Situation Analysis Report

Update on Current State of Scientific Knowledge on Kangaroos in the Environment, Including Ecological and Economic Impact and Effect of Culling

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Executive summary

The most significant publications since the last review of the literature in 2000 are those on the sophisticated models that have been developed based on harvesting statistics. These are providing insight into demographics, genetics, movements, and significant harvest refugia, as well as sustainability of the harvest and prediction of the likely effects of management variations and stochastic events. They offer the possibility of more cost-effective management through optimisation of monitoring.

A second significant development is the revision of the Dry Sheep Equivalent (DSE) for kangaroos, which suggests that previous estimates were as much as three times too high. Confirmation of this is critical to understanding kangaroo grazing impacts and interactions. DSEs should also be calculated separately for all four harvested species.

Areas of research need that were gleaned from the literature include: kangaroo land degradation impacts and effects on wool production; confirming the lower DSE estimate in free-ranging animals; and greater understanding of kangaroo movements. Knowledge of demographics has improved but is still in its infancy. Improved knowledge in these fields has potential to improve the predictive models.

The main findings were similar to those of the previous review:

- Shooting remains the most economical, humane and cost-effective way to cull/harvest kangaroos;
- Restricting access to water will not achieve significant improvement in vegetation, at least in the short term, and seems unlikely to substantially reduce kangaroo numbers at the landscape level;
- Reintroduction of predators may depress or regulate populations but is much more likely to cause stock losses;
- Knowledge of immunocontraception and contraception has improved but these are unsuitable for broad-scale management;
- Rainfall is the overriding driver of population density; predation, parasites and disease have much smaller impact. Drought can reduce populations by as much as half but even under current rates of harvest they have the capacity to recover;

- Habitat modification, particularly that associated with grazing, has generally improved conditions for kangaroos;
- It has been fairly well established that any genetic impact of harvesting is minimal.
- Grazing management remains poorly integrated with kangaroo management and farm management in general;
- Aerial survey remains the most effective means to monitor populations over the vast harvest area, and improvements have been made to techniques and correction factors;
- There is little doubt that current rates of harvest are sustainable, modelling suggests it is near optimal. In many ways the industry is self-regulating. Even if prices and demand increase, evidence suggests that commercial harvesting is not sustainable at densities that threaten any of the harvested species with extinction. Recent changes such as adjustments to quotas in response to drought and considerations of the optimising of survey frequency are making the guidance and auditing of the harvest strategy even more sensitive and accurate; and
- The current harvest strategy (15–17%) appears to be achieving its current twin goals of sustainable use of natural resources and the maintenance of viable populations of the four harvested species.

The discontinuation of damage mitigation as grounds for harvesting is in many ways a more honest approach to kangaroo management given that damage is difficult to monitor, predict and even to prove empirically to be an issue. It has also removes the implication that kangaroos are pests.

However, some landholders still perceive damage mitigation to be the main reason for harvesting and continue to call for greater quotas, mainly during the recent years of low rainfall. Arguably, this is a socio-economic problem rather than an ecological one. Certainly, the issue of land degradation will never be redressed by simple reduction in kangaroo numbers when there is no concomitant control of sheep and other introduced herbivore grazing impacts. Kangaroo management/commercial harvesting needs to be integrated with grazing management if land degradation is to be addressed.

Hence, a major unresolved issue is that of perceived conflict with pastoralism. Graziers are not significant participants in the kangaroo harvesting industry; and harvesters receive the greatest benefit from the current system. This raises another critical question: now that knowledge of levels of harvesting that can be sustained is well established, and it is clear that none of the four species is under threat, and control of land degradation is not a goal of kangaroo management, is kangaroo monitoring a priority for conservation agencies?

1.0 AIM

The aim of this document is to provide a review of the current state of scientific knowledge on specific issues and theories relating to kangaroo management in New South Wales. This was completed primarily by a comprehensive review of literature published in the five years since the previous review (Olsen and Braysher 2000).

2.0 BACKGROUND

Kangaroos in New South Wales are managed in accordance with the Australian Government-approved Kangaroo Management Program (KMP). The current KMP has approval until 31 December 2006. In accordance with the KMP, the program is being reviewed prior to its expiry and the development of a new program to be implemented from 1 January 2007.

Part of the review process involves the commissioning of reports addressing particular issues identified by the Kangaroo Management Advisory Panel (KMAP) and the New South Wales Department of Environment and Conservation (DEC). For this purpose, situation analysis reports are prepared. This document reviews specific issues relating to the current state of scientific knowledge on kangaroos in the environment, including the ecological and economic impact of kangaroos and the effect of culling, and is one of these reports. It updates the previous literature review (Olsen and Braysher 2000) commissioned to inform the preparation of the current KMP.

Only the larger, more abundant species of kangaroo can be harvested commercially—for human consumption, pet meat and skins. Most (60–70%) of individuals harvested are processed for pet meat, the remainder is processed for human consumption, of which about 70% is exported to overseas markets; skins are taken from the meat processing sector or the skin-only harvest which operates only in Queensland (Kelly 2005). Commercial harvesting of kangaroos requires prior approval by the Australian Government under *Environment Protection and Biodiversity Conservation Act 1999* of a Wildlife Trade Management Plan such as the KMP. As part of this process the government sets harvest quotas based on submissions from the States, harvest numbers, population trends and other considerations. Management plans must demonstrate that harvesting does not impact on the species concerned or their ecosystems (DEH 2004), though the latter is seldom, if ever, audited or addressed.

KMPs, or their equivalent, are prepared by each of the relevant States. These provide statements of the aims of kangaroo management, which are usually to maintain viable populations of the species throughout their ranges, minimise the unwanted impacts of kangaroos and, where possible, manage the kangaroos as a renewable resource provided the conservation of the species is not compromised. Since the last literature review (Olsen and Braysher 2000), New South Wales has rationalised its approach, rejecting damage mitigation as justification for management in part because it was not being audited, and it would be impractical to do so. Indeed, there is little convincing evidence of substantial damage by kangaroos to crops, pastoral production or rangelands, except in a few localized areas. Instead New South Wales has taken a more practical 'outcome and performance' driven approach and the stated goal of the KMP (2002–2006) is to 'maintain viable populations of kangaroos throughout their ranges in accordance with the principles of ecologically sustainable development'.

The legislative underpinnings, aims and processes of the New South Wales KMP have been summarized by Gilroy (2004). Recent improvements to the program include active use of adaptive management, the encouragement of greater stakeholder involvement and increased community awareness, and specific arrangements for ongoing audits and reviews. In 2001, changes were made to survey protocols and correction factors were revised (Cairns and Gilroy 2001; Payne 2005). In March 2004 a four-year trial was begun of harvesting in the south-east (South-East New South Wales, Zone 16), formerly in the non-commercial zone, to facilitate commercial use of kangaroos currently shot under non-commercial licenses (Pople et al. 2005). Its success will be evaluated against impact of the kangaroo population, the level of take in relation to quota and the impact on non-commercial culling (Payne 2005). Initial indications are that a switch to commercial licenses has begun.

The New South Wales KMP covers the four locally harvested species: the Red Kangaroo *Macropus rufus*, Western Grey Kangaroo *M. fuliginosus*, Eastern Grey Kangaroo *M. giganteus* and Common Wallaroo *M. robustus robustus.* New South Wales is a major harvester of kangaroos. For the past two years, the State accounted for 29% of the kangaroos harvested commercially in Australia, second only to Queensland (Table 1).

Around a million kangaroos are harvested annually in New South Wale, although harvest rates are heavily dependant on seasonal conditions as well as economic factors. In recent years actual harvest rates have been 6–12% of the total population; quotas have been set at 15–17% for the various species; and there has been 48–82% uptake of the quota. The recent drought has depressed kangaroo populations to about 30% of pre-drought numbers, resulting in reduced quotas.

The kangaroo harvest industry intends to continue to expand, particularly in the more secure domestic arena (Kelly 2005). Predictions are that the industry is likely to approach or fully fill the annual quotas in coming years, in part because quotas have been reduced because of drought and also because of a 7% long-term average annual growth in the value and volume of the industry (Kelly 2005). However, the proportion of the quota filled has increased only slightly during the drought, indicating that the industry is somewhat self-adjusting, with harvesting becoming uneconomical at reduced kangaroo densities.

Table 1.

a) Commercial kangaroo harvest quotas in 2004, actual numbers killed and the percentage of the quota taken up (Source: Department of the Environment and Heritage, Canberra).

State	Red Kangaroo	Eastern Grey	Western Grey	Euro/ Wallaroo	Total allowed	Total killed	% of quota taken up
New South Wales	400,970	751,575	200,255	35,611	1,388,411	877,225	63
Queensland	663,599	1,291,142	0	334,440	2,289,181	1,599,136	70
South Australia	198,800	0	102,200	60,300	361,300	178,126	49
Western Australia	262,000	0	121,000	0	383,000	337,584	88
Total	*1,525,369*	*2,042,717*	*423,455*	*423,455*	*4,421,892*	*2,992,071*	*68*

b) Commercial kangaroo harvest quotas for the four harvested species in 2005 and uptake by industry (Source: Department of the Environment and Heritage, Canberra).

Red Kangaroo	Eastern Grey	Western Grey	Euro/ Wallaroo	Total	Total taken	% of quota taken up*	% of previous year's population*
445,300	550,820	143,963	35,616	1,175,699	1,091,299	48%	9%

*to 1 September 2005

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3.0 LITERATURE REVIEW

The literature review was structured to address the five major areas of concern to the KMAP. The main focus was on the impact of kangaroos on vegetation/habitat/land resource/biodiversity and the impact of harvesting on the kangaroo population.

The major tasks were to:

- Compare the effectiveness of various existing and potential methods to control kangaroo populations;
- Assess the effect of other impacts on kangaroo populations including disease and habitat loss or habitat modification;
- Review the genetic impact of kangaroo culling;
- Review the scientific support for and practical application of the various grazing management theories that may be used as the basis for kangaroo management; and
- Assess the direct and indirect methods used to monitor kangaroo populations in New South Wales.

The review concentrates on publications since the last review in 2000 but occasionally refers to literature previous to that to support a statement or argument or when it was overlooked in the previous review.

3.1 EFFECTIVENESS OF METHODS TO CONTROL KANGAROO POPULATIONS

Task 1 – Compare the effectiveness of various existing and potential methods to control kangaroo populations, e.g., shooting (culling/harvesting), restricting access to water, reintroducing predators, and immunocontraception.

3.1.1 Shooting

Olsen and Braysher (2000) concluded that shooting is the most economical, effective and environmentally friendly means to harvest or cull large numbers of kangaroos, and there is nothing in the more recent literature to alter that finding. Shooting also remains the most acceptable method from an animal welfare perspective, though it is not without legitimate problems and critics (e.g., Croft 2000, 2004), mainly centered around joeys. Since 2000, the RSPCA has repeated their 1985 audit of the animal welfare aspects of the harvest (RSPCA 2002); the percentage of animals that were headshot, as required by the Code of Practice for the Humane Shooting of Kangaroos, averaged 96%, up from 85% for all States. For New South Wales compliance had increased from 95% to 99%. The State felt there was need for review of the Code in relation to low acceptance by industry of non-headshot animals.

The effectiveness of the current harvesting strategy, which relies on shooting in accordance with the Code, is discussed in section 3.6.

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3.1.2 Restricting access to water

Olsen and Braysher (2000) concluded that electric fencing to exclude kangaroos from water was of limited value, but noted that capping of inland bores and pumps might potentially reduce kangaroo numbers, however supporting research was scarce.

In the five years since their review, new information has been obtained about the impact on kangaroos of removing artificial water (old farm dams) from arid-zone National Parks, and these are considered in the following section.

One of the major premises for restricting access to water as a means of control—the assumption that establishment of waterpoints for stock is the main reason for range extensions in Grey Kangaroos and increases in abundance of Red and Grey Kangaroos—has been questioned (e.g., Blaney et al. 2000; Auty 2004; Dawson et al. 2004). Certainly, there is agreement that kangaroos are less constrained by the availability of artificial water than are sheep, especially the Red Kangaroo (Hacker and McLeod 2003).

Electronic ear tags will become a standard feature on sheep properties in future, creating the possibility that electronic systems could be designed that will admit sheep to water while excluding macropods.

Cattle are now individually microchipped, and the sheep industry is moving in this direction with E-sheep (www.sheepcrc.org.au/articles.php3?rc=140). The Sheep CRC is trialling electronic ear-tags that can be used in conjunction with electronic scales. A remote walk-through weighing system has been developed to electronically capture a sheep's RFID tag and body weight as it walks through a one-way gating system to a feeding or watering point. James Roe of the Sheep CRC (pers. comm.) said there might be some potential to control kangaroo access to water with this system. Access to a fenced water source could be restricted to animals wearing tags or matching a certain weight. This is merely an idea at present, which may prove impractical in practice, and no research is underway.

In combination with shooting, restricting access to water can be useful at the local scale for commercial harvesting or culling. Replacement of open drains with discrete sources of water may facilitate shooting of kangaroos that gather there, especially in dry conditions (Hacker and McLeod 2003). Similarly, Finlayson troughs, while not effective in the long-term, may also be useful for short-term concentration of kangaroos for harvesting or culling. Hacker and McLeod (2003) also suggest that self-mustering stockyards might have the secondary role of excluding kangaroos from artificial water when stock are absent, which may reduce grazing pressure and allow paddocks to rest, but evidence is lacking (also see Connelly et al. 2000).

There are potential animal welfare issues around closure of waterpoints, which don't appear to have been addressed in this research.

Overview

Electrical fencing has not been found effective for kangaroo control over large areas. When electronic ear tags are adopted by the sheep industry it may be possible to design gating systems to water that exclude macropods, but this is no more than speculation. Nevertheless, evidence presented in the following section suggests that exclusion of kangaroos from water may not achieve significant improvement in vegetation and seems unlikely to substantially reduce kangaroo numbers at the landscape level.

3.1.2.1 Specific Issue – An analysis of watering points (AWP), kangaroos, domestic grazing animals and biodiversity. Kangaroo population response to variations in AWP's

Closure of waterpoints is underway in parts of the rangelands, with uncertain impacts on kangaroo populations. Olsen and Braysher (2000) recommended a scientifically rigorous program to monitor the variation in kangaroo density following the closure of waterpoints. Preliminary studies suggested that, in the short-term, grazing pressure was not reduced following closure. For example, Freudenberger and Hacker (1997) concluded that kangaroo and goat grazing pressure was not depressed up to 10 weeks following water closure.

Removing artifical water has become a priority in many inland National Parks, following the influential work of Landsberg *et al.* (1997), who found an inverse correlation between livestock dams and biodiversity. They called for a staged closure of artificial watering points on conservation reserves. Most inland National Parks are former grazing properties, on which the removal of stock has not lead to substantial improvements in vegetation quality, even after many years, because kangaroos and feral animals suppress regeneration (with loss of topsoil and diminished seedbanks often contributing to the problem). Dam closures provide a better option than shooting, which is controversial in National Parks, is often made difficult by dense vegetation, and does not provide a permanent solution. Dam removal is opposed by some conservation managers who believe that dams should be kept open to compensate for natural waterholes silted up by livestock or lost from falling artesian water pressures (Pople and Page 2001). Dam removal has also been opposed by nearby farmers who fear that kangaroos will relocate from National Parks to their properties, where water remains available (Pople and Page, 2001; Montague-Drake and Croft 2004).

Pople and Page (2001) warn that, in any event, closing water points may not reduce herbivore numbers sufficiently to achieve vegetation or fauna recovery. An increased distance between water points may still be insufficient to alter kangaroo and feral herbivore distribution and abundance, because macropods can travel large distances to water and go long periods without drinking. Vegetation may be unable to recover unless grazing falls below some threshold that cannot be reached by closure of watering points.

In the five years since the Olsen and Braysher review, three studies have assessed the impact on kangaroos of closing waterpoints in arid-zone National Parks; these are described below. Kangaroo numbers diminished around some closed dams but not others. Vegetation did not improve in any of the three studies, which confirms that vegetation improvements are difficult to achieve, at least over the time scales considered.

Montague-Drake (2004) studied kangaroo distribution around closed and open watering points in Sturt National Park in northwestern New South Wales, and found no evidence to show that water influenced Red Kangaroo feeding behaviour (Montague-Drake and Croft 2004). Red Kangaroos preferred to graze within major drainage channels, which provide optimal foraging habitat plus good shade, irrespective of distance from water. Few areas within the park are more than 6 km from water. Eastern Grey Kangaroos showed a slight tendency to occur closer to dams (Montague-Drake 2004), but the sample size was very small. Montague-Drake radio-tagged several Red Kangaroos and concluded that one of them may have drunk as few as 12 times in a year, perhaps going 144 days between drinks, although this conclusion assumed that kangaroos only drank at the nearest available dams, which were the only ones electronically monitored.

In sheep paddocks in the Mulga Lands of southwestern Queensland Cowley (2001) also found no evidence that kangaroo distribution was influenced by water.

In Idalia National Park in central Queensland, one watering point within the park, and one on a nearby grazing property, were closed to kangaroos at a time when ephemeral surface water was available. Eight weeks after closure little impact could be detected on macropod distribution and density or vegetation cover (Lavery 2002). This study was limited by its short duration. Water was available within a few kilometers of the closed dams. Euros were the main macropod present, along with some Red Kangaroos. Previous studies have found that Euros are the kangaroo least willing to travel large distances to water (Ealey 1967; Pople and Page 2001), although they can survive indefinitely without water if they have access to caves for shelter.

Fukuda (2005) conducted a subsequent study within Idalia National Park at a time when macropod numbers were greatly reduced by drought. By closing two dams she hampered Red Kangaroo recolonisation by 40%, up to 21 months following the closure, with distances to alternative waterpoints being 3.8–6.6 km away. The vegetation did not improve, perhaps because the rainfall remained low. Fukuda concluded that large macropods could hamper regeneration after drought even when their densities remain at a relatively low level, of 10–15 per km^2.

Dam closures to date have not produced hoped-for improvements in vegetation quality. This can be explained in several ways: degraded environments around dams with limited potential for regeneration, the high mobility and low water requirements of kangaroos; and/or the short duration and other methodological shortfalls of the studies. The strong, persistent piospheres (damaged areas) around dams, with severe degradation evident closest to the waterpoints, are created by livestock rather than kangaroos (Pople and Page 2001), whose distributions reflect availability of food more than water (Montague-Drake and Croft 2004; Pople and Page 2001, and references therein).

Research is needed to determine how far kangaroos will travel to water from their feeding sites (Montague-Drake and Croft 2004) under different combinations of climate and food quality. There are also age and sex differences (and demographic shifts) in response to water closure that remain to be understood; for example, juvenile Red Kangaroos are more water dependent than adults (Munn and Dawson 2004) and lactating females may also be.

The distance, especially for Red Kangaroos, may be so large that closing watering points in National Parks will often do little to reduce kangaroo numbers. The comments of Pople and Page (2001) are pertinent: ‘For Red Kangaroos, the maximum distance they can move is somewhat academic for National Parks in the Mulga lands, because permanent water will always be available at natural waterholes or off-reserve at distances probably <10 km. More useful questions are what is the grazing impact of kangaroos with distance from water and how is this altered by increasing the distance between water points?'

Overview

Several studies have assessed the impact on kangaroos of closing waterpoints in arid-zone National Parks. Kangaroo numbers were suppressed around some closed dams but not others. Vegetation did not improve signficantly. The closure of waterpoints on National Parks may achieve localised reductions in kangaroo numbers, but the evidence so far suggests that waterpoint closure is not a viable method for large-scale control of kangaroos, because kangaroos are highly mobile and capable of travelling to drink, and water will often still be available.

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3.1.3 Reintroducing predators – Dingoes

A Dingo-proof fence protects most of the rangelands' sheep. Olsen and Braysher (2000) concluded that reintroduction of Dingoes, or the removal of Dingo controls, is not a realistic proposition for kangaroo control in the pastoral zone. There is circumstantial evidence that Dingoes can regulate kangaroo numbers, delaying recovery after drought, for example Pople et al. (2000), and greater evidence that they can depress kangaroo numbers (see section on Predation below). There is, however, no evidence that Dingoes would prey heavily enough on kangaroos to keep them at acceptable levels for pastoralists and it is highly likely that sheep would become Dingoes' preferred prey, especially where kangaroos were in low numbers.

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3.1.4 Immunocontraception (and contraception)

Olsen and Braysher (2000) concluded that antifertility control may prove effective at controlling small kangaroo populations in confined places, but, based upon present knowledge and constraints, was not applicable to large grazing properties. The only method proposed for broad-scale control is immunocontraception, but serious doubts remain about its safety and practicality, including concerns that it could cause population extinctions, and could pass via a viral vector from one species to another.

Advances in the last five years suggest that immunocontraception (reviewed by Rodger and Kay 2003) may become a practical method of control, but only for small kangaroo populations outside the rangelands. Contraceptive implants (recently reviewed by Herbert 2004) have now become available as a control method, but they too are only suitable for small kangaroo populations such as those in parks and on the urban fringe.

John Rodger (pers. comm.) is investigating an immunocontraceptive vaccine that is taken up orally in licks (containing molasses and salt). Kangaroos often prefer licks to pellets, especially in regions with mineral-deficient soils, although pellets may also prove suitable as a method of delivery if uptake by non-target animals can be prevented. The vaccine is absorbed in the buccal or nasal cavity and induces female animals to mount an immune attack against the proteins surrounding their egg, using ZP3 (Rodger and Kay 2003). ZP3 from Brushtail Possums *Trichosurus vulpecula* has been found effective against female Eastern Grey Kangaroo fertility (Rodger and Kay 2003). Rodger (pers. comm.) is optimistic that this vaccine will prove effective in controlling overabundant kangaroo populations in eastern regions of New South Wales. It would be most cost effective if a plant could be genetically engineered to produce the vaccine and then processed into edible pellets, and one plant, a legume (*Medicago*) is looking promising (Rodger pers. comm.). Such a method would remain too expensive for broad-scale use in the rangelands. Sperm proteins have proved less successful as contraceptive agents in the past (Rodger and Kay 2000), but recent successes have been achieved on Tammar Wallabies *Macropus eugenii* (Kay and Rodger 2003; Asquith et al. 2005). Sperm proteins offer the advantage of affecting both male and female fertility, since both sexes mount an immune reaction to sperm.

Immunocontraception has attracted criticism from some scientists, although much of the concern has focused on methods that deploy a virus to carry the immunising agent. In a major review of various mammal control methods, Cooper and Herbert (2001) noted the example of Australian mouse researchers who accidentally created a lethal virus during an immunocontraception experiment (Finkel 2001; Jackson 2001; Cooper 2004), killing all their mice, and raising global concerns that bio-terrorists could exploit the technology. Cooper (2004) raised different concerns, although some of these only apply if a vaccine is injected.

One of the criticisms of Cooper (2004) is that immunocontraception will lower disease resistance in a population by selecting for individuals that do not respond to their own immune system. Magiafoglou et al. (2003) concluded from antibody response data that slow evolution of contraception resistance could be anticipated, but by applying divergently acting multiple vaccines it could be averted. Rodger (pers. comm.) says that immunocontraception research on Brushtail Possums in New Zealand may lead to advances in kangaroo control here. If a bacterium that is engineered to carry a vaccine can also be engineered to die, the kangaroo's immune system would recognise the dead bacteria and mount an immunological response (Rodger and Kay 2003). However, the public might oppose the use of genetically engineered bacteria or plants, and research into public attitudes is planned (Rodger and Kay 2003).

Immunocontraception aside, major advances have been made in the testing of several types of contraceptive implants (reviewed by Herbert 2004). These have promise for control of small isolated macropod populations, but the findings do not alter the conclusion that fertility control is inapplicable to broad-scale kangaroo control.

Levonorgestrel is a steroidal contraceptive, currently used by women, which has been found promising in tests on macropods. Nave et al. (2002b) found it to be safe, highly effective, and a long-term method of contraception (lasting at least 27 months) when implanted in Eastern Grey Kangaroos, doing little to alter their behaviour (Pioani et al. 2002). However, synthetic progestins such as Levonorgestrel can harm the reproductive tract and cause metabolic changes, and Herbert (2004) cautioned that 'This [aspect] deserves further investigation before wide-scale use of synthetic progestins is advocated to control kangaroo populations'.

They are also expensive and cannot be applied without first anaesthetizing the animal (C. Herbert pers. comm.).

Recent trials of another hormonal implant, Oestradiol, were successful on Koalas *Phascolarctos cinereus* (Middleton et al. 2003) and this hormone would be expected to work on macropods as well. It proved slightly less effective than levonorgestrel at the trial doses used, producing infertility in 95% of Koalas compared with 100% using levonorgestrel, but it is cheaper to purchase. However, Herbert (pers. comm.) is sceptical about this product, warning that it could profoundly alter behaviour. A long-term study of its impacts on behaviour would be needed before it could be considered suitable.

Deslorelin, a non-steroidal contraceptive, is a synthetic analogue of the gonadotropin-releasing hormone (GnRH) (Herbert 2004; Herbert and Trigg 2005). It has only recently been trialed against wildlife, a long-acting formulation having become available for the first time (Herbert 2004). This was recently registered as an off-the-shelf veterinary product. In a detailed study, Herbert (2002) found it effective as a contraceptive implant in female Tammar Wallabies *Macropus eugenii* (Herbert et al. 2004a; Herbert et al. 2005). It has since been shown effective against Eastern Grey Kangaroos (Herbert et al. 2006), producing a contraceptive affect that lasted 559±111 days when a small dose was applied, or 651±21 days following a larger dosage. GnRH agonists do, however, have the potential to alter social behaviour, including dominance hierarchies (Cooper and Herbert 2001; Herbert 2004), which can influence access to food. Nevertheless, studies on wildlife overseas have not identified significant behavioural side effects (Herbert 2004), and none were observed in the kangaroos treated by Herbert et al. (Woodward et al. 2006). A large trial is now underway at St Marys in western Sydney (Environmental Resources Management Australia 2003) where deslorelin will be injected into 4,000 Eastern Grey and Red Kangaroos (D. Robertson pers. comm.). It will become cheaper to apply if a method can be developed for darting animals from a distance (Herbert pers. comm.). Deslorelin can theoretically work as a contraceptive on male animals, but a trial on male Tammar Wallabies was unsuccessful (Herbert et al. 2004b).

The limitations of surgical sterilisation, which is expensive, physically invasive and not always effective, were reviewed by Herbert (2004). Wilson (2003) described a method used to vasectomise male Eastern Grey Kangaroos on a golf course.

Overview

Because of a need to control over-abundant marsupials in situations where culling is socially unacceptable, major advances have been made in contraceptive methods of control. Deslorelin, a non-steroidal contraceptive, is now available off-the-shelf, and a project to inject 4,000 kangaroos in a peri-urban setting is now underway. Recent research suggests that the steroidal contraceptive, Levonorgestrel, and perhaps also Oestradiol, may be suitable for small-scale kangaroo control. Immunocontraception, using ZP3 applied orally in licks or pellets, is also looking promising for small-scale control. Because of the relatively high costs per kangaroo, and limited period of fertility control, none of these methods is suitable for broad-scale kangaroo control.

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3.1.5 Other potential control methods

Olsen and Braysher (2000) discussed various methods: distractant crops, exclusion fencing, poisoning, trapping and mustering and deterrents, and concluded that none of these are suitable for broad-scale application. There appear to have been no significant developments in this area since 2000 (but see section 3.1.2 Restricting access to water). A number of fencing designs that prevent kangaroos passing under as well as over have been used, but their effectiveness has not been evaluated (Hacker and McLeod 2003).

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3.2 OTHER IMPACTS ON KANGAROO POPULATIONS

Task 2 – Review the effect of other impacts on kangaroo populations, including disease and habitat loss or habitat modification.

Olsen and Braysher (2000) noted that kangaroo numbers can be affected by disease, habitat change and natural disasters, such as droughts and floods. Of these, only drought is considered to have a significant impact.

3.2.1 Drought and its impact on food

Olsen and Braysher (2000) concluded that rainfall, by influencing plant productivity, is the single most important influence on kangaroo populations. Kangaroo numbers fall dramatically during droughts, although their numbers can rise again quickly when good conditions return. In the five years since their review, drought has again shown its capacity to reduce kangaroo numbers.

Pople et al. (submitted b) drew upon aerial survey data to assess kangaroo numbers in eastern Australia over the past 30 years. They found that combined kangaroo numbers have fluctuated from 14.5 million in 1984 to almost 32 million in 2002. Three major droughts (more than 20 months duration) have struck during the previous 30 years—1981–1983, 1991–1993, 2001–2003—and each of these caused dramatic declines in numbers of the three major kangaroos (Red, Eastern and Western Grey). Populations fluctuated greatly, often but not always in response to drought, which was the main cause of perturbations.

In Idalia National Park in central Queensland, the drought in 2002—the worst since 1900—triggered a dramatic drop in macropod numbers. The average density of Euros declined by 97.7% while Red Kangaroos declined by 83.8% (Fukuda 2005). The combined densities of macropods fell by 120 per km^2. Numbers remained low because the drought was broken by below-average rainfall. In the nearby Blackall district, however, densities of these two macropods rose slightly during the drought, for reasons that Fukuda did not explain.

Cairns et al. (2000) monitored harvested Western Grey Kangaroos in the South Australian pastoral zone at the edge of their range and detected large fluctuations, but no overall trends, associated with severe drought but unrelated to antecedent rainfall. They postulated that the dynamics of emigration and immigration, and suitable habitat, were limiting these low-density populations.

In the Flinders Ranges in South Australia, Euro numbers dropped dramatically during the severe drought of 2002 (Hornsby and Corlett 2004). Larger Euros were more severly impacted, and a significant proportion of the population died, especially larger individuals, and probably from starvation rather than dehydration. Yellow-footed Rock-Wallabies *Petrogale xanthopus* were far less affected.

Bilton and Croft (2004) found that drought influences the reproductive capacity of female Red Kangaroos. Females experiencing two droughts in a lifetime did not live as long and weaned fewer offspring and grandoffspring (from their daughters) than did females who only experienced one drought.

Munn and Dawson (2004) found that among Red Kangaroos, young-at-foot and young weaned juveniles suffered higher mortalities during drought than adults because they need higher quality forage to sustain growth. Juveniles also need more water than adults for thermoregulation, and probably need to drink more often, exposing them to higher predation rates around waterholes and restricting their foraging distances from water.

Lee et al. (2004) counted roadkilled kangaroos near Broken Hill during and after the drought of 2001–2002. Drought reduced numbers of Red Kangaroos by 48% and Greys (Eastern and Western) by 73% between June 2002 and June 2003. Kangaroos often congregate along roads during drought because the vegetation remains greener. The mortality rate was 20.8 per month during drought and 2.6 per month afterwards, along a 21 km stretch a highway. For behavioural reasons, mortality rates were disproportionally high for Red Kangaroos and Euros, and low for Eastern and Western Grey Kangaroos, leading Lee et al. to suggest that road mortality could affect relative species composition after a drought. Male Euros are especially susceptible to road kills, and the population demographics of this species could also be affected. Nevertheless, there are probably compensatory mechanisms, such as the birth of more male offspring to females in good condition (Ashworth 1996).

McCullough and McCullough (2000) discussed the severe drought of 1982, when many kangaroos died at Yathong Nature reserve in western New South Wales. Kangaroo skeletons remained abundant around water tanks three years later. They considered that Feral Goats at Yathong competed with kangaroos only during droughts, when goats removed the shrubby vegetation that kangaroos turn to as emergency food.

Holden and Mutze (2002) found that foxes ate more kangaroo meat during the winter in 1998, and attributed this to drought and wet weather killing many macropods.

Buffenstein et al. (2001) assessed the dought tolerance of macropods by measuring their mean corpuscular fragility (MCF), which reflects their capacity to cope with dehydration. The Eastern Grey Kangaroo, which has only recently expanded its range into the arid zone, is slightly less tolerant of dehydration than the Red Kangaroo, but both these species, and the Western Grey Kangaroo, are far more resilient to osmotic stresses than sheep. Dawson et al. (2000) found that Red Kangaroos can pant more effectively than Eastern Grey Kangaroos, an advantage during hot dry conditions.

Red Kangaroos have previously been considered to be largely sedentary (Newsome 1965), and although long-distance movements are occasionally been recorded, these have often been considered an exceptional response to drought. But Pople et al. (submitted a) analysed long-term survey data in South Australia and found large population fluctuations, often in response to rainfall, suggesting that Red Kangaroos do undertake large-scale movements to reach better feed. Western Grey Kangaroos did not respond in the same way, and appear to be more sedentary.

Overview

Droughts greatly reduce kangaroo numbers, with big drops recorded during drought; they eventually recover, even with continued harvesting (see section 3.6). Red Kangaroos may undertake large-scale movements to reach better feed. Females that endure two droughts produce fewer young and do not live as long. Young Red Kangaroos are more susceptible to drought than adults.

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3.2.2 Disease – parasites and pathogens

Olsen and Braysher (2000) reviewed parasites and pathogens of kangaroos and found that although episodic outbreaks occasionally decimate populations, disease is not an important agent of mortality. Epidemics have caused significant short-term reductions in numbers in particular areas but these populations recovered rapidly.

In the five years since their review, much has been learned about macropod pathogens and parasites, but without altering the conclusion that disease is unimportant as an agent of mortality. Most of the recent studies were conducted on relatively healthy rather than dying kangaroos, and focused on the taxonomy, evolution or life history of parasites, or addressed human and livestock health concerns.

Lame kangaroos living near an aluminium smelter near Portland, Victoria, that emitted airborne fluoride, were found to be suffering from chronic fluoride poisoning (fluorosis), inducing lameness (Clarke 2003). They had lesions on their bones and teeth that were roughened, dull and stained. Kangaroos appear to be more sensitive to chronic fluoride poisoning than cattle.

Bird et al. (2002) investigated the oral health of six healthy Eastern Grey Kangaroos and another 84 marsupials, finding that all the kangaroos had slightly inflamed gingival margins, all bled at the site of plaque collection, and all had calculus and black stains on their teeth. Black-pigmented bacteria were cultivated from their plaque belonging mainly to *Porphyromonas gingivalis*-like species but also to *Prevotella intermedia/nigrescens* strains. Black-pigmented bacteria were isolated more frequently from macropods than from the other marsupials leading Bird et al. to suggest that *P. gingivalis*-like organisms may contribute to the expression of lumpy jaw, a sometimes-fatal disease that often afflicts macropods, although the bacterium *Fusobacterium necrophorum* is the main causative agent.

Bird et al. note that in captive macropods disease of the oral cavity is the most common cause of death. They noted recent reports of Eastern Grey Kangaroos in captivity with ‘symptoms of severe periodontal disease…such as inflamed gingiva, loose and missing teeth, leading to physical wasting and euthanasia’.

The cyst-forming tapeworm *Echinococcus granulosus* entered Australia on sheep and now infects kangaroos as intermediate hosts; in severe cases killing the host (Johnson et al. 1998), or rendering it more susceptible to predation by forming debilitating cysts in the lungs (Jenkins and Macpherson 2003). Jenkins (2005), Jenkins and Macpherson (2003), and Jenkins and Morris (2003) considered *Echinococcus* and macropods, mainly with a focus upon the impacts on humans and livestock. *Echinococcus* is most likely to attack macropods in areas supporting wild Dingoes or feral dogs, which serve as final hosts for the parasite. Foxes can also serve as final hosts but they usually carry much smaller worm loads and are not considered major carriers (Jenkins and Macpherson 2003). Swamp Wallabies *Wallabia bicolor* are important intermediate hosts in eastern Australia because they are favoured Dingo prey (Jenkins and Macpherson 2003). Hu et al. (2005) looked at genetic variation in the tapeworm genus *Progamotaenia*, which afflicts Euros and Western Grey Kangaroos.

Rose et al. (2004) reported cutaneous leishmaniasis in Red Kangaroos held in captivity near Darwin. Leishmaniasis is a serious disease of humans and wildlife, transmitted by a protozoan parasite, found widely overseas, but not previously recorded from Australia as a result of local transmission. The *Leishmania* species isolated from the kangaroos could not be identified and appears to be a novel species. Nothing is known about its occurrence in the wild or significance to wild kangaroos, although the captive infected kangaroos were suffering from chronic erupting lesions on the ears, limbs and tails.

Cryptosporidium is a protozoan parasite that can cause diarrhoea in humans and other mammals. Davies et al, (2003), Power et al. (2003) and Power et al. (2004) documented *Cryptospodium* oocysts in the faeces of Eastern Grey Kangaroos, but shed no light on the significance of this parasite to the well-being of kangaroo populations.

Portas et al. (2005) recorded serious blood infection by the nematode *Pelecitus roemeri* in a captive Western Grey Kangaroo. Co-evolution between macropods and parasitic nematodes was considered by Beveridge and Chilton (2001). Chilton et al. (2002) described a new nematode, *Papillostrongylus barbatus* from the Red Kangaroo, Eastern Grey Kangaroo and Euro, and Chilton et al. (2004) studied the genetics of the parasitic nematode, *Cloacina obtusa*, found in the stomachs of Eastern and Western Grey Kangaroos. Webley et al. (2004) documented the endoparasitic fauna of healthy Western Grey Kangaroos on Kangaroo Island.

The life history of the common marsupial tick *Ixodes tasmani*, which infects macropods, was studied by Murdock and Spratt (2006), although they conducted their study using Common Brushtail Possums as hosts.

Two studies were conducted into choroid blindness, which is caused by a biting-insect borne virus. Hooper et al. (1999) examined kangaroos blinded in a major epidemic in south-eastern Australia in 1994 and 1995, and detected orbiviruses of the Wallal and Warrego serogroups. Redacliff et al. (1999) reproduced the condition of chorioretinitis in a sample of three of eight kangaroos by inoculating them with preparations containing Wallal virus.

A survey in coastal central Queensland by Frances et al. (2004) found that 24 out of a sample of 70 Eastern Grey Kangaroos carried antibodies for Ross River Virus, and 36 had antibodies for Barmah Forest virus. Kangaroos were the main source of blood meals for mosquitoes in the area. Harley et al. (2001) summarising previous studies, found that 40–100% of Eastern Grey Kangaroos have antibodies to RRV. Macropods are the main carrier of this disease. No evidence of harm to macropods was presented.

Johansen et al. (2005) found antibodies to Trubanam virus in 21.1% of Western Grey Kangaroos sampled in Western Australia. No antibodies were found to Barmah Forest Virus (believed to be a recent arrival, or reintroduction, into Western Australia) or Sindbis Virus.

Overview

Recently obtained findings show that: black-pigmented bacteria occur frequency in macropod mouths and may contribute to lumpy jaw, a sometimes fatal disease; the cyst-forming tapeworm *Echinococcus granulosus* commonly infect macropods in areas where wild dogs or Dingoes are common, sometimes killing the kangaroos; choroid blindness, which sometimes afflicts kangaroos in major epidemics, is probably spread by Wallal and perhaps Warrego virus; and kangaroos are very susceptible to chronic fluoride poisoning (fluorosis) caused by smelter discharges, resulting in lameness. None of these findings alters the conclusion that diseases are not important agents of mortality in kangaroos in the long-term.

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3.2.3 Predation

<u>Specific issue</u> – Predation of kangaroos by Dingoes or any other predator, historical and current.

Olsen and Braysher (2000) listed Dingoes, humans, Wedge-tailed Eagles and foxes as predators of kangaroos. Dingoes and humans are the major predators, although Wedge-tailed Eagles can be significant predators, especially of young-at-foot. Foxes often feed on macropod carrion, and sometimes attack macropods as large as Euros, and young-at-foot Eastern Grey Kangaroos. Olsen and Braysher concluded that predators, notably Dingoes, can almost certainly limit kangaroo populations, but noted a lack of conclusive evidence to show this.

New information about predation on kangaroos has come from several studies, including a major study of kangaroos at Yathong Nature Reserve (McCullough and McCullough 2000).

Fleming et al. (2001) reviewed various studies which suggest that Dingoes exercise some population control over macropods (Caughley et al. 1980; Corbett and Fleming 1996b; Corbett and Newsome 1987; Fleming 1996; Newsome et al. 1983a; Pople et al. 2000; Robertshaw and Harden 1986; Thomson 1992). Although the examples provide evidence that impacts on macropod populations occur, Fleming et al. (2001) concluded that experimental studies were needed to determine if there was a regulatory effect, because alternative explanations could be found for some of the observed changes in prey abundance. Newsome et al. (2001) revisited one of these studies, that of Caughley et al. (1980), and did propose an alternative explanation. Caughley et al. had counted far more Red Kangaroos in New South Wales than in South Australia, and attributed this to the lack of Dingoes east of the Dingo Barrier Fence that divides the two states. In a detailed field survey, Newsome et al. found that the preferred feeding habitats of Red Kangaroos—open plains and floodouts—were 17.4 times more prevalent in New South Wales than in South Australia, providing a sufficient explanation for the higher kangaroo numbers. Newsome et al. do not dispute that Dingoes can regulate kangaroo numbers in some situations, but discounted the Caughley et al. study as evidence for this. Pople and Page (2001) weighed into this debate, noting that in northern South Australia, where kangaroos are scarce (Pople et al. 2000), the environment on both sides of the fence is the same, leading them to suggest that ‘Dingoes can regulate and not just limit Red Kangaroo populations’. They found further evidence for this conclusion in unpublished data showing that kangaroo numbers rise after Dingo control, and also drew upon Corbett and Newsome (1987), Newsome (1994), and Thomson (1992).

Aboriginal hunting of macropods was addressed by Bowman et al. (2001), who were told independently by four Aboriginal men in Arnhem Land that landscape fires were lit mainly to facilitate kangaroo hunting, by creating green pick, leading Bowman (2003) to conclude that ‘fire-stick farming’ should be called ‘fire-stick ranching’. Yibarbuk et al. (2001), also working in Arnhem Land, provided the first evidence that Aboriginal landscape burning increases kangaroo density. But Auty (2004) declared that neither Aborigines nor Dingoes were effective predators of kangaroos, although his conclusion was based only upon a selective reading of the historical literature. Auty disputes the prevailing view that kangaroo numbers have increased since white settlement.

McCullough and McCullough (2000) studied Eastern Grey, Western Grey and Red Kangaroos at Yathong Nature Reserve in western New South Wales for 13 months and concluded that predation was negligible and only relevant, if at all, for newly emerged pouch young (Dingoes are absent from this reserve). They twice saw wedge-tailed eagles swooping towards small young-at-foot kangaroos, but no contact was made. The kangaroo mothers ‘showed a surprising lack of alertness to these attacks’, behaving in a manner that was more curious than alarmed or protective, leading McCullough and McCullough to conclude that eagle attacks are so rare that there has been no selection for a defensive response.

Nevertheless, macropods make up 0–67% by number of items collected in and around Wedge-tailed Eagle nests in 15 studies at various times in various States (summarized in Olsen 2005), but an unknown proportion would have been taken as carrion. In the largest study, of 2703 food items collected from nests in western New South Wales, 14% were macropods (Sharp et al. 2002). The eagles can hunt cooperatively to kill adult kangaroos (e.g., Woodland 1998), but probably more often take smaller individuals.

Foxes were ‘extremely abundant’ at Yathong but they preyed mainly on rabbits, and no evidence was obtained of predation on kangaroos, although scavenging of dead kangaroos occurred. Mother kangaroos with young did not seem concerned when foxes were present.

Holden and Mutze (2002) studied the impact of rabbit haemorrhagic disease on introduced predators (foxes and cats) in the Flinders Ranges, South Australia. They found that when foxes had few rabbits to prey upon they ate more invertebrates and carrion but, judging from stomach remains, did not attack macropods at all. Kangaroo carcases (Red Kangaroo and Euro) left by kangaroo shooters were a significant food, and these could be identified in fox stomachs by their discolouration and presence of maggots. In winter 1998, 36% of fox stomachs contained kangaroo remains, a high level attributed to a drought and cold wet weather killing many macropods.

By contrast, Wilson and Wolrige (2000) found that large mammals, especially Eastern Grey Kangaroos and Swamp Wallabies *Wallabia bicolor*, made up 25% of fox diet on the Otway Ranges in Victoria. Following on from the study of Banks et al. (2000), which recorded macropod predation in Namadgi National Park near Canberra, Banks (2001) found that Eastern Grey Kangaroos in this park more often fed away from shelter, and more often fed alone, at sites where foxes had been removed than at sites where foxes remained. Foxes probably prey more upon macropods in habitats with thick vegetation.

Molsher et al. (2000) analysed the stomach contents of 225 foxes in agricultural land in central New South Wales and found that Eastern Grey Kangaroo remains made up 37.6% of stomach contents by occurrence and 16.4% by volume. Molsher et al. attributed all of this—probably incorrectly—to scavenged carrion. In central Queensland, Lapidge and Henshall (2001) found kangaroo remains in 21% of foxes examined, attributing all of this to carrion because foxes were often seen around carrion at night. They were also preying occasionally on female Yellow-footed Rock-wallabies *Petrogale xanthopus* with young.

Overview

There seems little doubt that Dingoes can limit kangaroo populations, but there is still no conclusive proof of a regulatory effect. Conclusive evidence requires monitoring of the effect of experimental removal of Dingoes. Other predators do not appear to exert much influence on the four harvested species of kangaroo.

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3.2.4 Habitat loss and modification

Olsen and Braysher (2000) concluded that kangaroos have largely benefited from habitat modification. Kangaroo numbers have increased because areas of grassland have expanded. Their numbers have, however, generally declined wherever there is intensive agriculture, urbanisation, or extensive clearing.

Pople et al. (submitted b) used aerial survey data collected over the past 30 years to conclude that Red Kangaroos have expanded their range eastwards into more mesic areas in response to land clearing; that Western Grey Kangaroos have spread northwards in South Australia into more arid areas, perhaps benefiting from artificial watering points; and Eastern Grey Kangaroos have spread westwards, probably benefiting in the same way. The correlation between Red Kangaroo numbers and land clearing was established by accessing the Statewide Landcover and Trees study in Queensland. Core ranges, where there are peak densities, remain similar to those in 1980–1982.

After studying kangaroo diet, Dawson et al. (2004) proposed that a shift in arid zone vegetation towards more grass and annual dicot forbs has been one factor in the westward expansion of the Eastern Grey Kangaroo, which is a grass specialist. The shift has been facilitated by tree clearing and overgrazing by sheep, leading to loss of chenopod shrublands.

Heywood et al. (2000) give case studies of properties where kangaroos are no longer a problem because the owners manage so that there is more tall rank grass, which livestock can handle but kangaroos avoid (kangaroos prefer short green feed). Several case studies attest to the production and biodiversity benefits of this strategy of increasing pasture biomass (increased perennial grasses), and always leaving some pasture cover.

Ramp (2005) suggests that where kangaroos shelter in remnant vegetation and feed in adjacent open farmland, fencing of remnants and planting with shrubs may be ways to discourage them.

Overview

Habitat modification may offer potential as a method for reducing kangaroo numbers. Recent survey evidence reinforces a common view that Eastern and Western Grey Kangaroos have spread westwards and northwards respectively, by exploiting farm dams and/or enhanced grazing opportunities, and that Red Kangaroos have spread eastwards following land clearing. Eastern Grey Kangaroos may have benefited as well from landscape changes producing more grasses and annual forbs. Hence, managing grazing so that periods/areas of short green grasses are minimized or lessened, and perennial grasses are encouraged, has considerable potential for limiting kangaroos numbers on properties.

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3.3 GENETIC IMPACT OF CULLING

Task 3 – Review the genetic impact of kangaroo culling.

3.3.1 Specific issue – Genetics – likely impact of harvesting, including an assessment of the 'worst case scenario', i.e. 20% of reds over 100 years (no unharvested areas)

There are concerns that commercial harvesting selectively removes individuals with certain traits from the population, which may eventually result in the loss of adaptive genotypes or genetic diversity, and a decline in evolutionary fitness (e.g., Croft 1999). Olsen and Braysher (2000) concluded that there was no evidence of real or potential genetic 'deterioration' at current rates of harvesting. Indications were that kangaroo numbers would have to be reduced to extremely low levels for genetic impacts to become significant and by then other impacts, such as demographic disruption, would have become overridingly important. Since 2000, several studies have directly addressed this issue via molecular study and predictive modelling.

Changes in body size due to selective harvesting have occurred in aquatic species (review by Ratner and Lande 2001), but these are organisms such as deep-water fish with slow recovery times (kangaroos recover rapidly after extreme reductions in populations of 50% or more). There is no evidence for body size selection among harvested terrestrial species although, as Pople (2004) points out, selective domestic breeding of livestock demonstrates the possibilities. Selection for animals with smaller 'trophies' (antlers and tusks) has been demonstrated theoretically by Hundertmark et al. (1993) and empirically Jachmann et al. (1995). These are organisms/populations harvested a much greater intensity than kangaroos and with more constrained geographical distributions.

Hale (2001, 2004) used allozymes and microsatellite loci in Red Kangaroos and Euros as indicators of genetic diversity. He compared harvested populations (some with harvest rates of nearly 30%) with unharvested populations and concluded that there was no difference in diversity. Tenhumberg et al. (2003) caution that longer time spans and an increase in harvesting across the landscape could alter this conclusion. They developed a population model to explore the genetic consequences of harvesting on Red Kangaroos. The model indicated that in a closed system harvesting could lead to genetic changes in the population, resulting in reduced size at maturity or a reduction in growth rate, for example (although these would not necessarily be harmful). However, when migration and dispersal was assumed, as would occur in a natural system, the gene frequency was predicted to be stable (Tenhumberg et al. 2002, 2004; Hacker et al. 2003, 2004; Hacker and McLeod 2003).

Nevertheless, the model suggested that gene frequency changes slowly, and hence change would be difficult to detect. Moreover, the current situation in which large areas go unharvested, providing dispersers and allowing gene flow, could change. The Tenhumberg et al. (2003, 2004) model also points to the value of these harvest refugia. The idea of refuges where there is no harvesting has been developed to reduce perceived threats to the genetic composition of populations. Knowledge on the optimum size, number, spacing and connectivity between refuges is lacking, and the means of implementation (incentive schemes etc., e.g., Hacker et al. 2004) of a formal system of refuges is problematic. In any case, such areas exist already in National Parks, isolated/inaccessible areas, areas of low kangaroo density (‘economic refugia’), farms and other areas where harvesting is not pursued (Hacker et al. 2003).

Hale (2004) reported differences in genetic population structure between the four harvested species, with more structure in the Euro population (with small home ranges) than Red Kangaroos, and Grey Kangaroos are expected to fall between the two. However, all these species’ geographic ranges are large, and gene flow may occur across the entire continental range of the Red Kangaroo, such that a small proportion of the population is exposed to harvesting and genetic interchange occurs over large distances.

Hale (2004) also argued that selection by harvesters for large animals was not strong, heritability is low when there is large variance in phenotype associated with environmental effects, which seems to be the case with size at least in the Red Kangaroo (Tenhumberg et al. 2000, 2004), and fitness traits (including size) are inherited from both sexes, whereas bias in harvesting is towards males. Hale (2001, 2004) noted several behavioural and life history traits that make genetic costs from size-selective harvesting unlikely. Lastly, Bilton and Croft (2004) found that environmental conditions were of overriding importance in determining the lifetime reproductive success of female Red Kangaroos, including the production of grandoffspring (a measure of fitness), although they did not account for body size.

Overview

There is an absence of theoretical, empirical and modelled evidence of genetic impacts at current levels of harvesting. The low risk of genetic effects occurring argues against costly interventions, such as the formalized creation of harvest refugia, on genetic grounds, but also indicates that the present inadvertent system of refugia is adequate and should be protected/maintained.

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3.4 GRAZING MANAGEMENT THEORIES

Task 4 – Review the scientific support for and practical application of the various grazing management theories that may be used as the basis for kangaroo management, e.g., total grazing pressure and carrying capacity.

Grazing management practices

Fisher at al. (2004, 2005) list the following commonly used grazing strategies in pastoral lands (and their associated management issues):

- Set stocking: stock levels set at a conservative rate (forced restocking one year in ten);
- Seasonal tracking: stock numbers adjusted according to seasonal conditions and forage;
- Set utilisation: mainly practiced in northern Australia; stock numbers set according forage levels at the end of each growing season;
- Rotational grazing and spelling: take many forms (e.g., regular spelling/grazing on a calendar basis, or on the number of days) and involve multiple paddock systems;
- Opportunistic: resting/grazing according to conditions (sometimes from necessity, e.g., water hole drying up); and
- Tactical grazing: adjusting stock numbers in accordance with seasonal and plant growth conditions; mainly managing perennial plants so that they persist.

Much of the commercial zone is in the rangelands where the most common grazing strategy is set stocking, which is the only practical method where properties have a few large paddocks and labour is costly or scarce (Hodgkinson et al. 2000). Tactical grazing, which involves moving livestock between paddocks (or off property) in response to seasonal conditions, allowing for periods of rest so that perennials can seed, is less common. The 'Holistic Resource Management' system includes flexible rotational grazing but also takes into account such factors as human, biological and financial resources.

A resting phase of a sufficient time improves the amount of desirable perennials, improves water absorption and drought hardiness, and lessens erosion. Tactical resting, for example, when suitable rain had fallen to allow grasses to seed, increased the number of tussocks per

m^2 over normal grazing (Hogkinson 2000). Dorrough et al. (2004) state that ‘intermittent grazing strategies are more likely to have biodiversity and conservation benefits’, but they note that empirical data on the different strategies in south-eastern Australia is sparse.

Heywood et al. (2000) give two case studies of properties where kangaroos are no longer perceived as a problem because the owners manage so that there is more tall rank grass, which livestock can handle but kangaroos avoid (kangaroos prefer short green feed).

None of these practices directly account for kangaroos or other grazers or allow for their strategic management. However, some practices such as tactical grazing, which is often guided by a measure of the height of perennial grasses, could be integrated with management of TGP (using the system developed by Campbell and Hacker (2000), for example see section 3.3.1). Nontheless, this is a paddock-by-paddock approach that is inappropriate for broad-scale management of kangaroos.

Recently researchers have been recommending landscape thresholds to guide grazing management (see section 3.4.2). These may have more success because they provide relatively simple ‘rules’ but may not prove so easy to apply and monitor.

Briggs (2001) argues that mismatches between the scale of biological processes and units of land management hamper the conservation of biodiversity. The same could be said of kangaroo management in that the scale of management required, and the demographic and other biological processes involved, extend over many, many properties and harvest areas.

There have been few recent surveys of farmers’ perceptions and attitudes (Brookman 2000), but they are central to the success of any grazing management system. The few studies indicate that there are major economic, time, labour and knowledge barriers to the adoption of management practices that utilise TGP or any other data-driven system.

Of rangeland grazing management systems Fisher et al. (2005, p. 13) stated ‘Those in common use have usually developed through practical experience over many years…in fact in many regions it is rare for insights from scientific studies to be incorporated into grazing management.’

In one survey, both cattle farmers and scientists agreed that excessive stocking rates, limited information and knowledge and adverse weather were the main causes of land degradation, and that present grazing practices were unlikely to be sustainable (McLeod and Taylor 1994). Kangaroos were not deemed to be of prime importance.

In another study, farmers said they were generally constrained by financial considerations, but also indicated they had some confusion about the technical aspects of land degradation processes and that adoption of appropriate land management practices were generally poor, but improving (Vanclay 1997).

O'Keeffe and Fletcher (1998) identified two different sets of landholder outlooks: one treated the farm as a family enterprise (business), the other as an occupation driven by income. The first group were more likely to be flexible and proactive in their management of grazing, the second tended to be reactive and set in their ways.

Overview

At present there is no integration of commercial harvesting with grazing practices, and limited practical application by rangeland managers of grazing management theory. Except at a very local level, the harvest isn't strategically targeted at areas of need. There appear to be several social and economic barriers to broad-scale integration of grazing practices and the commercial harvest.

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3.4.1 Specific issue – Total Grazing Pressure theory and practice for domestic grazing animals and application in kangaroo management, e.g., manage kangaroos as one component of TGP.

Olsen and Braysher (2000) concluded that Total Grazing Pressure (TGP) theory is a useful concept. Basing management decisions on an impact index such as TGP is good management practice because it focuses on the desired outcome, that is, the amelioration or avoidance of damage. However, TGP is complex and dynamic, with lags between pasture growth and some herbivore population responses, and feedback loops (Hacker et al. 2003). Drawbacks include that such an approach treats kangaroos solely as competitors without regard for their conservation, intrinsic value or value as a resource. Similarly, it manages for forage volume and not for plant species conservation and it doesn’t account for selective grazing by the different grazers or for inconsistent plant responses to grazing (such as those detected by Vesk and Westoby 2001). Kangaroos apparently are selective according to habitat but not patch (Ramp and Coulson 2002, 2004). In the rangelands vegetation growth varies mainly with environmental factors such as rainfall, but also offtake by herbivores and biomass of the vegetation itself, so that at any point in time vegetation biomass will rarely be systematically related to herbivore density. Hence, TGP-based management is unreliable in fluctuating environments because change can happen so fast.

Nevertheless, Olsen and Braysher (2000) concluded that management of TGP might have some use for the management of livestock on individual properties because stock are under the graziers’ control and can be sold, moved etc. Similarly, it has some application in other ‘simple’ or controlled systems, such as National Parks.

Since the last review, a field procedure has been developed for the estimation of TGP (Fisher et al. 2000). It involves estimating the relative abundance of sheep and kangaroos based on dung counts (Constable et al. 2000). Campbell and Hacker (2000) adapted the method to estimate the short-term stocking rate of paddocks. Their methodology may overestimate the contribution of kangaroos to TGP because they use a DSE of 0.75, which according to Grigg (2002) and Dawson and Munn (in press) is likely to be up to three times the actual DSE. Presented on paper the method probably appears complex to the average grazier; a computer program would make it more user-friendly. It also needs to be fully trialled.

Harvesting can change the age and size structure of populations, with potential consequences for TGP. In their model of kangaroo harvesting scenarios Hacker et al. (2003) included age and sex structure which has improved understanding of the relationship between forage availability, consumption by kangaroos and quantification of grazing pressure. They modeled several scenarios and concluded that seasonal variation, not kangaroo density, was of overriding importance in determining biomass production and total dry standing matter.

Hacker et al. (2003) suggest that their model may have some large-scale application through integration with the Aussie GRASS spatial computer framework, which is being used to estimate pasture growth, total dry standing matter, and other variables nationally, using the grass production model GRASP. Currently, meteorological data can be updated monthly but the calculation of consumption by livestock and non-domestic herbivores is based on inadequate data. GRASP has been developed into the PaddockGRASP system which is currently being trialled in Queensland and New South Wales (in conjunction with New South Wales Department of Primary Industries) (Timmers 2005).

PaddockGRASP is a ‘computer modelling tool that allows managers to calculate stock carrying capacities and economic yields on their properties.’ It allows for assessment of land condition across entire properties and takes into account a range of resources including different soil types, land systems, terrain, tree cover, pasture types, watering points and existing land degradation. The potential to integrate the latest kangaroo population models does not appear to have been taken up. One interpretation of this is that kangaroos are not a major consideration in grazing management.

Indeed, there is general agreement among scientists and graziers that kangaroos are seldom a problem to grazing enterprises unless forage conditions are poor, and their overall impact on TGP may be negligible (see sections 3.4.3 and 3.4.4). Except during severe drought, graziers rarely use culling to control total grazing pressure and then it is done in a non-strategic way.

Hacker and McLeod (2003, p. 31) state that: ‘Pastoralists often regard kangaroos as an unmanageable and damaging part of total grazing pressure on their properties…Yet few individuals actively strive to reduce kangaroo numbers beyond permitting access by a licensed shooter, and many examples may be cited of rangeland maintained in good condition despite the presence of essentially uncontrolled kangaroos.' Not least, stocking rate decisions are generally unrelated to the presence of kangaroos.

Fisher at al. (2004, 2005) discuss the various options for managing grazing pressure for sustainable use in the rangelands, and management issues. They conclude that there are limited options for managing TGP in the rangelands compared with the intensive use zone because of issues of scale, economics and unpredictable climate, instead they recommend some basic thresholds for landuse.

Fisher et al. (2005, p. 24) conclude: 'Options for managing total grazing pressure in the rangelands are limited by a range of factors operating at several levels'; these include climate, scale, labour availability, control of stock and pests, and economic realities. They list several barriers to better management at institutional, regional and individual levels, including poor techniques for monitoring TGP effects, inadequate and extremely costly techniques for managing TPG (including the cost of controlling animals).

There are also socio-economic constraints. 'Fifteen years ago it was proposed that the conversion of kangaroos from a pest to an economically valuable resource would allow graziers to reduce the numbers of domestic stock and thereby lower total grazing pressure. Since then little progress towards this goal has been achieved' (Chapman 2003). Chapman further concluded that graziers are not significant participants in the kangaroo harvesting industry. Graziers cited low prices and administrative, legal and institutional impediments. The latter three revolved around resource ownership issues and competition in the kangaroo harvesting industry. Chapman argued that until these issues are resolved graziers will stay largely uninvolved in the kangaroo industry. They considered that the harvesting of feral goats was much less fraught. Chapman believed that in South Australia graziers are better integrated into the industry by the issue of permits to them which can be traded with licensed processors, however there were still some problems to be resolved and improvement to TPG had yet to be realised.

Overview

As a broad-scale kangaroo harvesting management tool, the application of TGP theory is questionable. Kangaroos seem to contribute little to TGP except under conditions of very poor forage. The current KMP is not directed at damage mitigation, rather it is quota-based. Hence, TGP theory has little direct relevance.

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3.4.2 Specific issue – Carrying capacity theory and practice for domestic grazing animals and application in kangaroo management, e.g., set the ‘desired’ number of kangaroos (or an upper limit) based on carrying capacity.

Ecological carrying capacity (K) is that density attained when the population reaches an equilibrium with its resources, natural predators and competitors and in the absence of human induced mortality. Economic carrying capacity (l) is the population level that allows the maximum offtake for culling or cropping and is well below the ecological carrying capacity. Olsen and Braysher (2000) concluded that the concept of carrying capacity is appealing but its interpretation and application is problematic even for stable environments. The unpredictable nature of the climate in the harvesting zone (McLeod 1997), and the impracticality if not impossibility of estimating carrying capacity in a complex ecological system, make the concept impractical and too static for kangaroo management.

There does not appear to have been any substantial advancement in understanding or application of the concept since the past review. Nevertheless, the term is often used loosely, for example, when States recommend the number of animals per unit area for different land systems (but these recommended ‘carrying capacities’ do not take into account the number of other grazers, nor provide for extremes of climate etc). For example, Davies (2005) lists DSEs ranging from 3.8 (6–9 month calf) to 15 (fast-growing yearling), to allow estimation of the carrying capacity of beef enterprises.

In some respects the current KMP operates according to the Limits of Acceptable Change (LAC) process, which is used mostly in recreational settings such as National Parks in the USA but has potential for wider application (e.g., McLeod Institute 2002).

LAC may be worth further investigation. It is an attempt to overcome some of the limitations of carrying capacity practice by focusing on outcomes (resources or conditions to be maintained) rather than activities; recognising that any use causes an impact and that what constitutes an unacceptable change is a value judgement; and providing a framework for defensible value judgements. LAC is:

- Consensus focused – involving all the stakeholders
- Pragmatic – it acknowledges that certain human activities will continue
- Principled – it establishes limits based on social and ecological factors

- Transparent – it selects measures and indicators that focus on thresholds
- Action-oriented – it drives towards a management plan or similar (Macleod 2002).

Several recent studies recommend landscape thresholds for grazing management (e.g., Anon. 2001, Green and MacLeod 2002; MacLeod 2002; Fisher et al. 2004), which could be integrated into an LAC approach.

These have theoretical underpinnings in the 'state-transition' or 'state-threshold' models, which many regard as the most representative theoretical approaches to the understanding of rangeland grazing systems (e.g., Sullivan and Rohde 2002; Cingolani et al. 2004).

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3.4.3 Specific issue – Sheep compared to kangaroos – ecological and economic impact on: native vegetation and pastures; wool production; and the economics of properties generally (including fence damage and use of waters).

Olsen and Braysher (2000) noted that competition between sheep and macropods is less than is commonly supposed: macropods prefer grass, whereas sheep have a more varied diet of which grass is only occasionally the main component. Competition is only considered substantial when kangaroo numbers are high and pastures poor.

In the five years since their review, one publication presents important new information about sheep-kangaroo competition. Grigg (2002) casts serious doubt on the common assumption that kangaroos have 70% of the food requirements of sheep. The quantity of pasture consumed by one kangaroo in one year is commonly expressed as a dry sheep equivalent (DSE) of 0.7.

Grigg (2002) noted that this figure was derived from the resting metabolism of mammals when it should have been based upon the field metabolic rate (FMR), which considers the full metabolic requirements of an animal. Tests of carbon dioxide excretion show that the FMR of eutherians such as sheep is 3–3.5 times that of marsupials, producing a DSE of 0.29–0.33, not 0.7. Marsupials use food far more efficiently than placentals, for reasons that are not understood.

Grigg also noted that estimates of competition do not take into account the variable sizes of wild kangaroos, but operate from the assumption that sheep and kangaroos weigh the same. Sheep are managed in relatively uniform flocks, but kangaroo populations, especially those that are harvested, contain many small individuals, and this further undermines the industry assumption that 1,000 kangaroos can be equated to 700 ‘dry’ sheep. Grigg suggested that a DSE of 0.2 would be a more realistic (but still conservative) figure. A more recent study of captive Red Kangaroos also suggested that current estimates are too high and that a DSE of about 0.48 was appropriate (Dawson and Munn, in press). Grigg called for more research into this topic. Red Kangaroos are unlikely to be representative of all the harvested species, hence estimates should be made for all four under field conditions.

Preliminary results of a study using Applying Faecal Near Infrared Spectroscopy suggest that Eastern Grey Kangaroos eat mostly just high quality ‘green’ feed, and start to lose body condition when sufficient ‘green’ feed is unavailable; age, sex and forestomach parasites also influence body condition responses but pouch young do not (Billing 2005). The technique has potential to improve estimates of kangaroo DSE.

Witte (2002) demonstrated that at Fowler’s Gap association with sheep varied between kangaroo species: Eastern Grey Kangaroos overlapped little with sheep, abundant Red Kangaroos were relatively less numerous where sheep grazed than where they didn’t; and Western Grey Kangaroos and Euros showed the greatest overlap with sheep.

Dawson et al. (2004) confirmed that Eastern Grey and Red Kangaroos are dietary specialists, favouring grass, with ‘similar narrow dietary niche breadths’. But Red Kangaroos include more dicot forbs and malvaceous shrubs in their diet. Sheep, by heavily grazing and eliminating chenopod shrublands in the rangelands, have promoted their replacement by grasses and annual forbs, suiting kangaroos.

Pople and McLeod (2000) reviewed previous studies of competition between sheep and kangaroos and concluded, as did Olsen and Braysher (2000), that competition seldom occurs, either because food is not limiting, or because food choices or feeding sites differ. When competition does occur, sheep have the advantage, because their diet is more catholic and farmers manage to their advantage. Kangaroos, however, are more mobile.

At Fowler’s Gap, Witte (2002) reported a positive relationship between the biomass of both total pasture and green pasture and kangaroo density. In a survey of kangaroo distribution in the rangelands of South Australia, Jonzen et al. (2005) were surprised to find a positive correlation between kangaroo numbers and livestock numbers. They proposed that livestock presence was a surrogate for resource availability, although there was no evident correlation between rainfall and kangaroos. Several studies in the previous review also reported positive relationship between stocking rate and kangaroo density. These findings support the conclusion that kangaroos and livestock do not compete strongly for food (at least in the rangelands), that resource availability drives the grazing system, and that mixed species grazing regimes are more productive and ecologically sound.

Kangaroos have lower water needs than sheep, will drink water that is unacceptable to sheep and with their longer snouts and different mode of drinking can reach water inaccessible to sheep (Croft 1985; Croft 2005). A Red Kangaroo needs an average of 1 litre daily and a Grey Kangaroo 1.75 litres, some obtained from food; this compares with 10 litres for a sheep under average conditions, which doubles in the hottest weather (Hume 1999).

If the trend towards declining sheep numbers nationally continues (Figure 2), perhaps ground cover will improve and the perceived conflict between kangaroos and sheep will lessen.

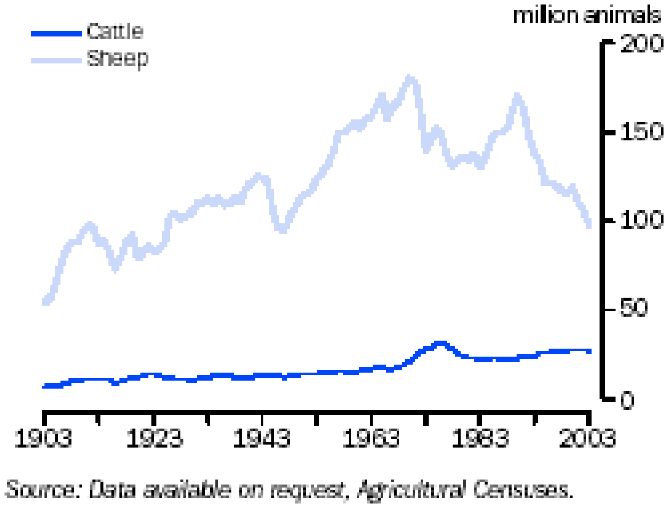

Figure 1. Sheep and cattle numbers Australia-wide. Source: *1370.0 - Measures of Australia's Progress*, Australian Bureau of Statistics, 2004.

Impact on native vegetation and pastures

Olsen and Braysher (2000) concluded that sheep and kangaroos can both have a serious impact on vegetation communities, but the impact of sheep is far greater.

During the current review period, several studies looked at grazing impacts, but none of them directly compared the impacts of sheep and kangaroos operating in isolation, although differences in impacts can be inferred from several studies.

Allcock and Hik (2004) created enclosures at Burrendong Dam, central New South Wales, where Eastern Grey Kangaroos are the major macropod but Euros and Swamp Wallabies also occur. The enclosures variously excluded livestock (both sheep and cattle), or livestock plus kangaroos, or all herbivores (livestock, kangaroos and rabbits). The results showed that all herbivores reduced survival rates of seedling Kangaroo Grass *Themeda australis* (also known as *T. triandra*), although livestock and macropods had the greatest impact. Kangaroos destroyed the most Kangaroo Grass seedlings in woodland, but not in nearby grassland quadrats, presumably reflecting their preference for proximity to cover. White Box *Eucalyptus albens* seedlings suffered the most from livestock and macropods, especially livestock. All herbivores reduced survival rates of seedling White Cypress Pine *Callitris glaucophylla*, with rabbits and livestock having the greatest impact. Harris and Lamb (2004) discuss the historical impact of rabbits and livestock on White Cypress Pine regeneration.

In the Mulga lands of south-western Queensland, Page and Beeton (2000) compared grass growth in three situations: a grazing property with (mainly) sheep, plus kangaroos and feral goats; Currawinya National Park, with kangaroos and feral goats only; and ungrazed exclosures. In each of three habitats—sandplain Mulga, dunefield, and wooded alluvial—sites with kangaroos and goats did not carry much more grass than sites with sheep as well. Kangaroos outnumbered goats in each habitat.

Also in the Mulga Lands of southwestern Queensland, Cowley (2001) recorded a massive increase in native woody weed growth when sheep were removed from a paddock but kangaroos remained.

Spooner et al. (2002) assessed 47 patches of remnant grassy woodlands in southern New South Wales fenced by Greening Australia 2-4 years ago to exclude livestock. By pairing them with unfenced sites they could assess the impact of current grazing, which is mainly by sheep (I. Lunt pers. comm.). They found tree recruitment in 59% of fenced sites compared to 13% of unfenced sites. Fenced sites also had more perennial grasses, fewer annual weeds and less soil compaction. Few shrubs were regenerating anywhere. The fences did not exclude kangaroos and the differences can be attributed to livestock impacts and especially to sheep.

Prober et al. (2004) looked at grassy box woodlands in the wheat-sheep belt of New South Wales and found that livestock grazing shaped understorey composition at all sites. They stated: ‘Effects of grazing included a decline in shrub abundance and loss of a range of native perennials across all woodlands, changes to the dominant grasses and a considerable increase in exotic annuals in the east, and a decline in native grass diversity and increase in native annuals in the west.' Their study did not compare sheep and macropod grazing because many of the grazed sites would have supported kangaroos as well as sheep, and many of their ungrazed sites (which were cemeteries) may not have been grazed by macropods.

In the arid woodlands in South Australia, Landsberg et al. (2002) found 16 plant species that were scarcer in sheep paddocks than on ungrazed Aboriginal lands. Their grazed sites carried many kangaroos as well as sheep, and kangaroos were scarce on the Aboriginal lands, so the impacts of each could not be isolated, but Landsberg et al. attributed the vegetation differences to sheep. Fourteen of the plants are ground layer plants, such as daisies, and Landsberg et al. (2002) proposed that short-lived palatable plants that sprout after rain are especially vulnerable to grazing because sheep seek them out, even well away from dams, by relying on ephemeral water supplies.

Landsberg et al. (2003), working at various sites in arid Australia, studied understorey plant composition along a series of transects radiating out from watering points. A small proportion of plant species declined consistently with distance from water. The study did not separate the impacts of livestock (mainly sheep) and feral goats from those of kangaroos, but the transect points further from water were more likely to be grazed by feral goats and kangaroos than by sheep. The most remote transects were 7–15 km from water.

Sheep browsing reduced seed production by Bladder Saltbush *Atriplex vesicaria*, an important fodder plant in inland New South Wales (Hunt 2001). Kangaroos seldom eat saltbushes (Dawson et al. 2004). In South Australia, Heshmatti et al. (2002) found that some saltbush species were scarce near watering points, attributing this to sheep browsing. In central Queensland, the saltbush *Atriplex lindleyi* only occurred 2 km or more from a dam, which Lavery (2002) attributed to browsing by sheep, although feral goats were also present. At another dam, grasses and forbs increased with distance away from the water.

The foregoing applies to kangaroos in the traditional harvest area, the rangelands. There have been few studies of kangaroo grazing pressure, and no comparisons with sheep, in temperate agricultural lands (Coulson et al. 2000; Yazgin 2000 and in progess; Viggers and Hearn 2005).

A study of sheep grazing in Tasmania found that native plant diversity was greatest in paddocks that were spelled in spring (Leonard and Kirkpatrick 2004). Weed invasion was highest on sites that were not rested and/or had higher stocking rates, and at more eroded sites.

Pettit and Froend (2001) compared grazed and ungrazed plots in Jarrah woodland in Western Australia, and concluded that ‘natural regeneration is possible after the removal of livestock, with the return (within 6 years) of native species richness to levels similar to those found in ungrazed vegetation. Re-establishment of cover, however, appears to take longer’.

Meeson et al. (2002) compared the impacts of cattle and sheep on River Red Gum *Eucalptus camaldulensis* germination in inland New South Wales and found that sheep facilitate germination by suppressing the ants that prey heavily on eucalypt seeds. Macropods would not be expected to suppress these ants. River Red gums are failing to regenerate over large areas of inland New South Wales because there are fewer trees in the landscape to produce seed and fewer floods to promote regeneration. Re-establishment is most likely in sites where sheep graze beneath remnant trees.

Economic Impact

Olsen and Braysher (2003) concluded that kangaroos do not appear to impact greatly on wool production and that mixed grazing systems (cattle and kangaroos/sheep and kangaroos) tend to be most productive. Impacts are most likely where kangaroo numbers are high and pasture biomass low.

The revised dry sheep equivalent (DSE) of closer 0.2, proposed by Grigg (2002), and confirmed to be about 0.48 by Dawson and Munn (in press), adds further support to the argument that kangaroos do not impact greatly upon sheep production. It is widely believed that 100 kangaroos consume pasture that would support 70 sheep, when a more accurate figure may be 48 sheep. Grigg (2002) concluded that removal of kangaroos will not bring expected benefits to woolgrowers in part because kangaroos are a much smaller component of total grazing pressure than is generally assumed. The DSE estimate needs to be accurately determined for free-living kangaroos, as suggested by Grigg.

As Duncan (1972) pointed out, sheep numbers and wool production are rainfall driven, and declines in all three are correlated. Kangaroo numbers are similarly rainfall-driven, hence declines in all four are probably correlated, making kangaroo impacts difficult to tease out.

Several case studies demonstrated that conservative stocking rate improved pastures and wool production in the Mulga lands even in the presence of kangaroos (Heywood et al. 2000).

McLeod (2004) estimated that kangaroos cost the nation $7.46 million in sheep production loss, $8.12 million in cattle production loss and $11.9 million in loss of crops annually. Damage to fencing is estimated at $16.7 million, and to collision with vehicles $30 million. $2 million is spent on research for a total cost of $76.18 million. This is considerably less than $200 million of an earlier estimate (Sloane et al. 1988) despite the passage of two decades. McLeod notes that this is partly because of reduced estimates of kangaroo impacts on pasture, including ‘limited evidence of competition above the very low pasture biomass of 50–60 g/m^2’ (p. 56), below which the presence of kangaroos reduced the liveweight of sheep.

McLeod (2004) cited Marsupial Cooperative Research Centre estimates made in 2000 that kangaroos contribute to the Australian economy $200 million and 4,000 much needed jobs in rural areas from the commercial harvest and, with other unique wildlife, over $1.8 billion in inbound tourist expenditure and over 14, 000 jobs. Others also argue for the importance of kangaroos to wildlife tourism, which need not be compromised by harvesting (Croft 2000; Croft and Leiper 2001; Higginbottom et al. 2005).

Grigg (2002a,b and previously) has argued that the best way to reduce grazing pressure is to develop a high-price market for kangaroo and encourage a switch to kangaroo farming. Others have calculated that it would be unprofitable to run kangaroos rather than livestock (Hardman 1996) and point to social, practical and other barriers (Croft 2000, 2004) to farming kangaroos in the conventional sense and on a large scale. Further, Hacker et al.’s model (2003) indicated that 20–40% of properties could not be harvested economically and only very small areas can be economically harvested at kangaroo densities of less than $5/km^2$

(minimum densities for conservation in the Murray-Darling Basin are considered by Hacker et al. to be about 2/km^2).

Overview

Kangaroos and sheep have not been demonstrated to compete to any significant degree because of differences in diet and spatial use of pastures, except under very poor forage conditions. The numbers of both are driven by rainfall rather than interspecific interactions. Grigg (2002) cast serious doubt upon the common assumption that kangaroos have 70% of the food requirements of sheep (a DSE of 0.7), proposing that the correct figure may be 20% (a DSE of 0.2). Dawson and Munn (in press) have since improved the estimate, to 0.48 (48%) using captive animals. This decreases any likelihood of competition and economic loss associated with grazing by kangaroos, and suggests that predictions and estimates based on the old DSE estimates exaggerate kangaroo impacts. Various studies that compared vegetation growth in different situations (fenced/unfenced, grazed/ungrazed, and along gradients from watering points) reinforce the conclusion of earlier studies that sheep (and cattle) produce substantially and consistently greater changes to native vegetation than grazing by kangaroos. Mixed species grazing systems tend to be the most productive in the agricultural sense.

Kangaroos contribute to the economy via the harvest industry and tourism but these gains are seldom realized at the farm level.

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3.4.4 Specific issue – Ecological and economic benefits of fewer kangaroos where domestic sheep, cattle or goats continue to graze.

Olsen and Braysher (2000) concluded that the simplistic removal of kangaroos will not necessarily allow replacement with the equivalent in stock, because kangaroos and sheep have differing diets. Limited evidence suggests that mixed grazing regimes are more productive and ecologically sound. Recent studies do not alter those conclusions.

There have been no studies in the last five years that expressly considered the benefits of having fewer kangaroos where livestock graze. But the various studies reviewed in the previous section found that grazing by livestock has significantly more impact on vegetation than grazing by kangaroos, and this reinforces the argument that removing kangaroos does not necessarily allow for their replacement by livestock. For example, sheep will eat large quantities of saltbushes (chenopods) (Hunt 2001; Heshmatti et al. 2002; Lavery 2002; Dawson et al. 2004), a very important food resource, but one that kangaroos avoid (Dawson et al. 2004).

Hacker et al. (2003) modelled the commercial harvest and various other factors, setting various harvest rates between 10 and 90%. The results indicated that only small increases in mean standing dry matter, and the proportion of the time pasture biomass will be above 300 kg/ha, will be achieved by any of the management regimes modeled. These included maintaining kangaroos at densities of 3–5/sq km, creation of refugia, and various quota sharing scenarios. In any case, the models indicated that harvesting could not reduce kangaroos to this level nor sustain this level if other means were employed to achieve the reduction. The model also indicated that at maximum yields (about the current rate of harvest) a theoretical long-term increase of up to 25% in clean wool production in the Mulga lands might be expected, but perhaps less elsewhere. However, the authors cautioned that they had several reservations about inputs to the model that make this projected improved wool yield uncertain. In addition, they used a DSE of 0.75 for kangaroos, which is an overestimate (see Grigg 2002 and Dawson and Munn, in press).

Overview

Reviewing the few studies since 2000 that compare kangaroos and sheep, the most significant finding is that the widely held assumption that one kangaroo consumes 70% as much pasture as one sheep is an overestimate. Grigg (2002) proposed 20% as a more realistic figure but called for more research. Hence, considering the various studies discussed in sections 3.4.3, removal of kangaroos appears likely to provide negligible ecological and economic benefits, except perhaps very locally in dry conditions.

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3.4.5 Specific issue – Other herbivores including invertebrates and their role in the ecological processes impacted by grazing.

Olsen and Braysher (2000) listed various wild animals that compete with, or potentially compete with, kangaroos for food: rabbits, goats, termites, ants, and grasshoppers.

In the five years since their review, significant new information about competition has emerged. Of note is a major study of kangaroos undertaken at Yathong Nature Reserve in western New South Wales, several studies into the impact of rabbit haemorrhagic disease, and emerging evidence that suggests deer may become major competitors of kangaroos.

Emus were considered dry-season competitors of kangaroos by McCullough and McCullough (2000) at Yathong. When green feed was available Emus often grazed alongside kangaroos, apparently on the same foods, in aggregations of 20 or more. Competition did not occur at this time because food was superabundant. But during drier times, when food was limiting, Emus possibly competed with kangaroos for the sparse remaining food. Because they prefer open habitat, Emus would compete more with Red and Western Grey Kangaroos than with Eastern Grey Kangaroos, which prefer woodland. Emu densities varied from 1.5 to 0.1 Emus/ km^2, depending upon food abundance, with a mean density of 0.8 Emus/ km^2. The population size of Emus at Yathong was similar to that of Eastern Grey Kangaroos but well below that of Red and Western Grey Kangaroos. McCullough and McCullough concluded that 'Nevertheless, Emus were a significant grazer in the Yathong herbivore complex' with the potential for 'serious competition' during dry periods, but they presented no empirical evidence. No aggression between Emus and macropods was ever noted. Emus have a more diverse diet than kangaroos, taking fruits and insects as well as leaves, seeds and pods (Marchant and Higgins 1990).

Feral goats were considered by McCullough and McCullough (2000) to compete with kangaroos at Yathong during extended droughts, by removing shrubby vegetation that kangaroos turn to as emergency food, but no data is presented. During good seasons goats and kangaroos do not compete because kangaroos avoided the dense vegetation preferred by goats.

McCullough and McCullough (2000) surmised that rabbits at Yathong were benefiting rather than competing with kangaroos by creating disturbed soil around their warrens that supported annual grasses and forbs. These germinate faster than perennial grasses, providing the first flushes of fresh food when rains follow dry times. Also, they are the only plants to respond to light showers of rain. Kangaroos were seen feeding on rabbit warrens under these circumstances. McCullough and McCullough (2000) discounted competition between rabbits and kangaroos at Yathong because kangaroo populations are usually far below carrying capacity during good seasons and far above carrying capacity during drought.

Two studies on the impact of rabbit haemorrhagic disease (RHD) obtained no evidence to suggest that rabbits are significant competitors of kangaroos. Edwards et al. (2002a) found that Red Kangaroo numbers did not increase in central Australia after rabbit numbers declined, although they questioned the quality of their data. Warren ripping following the impact of RHD also did not lead to an increase in Red Kangaroo numbers (Edwards et al. 2002b) in central Australia, although Edwards et al. (2002b) contrasted this result with the findings of two previous rabbit control programs (in the Coorong and Flinders Ranges in South Australia) that were followed by an increase in kangaroos (Edwards and Dobbie 1999). Edwards et al. (2002b) suggested that Dingoes, which were present in central Australia but not at the other sites, explained the difference.

In a third study on the impacts of RHD, conducted in and near Hattah-Kulkyne National Park in north-western Victoria, Sandell (2002) found that perennial native grasses and forbs did increase under lower rabbit numbers, but only in quadrats where there was no cattle grazing and relatively low numbers of kangaroos (Western Grey and Red Kangaroos). Dingoes were absent from these sites.

In Kinchega National Park in western New South Wales, Denham and Auld (2004) found that the suckers of declining shrub and tree species did better inside cages that excluded rabbits. They compared the impact of all grazers, verses all grazers except rabbits, on the survival rates of suckers and seedlings of declining shrub and tree species. Even though rabbits were in low numbers because of calicivirus and warren ripping, little vegetation recruitment occurred, partly because of the low rainfall.

In other studies on rabbits, Newsome et al. (2001) and Fleming et al. (2002) assessed rabbit and sheep competition, Sinclair (2005) looked at rabbit diet, Croft et al. (2002) studied rabbit impact on sheep pasture, and Denham and Auld (2004) assessed rabbit impact on declining shrubs and trees in Kinchega National Park in Western New South Wales. Moseby et al. (2005) and White et al. (2003) added to knowledge of rabbit utilisation of the landscape although they did not consider diet.

McCullough and McCullough (2000) listed Feral Pigs as competitors of kangaroos at Yathong, but decided that their impact was trivial because pigs prefer densely vegetated areas that kangaroos avoid, and because their numbers were kept low by control programs and paucity of suitable habitat. Pigs may be local competitors of Eastern Grey Kangaroos in moister environments further east in New South Wales.

Feral deer are multiplying fast in New South Wales (Moriarty 2004), and they have been identified as the most important emerging pest animal threat in New South Wales (West and Saunders 2003). Competition with kangaroos is probably occurring but is poorly documented. Deer are likely to become a major presence in the rangelands in future (Norris and Low 2005), and throughout much of New South Wales, and competition with macropods and livestock will become very significant as the many small feral herds, resulting from deer farm escapes or releases, increase in size and range. Deer have great potential to spread because they can leap over fences that constrain other livestock. Moriarty (2004) interviewed government agency land managers around Australia, 268 of whom reported feral deer, including 126 in New South Wales. Forty per cent of respondents reported ‘competition with native animals and or/or stock’ as an issue. The Eastern Grey Kangaroo is the kangaroo most likely to experience competition.

Five deer species occur in New South Wales, all within its range. Red Deer *Cervus elephus* and Fallow Deer *Dama dama* herds are scattered throughout the eastern half of the state (Moriarty 2004). Rusa Deer *Cervus timorensis* and Chital Deer *Axis axis* are also very widespread, although confined to the coast, tablelands and western slopes of New South Wales. Sambar Deer *Cervus unicolor* have a limited distribution in the state, but one that is likely to expand in time (Moriarty 2004). Hog Deer *Cervus porcinus* became established at one site near Sydney (Moriarty 2004) but were eliminated, although feral populations may arise again in future. The bioclimatic modelling of Moriarty suggests that deer could occupy the whole State, bringing them into competition with all macropod species, and their limited presence in the west only reflects a paucity of deer farms to act as sources. The New South Wales National Parks and Wildlife Service report *Pest Animal Management 2003* lists several National Parks in which feral deer roam.

Studies on deer in Australia are very limited, but the dietary evidence from here and overseas suggests that all of these deer species are dietary competitors with kangaroos. The deer found in New South Wales largely consume grass, but eat more browse and other plant items (bark, fruit, buds) than kangaroos. The Red Deer, the preferred species on deer farms, sometimes causes serious damage to pastures (Bentley 1998b, Long 2003). Fallow Deer feed on short grasses (Bentley 1998a), causing damage to early spring grasses in England (Long 2003), and they seem likely to become competitors with kangaroos in the Australian rangelands, adding to total grazing pressure (Norris and Low 2005). Chital Deer result in ‘vegetation grazed to bare ground’ in Queensland (Jesser 2005). In Royal National Park, Sydney, Rusa Deer cause ‘overgrazing of areas leaving soils exposed’ (New South Wales National Parks and Wildlife Service). Here they compete with the Swamp Wallaby (Hamilton 1981, New South Wales National Parks and Wildlife Service 2005), a macropod that relies largely upon browse, with a dietary overlap that reaches 60% in winter in certain habitats. Rusa Deer diet within the park also includes major grasses such as Kangaroo Grass (*Themeda triandra*), Couch (*Cynodon dactylon*) and wallaby grasses (*Danthonia* species) (Hamilton 1981). Davis (2004) recorded dietary overlap between Hog Deer and Eastern Grey Kangaroos at Wilsons Promontory in a habitat where grassland is declining and deer are now more common than kangaroos (Davis 2005), suggesting that competition may be occurring. The New South Wales government has listed ‘Herbivory and environmental degradation caused by feral deer’ as a key threatening process (www.nationalparks.nsw.gov.au/npws.nsf/Content/feral_deer_ktp).

Feral Horses *Equus caballus* also compete with macropods. Removal of 30 000 Horses from a central Australian national park was followed by a striking recovery by threatened Black-footed Rock-Wallabies (Edwards et al. 2003), presumably reflecting reduced competition for food. In Guy Fawkes River National Park in New South Wales Feral Horses compete with Eastern Grey Kangaroos. When horses were shot from grassy river flats in the park, kangaroos quickly replaced them in unprecedented numbers (Tony Prior, pers. comm.).

Grassy flats are scarce in the rugged park and kangaroos avoid them when horses are present. Horses in arid areas will forage further away from water than cattle (Dobbie et al. 1993) and sheep, and in this behaviour they resemble Red Kangaroos.

Woolnough and Johnson (2000) recorded a very high dietary overlap between Eastern Grey Kangaroos and endangered Northern Hairy Nosed Wombats *Lasiorhinus krefftii* in central Queensland. These wombats formerly occurred in the Riverina district of southern New South Wales but long ago became extinct in that State.

No studies undertaken since 2000 considered competition between kangaroos and invertebrates, although McCullough and McCullough (2000) noted that standing dry grass at Yathong was consumed by 'veritable armies of ants and termites' as well as by kangaroos, suggesting that some competition occurred.

Overview

Apart from the herbivores listed previously by Olsen and Braysher, Emus, feral deer (five species), Feral Horses, and Feral Pigs should also be considered competitors of kangaroos. Emus, horses and pigs are likely to be competitors only under limited circumstances. Deer are only limited competitors at present, but the boom-and-bust cycle of deer farming in New South Wales has resulted in many new feral herds becoming established in recent years, and deer are likely spread throughout the State and become a major ecological presence in National Parks, and a major economic presence on grazing lands. They have potential to become major competitors of sheep, cattle and macropods.

Studies are still lacking on total grazing impact from all grazers in various situations.

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3.5 DIRECT AND INDIRECT METHODS OF POPULATION MONITORING

Task 5 – Assess the direct and indirect methods used to monitor kangaroo populations in New South Wales.

Olsen and Braysher (2000) summarised the various methods used for estimating kangaroo numbers.

The three techniques used for direct monitoring for the New South Wales KMP, which guide the setting of quotas by the Australian Government, remain the same:

- Broad-scale aerial surveys using fixed-wing aircraft (Fixed-width strip transect surveys);
- Medium/small-scale surveys using a helicopter (line transect surveys) primarily in rugged or heavily treed areas; and
- Small-scale surveys conducted on foot (line transect surveys) (Gilroy 2004).

Under the present system, aerial survey remains the most cost-effective and practical means of monitoring over the vast harvest area (Pople 2004; Payne 2005). Most States use fixed-wing transect sampling of 100 or 200 m strips. New South Wales recently switched to 100 m transect to improve accuracy, which entailed application of a new correction factors (Pople 2004). Correction factors (based on walked ground or helicopter searches) are applied because not all animals are counted.

Surveys from helicopters are thought to allow more accurate counts than those from fixed-wing aircraft, especially in more rugged or treed areas, but are expensive. Helicopter and line transects are less common than fixed-wing surveys but their use has increased (Cairns 2003; Southwell and Sheppard 2000; Pople and Fewster 2005). The trial commercial zone in south-east New South Wales was monitored by helicopter (Pople et al. 2003).

DEC and the University of New England conducted a three-year research project (1998–2000) examining fixed-wing aerial surveys from the western plains (Cairns and Gilroy 2001). As a result, since 2001 DEC has:

- changed the survey strip width from 200m to 100m;

- implemented new bioregional correction factors for Grey and Red Kangaroos;
- implemented revised proportions of Eastern Grey and Western Grey Kangaroos; and
- implemented a new data analysis protocol (Payne 2005).

The latest KMP also allows adjustment to quotas based on mid-year surveys.

The new estimates (from both fixed-wing and helicopter surveys) are improved in accuracy but still err of the side of conservatism, which affords a buffer against overharvesting (Pople 2004). The new ratios of Eastern to Western Grey Kangaroos, species which cannot be distinguished from the air, are similar to the previous ones based on surveys in the 1980s (Cairns and Gilroy 2001; Graham 2003).

As Croft (2004) and others have concluded, the current strategy is low risk (in terms of likelihood of over or under-harvest), simple and robust and allows the harvest to be proactive. However, it requires an estimate of absolute population size and direct monitoring is costly. Indirect monitoring through harvest statistics, rainfall, or greenness index from satellite images may be possible. The most significant development since the last literature review is the collaborative attempt to develop such a model(s) (Pople 2004, 2005).

Pople's (2003) drought model suggests that rainfall is an adequate predictor of population, but only during drought. Jonzen et al. 2005 also found rainfall to be a poor indicator of kangaroo abundance. Pople (2003a) suggested that at other times harvest statistics, perhaps including sex ratios, age structure and condition, may provide adequate information in trends or status between aerial surveys.

Pople's drought model was a specific application of a comprehensive modeling project that Pople (2004, 2005) and others have begun. It uses 20 years of harvest statistics to model temporal variation in kangaroo density and harvest rate. It also includes rainfall or satellite imagery (greenness index or NDVI) as a potential predictor of kangaroo numbers. Pople (2005) also generated some preliminary models of harvest frequency using a simple estimate of survey cost and quasiextinction risk; at a frequency of greater than four years risk increased greatly. A reduction in harvest rate to 10% largely offset risks from a decrease in survey frequency.

The Pople (2005) report contains several papers on aspects of the model that are in preparation or submitted. Hauser et al. (submitted) used decision theory to investigate monitoring frequency, using data on Red Kangaroos in South Australia. Fixed interval monitoring was out-performed by monitoring according to the state of the system, for example, when the population estimate is uncertain, such as when populations are approaching critically low levels, it has been some time since the population was monitored, or when rainfall has been above average.

Hacker and McLeod have developed a powerful predictive model that requires only rainfall, starting densities and off-take (regional chiller returns) (Hacker et al. 2003; McLeod et al. 2004). Age structure (McLeod et al. 2006), sex structure and even condition of the harvested individuals can be built into the model (Hacker et al. 2004).

Other developments in indirect monitoring include better understanding of error factors in using counts of dung to estimate abundance of macropods (e.g., Bulinski and McArthur 2000).

Hacker et al. (2002, 2003) developed and tested a technique to estimate absolute or relative kangaroo numbers at the paddock level, based on the relative proportions of sheep and kangaroo dung seen on a step-point transect and the known number of sheep; it gave adequate estimates.

Fecal Near Infrared Spectroscopy (FNIRS) is a relatively new technique with a range of potential applications. FNIRS has been used to monitor the nutritional status of free-ranging deer, goats and cattle (Stuth and Tolleson 2000; Dixon and Coates 2005) and may have potential for kangaroos, allowing early management interventions (Billing 2005). FNIRS has been used to predict the sex, reproductive and condition of the individual producing the faeces (Tolleson et al. 2000; Tolleson et al. 2001a,b, Tolleson et al. 2005). It may prove useful for predicting the number of grams eaten but this capability is still being developed (e.g., Kamler et al. 2004; Landau et al. 2005). The technique has potential to improve knowledge of kangaroos (notably to improve estimates of DSE), and inform local management decisions.

Its broad-scale application is less clear but it could be used to monitor kangaroo condition, allowing early management intervention.

Overview

The present system of annual monitoring employed in New South Wales has been developed and fine-tuned over many years and, as a basis for setting quotas and conserving the harvested species, has more than adequately stood the test of time. The survey effort, continuing improvement to the survey protocols and estimates, and sophistication of the predictive models are impressive. They provide a robust foundation on which to base future management.

However, as has been recognized, such monitoring is costly and there is scope for optimizing monitoring methods, frequency and design (Hacker et al. 2003, 2004, Pople 2005). Three decades of harvesting have shown that kangaroo populations in the commercial zone can sustain a harvesting rate of around 15–17% per annum; the challenge is to develop a new system of estimating/monitoring populations that is adequate to set quotas and protect kangaroo populations. A system using a combination of indirect predictors such as harvest statistics and rainfall models, reduced frequency of survey, and with special safeguards to prevent over-harvesting during severe drought or in the event of an epidemic, would likely adequately conserve kangaroos and save on the limited conservation dollar, provided the harvest rate was topped at about 15–17% (also see section 3.6). The models themselves can be used to provide early warning of any potential occasions when harvesting could cause problems. Setting of minimum carcass weights during drought can help reduce the risk of overharvest (Pople 2003b).

That said, long-term datasets such as this are rare, and critical to understanding the dynamics of populations and the impacts of change. Hence, a case could be made for continuation of monitoring at present levels of effort. Certainly, the trial south-eastern zone should be monitored closely and directly; the relatively well-understood population in the rangelands may not be representative of populations in more mesic environments.

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3.5.1 Specific issue – Accuracy of kangaroo population estimation methods currently used in the NSW KMP.

A lot of effort has gone into improving population estimates and monitoring in general (e.g., Grigg and Pople 1999). The current system seems close to optimal in terms of accuracy and functionality, given the vast area to be covered and the need to account for four different species. The addition of a strategy to reduce the remaining quota for the year, if necessary, based on updated population estimates from the mid-year aerial surveys (Payne 2005), adds a safeguard. It reduces risk to populations whose numbers have been over-estimated or are falling rapidly as in drought, without additional administrative costs.

The accuracy of helicopter surveys has received less scrutiny than that of fixed-wing estimates; both can suffer from observer bias and variation in habitat and this is being investigated (Pople and Fewster 2005).

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3.5.2 Specific issue – The ecological and economic merits of managing kangaroos based on paddock or property density estimates, e.g., density for paddock/property is the basis for culling levels for that property. Two scenarios to consider are where only a proportion of the properties in a region have these paddock density estimates or where all properties in an area have the density estimate.

Olsen and Braysher (2000) concluded that managing kangaroos based on paddock or property density estimates has little scientific merit, would be labour and resource intensive, would raise regulation problems and is unlikely to be justified by property returns or supported by the market.

Since then Hacker and colleagues have developed a paddock level monitoring system based on dung counts to guide better grazing management (Hacker et al. 2002, 2003; Hacker and McLeod 2003). Other papers confirm the great mobility of kangaroo populations, especially Red Kangaroos, that allows them to range over large areas (e.g., Pople 2005; Pople et al. submitted). Hence, localized management is unlikely to be effective in anything but the very short-term.

Indeed, there is scant evidence that harvesting (or culling) controls numbers or mitigates alleged damage, except very locally. Hacker et al.'s model (2003) gave some indication that harvesting may lessen the population peaks and troughs, but this is yet to be confirmed.

Heywood et al. (2000) give the following examples of grazier views on kangaroo culling, presumably because they are typical:

'During the last major wet period in 1988, there was a major explosion in kangaroo numbers. We had four blokes shooting professionally out here on the property, and they could not keep up with numbers' (Kerry and Shane Smiles).

'In terms of kangaroos, we've never really considered them to be a big problem. We do have a shooter who comes out once a fortnight but I wouldn't say there has been any reduction in numbers. In fact, I think we have more kangaroos now that we've ever had. The kangaroos are eating some of the feed but they're generally dispersed when the season is good. I don't think they cause major problems unless the season is dry or paddocks are that are locked up receive rain' (James and Sue Stirton).

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3.5.3 Specific issue – The ecological and economic merits of managing kangaroos down to a pre-defined minimum density, i.e., keep harvesting the kangaroos while they remain above the minimum density.

Olsen and Braysher (2000) argued that managing down to a pre-defined level is unlikely to be achievable or economical, or environmentally sustainable on the broad-scale. It may have application for large parks and reserves in areas where the climate is reasonably predictable, the land is managed by the State, and the conservation or economic benefit is confirmed, but it is resource intensive to develop and maintain.

Nevertheless, the concept of a pre-defined minimum density is useful. For example, ensuring minimum viable populations could be an alternative strategy to the current sustainable yield of 15% of standing crop model. Ensuring that the four species do not fall below some critical threshold is a conservation goal, rather than a harvest goal.

Hacker et al.'s (2003) model suggests that harvesting below a long-term average density of 10 kangaroos/km^2 in the harvest zone should not be considered because it means unacceptably low minimum densities could be reached.

David Freudenberger (pers. comm.) suggests that the threshold could be based on the minimum post-drought densities recorded by aerial surveys (e.g., 1983/1984). Within individual management zones, there is no need for a quota when kangaroos are above a certain density. For example, quota-free at (fictional) densities greater than 20 kangaroos/km^2, a quota imposed at densities between 10–20/km^2 and no harvesting at all below 10/km^2. Such thresholds would protect kangaroo populations from improving economics in the harvesting industry whereby it became profitable to harvest a greater proportion of the population than is currently economically viable.

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3.6 HARVESTING CONCERNS

3.6.1 Specific issue – Impact of current management program with reference to the specific aims of the current KMP, including a simple analysis of the impact of the commercial harvest on kangaroo densities.

The aim of the current KMP (2002–2006) is to 'maintain viable populations of kangaroos throughout their ranges in accordance with the principles of ecologically sustainable development'.

As the previous review Olsen and Braysher (2000) concluded that there is little doubt that viable populations of the four harvested species have been maintained across their natural range. In 30 years of managed harvest the distributional ranges of the two species of Grey Kangaroo have expanded. Kangaroo harvesting has proven to be a ‘spectacularly successful ecologically sustainable wildlife harvest’ (Grigg and Pople 2001).

Harvest rates have proven to be sustainable and kangaroo numbers fluctuate primarily in response to seasonal conditions. The industry tends to be self-regulating because it concentrates where numbers are highest and is uneconomic at low population densities. That is, the commercial minimum viable population density is far above the ecological minimum population density (D. Freudenberger, pers. comm.)

From their comprehensive model of harvest figures, biological and ecological factors Hacker et al. (2004) concluded that a male-biased harvest (70% male) of 20% was the best compromise for pastoralists, harvesters and wildlife managers, who were consulted on their aspirations. An earlier analysis had indicated that a lower harvest rate (10%) was sustainable but by accounting for age and sex structure of the population in the model the rate was effectively doubled. ‘The extent to which commercial harvesting achieves maximum yield is unclear. Harvesting a greater proportion of females will lower populations but increase harvesting costs (because of lower yield and greater search effort) and increase vulnerability to extinction. Hence, current harvest rates, and male bias, appear to be near optimal for a sustainable yield.

Hacker et al. (2003, 2004) recommend re-evaluating the practicality of managing both the harvest and the sex ratio in the harvest for individual species. They also recommend that ways are identified to reduce the complexity and cost of KMPs in light of evidence that the industry isn't viable at kangaroo densities that might threaten the conservation of the species. Pople (2004, 2005) suggests that harvest statistics offer a means to predict population trends and responses to a range of scenarios.

As Tyndale-Biscoe (2005) points out, none of the three options for kangaroo management—full protection, damage mitigation and harvesting as a renewable resource (either by farming kangaroos or harvesting wild kangaroos)—has resolved the issue of perceived conflict with pastoralism.

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Simple analysis of the impact of harvest on kangaroo densities

A very simple set of analyses was carried out on the harvest and population data in Payne (2005) and, for the 2005 take, the KMP website. The South-eastern New South Wales surveys were not included.

Eastern Australia has undergone severe drought in recent years and, because the primary driver of kangaroo populations is rainfall (population peaks following a few years of good rain and troughs in drought), kangaroo numbers have declined. Considering only data since 1993, when new correction factors increased the estimates, populations show no particular trend until the recent drought (Figure 2). Since 2002 numbers of all species have fallen dramatically, by more than 50%.

The last severe drought resulted in similar dramatic declines in 1983/1984. Then populations took several years to recover; presumably the rate of recovery will depend on how improved conditions are in the recovery years. Harvest was continued during the recovery at rates up to 15% overall.

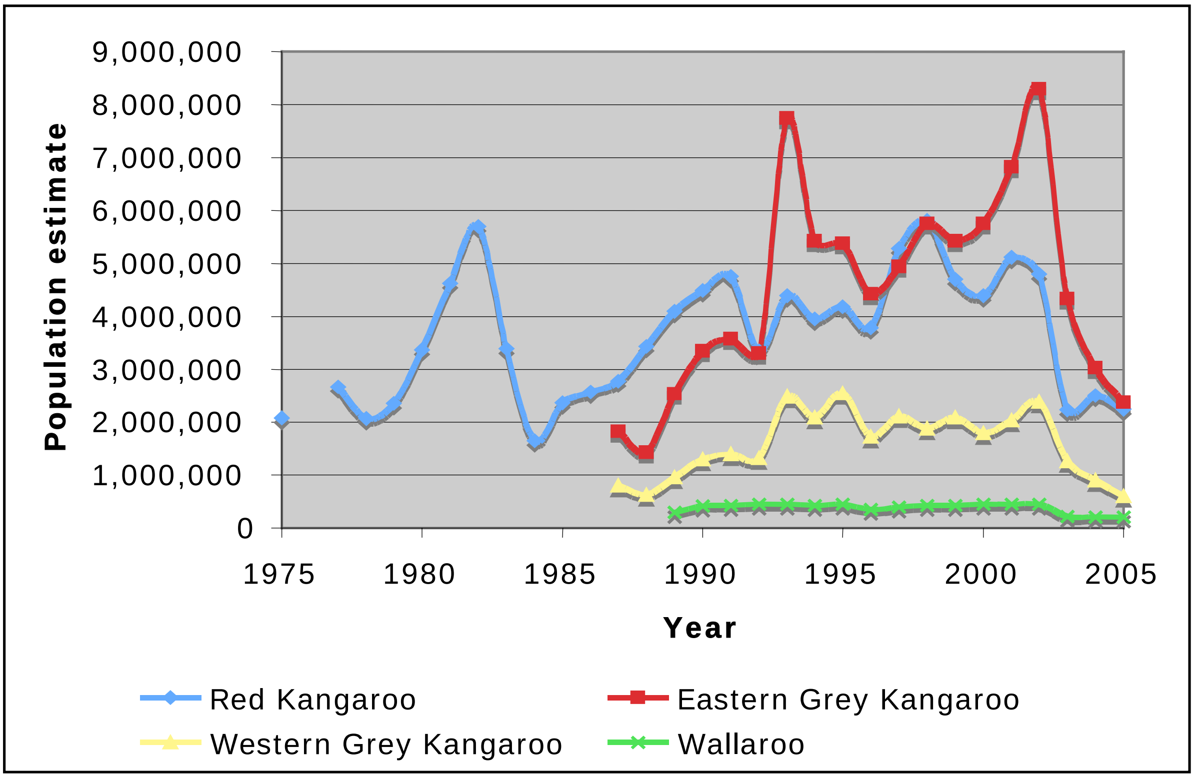

Figure 2. Population estimates for the four harvested species. New correction factors were applied in 1993 and 2001; the 1993 factor increased the estimate substantially.

The number of Red Kangaroos culled has shown a trend towards increase over the past 20 years, but harvest of all four species has fallen off by about half since 2002, with the drought and associated decrease in kangaroo numbers (Figure 3). There has been a general trend towards increase in the harvest of Grey Kangaroos, but a decline in the proportion of the quota taken since 1996 or so for Red Kangaroos and Western Grey Kangaroos.

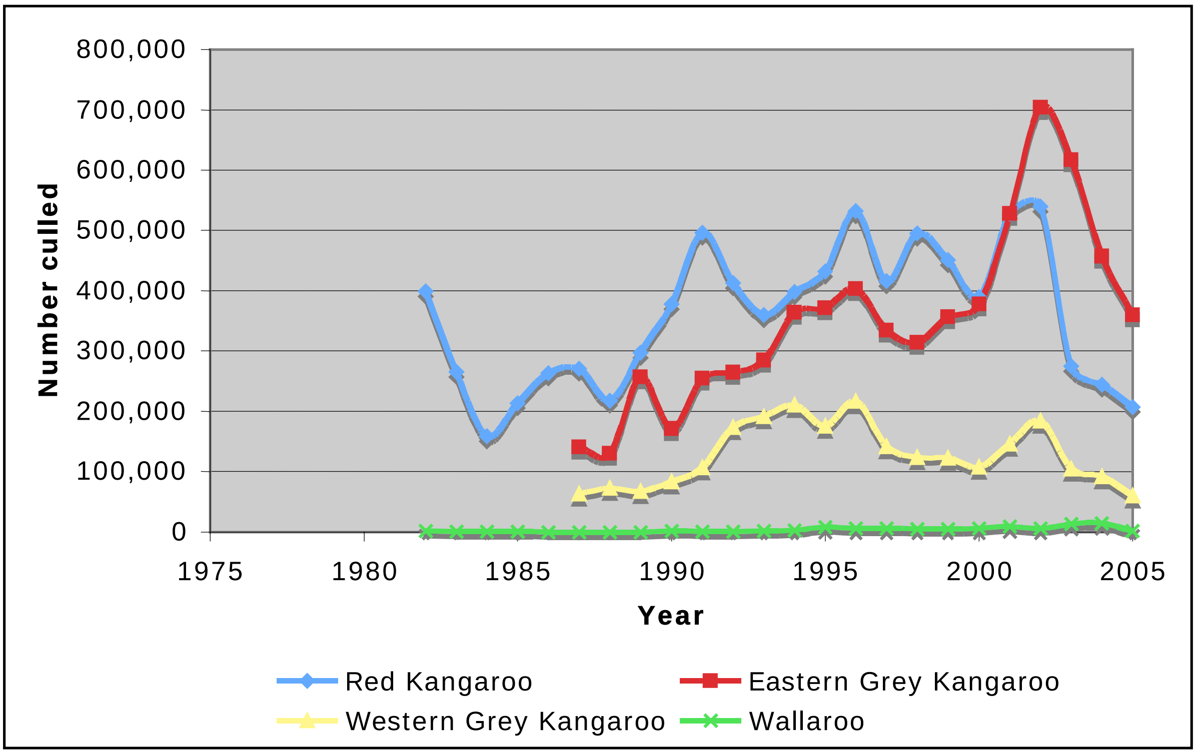

Figure 3. Numbers culled of each of the four harvested species.

Quotas allowed a greater harvest during these years of declining offtake but they were not filled (Figure 4) indicating a degree of self-regulation in the system, such that economic considerations limit the harvesting of kangaroos during drought despite available quota.

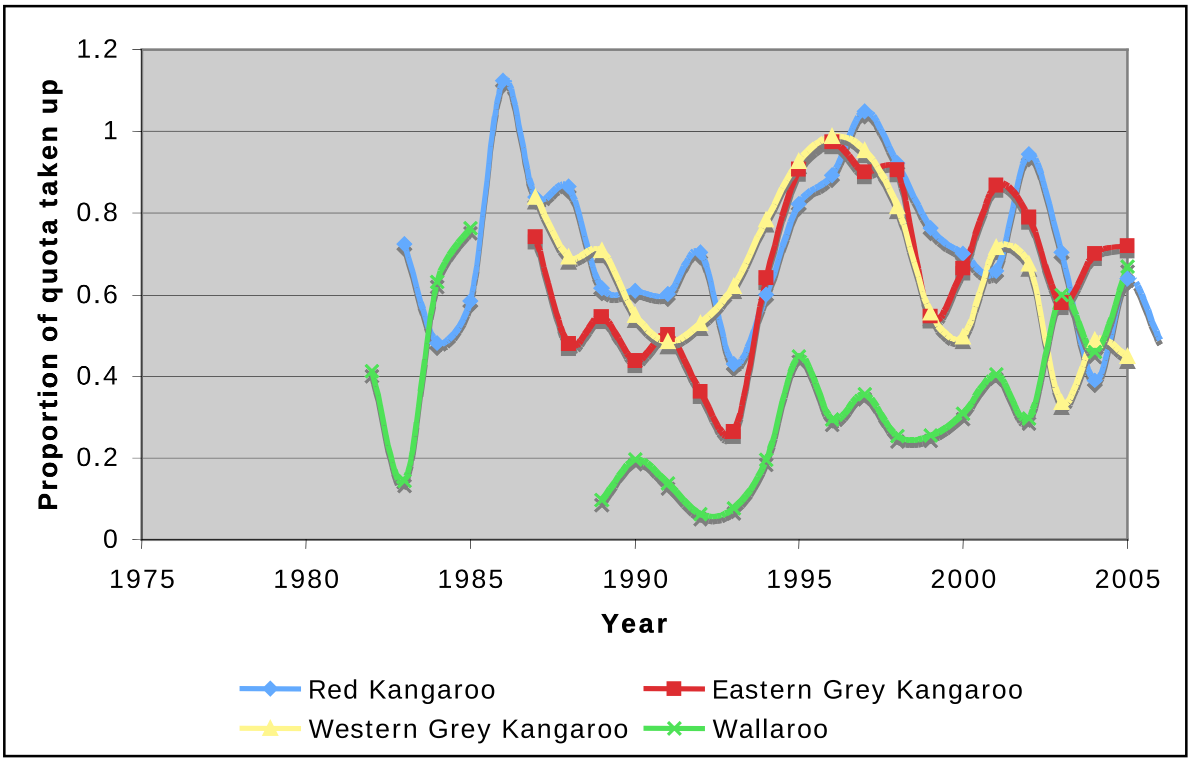

Figure 4. The proportion of the quota filled for each of the harvested species.

The numbers of kangaroos actually harvested is strongly positively correlated with population size (Figure 5); the larger the population, the more individuals are culled. However, the proportion of the quota taken up is unrelated to population size (Figure 6), with only a very weak trend towards an increased proportion in years of high population. Together these relationships these suggest that overharvesting in years of low population density is unlikely and that harvest is tracking kangaroo density regardless of the quotas set. However, markets are limited at present, providing little incentive to fill quotas.

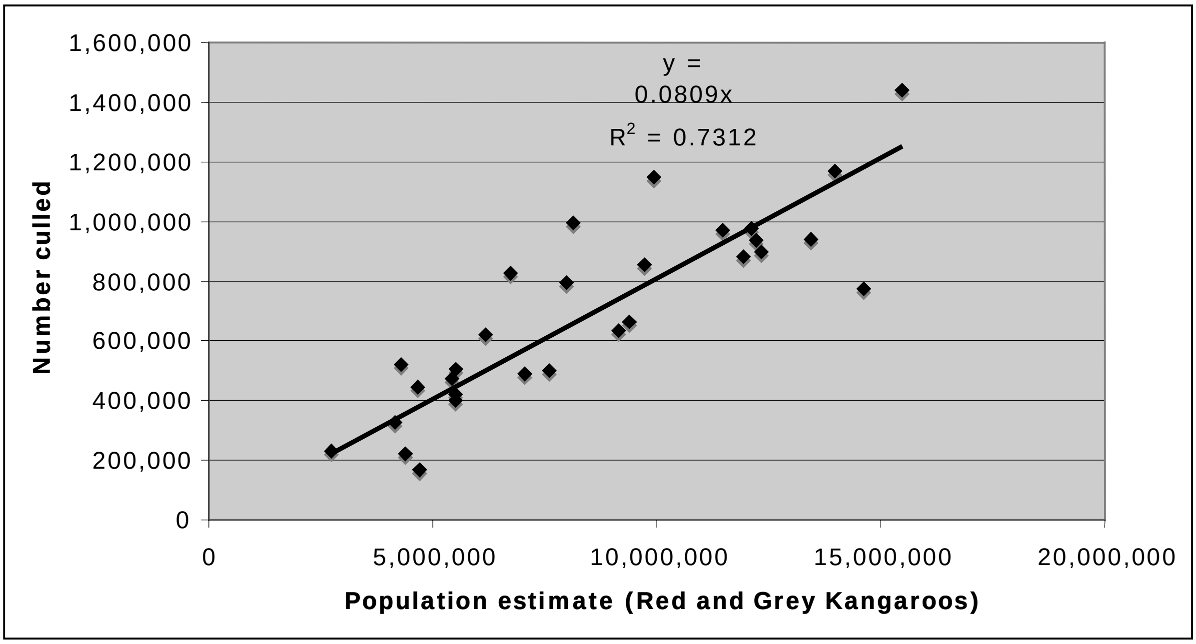

Figure 5. The relationship between the number of Red and Grey Kangaroos culled and population size.

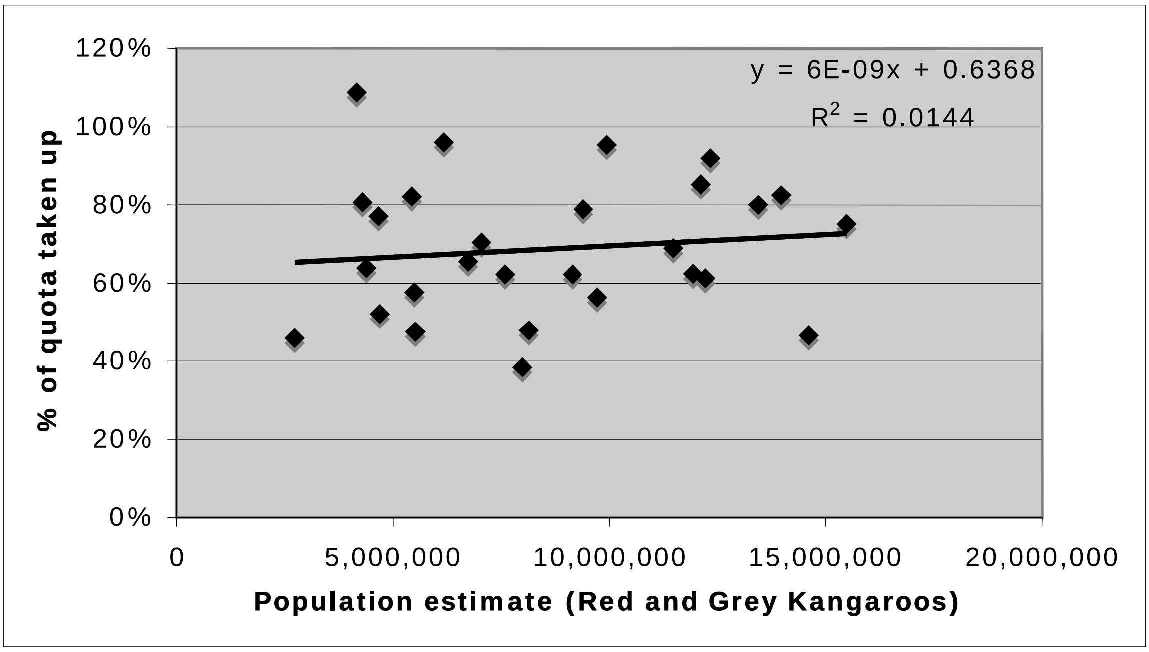

Figure 6. The relationship between the percentage of the quota of Red and Grey Kangaroos taken up and population size.

Figures 7a and 7b indicate that somewhere around 10% of the population is optimal as far as harvest yield is concerned, up to 13% for Red Kangaroos. This is very similar to the rate identified by Caughley (1987b) (Figure 8). Perhaps indicating that current harvest rates are close to optimal for sustainability.

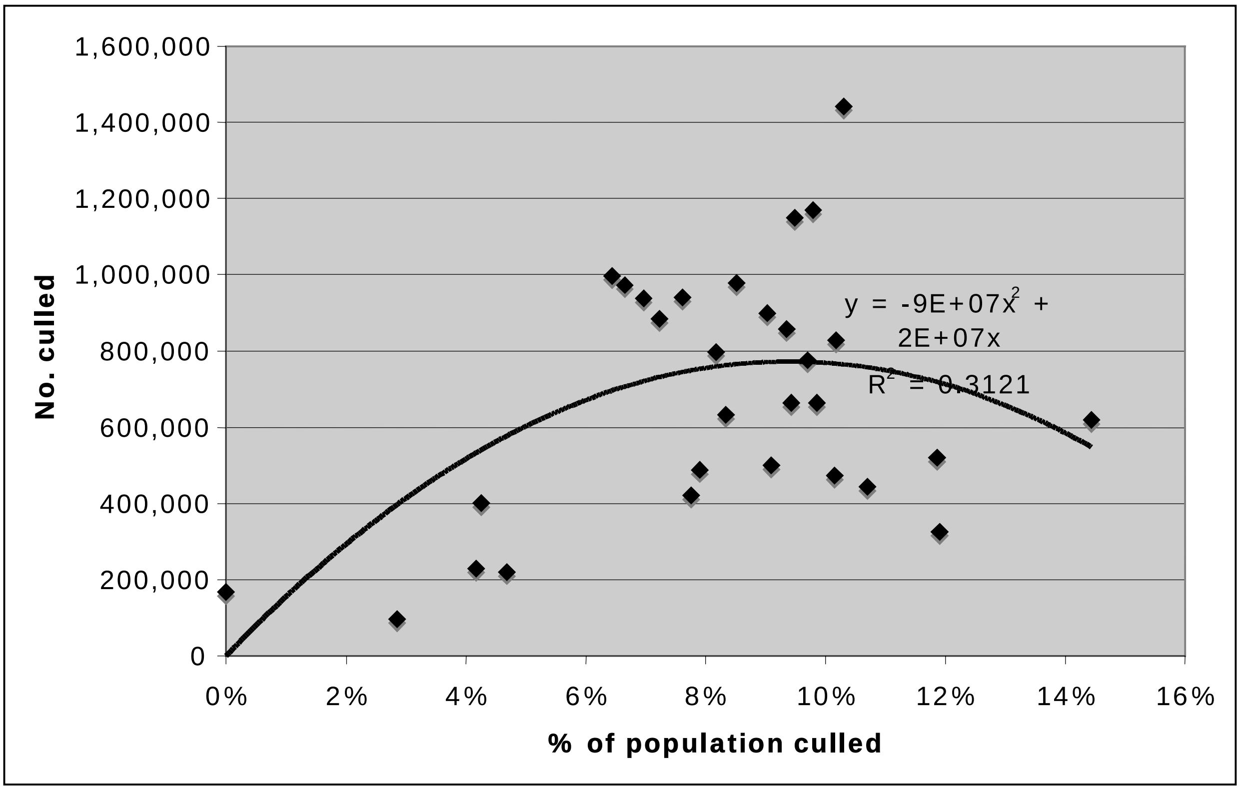

Figure 7a. The relationship between the percentage of the population culled and the number culled (yield) (Red and Grey Kangaroos combined).

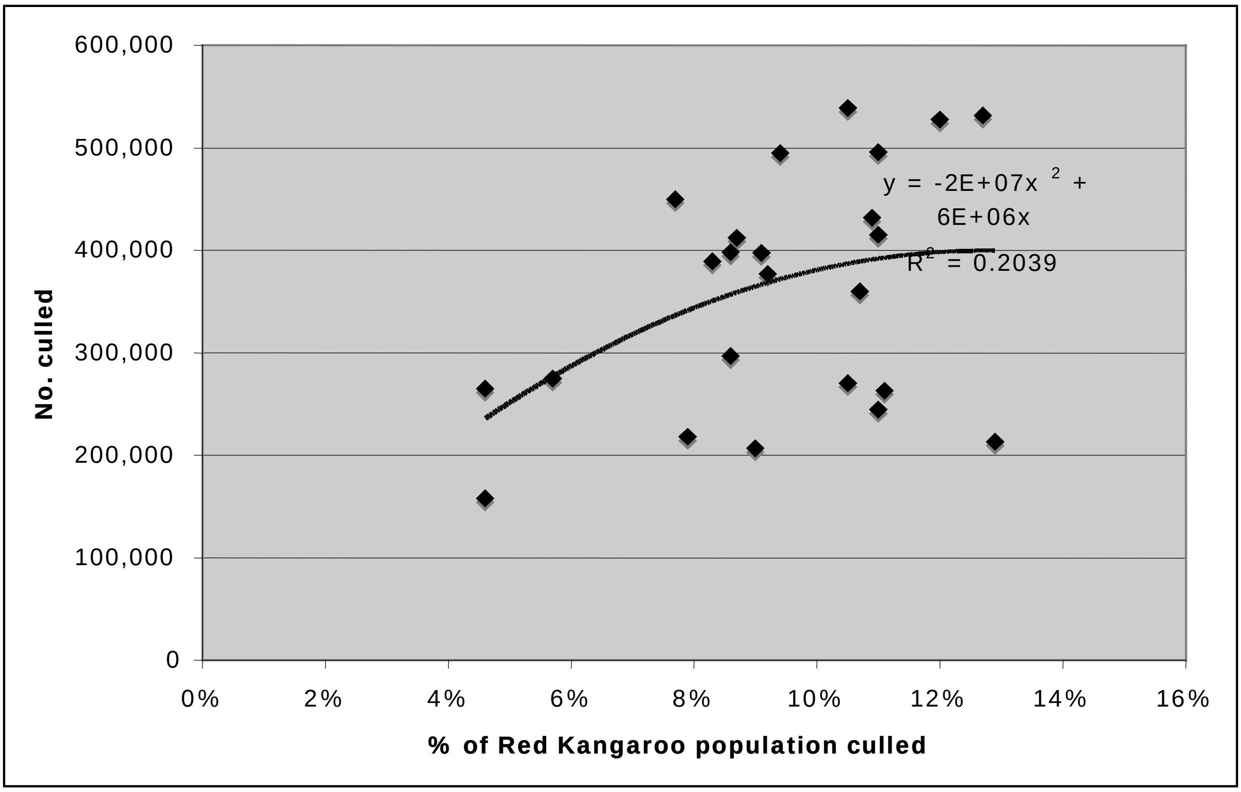

Figure 7b. The relationship between the percentage of the population culled and the number culled (yield) (Red Kangaroo only).

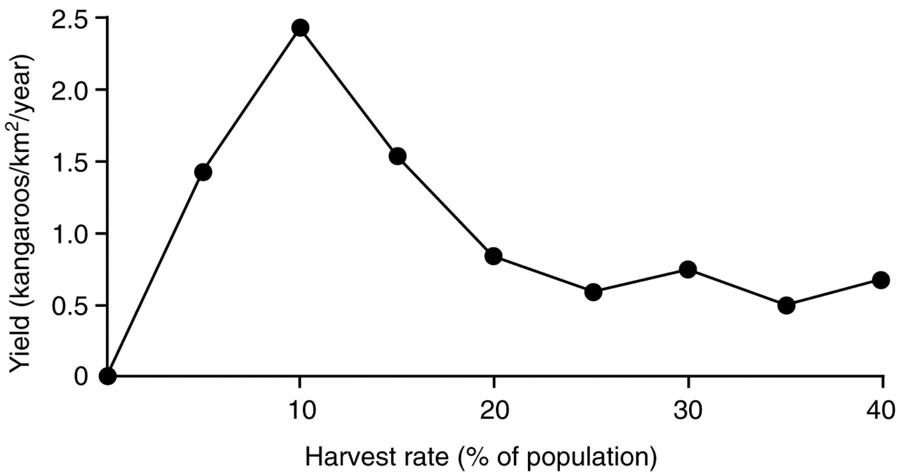

Figure 8. Variation in the average yield achieved by non-selective harvesting of a modelled Red Kangaroo population as a function of harvest rate (Choquenot et al. 1998, after Caughley 1987b).

In most cases, a wildlife population can be harvested sustainably if harvesting occurs at the same or a lower rate than that at which the population would otherwise increase (Caughley and Sinclair 1994). Average harvest rate is just under 10% as is rate of increase (Figure 9). There is a weak positive relationship between the harvest rate and the rate of increase (Figure 9) but rate of increase tends to outstrip harvest rate, except during years of drought. Pople (1996) points out that for fluctuating populations of herbivores, such as kangaroos, mortality (e.g., harvesting) tends to be additive when populations are declining but compensatory when they are increasing. Therefore harvesting will have a greater effect on rate of increase when forage is abundant than during drought.

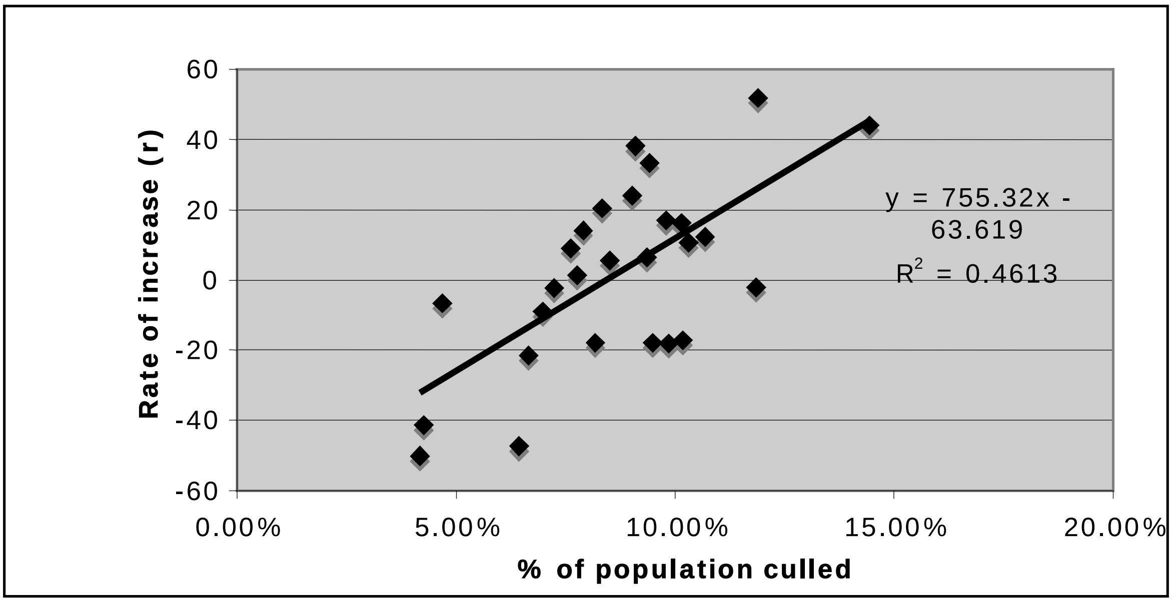

Figure 9. The relationship between the percentage of the population harvested (harvest rate) and the rate of increase in the population (Red and Grey Kangaroos combined). The rate of increase between 1992 and 1993 was excluded because new correction factors, first applied in 1993, greatly increased the population estimates.

Figure 10 shows that rate of increase is highest when populations are lowest, demonstrating the combined populations' ability to compensate and recover.

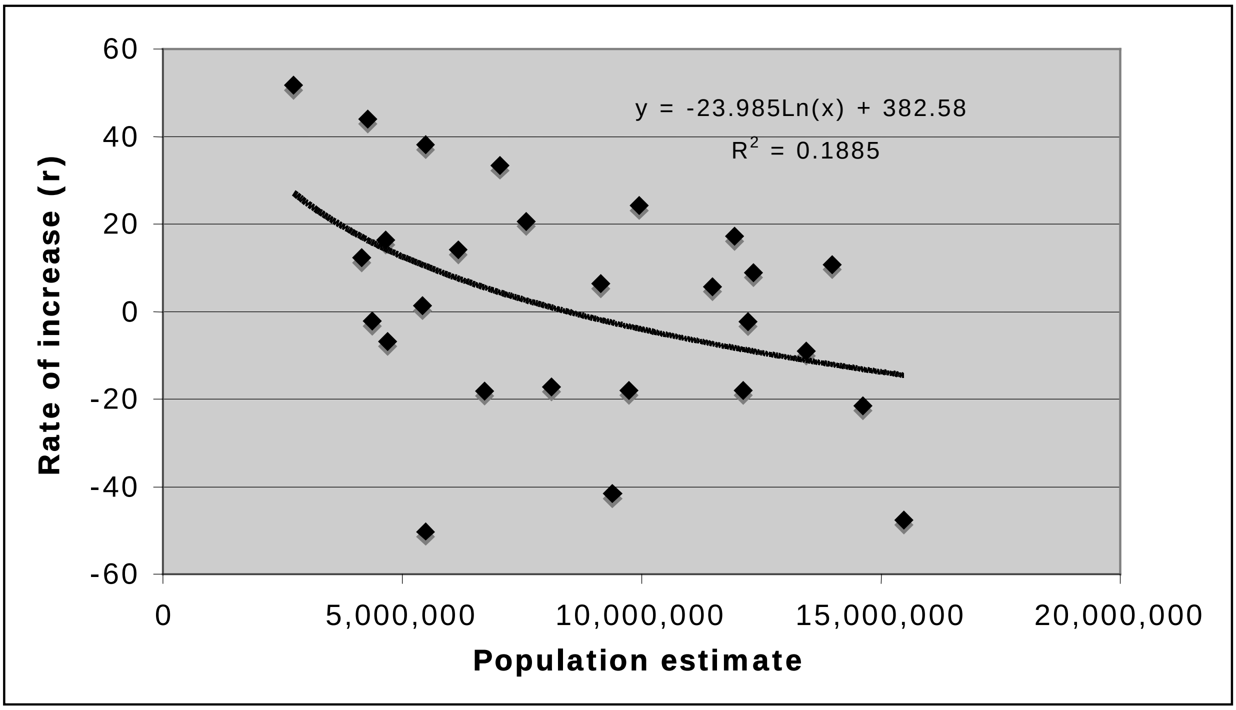

Figure 10. The relationship between population size (p) and the rate of increase ($p_2 - p_1/p_1 \times 100$) for Red and Grey Kangaroos combined. The rate of increase between 1992 and 1993 was excluded because new correction factors, first applied in 1993, significantly increased the population estimates.

Overview

This crude analysis of harvest statistics and population estimates indicates that kangaroo populations are dynamic and resilient, that harvesting at current rates has little or no impact because populations compensate, and that other forces (rainfall) are of overriding influence. It also indicates that the harvest is tied to population levels and hence, unless the economics of harvesting change greatly, overharvesting is unlikely.

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