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Balancing stakeholder interests in kangaroo management – historical perspectives and future prospects

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Abstract. Kangaroos are commercially harvested in five mainland states of Australia, with the harvest regulated by state government wildlife management agencies and overseen by the Commonwealth government. Non-commercial culling is permitted, and although most kangaroos have traditionally been taken by the commercial kangaroo harvesting industry, the proportion taken non-commercially has increased in recent years. Management plans that guide the regulation of the harvest support the management objectives of wildlife management agencies and the kangaroo industry, but the plans do not successfully address the objectives of other stakeholders including pastoralists and animal protection groups, which focus on minimising the grazing impacts of kangaroos and animal welfare issues respectively. We reviewed the objectives outlined in the management plans for kangaroos in the Australian rangelands and examined alternative systems for managing natural resources to identify if improvements to management could be made. Current management plans for kangaroos principally use fixed harvest rates that are responsive only to the state of the kangaroo population and not to changes in the environments in which kangaroos live. This type of management is reactive, and opportunities for improving management of the environment are limited. A viable alternative is active adaptive management which focuses on explicit measurement of the response of the natural system to management actions and use of this information to modify interventions to better meet management objectives. Active adaptive management is appropriate when management actions can strongly influence system state but the impacts of management are uncertain. We argue that the management of kangaroos and the environments in which they live would benefit from the adoption of an active adaptive management approach by wildlife management agencies.

Additional keywords: adaptive management, commercial harvest, non-commercial culling.

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Introduction

The management of kangaroos is a contentious issue. Depending on an individual's beliefs they are pests that need to be controlled, a valuable resource that can be sustainably harvested or a national icon that should be preserved. The aims of this paper are to present the historical background to the management of kangaroos, review the goals and objectives of key stakeholders, describe recent changes in kangaroo management, and illustrate an alternative approach to current management – based on active adaptive management – that provides a methodology for better considering the differing goals and objectives of stakeholders.

Historical aspects of kangaroo management

There is broad agreement[1] that kangaroos, particularly those inhabiting the rangelands, have increased in abundance since European settlement (Frith 1964; Newsome 1975; Shepherd and Caughley 1987). Factors suggested to have had a positive influence on kangaroo abundance include: the proliferation of man-made watering points; modification of vegetation communities by clearing trees and shrubs that consequently favoured the growth of foods preferred by kangaroos (grasses and forbs); near complete removal of dingoes across much of the pastoral lands; and changes to the lifestyle of Aborigines that resulted in reduced hunting effort.

[1]Agreement is not universal. See Denny (1982) for an opposing view.

This increase in abundance of kangaroos has brought them into conflict with pastoralists who contended that kangaroos competed with livestock for food and water, consumed crops, damaged fences and were the cause of road accidents (Pople and Grigg 1999). By far the biggest concern was competition with livestock. There is little doubt that under poor seasonal conditions kangaroos and livestock compete for food, but under good seasonal conditions when there is likely to be adequate food for both, competition is unlikely to occur (Edwards 1990; McLeod 1996). Landholders' perceptions that kangaroos were a major impediment to the sustainable use of rangelands for grazing livestock (see Gibson and Young 1987) led to the culling of kangaroos for damage mitigation and later the development of the commercial kangaroo industry.

Development of the commercial kangaroo industry

During the early part of the 19th century, kangaroos were killed for food, sport, and because they were perceived as pests (Pople and Grigg 1999). In the second half of the 19th century kangaroos were harvested in greater numbers, with most harvested for their skin (Shepherd and Caughley 1987; Lunney 2010). In the late 19th century, kangaroos were regarded as vermin and legislation was passed to declare them a pest and landowners were required to control them. Bounties were paid to encourage control. In 1903, New South Wales granted limited protection to red kangaroos (*Osphranter rufus*, Desmarest 1822) and common wallaroos (*Osphranter robustus*, Gould 1841) under the *Native Animals Protection Act*, *1903*. Protection was extended to eastern grey kangaroos (*Macropus giganteus*, Shaw 1790) and western grey kangaroos (*Macropus fuliginosus*, Desmarest *et al.*1817) in 1918 under the *Birds and Animals Protection Act*, *1918–30*. Similar protections were granted by other state governments (Boom and Ben-Ami 2010). In the 1950s – coinciding with the widespread availability of mobile refrigeration units – greater use was made of the meat from kangaroos shot for damage mitigation under permits issued by state authorities for export markets and the local pet food industry (Livanes 1971).

It was not until the 1970s that the harvest evolved into what we recognise today as the commercial kangaroo industry (Shepherd and Caughley 1987; Lunney 2010) following claims from some groups that unregulated harvesting or culling was leading to local extinctions. This was subsequently found by a Commonwealth government enquiry to be incorrect (Parliament of the Commonwealth of Australia 1972*a*, 1972*b*). In all states, the commercial harvest of macropods is regulated by wildlife management agencies that oversee harvesting operations, conduct surveys of populations, calculate annual quotas, monitor industry compliance with Commonwealth and state government legislation and aim to ensure that the harvest is conducted humanely, in accordance with a national Code of Practice (Anon. 2008). In Queensland, New South Wales, South Australia and Western Australia the harvest is based on the above-mentioned four species although not all species can be harvested in every state. Tasmania permits commercial harvesting of Bennett's wallaby (*Notamacropus rufogriseus*, Desmarest *et al.* 1817) and the Tasmanian pademelon (*Thylogale billardierii*, Desmarest 1822) for domestic consumption. Victoria is about to establish a kangaroo management plan that will allow the commercial harvesting of kangaroos for pet food in that state, following the recent completion of a Kangaroo Pet Food Trial (Anon. 2019).

The management plans of Queensland, New South Wales and Western Australia are primarily concerned with promoting sustainable harvesting of kangaroo populations and administration of the harvest to meet legislative requirements. This has not always been the case. For example, in New South Wales before 2002 the harvest of kangaroos was justified on the basis of damage mitigation to reduce the impacts of kangaroos on pastoral enterprises (Gilroy 2004). However, even with this stated objective, annual quotas were set on the basis of sustained yield, rather than some acceptable population level, and the program thus involved an inherent paradox. After 2002, the objective of commercial harvesting became sustained yield to support the kangaroo industry, partly to eliminate this conflict. To date this remains the overarching aim of the kangaroo management plan in New South Wales (Office of Environment and Heritage 2017*a*). The kangaroo management plans of these three states make explicit mention that the plans do not consider damage mitigation as an aim. In contrast, the South Australian plan includes, in addition to support for sustained yield harvesting, an aim to manage the impacts of kangaroos on land condition (Natural Resources South Australia Arid Lands 2017). All states and territories include separate legislation for the regulation of damage mitigation by non-commercial culling, thereby separating management to support the commercial kangaroo industry from management to reduce kangaroo impacts on primary production.

Damage mitigation vs sustained yield

The market forces that govern the commercial kangaroo industry operate independently of damage mitigation needs, and are often out of phase with them (Shepherd and Caughley 1987). This is a consequence not only of fluctuations in the demand for and supply of kangaroo products but also the boom and bust cycles that characterise the population dynamics of kangaroos in the rangelands (Bayliss 1985). The commercial industry is unable to expand or contract quickly enough to meet the short-term or long-term fluctuations in kangaroo abundance. In western New South Wales, for example, in the period from 2009 to 2014, kangaroo populations increased continuously (Lunney *et al.* 2018, fig. 2). During this time, eastern grey and red kangaroo populations increased annually at finite rates of 1.21 and 1.17, respectively, however, the commercial harvest rate for both species was only 0.04, and would have been only 0.15 and 0.17, respectively, had the quota been fully taken. Although taking of the full quota on a regular basis has the potential to reduce the long-term mean abundance of kangaroos by as much as 40% (Caughley 1987), the industry in its present state is an ineffective tool for managing overabundant kangaroo populations. Achieving the separate goals of the commercial industry (i.e. to maximise profit) and pastoralists (i.e. to reduce the grazing impacts of kangaroos) poses a demanding challenge. This issue is not a recent concern and was recognised by Shepherd and Caughley (1987; p. 209) three decades ago when they wrote,

> 'Thus, the industry cannot be a reliable partner in a kangaroo management program unless the quota rather than the market becomes the limiting factor…'

This situation is reflected in the stated aims of most kangaroo management plans[2] – there are provisions in the plans for the interests of the regulator (government management agencies) and the commercial kangaroo industry but no provision to address the concerns of landholders. However, the resolution of this issue is not straightforward. Without an objective system of measurement, 'damage' caused by kangaroos cannot be quantified and management decisions would remain subjective.

Attempts to balance stakeholder objectives

Stakeholders with a specific interest in the commercial harvest of kangaroos include government wildlife management agencies, the kangaroo industry, pastoralists, conservationists and animal protection groups. Broadly, kangaroos are variously perceived by these groups as a harvestable and renewable resource, a pest of agriculture, an object of conservation value that requires protection, and a sovereign species that should not be subject to any form of human exploitation. Despite decades of management experience and research there is still no agreement among stakeholders on how best to balance these competing objectives.

At a workshop held in Dubbo, New South Wales, in 1999, representatives of stakeholder groups, including government wildlife management agencies, non-government conservationists, the kangaroo industry and pastoralists, were asked to identify the objectives that they would like to see addressed in future kangaroo management programs (Hacker and McLeod 1999). Objectives were to be – as far as possible – specific, measurable, accountable, realistic and time-bound (SMART).

Government management agencies were concerned for the effect of kangaroos on sensitive conservation areas, such as remnant vegetation in national parks, and noted that the effects of management for conservation objectives (e.g. prolonged reduction in kangaroo density to allow threatened vegetation to recover) were unknown. The policies of non-government conservation organisations varied, ranging from rejection of any commercial harvesting to acceptance of commercial harvesting provided there were demonstrable gains in biodiversity. Regardless of the official policy of their organisations, all non-government conservationists insisted that kangaroo management be consistent with the principles of ecologically sustainable development (ESD) as outlined by Milner-Gulland (1999) and Commonwealth of Australia (1992). Pastoralists were concerned that kangaroos make a significant contribution to total grazing pressure, restricting their management options (Browne 1995), and that the commercial harvest did not reduce kangaroo density to sufficiently low levels. The kangaroo industry's objectives aimed at ensuring a sustainable industry, requiring sustainable yields from kangaroo populations and consistency of supply.

Given these general concerns, each group identified numerous aspirations. Some of these were 'ecological' – relating to aspects of the biophysical system – and others were 'non-ecological' – relating more to matters of economics, policy or administration. Those that could be stated as objectives are summarised below (see Hacker and McLeod 1999; Hacker *et al.* 2004).

Government wildlife management agencies

1. Kangaroo populations are maintained at levels that do not threaten remnant vegetation. (Note: this objective requires the simultaneous establishment of vegetation conservation targets).
2. Kangaroo pressure or density is reduced to low levels (say <5 kangaroos km^{-2}) for 10–30 years. (Note: this objective is related to 1 above and requires the simultaneous establishment of soil and vegetation recovery criteria).
3. Kangaroos are conserved across Australia, requiring (as a minimum) that:
   (a) kangaroo populations are conserved in every region;
   (b) viable populations[3] are distributed across each region; and
   (c) landholders receive economic benefit from kangaroos on their properties equal to the dry sheep equivalence of the population.

Non-government conservationists

1. Kangaroo management must be consistent with the principles of ESD and include:
   (a) an adaptive management approach;
   (b) creation of refugia;
   (c) creation of baseline and non-harvest areas (which can be used for comparison with managed areas to assess the magnitude of management actions);
   (d) maintenance of adaptive genotypes; and
   (e) understanding of the potential effects of climate changes (e.g. temperature and rainfall) on kangaroo population dynamics.

Pastoralists

1. Kangaroo density maintained at 3–5 kangaroos/km^2, depending on land capability.
2. Kangaroo density (expressed as dry sheep equivalents (DSE)) maintained at 5–30% of the estimated safe livestock carrying capacity, depending on land capability. (Note: this is an alternative to objective (1) above, and is intended to indicate the density of kangaroos that can be carried in addition to the estimated safe carrying capacity for livestock).
3. 'Improvement' in range condition through reduced kangaroo density (while maintaining the option to increase kangaroo density if required, and without impact on the genetic diversity of the kangaroo population).

Kangaroo industry

1. Full-time professional harvesters able to harvest around 5000 kangaroos of >20 kg carcass weight per annum (based on average dressed carcass weight of 20 kg).
2. Ability to harvest large, medium and small kangaroos in roughly equal numbers from a population of moderate density (Note: a population of 'moderate density' is one

[2]The exception being the South Australian Commercial Kangaroo Management Plan 2018–2022 (Natural Resources South Australia Arid Lands 2017).

[3]'Viable populations' are taken to mean populations that would not qualify for the International Union for the Conservation of Nature (IUCN) Red List categories of 'Vulnerable' or 'Near Threatened' according to the criteria approved by the 40th Meeting of the IUCN Council, 30 November 1994.

from which 50 animals can be harvested in 7 h of actual shooting, including field processing).
3. Ability to harvest, in an ecologically sustainable manner, 50 kangaroos of >20 kg bodyweight in 7 h of actual shooting (including field processing). (Note: This objective is an alternative to objective (2) above rather than a third objective).

There are substantial, and in some cases irreconcilable, differences between these stated objectives. Nevertheless, management strategies (based on changes to harvest rate and sex bias) were identified that reconciled these objectives as far as possible (Hacker and McLeod 2003; Hacker *et al.* 2003; Hacker *et al.* 2004), but the results have not been reflected in kangaroo management plans. Twenty years after this workshop was convened these objectives are probably still valid but management plans have changed. It would be timely to revisit these and the objectives of other stakeholders (Sinclair *et al.* 2019) and evaluate them with respect to the current management plans of each state. However, this is beyond the scope of the present paper.

Current developments and implications for stakeholders

In the last decade several significant developments have influenced the commercial harvest and non-commercial culling of kangaroos. These changes include: erection of barrier or exclusion fencing; male-only harvesting and, in New South Wales, changes to the permit system for non-commercial culling and removal of the cap on the number of processor licenses.

Exclusion fencing

Exclusion fencing is not new in Australia being first used in the 1860s by individual landholders to impede the spread of rabbits (McKnight 1969). Exclusion fencing includes cluster fencing (surrounding several individual properties), total grazing pressure (TGP) fencing (within properties) and other forms of fencing that exclude wildlife.[4]

Well designed and maintained barrier fences restrict the movement of large mammals such as wild dogs, feral pigs, feral goats and kangaroos (McKnight 1969). The main benefits to livestock production arise from the reduction of both predation by wild dogs and competition from non-domestic herbivores. Although the long-term impacts of barrier fencing on the ecology of kangaroos, both inside and outside of fences, are poorly understood, Wilson and Edwards (2019) suggest that there may be some benefits to harvesting practices within very large cluster fence complexes. They argue that enclosure of a population of kangaroos could foster a sense of responsibility for their control and provide an incentive to manage the population sustainably – if the value of the kangaroos was higher. However, while the value of kangaroos remains low there will be little incentive for landholders to manage kangaroos sustainably within their clusters.

Notwithstanding the advantages of barrier fences they can also have negative effects on species – such as kangaroos and emus – that are excluded from or contained within a fenced area. Fences may prevent access to familiar sources of food, water and shelter and potentially disrupt social groups and alter natural dispersion (Bradby *et al.* 2014). Entanglement in fences can also cause significant injuries and death, and they can prevent the movement of animals to safer areas during bushfires or flooding (Gadd 2012; Bradby *et al.* 2014).

Male-only harvesting

Male-only harvesting of kangaroos was introduced in 2012 by some kangaroo processors to address perceived public concerns for animal welfare aspects of commercial kangaroo harvesting, in particular the impact on dependent young (Borda 2018).

Sex-selective harvesting of wildlife is done to meet a variety of goals. Male-biased harvesting commonly occurs in hunted wildlife populations, particularly when males with large horns or antlers are targeted (Coltman *et al.* 2003). Alternatively, female-biased harvesting occurs when adult females reach a larger body size than males (e.g. Atlantic salmon) (Pérez *et al.* 2005). Factors that influence harvest selectivity include harvester preferences and opportunities to be selective which, in turn, are influenced by management regulations, harvesting methods, animal traits and abundance, population structure, and habitat openness (Mysterud 2011). Many of these factors influence sex bias in the commercial harvesting of kangaroos and limit its evolutionary consequences. Although there is strong evidence of size-selectivity, with harvesters preferring large males over other age/size classes (e.g. Pople 1996), Hacker *et al.* (2003) demonstrated that selectivity was set by a threshold in size, above which individuals were selected with equal probability. Therefore, selectivity did not increase with increasing body size once the size threshold was reached. Further limits on selectivity are set by quotas on the number of kangaroos that can be harvested per annum, individuals fleeing in response to disturbance by a harvester (and thus often restricting selectivity to the first animal targeted), hunting methods that allow only the taking of individual animals, and habitat openness, which restricts harvesting to a limited portion of the habitat (Hacker *et al.* 2003, 2004).

Trophy hunting may have an evolutionary effect if hunters target traits that are heritable (Festa-Bianchet *et al.* 2014). However, Hale (2004) concluded that the effect of kangaroo harvesting, as currently practiced, on the long-term evolutionary biology of kangaroos was negligible. Modelling of the effects of harvesting on gene flow in kangaroo populations has supported this conclusion (Hacker *et al.* 2004; Tenhumberg *et al.* 2004), even for male only-harvesting, due to the inability of harvesters to access all kangaroo habitat, assuming a free exchange of genes between harvested and unharvested portions of the population. However, Hacker *et al.* (2004) also concluded that in the long term (>20 years) male-only harvesting can result in slightly higher average densities than populations not harvested and consequently no reduction in grazing pressure. They also found that male-only harvesting skewed the sex ratio of the population in favour of females, thereby increasing the maximum rate of increase and consequently the rate at which populations could recover from harvesting or drought (Hacker *et al.* 2004; McLeod *et al.* 2004).

[4]The discussion of exclusion fencing in this paper is limited to recent initiatives to fence individual properties or groups of properties for the purpose of excluding dingoes, and by default kangaroos, and does not include the wild dog barrier fence that extends through Queensland, NSW and South Australia or the barrier fence network in south-western Western Australia.

A further consequence of the male-only harvest strategy has been that pastoralists have lost confidence in the capacity of the commercial industry to manage the impacts of overabundant kangaroos (S. R. McLeod and T. M. Sharp, unpubl.). Pastoralists felt that the commercial harvest would no longer serve as a means of reducing the density of kangaroos and therefore the grazing pressure which they exert.

Increase in damage mitigation permits

The number of kangaroos killed under non-commercial permits has increased in recent years. In New South Wales and Queensland, non-commercial culling of kangaroos is increasing (ESR 2019; Office of Environment and Heritage 2019), most likely in response to the ongoing drought and the small proportion of the commercial quota currently being harvested. In addition, in New South Wales, changes to the permit system introduced in August 2018 have simplified the granting of non-commercial culling permits (Office of Environment and Heritage 2018*a*). The intent of the new permits is to assist landholders to manage the impacts of kangaroos during drought.

Removal of the cap on processor licences

Throughout Australia, kangaroos are protected by law (Lunney 2010). Kangaroo management plans in each state that intends to export kangaroo products must be approved by the Commonwealth government, and the commercial harvest operates under state licensing frameworks that encourage compliance with the relevant legislation. Businesses that want to buy and sell kangaroo carcasses must be appropriately licenced. Queensland, South Australia and Western Australia have not placed a limit on the number of businesses wishing to trade in kangaroo products but until recently a cap on the number of processor licenses applied in New South Wales.

This cap was a legacy provision established in 1968 and limited the number of licenses to one per harvest management zone, of which there were 11. Since then new management zones had been created and old ones amalgamated but the number of licences had not changed. A review of the licensing cap system in New South Wales (ACIL Allen Consulting 2017) found it to be uncompetitive and to place unfair restrictions on new businesses wanting to enter the industry, in breach of the National Competition Policy (PWC 2013). The cap was consequently removed in 2018, allowing any business in New South Wales to buy and sell kangaroo carcasses if the requirements of the licensing framework are met. Since deregulation there has been an increase in the number of businesses buying and selling kangaroo products in New South Wales (B. Purcell, pers. comm.). However, following the collapse of the Russian Federation market (2007/08), demand for kangaroo products has remained low and the annual harvest has remained well below the quota. It remains uncertain if this deregulation will result in an increase in the proportion of the quota taken.

Implications of current developments

Although the move to male-only harvesting may have addressed perceived animal welfare issues associated with commercial harvesting, it did not remove welfare impacts due to management *per se* but rather substituted one impact for another. On many properties landholders would not permit kangaroo harvesters to harvest only males, instead resorting to the use of non-commercial shooters to cull kangaroos (S. R. McLeod and T. M. Sharp, unpubl.). The increase in non-commercial killing of kangaroos is likely to result in poorer animal welfare outcomes and wastage of carcasses (Wilson and Edwards 2019). Additionally, although enforcement of animal welfare standards is feasible in the commercial system since there are points in the supply chain (e.g. chillers and processing works) where carcasses can be checked for compliance with the Code of Practice, this is much more difficult with the non-commercial cull as there are no definable locations where checking can occur (Shepherd and Caughley 1987).

It is not clear what impacts the increase in the number of kangaroos culled non-commercially will have on the kangaroo industry. Prior to 2018, the number of kangaroos culled non-commercially in New South Wales was ~10% of the number harvested commercially (Office of Environment and Heritage 2017*b*). In 2018, the non-commercial cull was about equal to the commercial harvest (Office of Environment and Heritage 2019). If this trend continues, there will be need for research to examine the impacts of this change on the ecology of kangaroos and economic viability of the kangaroo industry, and timely to compare the situation in New South Wales with that in Queensland where the non-commercial cull is limited to two percent of the population size (Macropod Management Program 2019). The animal welfare issues described above arising from male-only harvesting obviously apply equally to the use of non-commercial permits for drought management.

Developing an alternative approach to kangaroo management

Integrating environmental, social and economic issues into the management plans for wildlife such as kangaroos, poses considerable challenges for natural resource managers. These challenges are heightened by uncertainty in the outcomes of management actions. In this section we describe alternative systems for managing natural resources, critique the current approach to kangaroo management, and suggest an alternative approach that might deal better with the uncertainties of managing this aspect of the national estate, and the conflicting objectives of stakeholders.

Types of management

Systems for managing natural resources can be separated based on the importance and use of learning to guide management. In order of the increasing value that the alternative approaches place on learning they are: passive management; reactive management; passive adaptive management; and active adaptive management.

A passive management approach does not use learning to inform management and therefore does not attempt to reduce sources of uncertainty due to management actions. This style can be variously described as ‘keep doing the same thing regardless of outcome’ or ‘let nature take its course’ (Agee 2002). There is no feedback between the impacts of management actions on system state and the management strategy. This type of management cannot address uncertainties in the response of the managed system to management actions but is appropriate

when change in system state is not sensitive to management. For example, if the current harvest has no impact on future yields – such as gathering fallen fruit from a tree – then any management of the harvest would be classified as passive.

Under a reactive management approach, events are dealt with when they occur, so that management becomes a 'trial and error' process. Reactive management is typically based on arbitrary environmental assessments, which might be based on an initial review of the managed system but which ultimately become inflexible and unfocussed (Holling 1978). Issues are often dealt with as if unique, and as if the environmental consequences can be separated from the social and economic ones. Reactive management strategies are unlikely to consider the perspectives of all stakeholders equally (Buysse and Verbeke 2003).

In a passive adaptive management system, management is modified on the basis of previous outcomes and can benefit from learning, but management is not motivated and guided by the pursuit of that learning. Passive adaptive management seeks to measure the effect of management on resources but not the influence of management in reducing uncertainty (Williams 2011).

Under an active adaptive management system, decision making focuses on learning. The management strategy focuses on predicting the influence of management actions on resource status in addition to explicitly measuring uncertainty in resource response, and using this information to modify future management actions (Williams 2011). Implied is the existence of a well-developed model of the system, either conceptual or mathematical, that provides a basis for predicting management outcomes that can be refined by observation of responses. It is the importance that active adaptive management places on learning to directly meet management objectives that distinguishes passive and active adaptive management (Williams 2011).

Adaptive management (in either form) provides benefits not readily achieved by passive or reactive management. The National Research Council (2004) summarised these benefits in the following terms:

> 'Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognises the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasises learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.'

Despite these advantages, there are circumstances in which adaptive management may not be appropriate (Williams *et al.* 2009). These include situations in which:

- decision making occurs only once, so there is no opportunity for learning to inform ongoing management;
- monitoring does not provide useful information, so there can be no comparison of alternative models;
- conflicts between stakeholder objectives cannot be resolved, so that definition of explicit and measurable objectives is not possible;
- decision making has little to no impact on the state of the managed system; and
- the risks associated with management actions designed to reduce uncertainty and improve learning are too high.

Nevertheless, adaptive management can be the preferred approach even for high risk situations if learning is rapid and management can be quickly modified to minimise risks. It should not be dismissed without careful analysis of the potential risks and benefits.

The current kangaroo management paradigm

The current approach to kangaroo management in all states involves annual or less frequent monitoring of kangaroo populations and the setting of annual harvest quotas as a fixed proportion of the population estimate. Quotas are set to achieve sustainable yields and remain fixed until the next survey is completed, which may include an annual allocation of no quota if the population size falls below a pre-determined threshold (McLeod and Pople 2018). Once set they remain fixed for the year without regard to changes in the state of the system (e.g. going into or coming out of drought). The population survey data, while carefully compiled, are not used in any systematic way to understand responses to local variations in management, or to reduce uncertainty regarding the likely outcomes of management actions, but merely to determine the overall harvest rate for the following year. Even when changes are made, they are most likely to be reactive, subjective or *ad hoc*, resulting in slow progress or misidentification of the true driver of any response to a management action.

The objectives for the management of kangaroos in states that allow commercial harvesting are largely inflexible and there is little capacity, either implicitly or explicitly, for changes in management due to variations in ecological, economic or cultural influences. When modifications are made, for example the inclusion of thresholds that trigger a reduction in harvest rate for populations at low abundance, once made the changes are static and do not include a mechanism whereby additional information can inform future management. Given these features we conclude that the current approach to kangaroo management is basically reactive and that it lacks the benefits of an adaptive approach outlined above.

An active adaptive management process

Williams *et al.* (2009) outline a nine-step process for planning and executing an active adaptive management plan that could potentially be applied to the management of kangaroos. The process involves two phases; the set-up phase, and the iterative phase. Details of each step are outlined below.

Set-up phase

Step 1: Involve stakeholders

From the beginning, stakeholders are involved in the assessment of the resource management problem. This step is the foundation on which management scope, objectives and actions are based. Once stakeholders have been identified and have

agreed to participate, they contribute to the setting of management objectives and potential management actions. Stakeholder commitment to the agreed objectives and actions must be maintained by their agreement to involvement in the decision-making process for the duration of the management plan.

Step 2: Set objectives

The objectives of the adaptive management plan play a crucial role in directing decisions, evaluation and learning. They should be clear and measurable so that the success of the plan's outcomes can be assessed or, if deviations from predicted outcomes occur, appropriate changes can be made to management. Conroy and Peterson (2013) describe two types of objectives – 'fundamental' and 'means'. Fundamental objectives represent core values of management, whereas means objectives are those that help achieve fundamental objectives.

Step 3: Develop management actions

Management actions must be compared using a system of monitoring and assessment. The rate of learning, with respect to the response of the system to management actions, is increased when the range of actions is wide and hampered when the actions differ only slightly. Thus, there is scope to include management actions that enhance learning even if they are not necessary to achieve the fundamental objectives of management. In addition, actions may change due to changes in the state of the system resulting from management actions themselves, stakeholder perspectives or as new information becomes available (Williams *et al.* 2009; Williams 2011).

Step 4: Develop models

The process of developing and implementing an active adaptive management plan is similar to the methods used for planning and conducting scientific experiments. In both, predictions are made regarding the outcomes of management interventions or experimental treatments using either conceptual or quantitative models. However, the processes also differ in that adaptive management should always consider multiple alternative models of the system being investigated, whereas experiments often only consider one model. The models are then tested by monitoring and analysis and those with support are refined, while those without support are rejected.

The development of models encourages managers, stakeholders and scientists to think carefully about the system, and its response to intervention. This important step is used to identify critical variables to be monitored, for identifying knowledge gaps that potentially influence decision making, and for evaluating the consequences of uncertainty (Williams *et al.* 2009).

Step 5: Define monitoring plans

Monitoring is a fundamental part of adaptive management. It is used to provide the data against which alternative models are tested. Without effective monitoring, adaptive management is not possible.

To reduce uncertainty in the outcomes of management actions, the monitoring system must be capable of detecting the effect of the imposed actions. If effects are small and monitoring is insensitive, changes might not be detected and learning will be hindered. Management actions need to have potentially dramatic effects on the system being managed or they will not assist learning (Doremus 2001), so they must include actions, even if applied over a restricted area that will test the limits or resilience of the system. Therefore, monitoring must be designed with the goals of high precision, and adequate sample and effect size in mind. The similarities of active adaptive management with the principles of experimental design are not accidental. The rate of learning is increased and uncertainty reduced when management actions are replicated, treatments are randomised and experimental controls are included.

Adequate planning and resourcing of the monitoring function is fundamental to the success of any adaptive management program.

Iterative phase

The iterative phase implements the alternative management actions identified by stakeholders to address the agreed objectives, the models used to predict responses and the monitoring required to assess the level of agreement between predicted and observed responses.

Step 6: Make decisions

As adaptive management progresses and management actions influence the state of the system, if uncertainty has been reduced and learning has occurred, then decisions must be made about how best to examine additional sources of uncertainty. The management objectives defined in Step 2 are used to guide the selection of the models which should be supported and how best to incorporate into them any learning that has occurred. Management is adjusted to suit the changing system state and to increase the rate of learning.

Methods for selecting management options include mathematical optimisation procedures (Chadès *et al.* 2017) and less formal methods, such as 'satisficing' (Conroy and Peterson 2013) where a decision is technically suboptimal but close enough to the best solution that stakeholders are satisfied. Even non-technical methods, such as common sense, may be acceptable under some circumstances (Williams *et al.* 2009).

Step 7: Carry out follow-up monitoring

Follow-up monitoring is used to measure a system's reaction to management actions. Since management interventions influence the state of the system, monitoring must be sufficiently frequent and accurate to detect any changes that occur. The variables that are monitored are dictated by the objectives and the models used to predict the outcomes of management interventions. Typical variables that are monitored relate to resource status but might also include drivers of system processes, such as climate or the vital rates of population dynamics.

Step 8: Undertake assessments

The information provided by monitoring, once analysed, is used to modify decisions, management actions, reduce uncertainty and improve learning. Progress is made when the predictions of models are tested against observed (monitored) responses. Confidence in specific models – and the variables

included in them – is increased when predicted responses match observed responses. Conversely, confidence in models that do not satisfactorily predict observed responses is decreased.

As evidence is collected, the hypotheses or models with the greatest support can be identified and understanding of the response of the system to management actions is improved. In addition to learning about important ecological factors, assessment also reveals the effectiveness of alternative management actions that best achieve management objectives. It is at this stage that ecological, economic and social comparisons between management actions, costs and benefits can be made.

Step 9: Repeat Steps 6–8

Active adaptive management is an iterative process that relies on incremental learning and refinement of management actions to meet objectives. As sources of uncertainty are resolved, Steps 6 through to 8 are revisited and the improved understanding of the response of the system to management actions is reflected in refinements in management decisions, which are in turn monitored and assessed. This sequence of events is repeated over the life of the management program.

The active adaptive management approach allows for additional experimentation and interventions as required by the objectives set by stakeholders. If management decisions are consistent with what has been learned and are aimed at improving resource management, then when additional sources of uncertainty are identified, the adaptive management approach should be continued. In the event that all sources of uncertainty have been resolved, management can progress from a learning-based adaptive approach to a non-adaptive approach (Williams *et al.* 2009).

An example of active adaptive management – adaptive harvest management (AHM) for waterfowl harvest

An example of the successful use of active adaptive management is the adaptive harvest management (AHM) program used in North America for the regulation of waterfowl harvests (Blohm 1989; USFWS 2018). This program has been in operation since 1995 and regulates the harvest of waterfowl by setting bag limits, season length and season opening and closing dates. Harvest policies are reviewed annually by comparing monitoring data with predictive models of population dynamics that simulate the response of waterfowl populations to changes in harvest regulations and environmental factors to achieve a preferred system state. An important component of the program is extensive monitoring of populations and harvest offtake that allows a comparison between predicted and observed responses to management.

Each year the AHM program updates harvest regulations using predictive models with the greatest support. For example, the relative importance of density-dependence, additive mortality and compensatory mortality is examined using an information-theoretic approach (Burnham and Anderson 2002), and the relative confidence in alternative models is expressed by model-specific weights based on comparisons of predicted to observed population sizes (USFWS 2018).

In a recent review of the AHM program, Johnson *et al.* (2015) concluded that the active adaptive management approach had been successful in reducing contention around the setting of harvest regulations and that much had been learned about the relative importance of environmental and anthropogenic factors influencing waterfowl dynamics. They also acknowledged that social and institutional aspects of hunting may not be adequately addressed by the current models, and represent a challenge for future management. They emphasised that the current annual process of monitoring waterfowl populations has provided valuable information regarding the sustainability of the harvest but further model development is needed to explore how attitudes towards risk by stakeholder groups might influence regulatory policy and complexity, and to consider trade-offs between hunting opportunity, sustainability and regulatory complexity. The review concluded that AHM has increased awareness of the role of social values, trade-offs, and attitudes towards risk, and has enhanced managers' appreciation of the difficulty of dealing with social and policy, compared with scientific, issues.

Management plans for wildlife should acknowledge that there may be shifts in public sentiment and the attitudes and beliefs of stakeholders, for example the increasing awareness of the public to the importance of minimising animal welfare impacts (Sharp 2015). For example, Sharp *et al.* (2014) found that in a large survey of the beliefs and attitudes of the Australian general public towards kangaroo management, that although commercial kangaroo harvesting enjoyed a high level of support from the general public there was concern about its animal welfare impacts. Although stakeholders consulted during the development of AHM included a wide range of representatives – federal, state, and provincial governments; academics; non-government organisations; and waterfowl-interested citizenry – it did not include representatives from animal protection groups (NAWMP Committee and others 2012; Roberts *et al.* 2018), and it would be important that delegates from these groups are involved in any active adaptive management program developed for the management of kangaroos.

We acknowledge that active adaptive management has much overlap with, and could even be considered simply a part of, a wider planning framework such as RAPTA (Resilience, Adaptation Pathways and Transformation Assessment; O'Connell *et al.* 2019). However, we stress the importance for progress in kangaroo management of a capacity to test responses to management actions through formal modelling and monitoring processes, and therefore endorse the explicit focus on this aspect which the active adaptive management framework entails. The success of this framework in the application described above, which operates at socio-ecological scales comparable to kangaroo management, has reinforced our preference for active adaptive management over the less widely tested RAPTA framework.

An active adaptive management framework for kangaroos

Despite more than 40 years of regulated harvesting which has successfully preserved kangaroo populations across their range in the Australian rangelands, ecological, economic and social uncertainties about kangaroo management persist. Many of the issues that preceded the adoption of AHM for waterfowl in North America are relevant to the management of kangaroos in

Australia, thus the success of AHM can provide a framework for tackling these issues.

For kangaroos, the major issue that remains unresolved is the lack of consensus among stakeholders on how best to manage kangaroo populations. In addition, despite considerable research effort devoted to understanding the ecology of kangaroos (e.g. Dawson 2012), and on-going monitoring of rangeland kangaroo populations (Industry and Development Assessment 2017; Natural Resources South Australia Arid Lands 2017; Office of Environment and Heritage 2017*a*; Department of Biodiversity, Conservation and Attractions 2019), there remain important sources of uncertainty surrounding the response of populations to management actions, for example the relative importance of compensatory versus additive mortality during phases of population increase and decrease (Boyle and Hone 2014), the impact of non-sex-biased culling on population viability (Shelly 1997) and the impacts of attempting to maintain populations above or below agreed thresholds (Chee and Wintle 2010).

Active adaptive management is appropriate when management can strongly affect the system being managed and when there is a high degree of uncertainty surrounding the outcomes of management actions (Williams *et al.* 2009). Management of kangaroos is a complex issue with stakeholders having different plans and objectives for management which include maintaining viable kangaroo populations, improving the health of rangelands, maintaining the profitability of farming and commercial harvesting enterprises, promoting high animal welfare standards, and advocating ethical treatment. Given this complexity and the uncertainties outlined above the demonstrated success of an active adaptive management approach in other parts of the world (Nichols *et al.* 2006; Madsen *et al.* 2017; USFWS 2018) suggests to us that the management of kangaroos should now be reconsidered from this perspective in order to address many of the ecological, economic and social deficiencies of the current system.

Applying the process outlined above to the planning and execution of an active adaptive management plan for kangaroos would involve the following considerations:

Step 1: Involve stakeholders

In addition to those parties engaged by Hacker and McLeod (1999) (pastoralists, non-government conservationists, government wildlife management agencies and the kangaroo industry), key stakeholders should also include animal protection groups and Indigenous Australians. Representation from the general public (i.e. those who do not identify with the objectives of any of the other groups) may also be sought. Representatives of these groups would form the basis of stakeholder involvement in the adaptive management program.

Animal protection groups actively carry out welfare work on behalf of animals and include a wide range of organisations with varying agendas from 'animal welfare' groups, who accept that animals can be used as long as this use is justified and that animal suffering is minimised, to the 'animal liberation' and 'animal rights' groups that are not accepting of animal use in any circumstance (Sharp 2015). However, not all groups may choose to participate in the adaptive management process if their core values cannot be accommodated by management that includes commercial harvesting, and this is likely to be the case for animal rights or liberation groups. In contrast, animal welfare groups, such as RSPCA Australia, have expressed a willingness to consider management that involves lethal harm, such as commercial harvesting, if it can be shown to be justified and humane (RSPCA Australia 2009). Furthermore, active adaptive management has been recognised as a way that can quickly identify strategies to maximise animal welfare and minimise pain and suffering (Vavra 1996; Blumstein 2007, 2010). Regardless of each stakeholder's agenda and values, it is important that all stakeholder groups should initially have the opportunity for participation to express their views and have them considered.

For those groups that do participate, a formal commitment to the adaptive management program and its processes for the duration of the management plan will be required.

Step 2: Set objectives

A workshop of all stakeholders, like that conducted by Hacker and McLeod (1999) would be a logical starting point for this process. During and following the workshop, explicit and measurable management objectives that are achievable and sustainable would be identified. Trade-offs between the objectives of different stakeholders would be identified and an agreed system of monitoring and assessment developed. Objectives would include both 'fundamental' and 'means' objectives. In the context of kangaroo management, examples of fundamental objectives would be to maintain viable populations throughout their range and allow sustainable use for commercial gain. A means objective might be to regulate the harvest by setting harvest rates that are compatible with the fundamental objectives. Some objectives may be required that are unacceptable to those stakeholders who oppose kangaroo harvesting for commercial gain alone but have agreed to contribute to the process. While these could not be fundamental objectives that relate to ongoing commercial harvesting, they could form a sub-set that contributes to system understanding within the adaptive management process. They could relate, for example, to non-commercial culling for damage mitigation and associated animal welfare issues, or the consequences of tradeable licences that are open to the kangaroo industry, landholders and animal protection advocates (Boronyak-Vasco and Perry 2015).

Step 3: Develop management actions

A wide range of management actions might be considered by the stakeholders. Harvest rates, for example, could be set to include 'no harvest' as well as harvest rates that are well above what is currently considered to be sustainable but could be applied experimentally for a short period of time, say a year or two. Simulation studies by Hacker *et al.* (2004) found that a harvest rate of 20% with 70% males gave the best compromise between the competing objectives of the stakeholders involved in their study. This option would ideally be included in the management actions identified.

Some management actions could be considered that do not require the harvesting or culling of kangaroos at all but rely on improved livestock grazing management to achieve improvements in land condition. Rotational grazing practices, for example, that result in a large proportion of a property being rested at any time may 'dilute' the tendency of kangaroos to concentrate

in destocked paddocks and thus remove the objection that pastures cannot be rested because of kangaroo incursions. This and other similar possibilities have been canvassed by Hacker and McLeod (2003). Although they could be accommodated within an active adaptive management program they would also represent legitimate opportunities for more traditional research funding organisations.

Step 4: Develop models

There are several models already available that could be readily applied to predict the impacts of culling or harvesting on population dynamics including simple, unstructured models of plant-kangaroo dynamics (e.g. Caughley 1987), models that examine eco-evolutionary impacts of harvesting (Tenhumberg *et al.* 2004) and complex age- and sex-structured population models (McLeod *et al.* 2004). If required, new models could be developed to predict the impacts of some of the identified management actions.

Step 5: Define monitoring plans

Methods for estimating kangaroo population size must include methods that improve the accuracy of population counts, such as the recent adoption of mark–recapture distance sampling methods (Burt *et al.* 2014) in New South wales (Office of Environment and Heritage 2018*b*). Other variables, such as pasture availability, that are not currently used for predicting changes in the population status of kangaroos, but which can be readily monitored at appropriate scales with available satellite or pasture growth modelling technology such as AussieGRASS (Carter *et al.* 2000; https://beta.longpaddock.qld.gov.au/aussiegrass/, accessed 12 January 2020) may need to be routinely incorporated into the assessment of management responses. Changes in the condition of land resources, reflected in fractional groundcover, could be monitored from large scale datasets routinely available, or subject to trend analysis within specific project areas based on comparison with a surrounding buffer zone of similar country (Waters *et al.* 2019). The variables to be monitored will ultimately be informed by the models chosen in Step 4.

The progress of an active adaptive management program in the iterative phase would follow the steps outlined above but cannot be more precisely specified at this time. Such a program would run in parallel with the current commercial harvest system which would in effect serve as a control for management experiments run for defined periods in specific places. This approach would require a commitment to increased investment in kangaroo management, particularly in the implementation and monitoring of management interventions, but not necessarily one which is open ended. We would expect that after several years the current management program would either be confirmed or refined in ways that demonstrably achieve a better balance of competing objectives. Management may then revert to a non-adaptive approach or continue to seek resolution of further uncertainties if the stakeholders are convinced of its efficacy. Costs ideally would be shared among stakeholders based on the anticipated benefits arising from a better accommodation of their interests. However, in the absence of any guarantee at the outset that such benefits will materialise some stakeholders may be unwilling or unable to contribute equitably. Inevitably, public funding would need to meet a substantial part, though by no means all, of the costs given the iconic status of kangaroos in the public mind, their role in the wider management of land resources, and the active involvement of government agencies in this sphere.

Discussion

The sustainable use of rangelands poses significant challenges due to factors such as a highly variable and harsh climate, a nutrient-poor environment, and unpredictable productivity (Stafford Smith *et al.* 2000; Eldridge and Beecham 2018). Heavy grazing pressure (from livestock and unmanaged herbivores) in association with drought has resulted in several discrete episodes of degradation in the Australian rangelands from which recovery has been slow (McKeon *et al.* 2004; Stafford Smith *et al.* 2007). The grazing pressure from unmanaged and overabundant kangaroos, particularly following peaks in population booms and the transition into drought, contributes to this problem (Hacker *et al.* 2004). However, the management of kangaroos should not be considered in isolation from other factors that influence the sustainable use of rangelands.

Sustainable use of a resource or environment, by definition, means that its use can continue indefinitely (Milner-Gulland and Mace 2009). However, the three components of sustainable use – ecological (where use does not irreversibly harm biological functions and biodiversity is not unacceptably reduced); economic (where use is profitable); and social (where use is culturally acceptable) – all need to be accommodated for sustainable use to be achieved. The dynamic nature of the interaction between ecosystems and their use often leads to trade-offs between these three components (Barbier 1987), the balance of which is likely to be constantly changing. Continuous assessment of the state of the system and the strength of interactions is thus crucial to any judgement about sustainable use and will need to be reflected in the policies and principles by which that use is governed.

Notwithstanding the challenges of implementing an active adaptive management program for kangaroos in the rangelands, this approach offers a basis for addressing multiple, and sometimes conflicting, stakeholder objectives and fine-tuning management to satisfy these objectives to the extent possible. Finally, we contend that active adaptive management provides the best prospect of safeguarding the sustainable use of rangelands, particularly against the uncertainties of climate change.

Conclusions

Kangaroo management programs that are approved and implemented by governments have operated in all Australian states with commercial kangaroo industries for over 40 years. These programs have been demonstrably successful in as much as kangaroo populations have been maintained, some degree of population control has been exercised in the absence of any major predator, and the operation of a commercial industry based on sustainable use of wildlife has been defensible in the public arena. However, stakeholder's aspirations for kangaroo management have not been entirely satisfied by these programs, and considerable conflict remains among competing objectives. The programs as implemented have been essentially reactive,

involving a relatively simple process of quota setting based on population estimates, and lacking any formal means of incorporating insights into system responses to even natural experiments let alone planned interventions. Active adaptive management offers a framework whereby stakeholder objectives can be defined, management interventions designed in the light of those objectives and the subsequent response of the system evaluated. Formal feedback of these assessments into the operation of kangaroo management programs should provide the best means of satisfying competing objectives to the extent possible and, indeed, of promoting the sustainable use of natural resources in the face of increasing uncertainties associated with climate change. Implementation of an active adaptive management approach would involve additional commitment on the part of stakeholders, both financial and emotional, but it also offers the prospect of progress on one of Australia's most vexed resource management issues.

Conflicts of interest

The authors declare no conflicts of interest.

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