frontiers | Frontiers in Conservation Science

TYPE Original Research
PUBLISHED 08 March 2023
DOI 10.3389/fcosc.2023.1126140

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to
Human-Wildlife Interactions,
a section of the journal
Frontiers in Conservation Science

RECEIVED 17 December 2022
ACCEPTED 09 February 2023
PUBLISHED 08 March 2023

CITATION
Boronyak L and Jacobs B (2023) Pathways
to coexistence with dingoes across
Australian farming landscapes.
Front. Conserv. Sci. 4:1126140.
doi: 10.3389/fcosc.2023.1126140

Pathways to coexistence with dingoes across Australian farming landscapes

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Introduction: Agriculture and biodiversity conservation are both vitally important human activities that overlap geographically and are often in conflict. Animal agriculture has been implicated in species loss and the degradation of ecosystems due to land clearing, overgrazing, and conflicts with large carnivores such as dingoes (Canis dingo). This paper explores the potential for transformation in Australian commercial livestock production from human-dingo conflict towards social-ecological coexistence.

Method: A qualitative model that depicts transformative change was developed from field observations and twenty-one in-depth interviews with livestock producers, conservation researchers, grazing industry representatives and policy makers across Australia. The model articulates the current state of dingo management and the drivers of system change.

Results: Seven pathways are described to catalyse transformation from routine lethal management of dingoes towards a future vision that embeds mutually beneficial coexistence. Central to transformation is the adoption by livestock producers of preventive non-lethal innovations supported by a new farming movement, Predator Smart Farming, that balances livestock grazing and wildlife conservation values to unlock the resilience of landscapes, animals (domesticated and wild) and livelihoods. Other key pathways include targeted research, capacity building, outreach and knowledge sharing networks; institutional (policy, legislation, and economic incentives) and cultural change; public awareness raising and advocacy to reduce lethal control; and greater involvement of Indigenous Australians in decisions relating to wildlife management.

Discussion: The seven transition pathways are discussed in relation to how they can collectively foster coexistence with dingoes in extensive rangelands grazing systems. International examples of interventions are used to illustrate the types of successful actions associated with each pathway that could inform action in Australia. The findings have implications for coexistence with large carnivores in rangeland ecosystems globally.

KEYWORDS

social-ecological systems, animal agriculture, coexistence, human-wildlife conflict, dingo

Introduction

Large carnivores such as wolves, bears, leopards and dingoes are considered valuable focal species for conservation efforts (Terborgh and Estes, 2010; Belant et al., 2012; Tshabalala et al., 2021). Conservation efforts have been directed to finding ways to reduce conflict and foster coexistence with large carnivores in multi-use landscapes (McManus et al., 2015; Stone et al., 2017; Young et al., 2019; Smith et al., 2021). Australia is endowed with rich biological heritage and a high species endemism (Chapman, 2009), yet the resilience of ecosystems is being degraded from a range of causes including climate change (Steffen et al., 2009), land clearing (Cocklin and Dibden, 2009), and loss of biodiversity (Woinarski et al., 2015). Loss of large carnivores, like the dingo, is increasingly identified as contributing to the decline of biodiversity through its impact on trophic cascades (Terborgh and Estes, 2010; Ripple et al., 2014). Studies show that dingoes reduce the density or change the behaviour of introduced meso-predators *via* trophic regulation, thereby assisting the survival of smaller native species (Letnic et al., 2009a; Wallach et al., 2010; Letnic et al., 2012). Dingoes can also regulate the abundance and movement of prey species, which in turn benefits plant communities and landscapes for livestock grazing (Letnic et al., 2009b; Wallach et al., 2010; Prowse et al., 2015). Dingoes are a native animal of high conservation priority due to their ecological, cultural and evolutionary identity (Cairns, 2021). The dingo as the primary endemic predator in Australia, therefore, provides an interesting case with which to explore human-carnivore conflict and coexistence (Smith et al., 2019).

Agriculture and biodiversity conservation are vitally important human enterprises that are increasingly in conflict (Bruskotter et al., 2021). Agriculture is essential to produce the food and fiber that sustains human wellbeing and the Australian economy. Extensive livestock grazing occurs across Australia and, in vast areas of the semi-arid rangelands, relies on native vegetation that also provides habitat for wildlife. Over half of all farms raise either cattle or sheep, making this the most common and widely dispersed agricultural activity in Australia (Frilay et al., 2015). It is within these multi-use landscapes that tensions can occur between grazing communities and wildlife. This tension, particularly with carnivores such as dingoes, distinguishes coexistence from cooccurrence (Harihar et al., 2013). Interactions between humans, dingoes and livestock can vary from direct conflicts to tolerance and mutually beneficial coexistence.

Dingoes are implicated in conflict with livestock producers (referred to in Australia as 'graziers') due to their ability to harass, harm or kill livestock (Fleming et al., 2014). This has resulted in the desire to suppress dingo populations using lethal control (trapping, shooting, or poisoning with meat baits containing sodium fluoroacetate, a pesticide commonly known as 1080) (Reddiex and Forsyth, 2006; Pacioni et al., 2018; Philip, 2019), primarily to mitigate their impacts on livestock grazing (Allen and West, 2013; Fleming et al., 2014; Campbell et al., 2019). Estimates of dingo arrival in Australia range from 4,000 to 18,000 years ago, dingoes have become integral to many Australian ecosystems as a top predator and endemic species have adapted to their presence (Carthey and Banks, 2012; Balme et al., 2018). In legislation and policy documents dingoes are referred to as wild dogs, a classification which also includes roaming domestic dogs and the hybrid descendants of dingoes and dogs (Letnic et al., 2012; Wicks et al., 2014). In most states landholders are compelled by law to control dingoes by designating them a declared pest or biosecurity threat (Australian Government, 2014; New South Wales Government, 2015). Although dingoes are blamed for livestock predation, they are known to consume a wide variety of more than 200 species such as rabbits, arthropods, birds, reptiles, possums, and macropods (Allen, 2012; Doherty et al., 2019). A growing number of cattle graziers are recognising that dingoes can be an ally to producers in restoring degrading rangeland ecosystems by regulating total grazing pressure (Emmott, 2020; Pollock, 2020; Campbell et al., 2022).

The killing of large carnivores that are widely considered to be charismatic wildlife, is a highly emotive and controversial issue (van Eeden et al., 2017). Moreover, evidence increasingly shows how terrestrial ecosystems become disrupted when carnivores, such as dingoes are removed, ultimately leading to ecosystem dysfunction through escalating loss of biodiversity and animal welfare implications (Letnic et al., 2013; Ripple et al., 2014). Coexistence provides a powerful way to reframe the relationship between humans and wildlife to maintain the ecological benefits that accrue from carnivore presence in agricultural landscapes. Coexistence with wildlife has an explicit spatial-temporal-ecological dimension, yet it also has a relational dimension as it encompasses how people can modify their behaviour and interaction with wildlife to ensure that it is based on cooperation (Marchini et al., 2019). Coexistence can be viewed from a systems perspective as encompassing interactions between social and ecological components (Glikman et al., 2021) of managed ecosystems. Among the ecosystems used for livestock production in Australia, rangelands are significant because they occupy over 75 per cent of the total area of Australia (Department of Agriculture Forestry and Fisheries, 2019). In addition, rangelands support extensive livestock grazing in less modified landscapes that are more biodiverse than in cropping systems (Scherr and McNeely, 2008). Rangelands can be considered as linked social-ecological systems as they form an interface where carnivores, prey, people and livestock co-occur (Zimmermann et al., 2010; Biggs et al., 2015; König et al., 2021) making them ideal for the study of human-carnivore coexistence. Furthermore, in such systems, wild prey is often displaced by domestic livestock that are semi-free-ranging and largely unprotected from carnivores (Zimmermann et al., 2010).

Establishing conditions for coexistence to enhance conservation of large carnivores in human dominated landscapes is challenging (Chapron et al., 2014). It requires identification of the causes and drivers of dingo intolerance and persecution to identify pathways (O'Brien, 2018) towards more sustainable agriculture that incorporates high animal welfare and coexistence with wildlife as social norms. Advocating for more sustainable forms of agriculture requires a systems-oriented approach to understanding complex ecological, social, and environmental interactions in rural areas (Pretty, 1994). Boronyak et al. (2021) used a social-ecological transformations framework to develop qualitative models that depict transformative change in rangelands grazing in the United

States and South Africa. Through close engagement with a broad range of stakeholders these models documented the current systems state, the factors driving human-predator conflict and a series of transition pathways towards a transformed future that embedded coexistence as central to rangelands grazing. A critical component of successful system transformation is the creation of an enabling environment to facilitate the adoption of preventive non-lethal tools and practices (herein preventive innovations), McManus et al. (2015); Stone et al. (2017); Much et al. (2018); Boronyak et al. (2020); Cleary et al. (2021); Smith et al. (2021) as an alternative to lethal control measures. While there are many tools and methods encapsulated within the term preventive innovations, these have been classified into three key areas: livestock husbandry (e.g., guarding and herding), enclosures (e.g., night pens, fencing), and predator deterrents (e.g., flashing lights). Each of the tools and practices operate differently, can be adapted to the local context (livestock type, terrain, local wildlife), and can be used individually (e.g., guarding dogs) or in combination (e.g., dogs by day, pens by night).

Here, we apply the approach of Boronyak et al. (2021) to explore with stakeholders the dynamics of system transformation to coexistence with dingoes in Australian rangeland grazing systems. We will identify and discuss pathways that bridge the gap between the current reliance on lethal control to a system of mutual coexistence. Individually the pathways are unlikely to create transformational change. However, collectively, progress along all pathways should be self-reinforcing and lead to the deep continuous change needed for system transformation (Termeer et al., 2017). Furthermore, the pathways are associated with diverse aspects of social-ecological systems such as human behaviour and beliefs, culture, governance, institutions, ecology and economy (de Haan and Rotmans, 2011) and reflect contemporary thinking about fostering human tolerance and coexistence for wildlife in shared landscapes (Lindsey et al., 2009; Slagle et al., 2013).

Methods

Twenty-one, semi-structured interviews (see Supplementary Material for interview guide) were conducted with Australian graziers, researchers, and conservation and government representatives across Australia. The interviewees comprised commercial livestock producers (13) and representatives of the livestock industry (1), the Centre for Invasive Species Solutions (1), state government agencies that oversee wildlife management and/or agricultural interests (one each from New South Wales, Victoria and South Australia), environmental and animal protection NGOs (2), and a researcher specialising in preventive innovations. The 13 graziers interviewed covered all of mainland Australia with the exception of the Northern Territory and within this sample, eight producers (seven cattle and one sheep producer) did not kill dingoes that inhabited or moved through their property (herein designated 'innovative producers'). The remaining five producers, all sheep producers, relied primarily on lethal management to reduce dingo predation (herein designated 'conventional producers'). We recognise that these designations are artificial and not intended to imply conventional producers were not innovative in any practices used in their production systems.

Two sampling procedures (purposive sampling and snowball sampling) were used to recruit interviewees. Firstly, purposive sampling was used to deliberately select candidates who met the criteria of having relevant experience or knowledge of livestock production, dingo management and/or conservation (Charmaz and Bryant, 2010). The emphasis of this sampling technique was on quality rather than quantity, with the aim to become 'saturated' with information on the topic (Morse, 2015). Additional participants were identified using a snowball or network sampling technique (Biernacki and Waldorf, 1981). These procedures yielded a varied sample of participants *via* referrals to various stakeholder groups such as government agents, NGO representatives and livestock producers, that would be difficult to reach without assistance (Etikan et al., 2016). This technique is useful to sample individuals from groups that are either reluctant to volunteer personal information or are geographically isolated from major cities (Sadler et al., 2010).

The interviews were conducted by phone or on-line video and averaged between 60–90 minutes duration. Interviewees were provided with an information sheet outlining the scope of the research, at the start of the interview they were provided an opportunity to ask questions about the research and completed a written consent form to participate in the research. Human research ethics approval was granted by the University of Technology Sydney (ETH18-2568— HREC). During analysis qualitative data were synthesised and anonymised and arranged thematically into five components (drivers, current system state, transition pathways and future desirable state) of a model template to describe system transition (Figure 1) through three rounds of manual coding using MAXQDA software (VERBI GmbH version 18.2.0) to refine concepts and remove redundancy. The qualitative model developed through this process is not intended to predict the future system state. Rather, the transformed system describes the set of normative aspirations, as identified by participants, that allow the shaping of pathways encompassing actions needed to promote transition between system states.

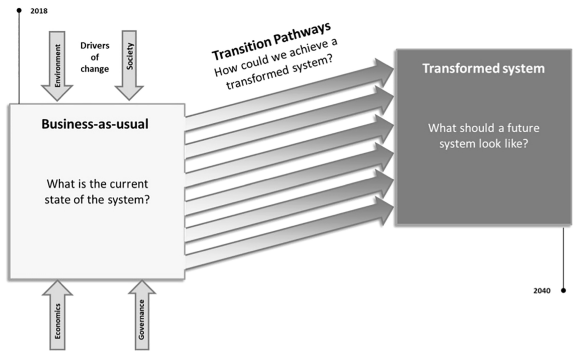

FIGURE 1
A conceptual model of transformation for extensive grazing of rangeland systems (Adapted from Jacobs et al., 2017).

The draft model was then validated using a modified Delphi approach. The Delphi approach seeks to ensure accuracy, reach a consensus, and check for omissions or misinterpretation (Mead and Moseley, 2001) by drawing on diverse knowledge and experiences of a range of stakeholders (Powell, 2002). The draft model was sent to eight key stakeholders representing a mix of livestock production, conservation, and governance to elicit feedback through two rounds of comments. At each round, the model was revised, comments anonymised and the revised model returned to the participants for further reflection. The model was finalised when consensus was achieved among the stakeholders consulted.

Results

The information gathered through key informant interviews was synthesised into a model of transformative change in Australian extensive grazing systems (Figure 2). In this section we explain each component of the model with a focus on the transition pathways.

Business-as-Usual

The use of lethal control of dingoes is widespread and occurs on both public and private lands in all mainland states. Across mainland Australia, legislation legally obligates landholders to lethally control wild canids on private properties except for the Northern Territory. Lethal control was also described as a 'conservation strategy' to reduce the perceived threat to dingo purity from dingo and dog hybridisation. The narrative of lethal control as conservation has created a shift in terminology from 'dingo' to 'wild dog' largely driven by industry to justify these methods. Lethal control methods are supplemented by landscape-scale fences; the Dingo Barrier Fence is the longest fence in the world running from Queensland to South Australia (5,614 km), and the State Barrier Fence in southwest of Western Australia are used to separate livestock grazing from dingoes (Philip, 2021).

Increasingly, wildlife exclusion fencing, referred to as cluster fencing, is being erected around private grazing properties (Smith et al., 2020). Although fencing is generally considered a non-lethal management strategy, it can restrict the movement of species other than dingoes and can cause entanglement and injury. There also appears to be polarised debate about dingoes between, on one side, the grazier-dingo conflict over livestock and, on the other side, the important ecological, cultural and social role of dingoes in Australian landscapes. The livestock grazing industry has significant influence on government policy, legislation and operational decisions about the management of dingoes. This influence tends to crowd out the voices of Indigenous Australians, conservation and animal welfare groups, and consequently dingoes are persecuted as 'agricultural pests'. A small but growing number of graziers are using livestock guardian animals or simply ceasing lethal control of dingoes on their properties. This reflects the growing body of evidence of the importance of dingoes to the health and function of Australian ecosystems.

Drivers of system change

The drivers of change cover four key areas – environment, society, governance and economics. Australia is amongst the top seven countries globally that contribute more than half of global biodiversity loss (Waldron et al., 2008). The lethal control of dingoes has significant impacts for small mammal biodiversity

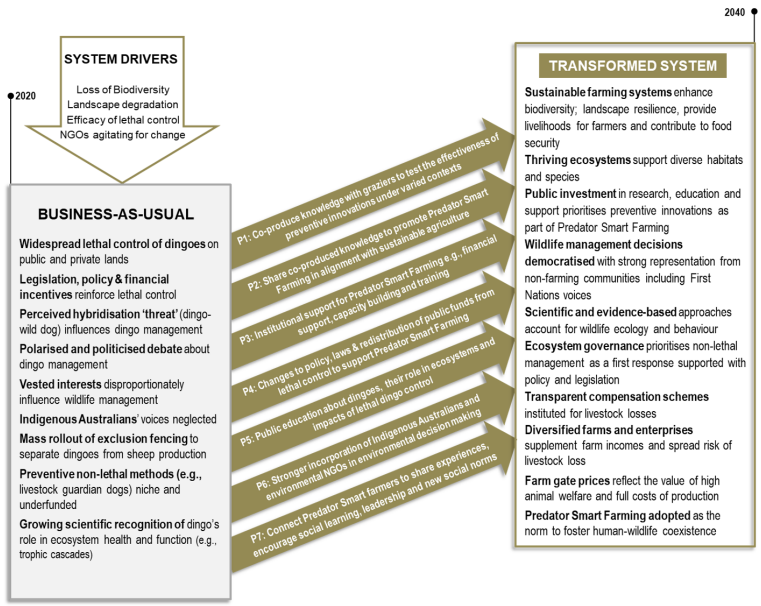

FIGURE 2
A qualitative model of transformative change in extensive grazing systems in Australia.

and contributes to loss of ecosystem services. This loss of ecosystem services combined with intensive grazing pressure from non-native herbivores is leading to degradation of rangelands ecosystems. There is growing awareness of the welfare costs of lethal control for dingoes and non-target species due to the indiscriminate nature of trapping and poisoned meat baits. This is leading to conservation and animal welfare NGOs seeking to raise public awareness of the costs of lethal control of dingoes, and to lobby government for greater investment in tools and practices that facilitate coexistence with dingoes and other Australian wildlife. These drivers of change appear relatively weak compared with factors that entrench lethal control in the current system e.g., government legislation.

Transition pathways

Seven pathways in the model (Figure 2) aimed to balance multiple stakeholder interests and overcome the entrenched paradigm of lethal control of dingoes.

Pathway 1 (P1) focuses on collaborations to co-produce research that investigates the efficacy of preventive innovations in a range of contexts, such as cattle or sheep grazing, and variations in rangeland ecosystems. The risks that dingoes pose to extensive livestock grazing means that graziers must be engaged as part of an integrated and collaborative approach to research, trials, and implementation of non-lethal methods. A collaborative approach would draw upon local knowledge to identify practical solutions combined with understanding of dingo behaviour from ecologists and wildlife managers.

This pathway seeks to shift the focus from managing dingo numbers *via* lethal control towards effectively managing the negative impacts of dingoes for graziers. It retains and enables the positive effects that dingoes have on ecosystems. The efficacy of a variety of preventive innovations (such as livestock guardian animals, predator deterrents, and grazing regimes that increase herd density of livestock) would be tested to understand the conditions under which they are most effective, and to build capacity to implement the most suitable approaches for a specific context. An iterative process of focused, independent, experimentation would create a sound evidence base for a range of preventive innovations that aim to proactively prevent livestock predation. Greater collaboration and mutual understanding with graziers is a key pathway to the adoption of preventive non-lethal tools and methods and to expand the implementation of Predator Smart Farming practice at regional scale.

Pathway 2 (P2) seeks to mobilise support for Predator Smart Farming through alignment with knowledge sharing networks associated with larger ecological movements, such as regenerative grazing, which has gained a foothold in Australian agriculture (Cusworth et al., 2022). This pathway builds on P1 through dissemination of the co-produced research outcomes to promote wider adoption of Predator Smart Farming practices. Predator Smart Farming is a holistic and conscientious approach to agriculture to increase the resilience of landscapes, animals (domesticated and wild) and rural livelihoods (Boronyak et al., 2021). The regenerative grazing movement in Australia has focused largely on ecosystem regeneration and carbon sequestration and has so far overlooked other factors that may contribute to ecosystem health underpinning rangeland agricultural productivity. P2 seeks to align Predator Smart Farming with sustainable agriculture by raising recognition among sustainable agriculture practitioners of the importance of carnivores to healthy ecosystems.

Pathway 3 (P3) advocates for greater institutional support for preventive innovations in the form of financial support, capacity building and training for Predator Smart Farming. Institutions in this context refers to governments, the meat and livestock industry, and NGOs involved in conservation and or animal protection. In P3, these institutions would offer financial support and capacity building (information and training on non-lethal alternatives) to assist graziers cover the upfront costs of trialling and adopting preventive innovations. Furthermore, the risks of adoption could be reduced through the implementation of a transparent compensation scheme for proven livestock losses to dingoes. Other potential funding streams include, for example, funds from compulsory levies, peak industry bodies, regional grants, certification schemes, philanthropy, and the redistribution of funds currently used for lethal control.

Pathway 4 (P4) builds on P3 by implementing changes in governance through policy and legislation, and the redistribution of public funds from lethal control to support Predator Smart Farming. A policy transition towards Predator Smart Farming would seek to balance agri-industry and conservation interests, reduce the need for controversial and expensive lethal control and create a cultural shift toward coexistence with dingoes and other native wildlife. However, fundamental re-calibration of the foundations of conservation policy would be required. Stakeholders provided several suggestions for how this transformation might be realised:

- Emphasising the conservation and protection (at an ecosystem level) of the diversity of wildlife over the lethal control and exploitation of wildlife;
- Introducing a public trust or interest principle that creates obligations on the state and its agencies to manage wildlife for the benefit of all Australians including future generations;
- Removing the management of wildlife from state agriculture departments and establishing a new and independent regulator to effectively govern, implement and enforce stronger regulations and policies which support responsible wildlife management, and build social tolerance and coexistence with wildlife;
- Formulating legislation that supports and prioritises non-lethal management as a first response;
- Funding to establish a multi-disciplinary advisory committee to investigate and develop a range of strategies, policy responses and programs to incentivise preventive innovations, and foster sustainable coexistence, and ensure a conservation approach to wildlife management;
- Bringing dingoes into the broader conversation about biodiversity conservation, and
- Engaging supportive politicians as agents of change.

Governance reform would also require proof that non-lethal methods have been exhausted before lethal control can be legally authorised. Landholders would need to make an application to harm dingoes and within that request provide evidence of the losses caused by dingoes. In addition to legislative and policy reform, a central component of P4 is the re-allocation of a portion of dingo-management budgets towards adoption of preventive innovations, and a compensation scheme. Currently, dingo management budgets are allocated almost entirely to lethal control and/or exclusion through the installation of large landscape scale fencing and the provision of bounty payments for lethal control. These types of financial subsidies would need to be withdrawn.

Pathway 5 (P5) aims to improve public education about dingoes, their important role in ecosystems and impacts of lethal dingo control. P5 incorporates the creation of space to rationally discuss dingo management, non-lethal alternatives, and ways to improve conservation, animal welfare and public safety. P5 advocates a public awareness campaign about dingoes to reduce public confusion around dingoes versus wild dogs, raise awareness of the impact of current management practices, as well as the ecological and cultural importance of dingoes. This would involve targeted dissemination of research by scientists and NGOs, as well as the sharing of experiences and knowledge of innovative graziers and First Nations Peoples. Information would be disseminated to government representatives, the meat and livestock industry, conventional producers, and the public.

P5 also calls for public pressure on government to modernise Australia's approach to dingo management. This pathway draws on the growing body of conservation research relating to the important role of dingoes in the health and function of ecosystems. P5 recognises the critical role for conservation and animal welfare NGOs and First Nations representatives as key stakeholders and change makers. These actors not only raise awareness of the animal welfare, ecological, economic, and social consequences of lethal control options, but also push for policy change through networks that reach into influential areas of Australian society. Ultimately this pathway would encompass a campaign to galvanise NGO and public pressure towards state and federal environment ministers to place restrictions on the use of lethal control practices especially on public land such as national parks.

To tap into the growing recognition of the significance of Indigenous knowledge of 'Country', Pathway 6 (P6) seeks to incorporate Indigenous Australians' voices in environmental decision making especially with regards to wildlife management. There is much potential to combine local and indigenous knowledge systems (such as First Nations people or local communities) with scientific knowledge for improved ecosystem management (e.g., Goolmeer et al., 2022). Environmental and animal welfare NGO actors are also important stakeholders that can agitate, in concert with Indigenous Australians, for coexistence to balance human and wildlife needs. Given the power and influence exerted by narrow vested interests in relation to dingo management, there is a need to raise greater awareness of the relationship that First Nations Australians have with the dingo and consider that relationship in management decisions (Brumm and Koungoulos, 2022).

The final pathway, P7, actively connects Predator Smart Farmers to share experiences, encourage social learning, leadership and create new social norms. Social learning involves deliberative interactions amongst multiple stakeholders in real world settings. P7 harnesses leadership to shape new social norms and identities and build a sense of reciprocity and trust among stakeholders. Development of a supportive social network would help graziers to deal with a range of social, institutional and economic pressures to conform to the use of lethal options.

A transformed future system for Australian grazing

We anticipate that progress along these pathways would lead to a future transformed system in which sustainable farming systems would be embedded into agriculture to enhance biodiversity, landscape resilience, food security, and provide satisfying livelihoods for farmers. The mainstream adoption of Predator Smart Farming would become an integral part of sustainable agriculture. The transformed system would see the restoration of the role of dingoes as apex predators, and the re-establishment of diverse species and healthy functioning ecosystems. Scientific and evidence-based approaches and Indigenous Australians' voices would play a greater role in environmental policy than politics. Dingo ecology and behavior would inform management decisions. In addition, sufficient public and private investment would be allocated to research, education, and outreach. This reallocation of funding would create an enabling environment for the adoption of preventive innovations as part of Predator Smart Farming. Farm gate prices would reflect the value of animal welfare and internalise the costs of agricultural production.

Discussion

Transformation is critical for regions where humans are degrading the capacity of the system to self-organise, maintain diversity, and provide critical ecosystem functions (Moore et al., 2014). Over 100 Australian species have become extinct since European colonisation and the number of listed threatened species has risen for almost all taxonomic groups over the past 5 years (Department of Climate Change, Energy, the Environment and Water DCCEEW, 2021). The loss of biodiversity across Australia constitutes a major social and ecological crisis. Human-dingo conflict further exacerbates this unsustainable trajectory of biodiversity loss and ecosystem dysfunction in social-ecological systems such as rangelands grazing. Biodiversity loss has, in turn, negative consequences for agriculture, society and the Australian economy that depends on commodity exports (Cocklin and Dibden, 2009). The challenge of halting land degradation and loss of biodiversity has been recognised in The United Nations' Sustainable Development Goal 15, called 'life on land' that aims to [p]*rotect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*

(UnitedNations, 2021 p25). This goal provides a framework to address species extinction and promote human-wildlife coexistence (Thomsen et al., 2021). However, the 'super-wicked' nature of the issues (Levin et al., 2012) within the Sustainable Development Goals makes monitoring and evaluation of progress problematical where disruption of the dominant regime requires multi-scalar action on multiple fronts by a range of actors, and progresses unevenly (Plag and Jules-Plag, 2019). The remainder of this discussion is devoted to explaining how the seven pathways described here collectively foster coexistence with dingoes in extensive rangelands grazing systems. International examples of interventions are used to illustrate the types of successful actions associated with each pathway that could inform action in Australia.

The adoption of preventive non-lethal innovations by producers is a critical pathway towards coexistence that can create a 'win-win' situation by simultaneously mitigating livestock predation and reducing the reliance on pre-emptive and retaliatory killing of dingoes. Preventive innovations can be highly effective (Stone et al., 2017; van Eeden et al., 2018), more acceptable to the public (Slagle et al., 2013), and preferable from an ethical and conservation standpoint. This accords with conclusions of Brink et al. (2019) p373) who suggest that the socio-ecological benefits of dingoes may be "*best conserved through a holistic approach to management, including increased investment in innovative combinations of non-lethal conflict-management tools and strategies*". However, the adoption of preventive innovations often requires new skills, competencies, networks and technologies (Smith et al., 2021). Farmers can acquire new knowledge, skills and attitudes through networks that advocate social learning in which participants learn from each other, work together, and build relationships that facilitate collective action and trust (Cundill and Rodela, 2012). Social learning can be beneficial in conflict situations because it requires people to learn how to work together. A combination of the contextual, constructive, and reflective aspects of social learning aids the acquisition of new knowledge and can catalyse changes in norms, perceptions, attitudes and behaviours of participants (Marchand et al., 2010; Moschitz et al., 2015). Co-learning is important to refine protocols and inform the selection process around each preventive innovation (Moore et al., 2014).

Community engagement and social learning proved successful in the Blackfoot Challenge in Montana, USA. The Challenge has taken a collaborative approach to conservation and fostered human-carnivore coexistence by engaging residents in meetings, workshops, field tours, and research. This action has built effective partnerships and working relationships (Wilson pers comm). For example, permission was sought from dozens of ranchers to conduct an annual winter wolf survey across their land. Local volunteers were recruited to conduct the survey (Wilson et al., 2017). This co-generation of research data led to a more collective understanding of wolf numbers, distribution, and activity, and built trust, ownership and credibility of information about wolves among stakeholders (Wilson et al., 2017). Collaboration, cooperation, and social learning are fundamental to successful management of social-ecological systems (Rodela, 2011).

The second pathway fosters coexistence through a combination of practical solutions, outreach, credible ecological information, and an understanding of the social psychology of the people affected (Zimmermann et al., 2010). According to Consorte-McCrea et al. (2022 p 8) it is vitally important to include stakeholders who may be affected by a reintroduction or re-wilding because "understanding positive interactions and addressing the social-psychological drivers of negative interactions are more likely to result in a greater sense of ownership, motivation and commitment to uphold support". A good example of P2 is evident in the Shepherding Back Biodiversity Project run by the Landmark Foundation in South Africa. The Landmark Foundation works with livestock producers to assist a transition to predator smart practices. The Foundation conducts economic and ecological monitoring (https://www.landmarkfoundation.org.za/fair-game/) and provides professional consultancy in non-lethal methods such as use of guardian dogs. Producers achieve a price premium through 'Fair Game' branding. In addition, participating producers receive compensation when domestic animals are killed by carnivores. The program has been successful for both carnivores and producers. The average cost of predation declined by 70 per cent regardless of the non-lethal method adopted (McManus et al., 2015). The Foundation also purchased a farm in the Karoo region of South Africa to demonstrate a range of predator smart practices. Holistic resource management was the primary grazing practice that involved a time-controlled, rotational grazing system with high-density, short duration grazing in paddocks, followed by long 'rest' periods without livestock to allow vegetation to recover (Savory and Butterfield, 1999). Livestock were guarded, kraaled at night and densely herded together. Strategic shepherding of livestock under a holistic resource management regime virtually eliminated predation, aided ecosystem restoration, and resulted in a 24 per cent increase in species richness and 73 per cent increase in the relative abundance of herbivores (McManus et al., 2018; Schurch et al., 2021). Night kraaling of livestock increased trampling and concentration of manure. Over time, this resulted in nutrient-rich, heterogeneous patches and increased vegetation cover (McManus et al., 2018). The improved vegetation productivity on this farm compared to neighbouring properties that used conventional set stocking and lethal carnivore control, indicates that Predator Smart Farming can improve rangeland productivity and resilience (Hasselerharm et al., 2021). While holistic resource management is not specifically advocated for Australian rangelands, the Landmark Foundation's Karoo farm demonstrates the potential of altered management regimes to reduce predation.

Building institutional support and capacity to adopt Predator Smart Farming is also an essential pathway to coexistence with dingoes. A leading example of institutional support for preventive innovations is the Montana Partnership. Formed in 2017, between environmental NGOs and the US Wildlife Services in Montana, this partnership was pivotal to building institutional capacity for the adoption of preventive innovations. The Partnership investigated the use of a non-lethal tool, turbo fladry, to reduce human-carnivore conflict. Turbo fladry consists of strands of flags (50 by 10 cm) sewn onto electrified poly-wire at 45cm intervals. Turbo fladry causes a shock when an animal touches it (Young et al., 2019). No livestock predations occurred across the 28 turbo fladry projects despite the

presence of a range of carnivores including wolves, grizzly bears, black bears, coyotes and foxes (Young et al., 2019; Boronyak et al., 2020). The Montana Partnership was effective because the United States Department of Agriculture Wildlife Services was allowed to access farms, and NGO Natural Resources Defense Council staff had practical knowledge of the use of turbo fladry (Young et al., 2019). This partnership created institutional support for preventive innovations, built new social norms to redress socio-cultural pressures, and provided financial support for preventive innovations to be mainstreamed.

Policy reform is required to de-legitimise lethal control, democratise decision making regarding wildlife, and introduce new governance structures that balance human and wildlife needs (Carter and Linnell, 2016). Policy reform would require the provision of technical assistance, education and support for landholders to use suitable preventive innovations. The combination of laws, polices and power creates institutional inertia in political debate and agenda setting that stifles progress towards human-dingo coexistence. Australian state government agencies enforce legislation across states in which landholders are legally obligated to control dingoes, referred to as 'wild dogs', irrespective of whether a dingo has harmed livestock or human safety. The reference to dingoes in industry and government policy as a 'wild dog' and 'declared pest' acts to devalue them and legitimise the lethal paradigm. For example, under the *Pest Plants and Animals Act 2005*, wild dogs and dingoes are declared pest animals in the Australian Capital Territory (ACT), and landholders must take steps to control declared pests. In both Queensland (*Biosecurity Act 2014*) and New South Wales (*Biosecurity Act 2015*), dingoes and wild dogs are considered a biosecurity threat (Australian Government, 2014; New South Wales Government, 2015). The general biosecurity obligation requires a person to take all reasonable and practical measures to prevent, minimise or eliminate risk. In this case, the obligation is to minimise the risk of any negative impacts of wild dogs on their land or neighbouring lands. In NSW, under section 138 of the *Biosecurity Act 2015*, a person who contravenes a biosecurity direction is guilty of an offence (New South Wales Government, 2015).

Financial incentives for lethal control (e.g., bounties for dingo scalps) cement the non-selective lethal treatment of dingoes that can destabilise dingo families (Zimmermann et al., 2010). Baiting efforts are jointly funded through public and industry support, yet the lack of target specificity can worsen livestock predation especially for the cattle industry (Zimmermann et al., 2010; Allen, 2014; Campbell et al., 2019). The complex relationship between carnivore control programs and the profitability of livestock production is not well understood (Macon, 2020). Smith et al. (2021) found that between 2016-2017 there were 288 incidences where wild dogs or dingoes killed or maimed livestock in Victoria, estimated to be worth $111,456 excluding cost of production. However, these losses represent only 0.86% of the minimum estimated total cost ($13m) of dingoes to the Victorian livestock industry, with the remainder spent on control efforts and incentives such as bounties, employing wild dog controllers and carrying out baiting. The national expenditure on 'wild dog management' activities is reported to be more than $27 million per annum (Brink et al., 2019). Brink et al. (2019) proposed a novel way to collect funds for dingo-conservation that could be channelled towards research of non-lethal tools and strategies. This proposal capitalises on Australians' love for domestic dogs with either a levy on domestic dog food (0.6%) or a one-off animal-sales levy (1.2% of the cost of domestic dogs) to raise AU$30 million or more annually, thereby matching the estimated AU$27 million that is currently spent on dingo management by state agencies (Brink et al., 2019). However, this could also be achieved by each state government re-directing a portion of the funding that is currently allocated to killing dingoes into viable alternatives that deter dingoes, reduce livestock vulnerability and guard livestock. Incentive-based strategies, such as payments for the presence of wildlife, have been shown to improve attitudes and behaviour toward large carnivores by distributing the benefits of carnivore presence more equitably to local communities (Hazzah et al., 2014).

Effective and equitable governance are essential to achieving sustainable sharing of agricultural landscapes with wildlife (Redpath et al., 2013). Institutions that achieve representation of and participation by diverse stakeholders, form an important part of well managed and adaptive governance systems (Daily et al., 2009). Good governance embodies representation, participation, deliberation, accountability, empowerment and justice (Lebel et al., 2006). Governance creates the structures and processes for ordered rule and collective action (Folke et al., 2005; Lebel et al., 2006). The development of good governance requires an understanding of the complex and interdependent linkages between social and ecological variables (Partelow, 2018). Effective governance is necessary to address the overrepresentation of narrow interests in wildlife management that appears to perpetuate the lock-in to lethal control of dingoes.

The livestock industry in collaboration with government, dictates the policy agenda. These powerful actors provide asymmetrical information about dingoes, and influence which initiatives and research are funded. Certain types of information are disseminated or withheld depending on whether they support or destabilise dominant power structures (Abson et al., 2017). Information about predation risk, disseminated from government and industry to producers, is inherently biased towards lethal control. This is important because institutions facilitate the production, inclusion and dissemination of knowledge within a decision-making process. Beddoe et al. (2009) identified that institutions, technologies and world views, are mutually interdependent and mutually reinforcing. Industry capture of the policy process by these groups has undermined the broader public interest in wildlife management.

Transcending the lock-in to lethal control of dingoes requires not only innovative thinking but also NGO, consumer, and public pressure to push for institutional and cultural change. In Australia, only a few conservation NGOs advocate for dingo conservation, such as the Humane Society International Australia. Yet environmental and animal protection NGOs play a crucial role in steering transformational change toward coexistence as they are well placed to raise public awareness of current dingo management, mobilise support and resources and lobby for industry and government policy change. Currently, there is low awareness among the general public of dingo management (van Eeden et al., 2019). A recent survey of 811 Australians revealed that only 19 per cent were aware that wild dog management included dingoes

(van Eeden et al., 2021). This confusion in the minds of the public is likely to have arisen from dingoes being labelled as wild dogs in policy and legislation (Brink et al., 2019; van Eeden et al., 2021). Most respondents (85 per cent) considered dingoes to be native to Australia and supported the use of non-lethal methods (e.g., livestock guardian animals and fencing) as alternatives to lethal methods (i.e., shooting, trapping, aerial baiting and ground baiting) (van Eeden et al., 2021). Public awareness and campaigning can improve animal welfare outcomes. In 2005, the United Kingdom banned hunting foxes with hounds (Anderson, 2006). This form of hunting had been practised for 300 years. However, there was mounting public and political pressure to stop the hunts. Political pressure came from Labour Members of Parliament supported by anti-hunting pressure groups, such as the League Against Cruel Sports, the Royal Society for the Prevention of Cruelty to Animals and the International Fund for Animal Welfare. Ultimately, this pressure brought about a ban due to animal welfare concerns (Anderson, 2006). This example shows that when a range of diverse stakeholder groups campaign collaboratively it can lead to improved outcomes for wildlife management.

Dingoes are of cultural, social, and spiritual significance to a great many Australians; most significantly Indigenous Australians who hold kinship ties and traditional knowledge about dingoes, other native animals, and the Australian landscape (Rose, 2000; Smith and Litchfield, 2009). However, decisions regarding the management of dingoes are shaped by narrow vested interests that wield significant power. This power dynamic was evident in response to a proposal to reintroduce dingoes into the Grampians National Park (Gariwerd) in Victoria. In the Greater Gariwerd Draft Landscape Management Plan 2021 that aimed to restore native ecological systems and culture, a proposal to reintroduce dingoes to the park was rejected due to outcry from sheep graziers (Sheep central, 2021). The fifteen-year draft plan was developed in collaboration between Parks Victoria and three Traditional Owner groups: the Gunditj Mirring Traditional Owners Aboriginal Corporation, Barengi Gadjin Land Council Aboriginal Corporation and the Eastern Maar Aboriginal Corporation (Parks Victoria, 2020). However, when the plan was released for community consultation in 2021, it was fiercely opposed by local landowners and graziers who held concerns that the dingoes would endanger nearby livestock (Parks Victoria, 2020). Although the plan provided an opportunity to align Indigenous aspirations with long overdue reforms for dingo conservation, it was quashed. Despite growing public support for rewilding initiatives to maintain or restore dingoes in the landscape as top carnivores, narrow interests continue to overpower efforts to democratise dingo management (van Eeden et al., 2021). The combination of laws, polices, language and power create institutional inertia in the political sphere that stifles progress towards the implementation of alternatives.

Social support and networks of likeminded communities is vital to facilitate human-dingo coexistence as denoted by pathway 7. Forming these connections is integral to the development of social capital (networks, support and knowledge sharing) (Putnam, 2001). Decisions to adopt preventive innovations are influenced by what is considered socially and culturally acceptable by members of the potential adopters' social or reference group (Stratford and Davidson, 2002; Amel et al., 2017; Stern, 2018). Dietsch et al. (2019) p36) argued for a greater acknowledgment of "*the strong influence of groups (e.g., cultural affiliation, formal organisations, social classifications, norms) on how people think and behave*" in relation to wildlife management. As environmental practices are often new subcultures, a supporting environment of family, neighbours, and peers shapes the acceptability of this new farming subculture and associated norms (Stratford and Davidson, 2002). In this way, P7 facilitates a shift away from an unsustainable regime reliant on lethal control to a more sustainable social, ecological and economic system (Beddoe et al., 2009).

A group called Landholders for Dingoes (https://landholdersfordingoes.org/) has been formed to discuss the important role of dingoes on agricultural land. Some cattle producers have ceased dingo control efforts due to evidence that indicates dingoes could indirectly benefit some livestock producers by reducing the abundance and impact of wild herbivores, contributing positively to pasture growth and soil management strategies (Wallach et al., 2010; Letnic et al., 2012; Prowse et al., 2015; Campbell et al., 2022). This can benefit graziers through improved livestock condition, weight gain and fertility due to less competition for pasture (Prowse et al., 2015). The recovery of dingo populations may facilitate the functionality and resilience of ecosystems that underpins agricultural productivity (Wallach et al., 2010). The ability of a growing number of cattle producers to transcend the existing lethal control paradigm and cultivate a 'consciousness' that is conducive to coexistence with dingoes has the potential create profound and lasting transformational change.

There are three main limitations of this research. Firstly, despite attempts to include a range of diverse stakeholders the sample size is small (n=21). Secondly, despite extensive cattle grazing operations that occur across the Norther Territory the authors were unsuccessful in recruiting livestock producers and government representative from this region. Thirdly, the research did not cover in-depth the differences between raising cattle and sheep. Across Australia, there is a difference between sheep and cattle in relation to threat posed from dingoes. Cattle graziers appear to be less inclined than sheep graziers to use lethal control as dingoes pose less of a threat to healthy adult cattle. However, calves are vulnerable to predation (Allen and Sparkes, 2001; Letnic et al., 2012).

Conclusion

This paper explores a critical issue of human carnivore coexistence in social-ecological systems. A social-ecological systems framing was used to identify the causes and drivers of dingo intolerance and persecution and strategic pathways to intervene in the current social-ecological system to catalyse a new paradigm of coexistence between livestock producers and dingoes. This paper draws attention to the underlying causes of biodiversity loss from human intolerance, and conflict in social-ecological systems that are used to graze livestock and support food security and conservation. Over time, Australia has become locked-in to an unsustainable 'conflict paradigm,' in which dingoes are viewed primarily as a 'cost' (financial, social or ecological) and killing them is justified to improve agricultural productivity. Trapping, shooting, and poisoning are primary management tools used to 'control' dingoes in Australia. However, lethal control has high

costs to carnivores in terms of injury, death, disruptions of social groups, or loss of access to resources, and cascading ecological consequences for other species and ecosystem services. In light of the escalating biodiversity crisis, the time has come to modernise and democratise Australia's approach to wildlife management.

We present a model of transformative change that examines human-dingo coexistence in rangeland grazing systems in Australia. The model emerged from an engagement process that included in-depth interviews with Australian livestock producers, ecologists, conservation and animal welfare NGOs, livestock grazing industry representatives and policy makers as well as field observations and document analysis. The pathways can be considered as key interventions that collectively alter social or ecological feedbacks and aim to establish and strengthen the future transition towards human-carnivore coexistence. However, as Plag and Jules-Plag (2019) make clear, while the iterative nature of implementing transformation requires monitoring and evaluation to detect system trajectories during transition, the epistemic knowledge to support planned transformation remains under-developed. However, we believe system transformation to coexistence would restore the role of dingoes as apex predators to regulate introduced species and contribute to healthy rangeland ecosystems. The mainstream adoption of Predator Smart Farming as an integral part of sustainable agriculture has the potential to enhance biodiversity, landscape resilience, food security, and livelihoods for livestock producers.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by University of Technology Sydney Ethics Committee ETH18-2568— HREC. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LB conducted the data collection (workshop and interviews), analysed the data and drafted the majority of the manuscript. BJ assisted with the analysis interpretation of results, contributed to the discussion and reviewed the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by the University of Technology Sydney (UTS) under the UTS Research Excellence Scholarship.

Acknowledgments

The authors would like to acknowledge the support provided by Humane Society International Australia, the Institute for Sustainable Futures, University of Technology Sydney. As well as the help, support and expertise to shape the research provided by Dr. Bradley Smith and Dr Arian Wallach and the reviewers.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2023.1126140/full#supplementary-material

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