the threatened species list would benefit from reintroduction of the dingo into the fragile and damaged ecosystems of the NSW Western Division. However, a proposal to have the control and removal of dingoes listed as a key threatening process under the NSW Biodiversity Conservation Act 2016 in 2020 was rejected (Kerle 21/08/2020). This was due to differences in scientific opinion about ecological role of the dingo, and the additional

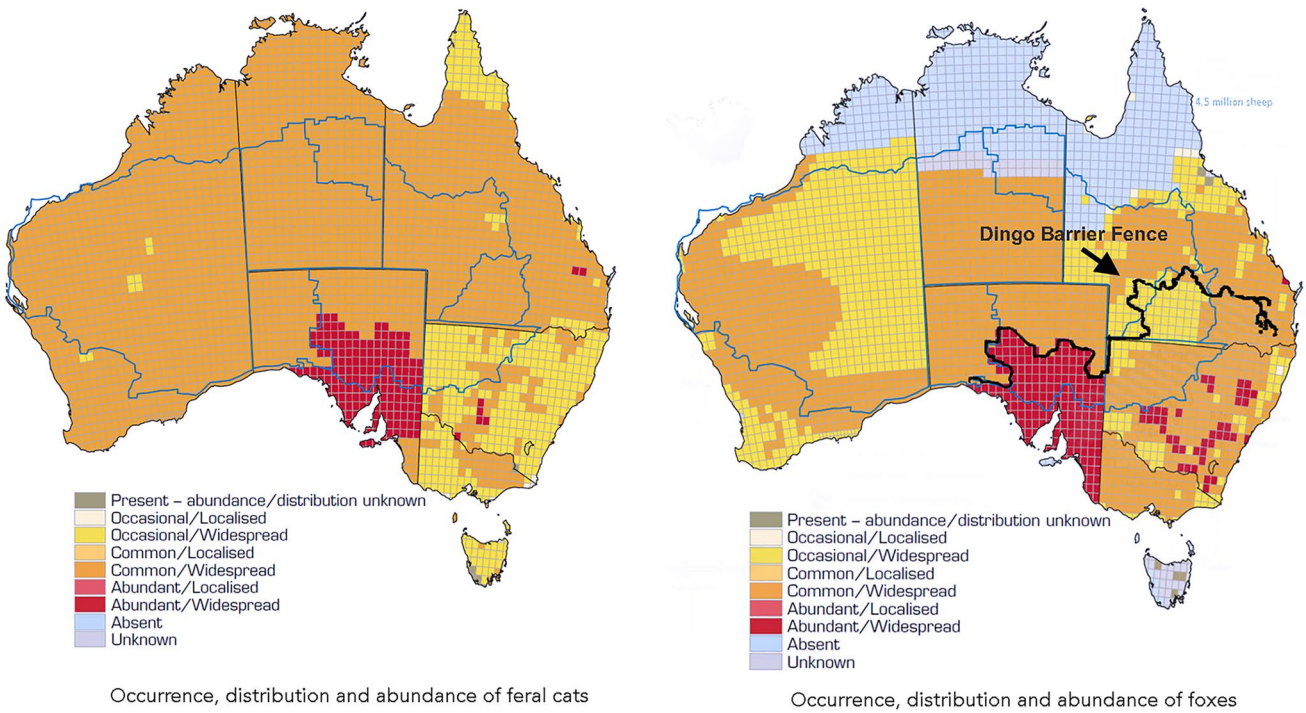

Fig. 9 Surveys of fox and feral cat numbers undertaken in 2008 show direct correlation between the dingo fence and the abundance of introduced predators. *Source:* West (2008)

threat their reintroduction could pose to the remaining threatened species through predation. There is a lack of emphasis on the evidence that it is not just the *absence* of the apex predator that is causing the crisis, but the *methods* of dingo eradication that are hazardous to the entire ecosystem. The impact of fencing, poisons and traps on non-target species is difficult to quantify, is largely unrecognised and is possibly a key factor preventing wide-scale recovery. These will be examined further in this review.

Environmental health scores along the Dingo Barrier Fence

The regions along the pathway of the Dingo Barrier Fence scored between 0.1 and 2.4 out of 10 in their environmental condition reports for 2019 with the Centre for Water and Landscape Dynamics (WALD 2021) at the Australian National University. In a report on the Western Division of NSW in 1984, 52% of mammals were believed to be extinct in the region, along with six bird species (Olsen 1998). 59% of all species in the Western Division were classifies as threatened in 2003 and this figure is around 60% in 2021 (Lunney et al. 2000; NSW Government 2021). After the rains of 2020 the WALD health scores are considerably higher than 2019, rising around ≈4/10 points, but have not improved on a scale relative to the broader region. This ability to rejuvenate after the 2016–2020 drought years is an indicator that the region is far from irreparably damaged, suggesting that potential for ecosystem reconstruction can be an attainable goal if the land is protected and rested through times of abundant growth. This would require allowing the free movement of wildlife between food and water sources, reduction of the current heavy chemical load and livestock rates, a halt to all unmonitored predator control and reintroduction of traditional Aboriginal land management such as cool fire burning to regenerate the vegetation.

Entrapment

A review into the direct impacts of the Dingo Barrier Fence in NSW identified entrapment in the wires of the structure as problematic for the majority of wildlife in the region including birds, kangaroos, bats and reptiles (Michniewicz 2020). Threatened species impacted include the long-haired rat *Rattus villosissimus*, desert mouse *Pseudomys desertor*, Stimson's python *Antaresia stimsoni*, Mallee slender blue-tongued lizard *Tiliqua scincoides*, Bardick *Echiopsis curta*, western blue-tongued lizard *Tiliqua occipitalis* and Lace Monitor *Varanus Varius*. Other species identified at risk include macropods, frogs and echidnas—the wire mesh is hazardous particularly because of their unique morphology. Likewise, reptile entanglement is noted as *exacerbated by morphology, whereby triangular heads and body scales can allow partial, uni-directional passage, without permitting retreat (*Michniewicz 2020 p. 28)*;* a particularly brutal fate for the desert specialists like the Thorny devil *Moloch horridus*. Sand goanna *Varanus gouldii* and perentie *Varanus giganteus* are at risk of entrapment or mutilation while trying to scale the structure (Fig. 10).

Fence death rates for birds have been recorded on average of one bird per five kilometres of fence per year for exclusion fencing (Australian Wildlife Conservancy 2021)—this translates to ≈1122 birds per year on the Dingo Barrier Fence. Fence hangings are commonplace for large macropods—kangaroo *Osphranter rufus*, *Macropus giaganteus* and euro *Osphranter robustus*, resulting from hind legs getting caught

Fig. 10 Sand Goanna *Varanus gouldii*, a large monitor lizard on the fence. Source: Royal Society Biology, n.d

in the wires while trying to jump clear of the barrier. These animals have a good chance of survival with aid, but in this remote region off-limits to the public, rescue is not possible.

Limiting mobility and dispersion

Loss of connectivity between the central desert and the Murray Darling Basin has affected the dispersal and survival of terrestrial wildlife, cutting off this access to vital water sources and preventing free movement in times of drought, flood and fire. Emu, a large nomadic ratite, range hundreds of kilometres in search of water and food sources, with movements dictated by climatic conditions (Olsen et al. 1993). At the Dingo Barrier Fence, they get trapped and disorientated, typically running the fence line until they veer off or die of exhaustion. Emu travel at high speeds of up 50 km per hour and collisions with the structure regularly result in death or mutilations. They are slaughtered along the fence line in the tens of thousands in times of drought. This is considered more humane than leaving the animals to die of dehydration and starvation, and prevents damage to the structure (*It's dog eat dog along the fenceline* 1994).

As a species, Emu are the long-distance dispersal vectors for seeds and spores, carrying some large seeds in their gut for over three months across hundreds of kilometres. Continental scale exclusion is described as the worst-case scenario for animal-generated seed dispersal patterns (Nield et al. 2020). As such, the Dingo Barrier Fence represents a critical loss to vegetation diversity, floral health and genetic transfer (Bradby et al. 2013). Other fence line casualties include ecosystem engineers such as bare-nosed wombats *Vombatus ursinus*. Each year, the local National Parks and Wildlife Service issue permits to cull the ground dwellers, as they tunnel under the fence leaving pathways for other wildlife to follow (Environment NSW 2021; *It's dog eat dog along the fenceline* 1994).

In Sturt National Park, enclosed by the Dingo Barrier Fence along its northern and western boundary, all of the 18 species of native mammal identified in the park are in danger of lethal encounter with the structure, including Dunnarts *Sminthopsis crassicaudata*, three species of bats and two endangered rodents: Forrest's Mouse *Leggadina forresti* and Sandy Inland Mouse *Pseudomys hermannsbergensis* (Michniewicz 2020).

Kangaroo and euro populations rise to problematic numbers inside the fence line, unable to disperse and unregulated by native predators or traditional hunting. The macropods are particularly susceptible to bottlenecks, such as the corner fence in Sturt National Park. These animals must be culled by the thousands, or techniques such as water point closure are used to drive the numbers down. Harvesting the animals would appear to be an ethical option; however, wild animals cornered by these wire mesh barriers suffer from post-capture myopathy. They tend to be in poor condition, highly stressed with bruising, cuts and broken bones (Descovich et al. 2015). This affects meat quality, making them unsuitable for market.

Between 2011 and 2014, Queensland spent $31.8 million on cluster fencing in the central region around the existing dingo fence, constructing an additional 3376 km of exclusion fencing. They eradicated all dingoes within the cluster zones, resulting in a huge surge in populations of kangaroos and euros. The fences have proved detrimental to the kangaroo harvest, crippling the industry with few animals to harvest on the outside of the fences and ailing wildlife within (Morris and Bradfield 2019).

Lethal traps and toxic load

Consideration for animal welfare is not a conditional requirement for animals classified as vermin such as the Australian dingo (PestSmart 2021), and the fortification of the Dingo Barrier Fence has been considered essential to the success of the sheep industry for the past 70 years, so the benefits are considered to outweigh any risks of the technologies employed. This includes the use of large steel padded-jaw traps that are banned in around 88 countries. "Off-the-shelf" padded Lanes Dingo Traps are lined with strychnine and approved by the RSPCA (2021a, b) for use in remote areas where it is not possible to check the traps daily. It can take between one to twenty-four hours for strychnine to cause morbidity to entrapped wildlife, and the level of suffering is classified as extreme (Humaneness Assessment Panel 2010). However, this is considered preferable to leaving the animals to die without food, water or shelter in the extreme temperatures. There are no records of how many animals get caught in the traps, and no public surveillance is possible.

Padded-jaw traps do cause serious injuries to non-target species, including wallabies who are highly susceptible to dislocations due to their morphology and tendency to panic (Sharp 2012). Goannas suffer dislocations and can die of hypothermia when caught in the traps. Birds and small mammals are at risk of being preyed upon when ensnared—this makes the risk of secondary poisoning a danger to the guild of Australian carnivores in the region including not just the dingo, but remaining spotted tailed quoll *Dasyurus maculatus* populations, sand Goanna *Varanus gouldii*, lace Monitor *Varanus varius* and bird species including kookaburras and raptors—largest being the wedge tailed eagle *Aquila audax* with a wing span up to 2.8 m (Bush Heritage Australia 2021).

Action

The cost of maintenance of the Dingo Barrier Fence is estimated at around A$10 million per year (Bradshaw and Ritchie 2012), with full time boundary rangers maintaining fence repairs, working across three State jurisdictions. Rangers are armed to dispatch dingoes within range and to dispatch wildlife trapped in the wires or causing damage to the structure. They also maintain the traps and poisons along the base.

The main enemies to the fence itself are natural events: floods rupture the fence line, wire netting disintegrates in saline lakes, sandstorms bury posts or join forces with buckbush (*Salsola tragus* or rollypolly) to push the structure over—sometimes providing an arboreal bridge over the wire for marooned terrestrial wildlife (Woodford 2003). Ants eat the posts, bush fires send terrified animals crashing into the wire, sand sometimes buries areas of the fence completely. During droughts, thousands of parched and starving animals are killed in stampedes, crushed up against the wire and prevented from accessing water sources across the continental barrier. In corners of the structure, animals die in such large numbers that their bodies have formed bridges over the fence, allowing other wildlife to disperse (Parker 2006; Woodford 2003).

Research comparing sides of the fence reveals differences in vegetation structure, geomorphology, soil quality and species composition (Letnic and Koch 2010; Lyons et al. 2016; Morris and Letnic 2017). Large areas of the marginal grazing land exhibits extreme exposed and dry soils, with the lack of soil moisture causing dust storms throughout southeast Australia. Soil exposure is the result of overgrazing and lack of vegetation cover, causing wide ranging impacts on the health and fitness of the entire biota—including human health as previously recorded during the Federation Drought. With climate change, the situation is predicted to decline; however, addressing the crisis early presents an opportunity to prepare the landscape for coming challenges and to re-establish resilience and adaptation. The considerable effort and financial investment spent on maintenance, reinforcement and extension of the Dingo Barrier Fence could be redirected towards ecosystem reconstruction and mitigation for climate change across the region.

Sturt National Park

Sturt National Park in the corner of NSW has been under government management for over 50 years. Despite attempts to restore the area over a 50-year period, the park was given 0.8 out of 10 on its health score card from the Centre for Water and Landscape Dynamics in 2019. It recorded the lowest level of vegetation coverage in 20 years, poor vegetation growth, high bush fire risk, poor soil moisture and endured a record number of hot days. Kangaroo populations in the park declined over 99% in the 2016–2020 drought, unable to disperse or access water (Kingsford et al. 2021). In contrast, the whole western region (Broken Hill and Far West) collectively scored 1.6 out of 10, a poor score but twice that of the National Park.

The park is a dingo eradication zone like the rest of the Western Division and regularly baited to control any dingoes that crossed the barrier and to try and reduce the abundant fox and cat populations. A new programme of ecosystem reconstruction in the park commenced in 2019, with three large-scale predator-free enclosures constructed, and the reintroduction of 13 locally extinct mammals planned over the following 10 years (Kingsford et al. 2021; see *Reintroduction of locally extinct mammals* 2020). The project, while an encouraging initiative, relies greatly on interventionist work involving heavy chemical loads targeting fox and cat populations as ongoing maintenance.

The current scale of chemical load for dingo eradication in the Western Division involves hundreds of thousands of meat baits per annum. The nil tenure approach requires baiting across all private and public lands. In April 2020, ground baiting covered 7,594,675 hectares of land and additional 48,214 baits were dispensed by air. In September 2020, ground baiting covered 10,351,829 hectares of land, backed by 53,000 baits distributed from air (LLS Data 2021). A total of one million meat baits were scheduled for distribution in 2020 over unpopulated regions of New South Wales after the 2019–2020 bush fires. These were the most severe wild fires on record. The targets were dingoes, foxes and feral cats—aiming to protect what was left of faunal communities after an estimated 3 billion animals were killed or displaced in the fires (van Eeden et al. 2020b). This is concerning, in an already depleted landscape. General trials of baiting technology reveal a 71% uptake of baits by non-target species (Kreplins et al. 2018; Philip 2020).

Following the baiting programme, a severe outbreak of ship rats *Rattus rattus*, and a mouse plague *Mus dometicus*, impacted the State in early 2021, an infestation described as the worst in living memory (Condon et al. 2021). In the Western Division, the Australian Pesticides and Veterinary Medicines Authority (APVMA) granted emergency permits to use zinc phosphate dispersed by drones over the plague areas, further raising the chemical burden on the environment (*Are poison-packed drones the answer to eastern Australia's mouse plague?* 2021). Zinc phosphate is classed as very highly toxic and highly toxic to many bird species and small mammals (AVPMA 2008). In addition, there are 67 rodent species in Australia, mostly native, endemic and include threatened species in the Western Division, that provide a breath of ecosystem services including simple to complex allogenic engineering—constructing burrows, moving

stones, weaving nests of vegetation and sticks, digging for food, providing habitat and food for other species, promoting nutrient flow, seed and spore dispersal (Dickman 1999; Singleton et al. 2007a, b). Ecosystem modelling suggests that these heavy chemical burdens could be avoided if there is a stepping back from predator control.

Fowlers Gap Research Facility

Projections for the Western Division over the next 20 years predict a decrease in human population (NSW Government 2021). The corner unincorporated region of NSW between Sturt National Park and Broken Hill is forecast to decline from a population of 1100 in 2016 to 900 in 2041. This sparsely populated region is home to the only arid zone research station in south-east Australia, the Fowlers Gap Research Facility. The centre is currently undergoing a change in operations making it well situated to become the hub for a United Nations Ecosystem Restoration programme and a facility for global research (BCT 2021).

Fowlers Gap covers 39,000 hectares, with sheep farming on the land dating back to the 1870s. It has been operating as a research station concurrently as a working sheep station since 1966 under the administration of the University of New South Wales (UNSW). It is listed on the register of the National Estate for its unique long-term monitoring of its flora, fauna, soil quality, solar energy and astronomy (Fowlers Gap 2013).

Fowlers Gap was first used as a conservation area in the late 1930s, after the state of the landholding was described (in keeping with the rest of the region) as appalling, initiating the first government funded studies into soil stabilisation and vegetation regeneration in the arid zone (Mabbutt 1973). From 1953, alongside the construction of the Dingo Barrier Fence the sheep market was rapidly expanding, so the conservation land was sublet for grazing. As a result, by 1965 the landholding was so severely degraded it proved unprofitable for either livestock or research. UNSW then took over the lease from the government to use as a teaching facility and to investigate land use and the biology of the native ecosystem of the area.

Described as a working farm from 1966 to 2021, Fowlers Gap Research Station is currently under further transition. De-stocked in October 2021, the area is to be managed as a conservation property into the future. Funding is being sought from the NSW Government Biodiversity Conservation Trust to keep the research facility operating. The current Managing Director, Keith Leggett, describes the move as a reflection on University of NSW priorities that anticipate the future for science and student interest to be in restoration ecology, not sheep (*pers. Comm.* 6 April 2021). The centre notably has not been consulted about the NSW Governments A$37.5 million Dingo Barrier Fence Extension project. After 12 years living on Fowler Station, Leggett reports ground and aerial baiting has been carried out there twice each year, and there has only ever been one sighting of a dingo on the property. This appears an excessive chemical load on a barely present threat, questioning if the loss of livestock on other stations is accurately attributed to dingo kills or simply natural attrition.

Generally, a dingo diet consists of ≈4% livestock (including carrion), mainly sheep or cattle (Stephens 1969; Corbett 1995). Sheep are not a preferred target prey species for the carnivores; however, with the compromised welfare of arid zone livestock, perhaps ailing animals invite an escalating predator response. In rising temperatures animal welfare is becoming an increasing issue, with sheep close to the limits of their reproductive range.

Climate change

With climate change, sheep face additional stresses including poor fertility, increased demand for water and changes in grass composition There are over 172 species of native grasses in the central Western Division—of which 83% have the C4 photosynthetic pathway specific to only 1% of the world's flora (Hattersley 1983). In the current rising temperatures, these grasses are desert specialist and can thrive, providing a key to restoration and adaptation of the region's flora and fauna. These plants are of little nutritional value to sheep; however, the deep-rooted perennial forage is essential for driving soil health and the nutrient cycle—they aid water retention, prevent erosion, aid the carbon cycle and drive the microbial cycle through releasing available nutrients and minerals deep beneath the earth's surface. Kangaroo grass, *Themeda australis*, a native C4, is highly valuable as a food source for marsupials, seed eating birds, parrots and insects. It provides a place for butterflies to lay eggs and habitat for small ground nesting species. Native C4 grasses are more flammable and burn hotter than grasses suitable for pasture, suggesting that in the rising temperatures, grasslands can recover but grazing foliage suitable for sheep will deteriorate. Fire risk will increase, as will the need for cool burning maintenance.

Thermal stress in the Western Division is an issue for native wildlife as well as livestock, with freedom of movement being a vital key adaptation to climate change. Many countries have some opportunity for adaptation with species able to migrate to higher altitude. Moving uphill, however, is not an option available to most species across Australia where the average elevation across the continent is only 440 m (Hughes 2012). The alternative of significant overland shifts in populations is needed, even to adjust to small levels of environmental warming. As such, decommissioning

the Dingo Barrier Fence is perhaps an essential key towards climate change adaption in the marginal grazing zone.

Organic certification and the chemical load

Most land operating as organic farms in Australia involves beef cattle production. This is an industry that widely recognises dingoes as allies in the farming operation, for their control of native herbivores and improved pastures (Emmott 2020; Prowse et al. 2015; Wallach et al. 2017). Organic certification requires that no 1080 poisoned baits are used on the land for three years prior to certification, so moving to the positive predator management system across the entire marginal grazing zone would facilitate organic production in the region and encourage a younger generation of farmers back to the land—a demographic described as well educated and keenly interested in new agricultural enterprises (Future Farmers 2021).

Moving away from chemical control is being market driven across all areas of farming, and many countries have learned to make their peace with predator populations without crippling local economies—even in areas of dense human populations (Wallach et al. 2017). Australia's challenge in this regard is less complicated—the marginal grazing zone is a vast area of largely unpopulated land. The potential for ecosystem reconstruction could be transformative.

Dismantling the fence line during the rains would allow for an influx of wildlife to flow through the region. This would enable seed dispersal and genetic transfer, and for the flourishing of plant life and vegetation cover. Instead of increasing livestock numbers during these years of bounty, the land should be protected, livestock reduced to a minimum (as is within the powers of the Commissioner for Crown Lands to prescribe, in The Act 2016). This would enable plant and animal communities to build some resilience to survive the next round of drought years and to mitigate climate change.

The stability of dingo population is likely to be self-regulating once established, as is characteristic of apex predator populations (Wallach et al. 2015). The dispersal of individuals could be monitored and controlled by Aboriginal rangers whose heritage reveals in-depth understanding of the movements and dynamics of dingoes and their prey on a landscape scale (Thomson et al. 1985).

The Crown Land Commissioner: a potential leader in ecosystem reconstruction

The post of Commissioner of Western Lands, who oversees the management of the region, is held by a sole representative appointed by the NSW Governor. Since 1934, the post has been responsible for *initiating actions aimed at the eradication of dingoes and wild dogs* (Australian Research Data Commons ARDC 2021). Since 1957, this has included holding the position of Director of the Wild Dog Destruction Board, the Office that manages the NSW section of the Dingo Barrier Fence.

The Crown Land Management Act, first formulated in 1901, was an attempt to reverse destruction of the arid lands, the result of vast overstocking in the 1890s (Lunney 1994). The act has been revised over the years, but one constant has been the directive to exterminate the dingo, despite growing appreciation of their ecological and cultural significance, and despite the heavy chemical burden and hazardous nature of the operation for the rest of the biota.

Key aspects of the Crown Lands Management Act 2016 are essentially incompatible with dingo eradication policies. The ecological role of the dingo is understood as essential to ecosystem health in the majority of biological and environmental studies (Dickman et al. 2009; Emmott 2020; Letnic et al. 2012; Wallach et al. 2017). The only school of thought that argues this point are the agricultural scientists (Allen et al. 2011, 2013; Ballard et al 2020; Fleming and Ballard 2014), under whose guidance the 82-million-hectare marginal grazing zone region has become one of the world's worst examples of land degradation and species extinction.

The principles of the Crown Land Act 1.4 (a-d) prioritise the conservation of water, soil, flora, fauna and scenic quality. Public use and enjoyment of land are encouraged, as is multiple use of the land. Act 1.4 (e) states *where appropriate, Crown land should be used and managed in such a way that both the land and its resources are sustained in perpetuity.* Objects of the Act (1.3 d-e) state that the land should be managed for the benefit of all the people of NSW. It should facilitate use and co-management of Crown Land by the Aboriginal people, recognising the importance of their spiritual, cultural, social and economic connection to country. None of these principles are adhered to or delivered through the current system of management. However, changing focus is well within reach for the NSW Crown Lands Department, providing a template for other jurisdictions in the marginal grazing zone to follow:

The position of Commissioner of Western Lands should be held by Australia's pre-eminent arid zone ecologist, concurrently as Director of a dedicated arid zone biodiversity research centre. Fowlers Gap Research Facility is well suited for this role.
Research should focus on regenerative land management and traditional harvests. This would support:

- Fostering partnerships between Aboriginal communities and science-based arid zone ecosystem reconstruction projects
- Support for large-scale conservation zones with educational and eco-tourism potential.
- Enforcement of the Western Lands (Amendment) Act No. 45 1949, 6(iv–v), that states all Western land leases must assist in land regeneration and permit natural reseeding on the landholdings. [Under this amendment, overstocking the land is an offence, and the Commissioner has the authority to set the limits for carrying capacity.]
- Crown Land should be reassigned from outmoded Grazing Leases to other tenures including mosaic systems of mixed farming practises, predator-friendly meat production systems, permacultural systems, dual lease holdings (such as solar farms and organic enterprises) and re-establishing traditional crops.

Graziers in the arid zone are already being encouraged to diversify stock holdings and farming operations to mitigate the impacts of climate change (Bastin et al. 2014), with many operations—particularly in Corner Country NSW—transitioning to organic goat and cattle farming or out of farming all together—see Narrierra Carapundy Swamp National Park formed in 2020 (NSW Government 2020).

If positive dingo management is prescribed across the existing marginal grazing zone, and sheep moved to the proposed protection limit south in the sheep–wheat belt (Fig. 11), this would greatly lower the chemical burden on farmlands, opening up potential for regional organic certification, and encourage participation in new, rapidly expanding and eco-conscious markets. Twenty-first-century non-lethal technology is available to be employed in the protection of livestock in and outside of the marginal grazing zone. These include aerial surveillance, livestock guardian animals, livestock collars, mixed stocking, mobile fencing, etc. (Smith et al. 2020).

The removal of the Dingo Barrier Fence could aid the natural dispersal of semi-migratory species and permit the gradual reintroduction of the dingo into an ecological reconstruction zone. Aboriginal Rangers are well placed to oversee the transition. Diverting funds from the $37.5 million Dingo Barrier Extension Fund would help facilitate the transition for NSW and provide a compensation fund for any stock losses.

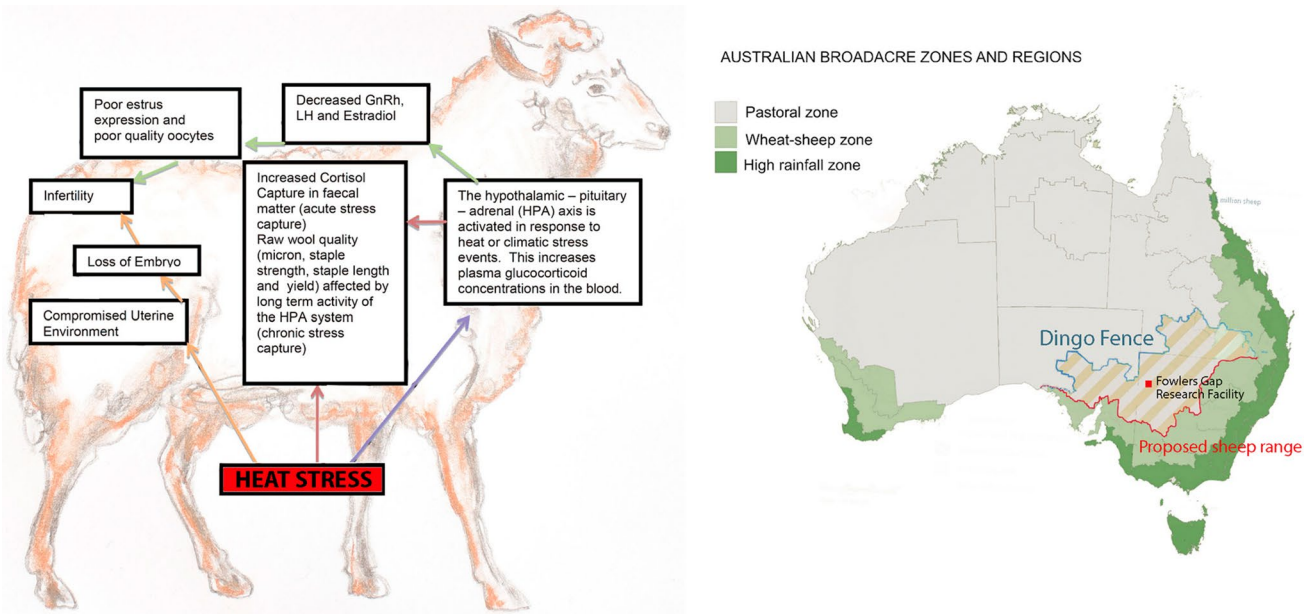

Fig. 11 Fowlers Gap Research Facility is registered on the National Estate for long-term monitoring of livestock, soils and ecosystem function. Sheep here are at the limits of their reproductive range due to increasing heat stress affecting health and reproduction. Data source: Sawyer and Narayan (2019), Artist: J Philip

In conclusion

The impact of the Dingo Barrer Fence project on the south-eastern ecology has been immense, severing connections between central and south-east Australia. It has restricted the movement of terrestrial wildlife on a continental scale and rendered the apex predator ecological and culturally obsolete across the south-east of the continent.

The physical structure and its lethal support systems present a hazard to wildlife and human communities, with the kill zone around the 5614 km trajectory of the fence presenting a vast, hostile, uninhabitable hazard zone. It has replaced the stable traditional occupation and management of the land—occupied pre-colonisation by over 23 Aboriginal language groups—with volatile and unreliable livestock production, at incalculable cultural and ecological cost.

To continue to maintain, reinforce and extend the range of the Dingo barrier Fence, along with its support systems and management base, is incompatible with any transformative ecosystem reconstruction programme or cultural restoration in the region. Moving 6% of the Australian sheep flock into mixed farming systems or south to the higher rainfall areas is not going to cripple the sheep industry in Australia. It offers a viable economic alternative to facilitate ecosystem renewal and would provide opportunities for participation in emerging ethical, consumer-driven markets. Encouraging this transition requires systematic shifts in land management and policy, such as a cultural change for leadership and governance in the arid region. Reassigning the position of Commissioner of Western Lands to the country's leading ecologist could expedite this transition towards ecological renewal.

Supporting arid ecology that is hanging on to the edges and borderlines is of immense importance. These animals and plant species are so unique in their adaptions that they are not just extraordinary in their own right, but their preservation may hold the keys to improving food security, adaptation and resilience in the time of rapid climate change.

The marginal grazing zone was home to highly specialised human, plant and animal communities that thrived over tens of thousands of years in the region. For the past few thousand years this included dingo populations, organising the biota alongside the Aboriginal communities with such precision that large areas of the region were described by British explorers, as a thriving parkland. Using this same land as a marginal grazing zone has deteriorated the environment to the point where the ecosystem is described as being vulnerable to total collapse.

Following reparative action to remove the Dingo Barrier Fence from Australia's heartlands, prescribing rest plus a long-term transformative ecological health plan, can potentially restore resilience and health of 82 million hectares of land. This would affect not just the deteriorating marginal grazing lands, but has potential to improve air quality, protect biodiversity, and increase food security across central and south-east Australia.

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