Situation Analysis Report:
Current state of scientific knowledge on kangaroos in the environment, including ecological and economic impact and effect of culling

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CURRENT STATE OF SCIENTIFIC KNOWLEDGE ON KANGAROOS IN THE ENVIRONMENT, INCLUDING ECOLOGICAL AND ECONOMIC IMPACT AND EFFECT OF CULLING

1.0 AIM

The aim of this report is to review the current state of scientific knowledge on kangaroo management in NSW, primarily by means of a comprehensive survey of the literature. In particular, the brief was to address a number of specific questions posed by the Kangaroo Management Advisory Committee, including the ecological and economic impact of kangaroos and the effect of culling on kangaroo populations (see Appendix 1).

2.0 BACKGROUND

Kangaroos in NSW are managed in accordance with the Commonwealth-approved Kangaroo Management Program (KMP). Periodic review of the KMP is required and a review is currently underway. Previously, stakeholders have been restricted to commenting on a new draft plan developed in isolation by the government. The current review process involves the stakeholders prior to the preparation of a new draft KMP.

Part of the current process involves the review of relevant issues identified by the Kangaroo Management Advisory Committee (KMAC) and NSW NPWS. For this purpose, situation analysis reports will be prepared. This review of the current state of scientific knowledge on kangaroos in the environment, including the ecological and economic impact of kangaroos and the effect of culling, is one of these reports.

Today, only the larger, more abundant species of kangaroo can be harvested commercially and there are three recognised aims for their management (ANZECC 1996). The primary aim is to ensure the conservation of all harvested species and to maintain them over their natural ranges. Secondary aims, which are permitted only if they do not compromise the primary aim of conservation, include reducing the damage they cause to rural production and, where appropriate, ensuring sustainable use of the resource (Maynes 1993). Under the *Commonwealth Wildlife Protection (Regulation of Exports and Imports) Act* 1982, commercial harvesting of kangaroos for export requires prior Commonwealth approval of a kangaroo management program.

Under the *Act*, the New South Wales Kangaroo Management Program has approval from 1 January 1998 - 31 December 2002. The programme covers the four locally harvested species, the Red Kangaroo *Macropus rufus*, the Western Grey Kangaroo *M. fuliginosus*, the Eastern Grey Kangaroo *M. giganteus* and the Wallaroo *M. robustus robustus.* The aims, which are underpinned by the national guidelines, are to:

a) maintain viable populations of Red Kangaroos, Western Grey Kangaroos, Eastern Grey Kangaroos and Wallaroos throughout their natural range;

b) minimise the adverse effects that certain densities of these four species may have on rangelands, on pastoral and agricultural production and other land uses;

c) to maintain populations in these areas at levels which will not, in the long term, adversely affect these habitats; and

d) where possible, manage the species as a renewable resource, providing conservation of the species is not compromised.

NSW is a major harvester of kangaroos. In 1999, the State accounted for 36% of the kangaroos harvested in Australia, second only to Queensland, and took up a greater percentage of their quota than any other State (Table 1).

Table 1. Numbers of kangaroos killed under commercial harvest quotas in 1999 (Source: Environment Australia 2000).

State	Red Kangaroo	Eastern Grey	Western Grey	Euro/ Wallaroo	Other species[1]	Total	% of quota taken up
New South Wales[2]	450,020	355,845	122,481	9,296	0	937,642	56
Queensland	457,177	570,101	0	119,767	1,279	1,148,324	41
South Australia[3]	231,327	0	63,672	18,988	0	313,987	42
Western Australia	139,945	0	54,574	4,731	0	199,250	46
Flinders Is., Tas.	0	0	0	0	936	936	4
Total	1,278,469	925,946	240,727	152,782	2,215	2,600,139	46

[1]Other species include the Whiptail Wallaby *M. parryi,* Bennetts Wallaby *M. rufogriseus,* and the Tasmanian Pademelon *Thylogale billardierii.*

[2]Beginning in 1997 New South Wales has included a provision for animals previously killed in the commercial zone under non commercial permits to be included as an identified component of the quota (damage mitigation quota). This part of the quota will be released only when the regional commercial quota has been used and then only based on consideration of property inspections, kangaroo population trends and climatic trends.

[3]In 1996, South Australia refined the setting of the commercial harvest quota to provide for the separate identification of a sustainable use component to the quota and an additional land mitigation component. This latter component will be released only when there is an identified threat to land management goals in an area that the sustainable component of the quota has been taken.

Incomplete knowledge

It is now recognised that natural resource systems such as those in which kangaroos exist in NSW are complex and our knowledge about them and how best to manage them is inadequate (Braysher 1993; Olsen 1998). Not only is the science imperfect, but the system itself is a dynamic moving target, evolving because of the impacts of management and the progressive expansion of the scale of other human activities. This is especially so concerning the relationship between animal density and the level of impact caused. Despite extensive studies, the level of impact attributable to a given species, be it a kangaroo, rabbit or feral goat, has rarely been well quantified.

Hence, managers need to make decisions based on this imperfect knowledge. One approach for dealing with this situation has been to adopt an adaptive management approach (e.g., Pople and McLeod 2000). This approach assumes that our knowledge about a system will always be inadequate. Rather than undertaking detailed scientific studies to try to understand the complex interrelationships, managers, in consultation with other key stakeholders, determine how they think that the system might best be managed and apply the best option in a widescale experimental approach. The key is to be specific about what each management program is meant to achieve, to monitor progress and to evaluate results. In doing so it is important to recognise that knowledge and insights can come from programs that fail to meet the desired result as well as from those that succeed. Flexibility is also important, that is, recognising the different circumstances and restrictions at each site and the need to adapt accordingly.

An adaptive management approach may be the most appropriate means for addressing many of the information deficiencies that are identified in this report.

3.0 LITERATURE REVIEW

The literature review was structured to address the five major areas of concern to the KMAC (Appendix 2). The main focus was on the impact of kangaroos on vegetation/habitat/land resources/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 NSW.

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.

Shooting

A limited number of licences are issued for non-commercial kangaroo culling but these make up 1% or less of the total numbers culled (Ramsay 1994). Kangaroo harvests are carried out by licensed shooters, who are issued with permits by state and territory wildlife authorities. Commercial harvesting of kangaroos is restricted to leasehold and freehold land that is being used for primary production. Such harvesting takes place in Queensland, New South Wales, South Australia and Western Australia. It is not permitted in national parks, state forests or conservation reserves. With the landholder's consent, the shooters work at night on those properties where authorities consider kangaroos are causing damage. Shooting is carried out humanely, according to a Code of Practice formulated with the assistance of the RSPCA and meeting their approval. Shooters are required to shoot at the head and to use powerful centrefire rifles that shoot accurately, causing instant death.

There is only a small number of licensed shooters and processors and it is in their best interests to work within the regulations. If the controlled commercial harvesting of kangaroos were to stop, this ability of governments to oversee and regulate the harvest would be reduced. There would be no effective means of enforcing limits on the number of kangaroos that may be killed; authorities would not be able to check for evidence of cruelty; and landowners may be forced to use inhumane control methods that may also endanger other wildlife, domestic animals and even humans (RSPCA 1985; Senate Select Committee on Animal Welfare). Gibson and Young (1987) asked landholders what action they would take if a commercial kangaroo shooter was unavailable and 80% said they would undertake the shooting themselves, which would be costly and time consuming. Others indicated they would seek cheaper control methods, such as encouraging amateur shooters onto the property or poisoning water supplies. These methods have serious ethical drawbacks. Landholders and amateur shooters may be less accurate and thus less humane than professionals — professional shooters aim for a head shot to maximise the value of the carcass and to meet the requirements set out in the Code of Practice for taking kangaroos. It is also possible that some landholders may engage in desperate measures such as poisoning water supplies, which would kill non-target animals as well as kangaroos.

Lastly, unlike many other control methods, shooting is most effective where densities are greatest, that is, where it is most needed (e.g., Young and Morris 1985). This also means that shooting is to some extent density dependent, a requirement if harvesting is to have a regulating effect on populations (Caughley and Sinclair 1994).

Overview

Given the wide range and high numbers of kangaroos that need to be culled to protect environmental or grazing interests, shooting remains the most economical, effective and environmentally friendly technique. It is also the most acceptable from an animal welfare perspective and is target specific. The current system allows a degree of control of harvesting and management of kangaroos that would not be otherwise possible. Not least, under the present system, commercial removal has no direct cost to the landholder.

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Restricting access to water

The provision of water is thought to have allowed range expansion (Kilpatrick 1967; Caughley et al. 1984) and changes in distribution of the Red Kangaroo (Newsome 1975; Oliver 1986). This dependence of kangaroos on waterpoints and their habit of congregating around them, especially during drought, presents opportunities for control.

The Finlayson trough is a low lying electrical conductor set around a waterpoint to selectively exclude kangaroos from water (Norbury 1992). Norbury reported 99% exclusion of kangaroos from water, King et al.(1995) 85% of Red Kangaroos and 82% of Euros. Freudenberger and Hacker (1995) found that 78% for Red Kangaroos were deterred from drinking and expressed concern that a greater percentage of Grey Kangaroos drank. Provided that they keep working, which can be a problem, the troughs exclude the animals only from selected areas. In some cases domestic stock were deterred from drinking, but this was circumvented by fitting timers that turned on at night – when kangaroos drink (Dawson et al. 1975) – and off during the day for stock (Freudenberger and Hacker 1995; King et al. 1995). King et al. 1995 trialled the troughs over 100 000 ha with a number of waterpoints (21) and found that they were ineffective. They attributed this to largely to the fact that kangaroos are reluctant to leave their home range even during drought (Ealey 1967; Pridell et al. 1988; Norbury et al. 1994) and found physical ways to circumvent the devices. Presumably, given time, some kangaroos would also have learnt to drink during the day. Also, except in very dry times, the kangaroos would locate other sources of water (Pople and Grigg 1999).

Norbury (1992) noted that kangaroos tend to congregate near waterpoints from which they are excluded by low electric fences. In an attempt to make use of this behaviour, Freudenberger and Hacker (1995) trialled the usefulness of such fences to concentrate kangaroos so that they could be more easily shot. They found that significant numbers of kangaroos gathered near water only in the warmer dryer months. Thus this technique only has potential to be effective locally, seasonally and in the absence of nearby water.

Presumably, capping of some of the troughs, bores and pumps, where they are not needed by stock, may reduce inland kangaroo numbers in the longterm (e.g., Gibson 1995) but studies are few. The impact of closure on other wildlife, particularly endangered species, would need to be investigated before broadscale closure was embraced.

Overview

Electrical fencing to restrict access to water is not effective for kangaroo control over large areas. It has limited potential to ameliorate the impact of kangaroo grazing locally, either directly through from restricting water or indirectly through concentrating kangaroos so that they are more easily shot, and has unresolved animal welfare and conservation issues. The capping of inland bores and pumps could potentially reduce kangaroo numbers but other environmental issues must first be taken into account.

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

Until recently prescriptions for better management of rangelands have included the provision of regular waterpoints to spread the impact of grazing over a wider area (Harrington et al. 1984). One outcome is that there are now so many artificial waterpoints that areas previously unsuitable for large herbivores are subject to sustained grazing (Landsberg et al. 1999). For example, using three NSW 1: 250 000 map sheets, for Balranald, Angledool and Anabranch, Landsberg et al. (1999) were able to plot nearly 5 000 waterpoints, and most were artificial. These maintain large kangaroo populations but it is not clear whether they have led to an increased total population, at least of Red Kangaroos (Landsberg et al. 1999).

In the rangelands, the main grazing impact from sheep is about 5 km from a waterpoint and 10 km for cattle (Arnold and Dudzinski 1978). Each species travels up to twice those respective distances to reach preferred grazing areas. The figure is unknown for kangaroos but estimated conservatively at 20 km (James et al. 1999). Across the NSW rangelands, indeed the rangelands in general, there are few places more than 10 km from a waterpoint (Landsberg et al. 1999). There were major changes in biodiversity composition at different distance from water. Some species (between 10 and 33% of species in the various taxonomic groups) increased closer to water, others decreased (15 to 38%). Among the 'increasers' were exotic plants and birds that have expanded their range following provision of water. All of the 'decreasers' were native species. Using this terminology, sheep and other stock are increasers and kangaroos show no pattern, with the amount of kangaroo dung being evenly spread in relation to waterpoints

(Freudenberger and Hacker 1995; Rebecca Montague-Drake in NSW and Robyn Cowley, Qld, Cowley pers. comm.).

Landsberg et al. (1999) argued that artificial water was probably more important for Grey Kangaroos and Wallaroos than for Red Kangaroo, the density of the latter varying greatly independently of waterpoints. For example, Newsome (1965) found that 68% of Red Kangaroos were near water during drought and this dropped only marginally to 63% after rain.

Landsberg et al. (1999) and Freudenberger and Landsberg (2000) recommended the introduction of strategic closure of artificial waters involving staged closure in reserves and selective closure on private lands to ease grazing pressure and enhance biodiversity. Recent Management Plans of western NSW National Parks have actions involving the closure of all artificial waterpoints with the exception of those necessary for domestic use or fire fighting, with the aim of restoring truly arid conditions for those species adapted to them and averse to the altered grazing pressures introduced by the provision of water (Freudenberger pers comm.). In some parks, fencing that selectively excludes kangaroos is being considered, but is costly (Freudenberger pers comm.). Whether, as a consequence, these areas will support fewer kangaroos is unknown. However, (Gibson 1995) reported a reduction in kangaroo abundance following waterpoint closure. Of the large herbivores only Euros are able to survive in the absence of water (Ealey 1967).

On a more limited scale, in the southern mallee of NSW, Property Management Agreements have been crafted that encourage farmers to set aside reserves free of artificial water in exchange for clearing for cropping, and so forth, of other parts of the property (Freudenberger pers comm.). These are aimed at easing grazing pressure from kangaroos but not at control of kangaroo numbers, which are unlikely to be significantly affected because of kangaroos' mobility.

Unfortunately, there is no scientifically rigorous routine monitoring in place to assess any impacts of waterpoint closure on kangaroos. This would be especially informative in areas where the closure will be broadscale.

Overview

On the small scale, studies show no relationship between kangaroos and waterpoints. On the large scale there is little doubt that parts of the inland that only supported kangaroos in good years or not at all, now support them all year round. Closure of these points is likely to have an impact but elsewhere the situation is less clear.

Closure of waterpoints in parts of the Western Division is proceeding (Freudenberger pers. comm.). It is not clear what the overall impact will be on kangaroo populations, although it is likely to reduce the density and hence the damage caused by exotic pests such as feral pigs and feral goats. It is recommended that a medium- to long-term, scientifically rigorous program be established to monitor the variation in kangaroo density and other aspects of the system caused by closure of water points. Special attention should be given to kangaroo densities in reserves where closure of artificial water points is to be broadscale.

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Reintroducing predators – Dingoes

The relationship is complex, but evidence suggests that Dingo predation can limit, if not regulate, kangaroo populations (Caughley et al. 1980; Thomson 1992; Banks et al. 2000; Pople et al. 2000). However, prey switching is likely to be an integral part of this process. The Dingoes turn to alternative prey when kangaroo densities fall, such as during drought (e.g., Corbett and Newsome 1987; Corbett 1995), although the concentrations of kangaroos around water at this time also makes them more vulnerable to Dingo predation (Thomson 1992). In sheep growing areas alternative prey is likely to include sheep, hence Dingo reintroduction is an unacceptable solution for graziers. Whether sheep losses due to wild dogs are preferable to pasture damage caused by high numbers of kangaroos and Emus in areas protected from Dingoes is likely to be a moot point in the face of Dingo predation of stock.

Further, it is likely that, given the opportunity, Dingoes will prey heavily on sheep regardless of kangaroo numbers, because sheep are a confined, easier and more accessible prey, kept at relatively steady densities (unlike rabbits). Prior to effective Dingo control, attempts to farm sheep in the area east of the fence would suggest that this outcome is likely. If such is the case, then Dingoes would be ineffective in controlling kangaroos in areas where sheep farming is extensive.

Overview

Reintroduction of Dingoes, or the removal of Dingo controls, is not a realistic proposition for kangaroo control in the pastoral zone. There is no evidence that Dingoes would prey heavily enough on kangaroos to keep them at acceptable levels and it seems highly likely that sheep would be the preferred prey.

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Immunocontraception

Contraceptives (or other birth control measures) are often viewed as safe and humane way to control wildlife. They may be effective when used with kangaroos that are confined to a particular area and closely managed (Garrot 1995; Stelmaziak and Mourik 1987; Tyndale Biscoe et al. 1990). However, they have little application for broadscale use (Bomford 1990). Major drawbacks are expense and the necessity for repeat doses to be administered.

Immunosterilisation or immunocontraception aims to overcome some of these problems (e.g., Tyndale-Biscoe 1990, 1994, 1995). A virus, or some other vector, is used to carry an agent that stimulates an auto-immune response in the pest animal and renders it sterile. The agent can be a protein from the pest animal's reproductive system, which is introduced into the virus' genetic material. When the virus infects the pest animal and multiplies, it also replicates the protein. The immune system identifies the virus, and protein, as foreign and attacks the protein even where it occurs in the animal's own reproductive system, making the animal sterile.

The Cooperative Research Centre for Marsupial Conservation and Management is developing immunogenic antigens that could make kangaroos sterile for long periods, perhaps up to a year (Pople and Grigg 1999). However, this would only be of use in a few, small-scale situations.

Even if a broadscale, self-spreading technique were developed, there are likely to be a number of undesirable social and ecological consequences and concerns. McCallum (1996) pointed out that kangaroos are a problem to farmers mainly during drought, when there is no recruitment anyway, so it is difficult to see what immunocontraception might add. Further, an effective, uncontrolled agent may well drive the population towards extinction causing conservation problems (Pople and Grigg 1999). There are also concerns that the method is likely to non-specific to species, with the possibility that it could pass to other macropods not in need of control (Pople and Grigg 1999), but others consider that it will be highly species specific (Caughley and Sinclair 1994).

Overview

Many see antifertility control as low cost, long-term and, in some cases, humane alternatives to conventional pest control (Bomford 1990). In reality, the release of agents to control pests is unlikely to be the full solution, is likely to be expensive in the limited situations in which it might be useful, and carries risks. At least in the medium-term, the development of an effective fertility control agent for broadscale kangaroo control appears highly unlikely.

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Other potential control methods

Habitat manipulation

The principle of control by habitat manipulation is to modify the habitat so that it is less favourable for the pest and/or more favourable for the threatened native plant or animal. In this case it could involve altering the habitat so that it was less attractive to kangaroos. In principle this would be possible in some areas, if the changes that have caused populations and distributions of the harvested species to increase (Calaby and Grigg 1989) could be reversed, and this might be feasible in areas such as national parks (Lavery and Caughley 1987). However, at any significant scale, it would be impossible.

On a small scale, where kangaroos damage crops, crops could be grown that are unattractive to macropods and areas adjacent to cleared land could be avoided (Lavery and Kirkpatrick 1985). Distractant crops could also be planted (Lavery and Kirkpatrick 1985).

Exclusion Kangaroo proof fencing is expensive to erect and maintain and electric fencing, although less expensive, becomes ineffective over time and in times of drought (Lavery and Kirkpatrick 1985). Fencing also has adverse impacts on other wildlife (Shepherd and Caughley 1987) and government agencies have little control over its use (Ramsay 1994). Also see Finlayson Trough (under 'Restricting access to water', above).

Poisons – such as 1080 – can be used to poison kangaroos but they are not selective and many smaller macropods (and dasyurids) that are more susceptible and would be at risk. Animal welfare groups deem such methods 'cruel and unacceptable' (RSPCA 1987).

Trapping and mustering have been used in the past but for broadscale use they are inefficient, unsuitable for commercial harvest and have unresolved animal welfare implications (e.g., Senate Select Committee on Animal Welfare 1988).

Deterrents Scare guns and other sonic deterrents etc. are ineffective except on a very small scale and for a limited time (Bomford and O'Brien 1990). Ultrasonic devices are thought to be totally ineffective (Bomford and O'Brien 1990). The application of meatworks fertilisers, which makes cane unattractive to kangaroos, is said to protect cane for about a month (Lavery and Kirkpatrick 1985). Such techniques have no broadscale application.

Overview

None of these methods would be suitable for kangaroo control on the scale required and all suffer from other drawbacks such as cost, risk of secondary poisoning, limited effectiveness, inability of governments to control their use, and conservation and animal welfare problems.

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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.

Flood

Changes that might affect kangaroo numbers include disease, habitat change and natural disasters, such as droughts and floods. A study in NSW of the short-term effects of flooding on the number and distribution of kangaroos in New South Wales found that when an area was flooded, kangaroos simply moved to graze on higher ground (Choquenot 1991). However, there have been occasional localised epizootics associated with floods (Clancy et al. 1990 for Queensland; also see section 'Disease').

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Drought and its impact on food

Before European settlement kangaroos probably declined during drought, when they became more restricted to refugia with permanent water, from which the expanded out when conditions improved (Landsberg et al. 1999). As the result of the spread of pastoralism, food is thought to have replaced waterpoints as the major limiting factor to large herbivores in many arid and semi-arid areas (Newsome 1971a, 1975; Oliver 1986; Caughley 1987a; Robertson et al. 1987a).

Rainfall (especially lack of) and its impact on plant productivity have a profound impact on kangaroo populations (e.g., Bayliss 1987; McCarthy 1996; Cairns et al. 2000). For example, drought in 1982-1983 resulted in population declines of about 40% in the three large kangaroo species over more the one million square kilometres, attributed to food shortage (Caughley et al. 1985). Rainfall and pasture biomass are correlated strongly with rate of increase in the kangaroo population and the relationships appear to be causal (Caughley et al. 1984; Bayliss 1985a,1987; Caughley 1987; Shepherd 1987; Cairns and Grigg 1993). Direct benefits of rain, such as water for drinking, are not thought to be as important in general.

Kangaroos are most numerous around water during dry periods and drought (Newsome 1965; Norbury and Norbury 1993; Gibson 1995) when they require the most water (Dawson et al. 1975). Dispersion is influenced by pasture quality, with green pasture favoured (Frith 1964; Newsome 1965a; Bailey 1971). For instance, Newsome (1965) reported that 83% of Red kangaroos were within 2 km of green pick when conditions were dry and this fell to 48% after rain. Although they are often painted as highly mobile and movements are longest during drought (Frith 1964; Newsome 1965a; Bailey 1971), only a small portion of the population, mainly young males, moves far. For example, Newsome (1965) found that 68% of Red Kangaroos were near water during drought and this decreased only marginally to 63% after rain. On the New England Tablelands, home ranges of Eastern Grey Kangaroos averaged 4 km^2 and 70% of movements were for distances of less than 2.5 km (Jarman and Taylor 1983).

Body condition and reproductive performance are also related to rainfall (Kirkpatrick and McEvoy 1966; Shepherd 1987; Moss and Croft 1999). During drought, mortality is high especially among adult males and juveniles (Bayliss 1985; Robertson 1986a; Pople 1996). More kangaroos are killed on the road, as they increasingly seek green pick to graze on the verges (Coulson 1989), the risk of epizootics increases (Ealey and Main 1967; also see Disease section), and they are more vulnerable to Dingo predation when they congregate around water (Corbett and Newsome 1987). These factors are compensatory, removing a ‘doomed surplus’ that would die anyway from one cause or another (e.g., Caughley and Sinclair 1994).

High male mortality and low juvenile recruitment during drought results in high rates of increase when conditions begin to improve (Bayliss 1985; Pople 1996). A similar age-sex structure is created in harvested populations. Thus, the potential rate of increase is higher in harvested than unharvested populations and there is a strong female bias (Pople and Cairns 1995). However, this difference may only be important when pasture conditions are good.

Overview

Rainfall via its influence on plant productivity is the single most important factor impacting on kangaroo populations. However, kangaroo are well adapted to a dynamic environment and recover quickly after drought-driven population crashes (e.g., Caughley et al. 1985; Bayliss 1987a; Cairns and Grigg 1993).

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Disease – parasites and pathogens

The most recent review of diseases of wild-living macropods is by Speare et al. (1989). A number of pathogens and parasites have been identified but their ecology and influence of disease on wild populations is little understood. Nevertheless, although episodic outbreaks occasionally decimate populations, the consensus appears to be that, in general, disease is not an important agent of mortality (e.g., at Kinchega, Caughley 1987b).

Lumpy jaw syndrome is one of the best known pathogens for marsupials. The micro-organism most often associated with the condition is a bacterium *Fusiformis necrophorus* (= *Fusobacterium necrophorum*). Most often, it affects the lips, jaws, tongue and invades the mandibles and maxillae. In the acute disease the animal dies between a few days and 2-3 weeks and before it has lost much condition. The infection is thought to be initiated by trauma to the soft tissues by sharp feed, perhaps during drought, which allows entry to the bacterium (Samuel 1978; Munday 1978). In wild populations, outbreaks of lumpy jaw have been reported for Red Kangaroos (Tomlinson & Gooding 1954), Grey Kangaroos, Euros (Calaby & Poole 1971) and various wallabies (references in Munday 1978 and Speare et al. 1989). Apart from epidemics in Western Australian Red Kangaroos in 1918, 1927, 1935-6, 1952 and 1953-4 (Tomlinson & Gooding 1954), in the wild the incidence of the syndrome is sporadic and limited in extent. As with outbreaks of many pathogens, it appears to have been associated with drought, over-crowding and build-up of faeces (Finnie 1978; Speare et al. 1989).

Parasites, both external and internal, can cause death or loss of health. If parasitism lowers average health it can have an impact on reproductive rate, which might be difficult to detect. However, in general, parasites have ‘no discernible affect upon the health of their host' (Caughley and Sinclair 1994). The effect of macropod parasites is often obvious only in times of stress, particularly drought (Kirkpatrick 1985). An epidemic attributed to the intestinal parasite *Globocephaloides trifidospicularis* caused the death of many subadult Eastern Grey Kangaroos following over-crowding, in Victoria in 1971-2 (Arundel et al. 1977). In Victoria in 1970, a coccidiosis (a protozoan) outbreak caused the deaths of a large number of juvenile Eastern Grey Kangaroos stranded by flood, again associated with over-crowding and faecal build-up (Barker et al. 1972).

A spectacular, fatal disease of uncertain aetiology mainly seems to affect Red Kangaroos, but also Grey Kangaroos, and Euros, and is associated with the periodic floods inland and resulting build up of biting insects (Kirkpatrick 1985). The disease may cause partial blindness, swelling and paralysis and kills large numbers of animals over a wide area. In October 1998, an epidemic struck the Tibooburra over 2-3 weeks (Gilroy et al. 1999). The Red Kangaroo population was estimated to have been reduced from 908,000 to 522,000, which equated to a 40% loss, leaving the lowest population since 1985. It was concluded that it was the same disease, believed to be caused by an unidentified insect borne virus, that occurred in Queensland in 1998-1999 and Currawinya in 1999 (Gilroy et al. 1999). All ages seem to have been affected.

The same or similar insect borne virus that may be an arbovirus with a sandfly vector (Speare et al. 1990) is thought to have caused up to a 60% reduction in the Red Kangaroo population and high mortalities of Eastern Grey Kangaroos and Wallaroos close to the flooding Thompson, Barcoo, Cooper river system of Queensland in 1990 (Clancy et al. 1990). Elsewhere during the same flood event, Choquenot (1991) found no evidence of mortality, indicating that the epizootic was local and not an inevitable consequence of flooding. In between outbreaks the virus must persist, possibly in an alternative host(s).

Concerns have been expressed that this or another unidentified insect borne virus that causes occasional epidemics in kangaroos resembles Paroo Staggers in sheep, which appears under similar environmental conditions but is not as lethal (e.g., Minutes 37th Meeting of KMAC, 1999). Parasites and pathogens that jump hosts are potentially serious because the naturally selected processes that ensure the persistence of the host and the parasite can be overidden, unleashing increased virulence (Caughley and Sinclair 1994). The impact of the viral-caused rinderpest in Africa is an example. Introduced in domestic cattle, it jumped to wild ungulates, causing massive mortality, and an increased reservoir for re-infection of domestic stock.

Ealey and Main (1967), describe irregular population ‘crashes’ of Euros in the Pilbara that they attribute to a degenerating environment, and exacerbated by pathogens. Newsome (1977a) noted a similar pattern in Red Kangaroos, especially where ruminants are allowed to over-graze.

Choroid blindness is also triggered by a biting-insect borne virus (Minutes 37th Meeting of KMAC, 1999), possibly one of the macropod herpesviruses described in Speare et al. (1989) or Wallal virus, an orbivirus, vectored by *Culiccicoides* sp. (Pople and Grigg 1999). Although causing a distressing condition in affected animals, these viruses are extremely common in kangaroos, but few are affected and mortality is uncommon. A NPWS funded survey showed that 50-80% of populations had been exposed to the virus but only 1-3% of kangaroos were affected (Minutes 37th Meeting of KMAC, 1999).

Overview

From the above, two interrelated conclusions can be reached:

- Parasites and pathogens per se appear not to be important agents of mortality, rather they are compensatory, having an impact when macropod populations are stressed or over-crowded (leading to poor nutrition and/or unhygienic conditions and ready spread of the infection) and during short, highly virulent outbreaks following periodic flooding. None of these epidemics is well-understood but kangaroo populations recovery after the event (e.g., Pople and Grigg 1999); and
- There may be potential for harvesting to be used preventatively, when populations are unusually high and extremes of weather, either drought or flood/high rainfall, are predicted.

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Predation

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

In their review of predators of macropods, Robertshaw and Harden (1989) concluded that there were only two important predators of the larger macropods, the Dingo and humans. More recent studies suggest that under certain circumstances other predators may also contribute to population limitation.

Robertshaw and Harden (1989) found no evidence that, over the last 200 years, direct human predation has altered the numbers or distribution of larger macropods in NSW and elsewhere on the mainland. They concluded that the Dingo is capable of altering the numbers and distribution of macropods, and hence limiting the macropod population, but that there was no evidence that predation has a regulatory influence on populations.

Population limitation is usually defined as the process that sets the equilibrium point of a population, and limiting factors can be either density-dependent or density-independent (Sinclair 1989). Thus, the predator-limitation hypothesis (Boutin 1992) contends that predators remove individuals that would otherwise contribute to the population, and is not just interchangeable with some other agent of mortality. The process that returns the population to its equilibrium point is known as regulation, and can only be density-dependent.

Of the raptors, only the Wedge-tailed Eagle is a significant predator of macropods. It is a capable predator of Red, Eastern and Western Grey Kangaroos, Euros and various wallabies (Jarman and Coulson 1989; Marchant and Higgins 1993; Leopold and Wolfe 1970), the majority being young at foot (e.g., 83% in parts of Western Australia;

Brooker and Ridpath 1980). To overcome larger, adult kangaroos, including Red Kangaroos, the eagles hunt co-operatively (various references in Marchant and Higgins 1993). The impact of eagle predation on kangaroo populations is unstudied.

Kangaroo remains in fox scats were formerly assumed to be from carrion (e.g., Jarman and Coulson 1989) but there have been reports of attacks on animals as large as Euros (Hornsby 1982) and a young at foot Eastern Grey Kangaroos. Banks et al. 2000 demonstrated that fox predation limited recruitment of juvenile Eastern Grey Kangaroos in Namadgi National Park. They also concluded that fox predation was an important population limiting factor. However, they did not monitor other factors often associated with increased recruitment, such as the resulting decrease in fecundity, which usually intervene in such systems so that the net loss is insignificant (e.g., Boutin 1992) and their interpretation of population trends was tentative.

The Dingo has been in Australia for several thousand years and is a significant predator of macropods. The impact of Dingoes is illustrated by the Dingo-proof fence in northern New South Wales, which separates areas with few Dingoes and abundant kangaroos from those where kangaroos are much less common in the presence of numbers of largely uncontrolled Dingoes (e.g., Jarman and Denny 1976; Caughley et al. 1980). For example, Caughley et al. (1980) argued that a 1 to 2 order-of-magnitude higher density of Red Kangaroos in northern NSW, compared with adjacent areas of Queensland and South Australia, was attributable to low predation in the absence of alternative prey (rabbits) to maintain Dingo populations at a level at which they could have an impact on the kangaroos.

Dingo destruction is thought to be a major reason for the increase in Red and Eastern Grey Kangaroo numbers and possibly range since settlement (Calaby and Grigg 1989).

Dingoes prey on a wide range of prey including the larger macropods, which constitute the major part of Dingo diet in most areas except drier inland sites where rabbits predominated (e.g., Shepherd 1981; Newsome et al. 1983; Robertshaw and Harden 1985a, 1985b, 1986). Juveniles rather than adults, especially of the larger macropods, are most prevalent in Dingo prey, which may impact on recruitment, demography and breeding patterns but this has yet to be demonstrated conclusively (Robertshaw and Harden 1989). Macropods are more vulnerable to Dingo predation during drought when they congregate around water (Corbett and Newsome 1987). However, under these conditions predation is likely to be compensatory – by removing a 'doomed surplus' (Errington 1946) that would die anyway either from stress-aggravated disease, predation or starvation (e.g., Caughley and Sinclair 1994).

Selective predation of juveniles of kangaroos and Wallaroos and of old male Wallaroos has been reported (e.g., Oliver 1986; Robertshaw and Harden 1989; Shepherd 1981). How this affects populations is poorly known. However, there are indications that the composition of populations may differ according to whether they are protected from Dingoes and either harvested or unharvested, or subject to predation by Dingoes (Pople and Grigg 1999). Predation can also improve the health of the population by removing the old and weak as well as by lowering density (Caughley and Sinclair 1994) although this has yet to be demonstrated in macropods.

Jarman and Coulson (1989) discussed the role of predators – including prehistoric hunters such as humans, marsupial lions (the Thylacoleonidae) and thylacines – in shaping kangaroo behaviour, especially grouping. Banks et al. (2000) reported that in areas subject to fox removal Eastern Grey Kangaroos grazed in more open situations and broke up into smaller groups. These changes could affect harvesting success.

Predator control is often conducted with the aim of increasing harvests of their prey, particularly in North America where predators are controlled to increase the numbers of ungulates available for recreational hunting. Boutin (1992) reviewed the outcomes of seven such programs and concluded that while predator removal appeared to generally enhance juvenile survival, there was evidence of an actual increase in ungulate abundance in only one case, moose responding to wolf removal in central Alaska. Boutin (1992) concluded that increased recruitment resulted from predator control, but this was compensated for by a shift in some other demographic trait, such as adult survival and/or fecundity, resulting in no net gain in the size of the ungulate population available for harvesting.

In harvested populations, depending on whether all, some or no animals that are harvested from a population would otherwise have been doomed to predation, predation could represent compensatory, partially compensatory or additional removal of animals from the harvested population (Caughley and Sinclair 1994). In the first case, predation has no effect on the harvest, although it may influence the abundance of the predator and/or alternative prey species. In the second and third cases, however, the number of animals removed from the population through predation will reduce the size of the population independently of the harvest. This will have consequences for the size and/or sustainability of a harvest, which may or may not have been accounted for in determining an appropriate harvesting rate, depending on how the rate was estimated, whether predation was operating at the time the rate was estimated, and the constancy of the impact of predation. Current harvest rates have been determined in the absence of significant predation and, in the light of Boutin's findings, may still be maintainable in the event of removal of Dingo control. However, if harvested kangaroo populations are limited by predators to a lower density than at present, then the net harvest would be lower (but see section 3.1 – reintroduction of predators – on the likelihood of smaller populations being the outcome).

Overview

There seems little doubt that predators can limit kangaroo populations (e.g., Jarman and Denny 1976; Caughley et al. 1980; Thomson 1992; Banks et al. 2000) and there is increasing evidence for a regulatory effect. In a comparison of populations separated by the dingo-proof fence, Pople et al. (2000) found indirect evidence that, in some situations, Dingoes regulated kangaroo populations. However, conclusive evidence requires monitoring of the effect of experimental removal of Dingoes and, if kangaroo populations increase, replacement of Dingoes at the critical time (Pople et al. 2000). Studies of the combined impact of predators – Dingoes, eagles and foxes – may also be enlightening.

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Habitat loss and modification

In the 200 years since European settlement, much of Australia's woodland and forest has been cleared. Of the estimated 52 million ha of forest and woodland at settlement, 21 million remain and the rest has been cleared or converted to open woodland (Biodiversity Unit 1996). Clearing has been most extensive in a 150 km wide strip of land along the eastern and southern edges of the Western Division and the northern wheatbelt within the Central Division (Biodiversity Unit 1996). In the rest of the Central Division, the northern tablelands and along the coastal strip clearing has been less extensive but targets remnant vegetation and so has concern for conservation. The larger kangaroos are the only native mammals to have benefited, overall, from these changes (Calaby and Grigg 1989). Most authors believe that, since European settlement, kangaroo numbers have increased substantially in Australia's rangelands, at least in the eastern pastoral zone where grasslands have been expanded (e.g., Shepherd and Caughley 1987; Pople and Grigg 1999). This is particularly so for the three largest species, the Red Kangaroo and the Eastern and Western Grey Kangaroos which are all thought to have increased in numbers and possibly range (Calaby and Grigg 1989; Pople and Grigg 1999). The Wallaroo is thought not to have undergone a significant change in either numbers or range.

How much of the changes in kangaroo populations can be attributed to habitat alteration is difficult to tell because other changes such as provision of water and Dingo control have occurred simultaneously. However, Southwell et al. (1999) clearly demonstrated gradients of macropod (Red Kangaroo and Wallaroo) abundance along a climate-human influence gradient, with low abundance at the extremes. Human influences included number of landholders, distance to the nearest house and town, and livestock density. Heavily cleared areas are thought to be detrimental (Pople 1989).

Surface water can be viewed as an element of habitat, but is dealt with in another section (‘Restricting access to water’).

Red Kangaroo

In NSW, Red Kangaroos occur west of the Great Dividing range in arid areas defined by the 400 mm isocline of average annual rainfall in the south and 700 mm in the north (Caughley et al. 1987b). Within this zone they are most abundant in arid areas, usually within mulga woodlands (Sinclair 1980; Pople and Grigg 1999) and least common in cultivated land with few shelter trees (Short and Grigg 1982).

Clearing to create a more open mosaic of habitats (as well as Dingo control and water provisioning) is thought to have resulted in an increase in population size since settlement (e.g., Russell 1974; Caughley et al. 1980; Squires 1982). Nevertheless, Red Kangaroos do not thrive in areas of intensive agriculture which, however, are not common within their range (Grigg 1982; Short and Grigg 1982). Pople and Grigg conclude that there have been no obvious shifts in overall distribution this century.

Eastern Grey Kangaroo

Eastern Grey Kangaroos occur in the east, within the 250 mm rainfall zone (Caughley et al. 1987b) in habitats ranging from semi-arid mallee to forest (e.g., Strahan 1995). In general, it thrives in pastoral areas and its distribution has shifted westwards into drier areas (Caughley et al. 1984) and may still be expanding (Cairns and Coombs 1992). Nevertheless, its numbers are lowest in intensively farmed areas, especially those without belts of trees along waterways (Short and Grigg 1982). For example, in the cropping/irrigation areas of the Parkes/Forbes region.

Western Grey Kangaroo

The Western Grey Kangaroo occurs across southern Australia, in NSW west of the Great Divide, in areas of aseasonal or winter rainfall (Caughley et al. 1987b). The Western Grey is more abundant where the ranges of the Eastern and Western Grey Kangaroos overlap in central and western NSW that is, areas into which the Eastern Grey has expanded, (Caughley et al. 1984). Like the Eastern Grey, in general. the species has been advantaged by pastoralism, but disadvantaged by intensive agriculture and over-clearing (Short and Grigg 1982).

Wallaroo

The Wallaroo occurs across almost the whole State, with the exception of the southern coastal strip. It is found in a wide range of habitats, especially in stoney, hilly country (e.g., Strahan 1995). Such areas generally are subject to less clearing than flatter, more open habitats of the other kangaroos.

Overview

Despite more than 200 years of heavy exploitation and clearing of the land, the larger macropods have maintained their populations or increased in abundance and range. Areas of extensive clearing, intensive agriculture and urbanisation appear to be the exceptions and support few kangaroos.

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3.3 GENETIC IMPACT OF CULLING

Task 3 – Review the genetic impact of kangaroo culling.

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).

Harvesting may alter the genetic structure and genetic diversity of a population (Caughley 1994; Pople and Grigg 1999). Concerns have also been expressed over the impact of harvesting on the maintenance of genetic diversity and fitness, particularly by the selective removal of big males. However, disruption of demographic processes may be more important than loss of genetic variation (Lande 1988), especially in such common and widespread species.

There is also the difficulty of detection of genetic problems. Even the practitioners of molecular studies caution that identifying what molecular variation is the 'stuff of evolution,' that is adaptive, remains an unsolved but important question for conservation (Hendrick 1996). Nevertheless, for harvested kangaroos, current techniques have the potential to detect, for example, whether there has been disruption to the mating system and to movements, and to assess genetic variation within populations (Moritz et al. 1996; Lynch 1996). Molecular studies have been relatively few. However, those and ecological studies of traits that reflect fitness point to absence of genetic impacts at current harvesting rate. The findings include:

- No change in genetic diversity detected after 10 years of heavy harvesting compared with unharvested Red Kangaroo populations (Clegg et al. 1998).
- No difference in gene diversity between heavily harvested and lightly harvested or unharvested Wallaroo populations (Hale et al. in prep.).
- Kangaroo populations (particularly those in the commercial zone) are adapted to periodic, drought-induced population reductions of as much as 40% over very large

areas (Caughley et al. 1985). Clegg et al. (1998) show that populations expected to be worst affected are less restricted genetically and that this is likely to be the effect of a high ability to disperse and recolonise.

- High genetic interconnectivity in Red Kangaroos across Australia (Clegg et al. 1998) making loss of genetic diversity due to present rates of harvesting extremely unlikely.
- Rapid recolonisation of areas where kangaroos have been heavily depleted by shooting (Edwards et al. 1994; Pople 1996), facilitated by mosaic of harvesting zones interspersed with conservation reserves, non-commercial areas, etc. (Pople and Grigg 1999), ameliorates any harvesting impacts.
- Genetic structuring in Wallaroo populations may require their management as distinct units (Moritz 1994; Hake and Moore in prep.) but this is not an issue in New South Wales where the population is continuous.
- No change in fecundity in heavily harvested Red Kangaroo populations (Pople 1996), indicating that there is no loss of reproductive fitness.
- Average carcass weight at chillers is consistent across NSW and years (Gilroy, March 1999, KMAC Meeting). Assuming harvest effort is similar, one interpretation of this is that there is no effective selection against big males, that is, no shortage in the population.

Older and larger males are harvested selectively (Jarman 1989) and these are the males that generally gain greatest access to females (Croft 1989). Thus, harvesting of the largest males is likely to increase the potential for a greater number of males to gain paternity and hence might actually increase genetic diversity, albeit with a slight risk of simultaneously increasing the frequency of harmful alleles (Pople and Grigg 1999).

In natural populations most selection occurs via the heavy mortality among the young and, particularly, via selective paternity. Observational studies indicate that males over 10 years old, and high ranking males, have greatest breeding success (Croft 1980, 1981, 1989). This is not unexpected but is yet to be confirmed by molecular assignment of paternity. Nor has the effect of size, independently of age, on mating success been determined, but there are indications that females tend to avoid copulations with the largest males (Peter Jarman pers. comm.) and large males are unlikely to gain all paternity otherwise selection would be for ever-bigger males. Hence, natural selection for large male size is likely to be complex.

If selection of kangaroos for harvesting is random except for body-size, which is likely to be the case, removal of 20% of the population across the board is unlikely to alter the measurable genetic composition, resulting for example, in selection against large males. Males mature sexually at 3-4 years and presumably ‘good’ males or (one day to be) largest males have already gained some paternity by the time they are ten, the age of greatest breeding success. Furthermore, harvesting is carried out in a mosaic, so there will not be total removal of the biggest males and, if the largest males are the most successful at gaining paternity, the remaining large males may simply gain access to more females than they might have in the absence of harvesting (this could be tested experimentally). Also, as mature males become scarcer, shooters typically become less selective (Pople and Grigg 1999). Lastly, selection imposed by a dramatically fluctuating environment, that imposes heavy mortality on males during drought, is natural and likely to override harvesting impacts (Pople and Grigg 1999).

Overview

Currently, there is no evidence of real or potential genetic ‘deterioration’ due to harvesting, nor any reason to suspect it. Indeed, indications are that kangaroo numbers would have to reduced to extremely low levels for genetic impacts to become important and by then other impacts, such as demographic disruption, would be overridingly important (e.g., Lande 1988; Pople and Grigg 1999; Caughley 1994).

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3.4 GRAZING MANAGEMENT

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.

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

One of the most important elements in any grazing system is the stocking rate (Wilson and Hodgkinson 1991). It is generally considered that overstocking and hence overgrazing by sheep and other herbivores has led to degradation of Australia’s rangelands since European settlement (Graetz 1988). While domestic and feral herbivores are generally viewed as the major agents of overgrazing, native herbivores also contribute to changes in pasture biomass and species composition, and hence contribute to total grazing pressure (Freudenberger 1995). This has resulted in changed species composition of grasslands toward a community containing more annual forbs and grasses and fewer perennial species (Beadle 1948; Perry 1977). Grazing is also believed to have inhibited the regeneration of some species of trees and shrubs (Harrington et al. 1984). These changes have increased soil erosion and reduced water recharge rates (Woods 1984). Management of total grazing pressure is necessary if continuing degradation of the rangelands is to be slowed, halted or reversed (Ludwig et al. 1997).

One of the ways to monitor overgrazing is through an index of impact, such a by measuring total grazing pressure (TGP). TGP is an understandable concept that can be defined in various ways, often, for example, as some variation on ‘demand or amount of feed available for grazing animals divided by the number of grazing animals' (Carman and Heyward 1998). At a given herbivore density, TGP increases as the amount of forage decreases. Total Grazing Pressure is best defined as 'the sum impact of stock, native herbivores and introduced species on pastures' (Choquenot et al. 1998). This is usually but not always what is commonly referred to as TGP. Hence, a preferable term is Total Grazing Impact (TGI), which places the focus on alleviating impact, a sensible management approach. Biomass and structure are elements of this, both of which can be altered or maintained by grazing. In the case of over-grazing, the alteration can escalate into degradation.

Kangaroos and goats are responsible for more than half the TGP in some southern rangeland areas (Dawson et al. 1975; Landsberg et al. 1992) and some studies indicate that kangaroos alone can account for over 50% of total grazing pressure in certain areas (unpubl. data cited in Freudenberger and Hacker 1995). There has been a recent push from pastoralists and some sections of government to reduce kangaroo numbers to reduce TGP (Pople and Grigg 1999).

It is important to note that TGP measured simply as grazing pressure in terms of total food available and total required by grazers has little practical meaning or application. It cannot address problems of damage (aim c of KMP), particularly because it does not tackle qualitative changes to vegetation such a structure and species composition, nor are the various grazers interchangeable, because each has a different impact on the vegetation. Neither does alleviation of TGP thus defined translate into greater production, as is often anticipated (see below: Specific issue – Ecological and economic benefits of fewer kangaroos where domestic sheep, cattle or goats continue to graze, and 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).

Hereafter, in this section TGP and TGI will be used interchangeably, although, with a few exceptions, the studies mentioned rarely measure either adequately.

Estimating TGP

Most often grazing pressure is estimated from the change in dry plant biomass (e.g., Caughley et al 1987; Short 1987) or the average amount consumed by a non-lactating individual of that species. The latter is converted into dry sheep equivalents for the major grazers in the system of interest and their combined impacts summed (Robertson 1987; Short 1985; Pickard 1988), see, for example, Table 2. Because it is difficult to monitor all the grazers in the system, TGP is probably more accurately reflected in damage estimates such as changes in pasture biomass.

Table 2. Comparative grazing pressure by six species of vertebrate herbivore on the rangelands of NSW.

	No. (millions)	Dry sheep equivalents	Grazing Pressure	Comparative contribution
Sheep	47	1	4.7	All livestock 55%
Cattle	0.18	7	1.26	
Goats	1.4	0.7	1.0	10%
Red Kangaroos	2.9	0.7	2.03	All kangaroos 35%
Grey Kangaroos (2 spp)	2.4	0.7	1.68	

Source: Alan Wilson in presentation to the KMAC's 35th Meeting, November 1998. The figures are generalised, TGP will vary from place to place and time to time.

It is also possible to roughly gauge TGP indirectly. For example, in Carman and Heywood's survey (1998 a), graziers reported using a variety of signs to manage TGP, these included various combinations of seasons and weather, rain and wind and temperature. They checked waterpoints for damage and to see whether animals were congregated (a sign of high grazing pressure), and also assessed condition of stock, numbers of kangaroos, plant condition etc.

One problem in the estimation of TGP and the application of TGP theory is that there is a functional response in plants to grazing, as well as a functional response in grazers to plant growth, so that there is not a simple linear relationship between plant biomass and grazing pressure (Short 1985; Ginnett and Demment 1995; Gross et al. 1993). So, for example, plant growth can be stronger in the presence of heavy grazing when conditions are good and the reverse applies in drought. Grazers may eat relatively more pasture when it is young and sweet. There are also alternative foods that are outside the usual grazing system, for example, pasture grazers may turn to other plants (e.g., shrubs) when conditions become tough. Another problem is that quite often there is more than enough vegetation to support all the herbivores and under such circumstances interrelationships are difficult to detect and measure (Short 1985).

Grazing pressure studies

Caughley (1985) stated that a herbivore mix of 60% sheep and 40% kangaroos cropped about the same biomass of pasture as did kangaroos alone. An exclusion experiment on grazing pressure involved Black-striped Wallabies in Queensland, in which there were three treatments, wallabies, wallabies and cattle and cattle alone (Lavery 1985). During a dry year, wallabies alone had the same impact on the pasture as did a mixture of cattle and wallabies.

Between 1980-1985, rainfall and grazing by mammals were the major determinants of pasture biomass at two study areas, one in Kinchega National Park, the other at a nearby sheep station (Robertson 1986b). Rainfall accounted for 69% of the variance in biomass. Kangaroos removed about the same biomass at Kinchega as sheep and kangaroos combined at the station. Grazing had minimal impact on pasture biomass in most seasons except the drought of 1982/3. Indeed, it is important to note that much of the time pasture systems produce more feed than grazing animals can eat. As an example, in western New South Wales, it is not until the pasture biomass falls below about 250 kilograms per hectare that there is significant competition for pasture between sheep and other grazers such as rabbits, feral goats and kangaroos (Short 1985). At Kinchega, kangaroos and sheep are thought to compete when pasture biomass falls below 300 kg/ha (Caughley et al 1987; Short 1987).

At Hattah-Kulkyne National Park, Victoria, the dry biomass of monocotyledonous plants is used as an index of impact and studies have indicated that, under average conditions, kangaroos must be kept to a density of about 5 animals/sq km to maintain the pasture at 400 kg /ha (in the absence of stock and with rabbits kept to low numbers) and prevent pasture degradation (Coulson 1990 a, b; DCE 1990). At Wyperfield, where vegetation-promoting events are more episodic, the index on which kangaroo management is based is vegetation condition dependent and the models take rainfall into account (Andrew Marshall, pers. comm.; Morgan 1999; Wouters et al. 2000).

Perceptions of TGP

Carman and Heywood (1998b) interviewed graziers in the mulga lands to ascertain their perceptions of total grazing pressure (defined in the simple sense, as total food – total grazer requirements). Graziers believed that about half the total grazing pressure on their properties was from domestic stock, and the remainder from feral and native grazers and insects. NSW graziers estimated that 19% of TGP could be attributed to kangaroos and goats.

In Carman and Heywood's survey (1998 a), to alter total grazing pressure, graziers reported that they sold or agisted stock or took it on the road. Alternatively, a number of graziers kept low numbers of stock so that feed was always available, even during drought.

The graziers also culled kangaroos and feral goats, and controlled rabbits (Carman and Heywood 1998 a). Ninety-one percent (of 74) of graziers said they culled kangaroos (self or 'roo shooter) when grazing pressure was high, but 88% said they also culled when pressure was low. Only 8% said they would cull native animals or ferals to ease grazing pressure. Clearly, graziers see kangaroos as a pest but do not manage them according to total grazing pressure.

Further, graziers' management of TGP was often constrained, for example, by financial circumstances, lack of time or assistance or low market prices. It was concluded that graziers have the skills to manage 'TGP' but that this was often frustrated by off- and on-property factors.

Another plant-grazer harvest model

Choquenot et al (1998) describe the following model:

'The value of H (instantaneous rate of harvest) required to hold a population at given N (population size) is the population's annual productivity (HN). …..Because vegetation growth (and hence biomass) varies with environmental factors such as rainfall, offtake by the herbivores and the biomass of the vegetation itself, at any point in time vegetation biomass will rarely be systematically related to herbivore density. This means that both vegetation biomass and herbivore density need to be taken into consideration in order to accurately predict HN, and that predictions of HN may hold for only short periods of time.

For example, Caughley (1987b) estimated the interactive model for a grazing system comprising red kangaroos and chenopod shrubland pastures in Australia's semi-arid rangelands, and used the model to explore harvesting strategies for kangaroos. To account for the intrinsic lability (variability) of the grazing system, Caughley advocated harvesting a set proportion of the kangaroo population rather than a set density or quota as is the usual case for harvests based on logistic harvesting models. By simulating repeated harvesting of a kangaroo population at different proportional rates, Caughley identified that a harvest rate of 10 to 15% of prevailing density maximised long-term red kangaroo offtake on an area basis (that is, Red Kangaroos harvested/km2). This proportional rate corresponds to an instantaneous harvest rate of H=0.14, which is taken regardless of prevailing population density or whether kangaroo abundance is increasing or decreasing.

Such a strategy balances the offtake of kangaroos against stochastic variation in the availability of their food resources. In a general sense, the rate of harvest which achieves this balance will depend on the variability of the environment which the harvested population inhabits and the relative efficiency of the three functions defining the interaction between the population and its food resources.'

Overview

TGP theory is a potentially useful but often misunderstood concept. Measured, as it often is, in terms of total food available and total required by grazers, TGP theory has little practical meaning or application. It would be better renamed Total Grazing Impact

(TGI) and focused on impact (as per Choquenot et al.'s 1998 definition). Basing management on a damage index, such as TGI, is good management practice because it focuses on the desired outcome, that is, the amelioration or avoidance of impact (e.g., Braysher 1993). TGP can then be used for example, to alleviate impact on pasture species, a rare plant, or a plant community. It requires a model to be developed of the relationship between the impact and the causes of that impact (herbivores). Then herbivores can be managed to keep the impact above the desired level, presumably that at which they are damaging the species or system.

TGP carries with it fewer problems than carrying capacity theory (see below). It has the advantage of being applicable even in disturbed environments. However, vegetation growth varies with environmental factors such as rainfall, 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 (Choquenot et al. 1998). Hence, TGP/TGI-based management is particularly unreliable in violently fluctuating environments because change can happen fast.

On individual properties, management of TGP has some use for the management of sheep because they are under the graziers' control and can be sold, moved, etc. Similarly in other 'simple' or controlled systems, such as Hattah-Kulkyne National Park, where rabbits are controlled and there are no stock, that is, kangaroos are the major contributors to TGP, managing kangaroos according to their impact on pasture is possible.

Nevertheless, as a broadscale kangaroo harvesting management tool, the application of TGP theory is highly questionable. Harvesting takes place over a wide range of habitat and pasture conditions, in the presence of a suite of grazers that varies from place to place and time to time, and various climatic conditions. It would be difficult if not impossible to devise and implement a TGP-based management system that could allow for all the confounding factors. The resources and expertise required would be formidable. Further, Pople and Grigg (1999) point out that harvesting solely to mitigate damage requires no quota and is based on a damage index (such as a measure of TGP). This approach treats kangaroos solely as pests without regard for their conservation or their value as a resource.

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.

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 (Caughley 1980). This is ecological carrying capacity and should be distinguished from economic carrying capacity (Shepherd and Caughley 1987).

Economic carrying capacity is the population level that allows the maximum offtake for culling or cropping and is well below the ecological carrying capacity (Caughley and Sinclair 1994). For a population increasing logistically economic carrying capacity is 1/2K (Caughley 1976).

Carrying capacity can also be what is tolerated or acceptable to land use practices, for example, it may be zero where there is no value placed on the presence of kangaroos (Caughley and Sinclair 1994).

An example of the application of carrying capacity theory to wildlife management is Coe et al. (1976). From the relationship between large grazers and rainfall, they developed a method to measure total herbivore carrying capacity and use that to estimate a grazer's contribution: $K = \log_{10}$ (herbivore biomass) + 1.55 $\log_{10}$ (rainfall in mm) – 0.62; this gives a value of K of between 20 and 36 goat equivalents per square kilometre. Parkes et al. (1996) considered Coe et al.'s method for use in Australia for feral goat management. They found it had problems which included that it was calculated for African conditions that were more fertile than the Australian rangelands and it was based on goats alone, which may have a different relationship with rainfall than would a suite of herbivores.

Shepherd and Caughley (1987) argued strongly that in much of the commercial zone marked fluctuations in rainfall occur unpredictably, hence, carrying capacity theory, which was developed for stable temperate and tropical areas, is invalid and has no relevance. McLeod (1997) agreed that its use was questionable for variable environments.

Carrying capacity is not intrinsic to certain species, but the range of carrying capacities is likely to be (Milner-Gulland and Mace 1998). By definition it can be estimated (and therefore applied) only for undisturbed situations. Hence, its estimation for the four harvested kangaroo species in the range of habitats they occupy would be an ambitious if not impossible undertaking.

Overview

The concept of carrying capacity is catchy, but its interpretation is problematic even for stable environments. It does not allow for qualitative aspects grazing impact that involve, for example, structural rather than biomass changes. In Australia, it may only be applicable to domestic stock, when considering economic carrying capacity. The unpredictable nature of the climate in the harvesting zone and the impracticality if not impossibility of estimating carrying capacity, make the concept irrelevant to kangaroo management.

<u>Specific issue</u> – 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.

The current harvesting strategy uses a variable quota that is proportional to population size and can be adjusted according to conditions, such as in time of drought or disease. Under section 4.9 of the KMP proposed quotas are based on information relative to:

a) the population estimates from the most recent annual survey figures;
b) recent trends in population numbers and distribution, as obtained from the aerial surveys, any ground surveys, and field officers' reports;
c) monitoring strategies as outlined in sections 4.4 and 4.12;
d) non-harvest mortality, and its significance;
e) non-commercial harvesting, and its significance;
f) climatic conditions over at least the previous year;
g) current land use, and trends;
h) proportion of population (and land) not subject to culling for agricultural damage mitigation purposes; and
i) damage mitigation and potential damage mitigation reports and information collected by NPWS from land occupiers and land managers.

The current harvesting system is administratively simple, able to cope with the broad scale of the management and monitoring issues, provides good balance between damage mitigation and conservation objectives, is flexible and has been operated successfully and improved over two decades (e.g., Shepherd and Caughley 1987; McLeod and Pople 1995; Pople and Grigg 1999). At least for Red Kangaroos in Queensland, where the quota set has been regularly approached over recent years, preliminary evidence suggests quotas are an adequate system of regulation (Choquenot et al. 1998).

To harvest kangaroos down to a pre-defined minimal density has several requirements. The minimal density would have to be determined, perhaps based on a plant-herbivore model that would need to be developed for particular areas and suites of grazers (see sections 3.4 on TGP, carrying capacity etc) and not compromise conservation goals. This would require a rigorous research over several seasons. It would be resource intensive both to develop and administer and probably only possible in more controlled areas like parks and reserves where stock is not a confounding factor. For example, at Hattah-Kulkyne National Park, kangaroos are kept to a minimum density of about 5 animals/sq km to maintain monocotyledonous plants at 400 kg /ha (Coulson 1990a, b; Coulson and Norbury 1988; DCE 1990). However, the Park is a relatively simple system where rabbits are kept to low numbers, there are no stock, and the climate is relatively predictable.

On private land the problems of setting minimums, monitoring and managing all the major confounding factors that impinge on plant-herbivore systems management would be formidable, as would the actual maintenance of kangaroo numbers at a minimum.

A set density system would not be appropriate in areas where the climate is unpredictable, vegetation damage is periodic and kangaroo numbers (and stock etc.) vary widely. By contrast, the current method for setting quotas can account for the intrinsic variability of grazing systems Caughley (1987b). This strategy balances the offtake of kangaroos against random variation in the availability of their food resources.

Overview

Managing kangaroos down to a pre-defined density is unlikely to be economical on the broadscale and also on individual properties. It may have application for large parks and reserves in areas where the climate is reasonably predictable, but it is a resource intensive management system to develop and maintain.

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

Because of their similar diets, the impression could be gained that more sheep can be run where kangaroos are reduced (Shepherd and Caughley 1987). However, Hassall and Associates (1982) showed that, in the Western Division, pastoral enterprises were performing badly and had problems of chronic overstocking compared with agricultural enterprises elsewhere in NSW. The situation has worsened in the subsequent 20 years. This led Shepherd and Caughley (1985) to strongly recommend that holistic management of the rangelands was the solution, rather than seeking ways to increase stock numbers in the short-term (Shepherd and Caughley 1985).

There have been no experimental studies on the impact of kangaroo densities on sheep densities, but it has been shown that sheep prevail in competition for pasture during drought (Caughley 1985). Clarke and Cottam (1995) reported that simultaneous culling of kangaroos and reduction of stock resulted in more efficient production per animal and other benefits. However, it is not possible to know whether removal of kangaroos and/or reduction of stock produced this outcome.

Data supporting the contention that reducing domestic animal stocking rates increases kangaroo density (and hence harvest yield) are equivocal (Choquennot et al. 1998; Pople and Grigg 1998; Pople and McLeod 2000). Kangaroo densities on Kinchega National Park between 1973 and 1984 were on average twice that on Tandou, a neighbouring property (Robertson 1987). While some of this difference probably reflected an impact of sheep on kangaroo density, other factors also differed between the two sites. These included a variable degree of kangaroo harvesting on Tandou, the disruptive effect the kangaroo-proof fence between the two sites may have played in dispersal, and the potential effect dryland cropping over a large portion of Tandou had on kangaroo densities on that property. In contrast, a study by Denny (unpubl. data cited in Edwards 1989) reported that there was no difference in kangaroo density between Sturt National Park in northwestern NSW and adjacent pastoral properties.

Gibson and Young (1987) found that kangaroo density in the rangelands averaged about 20% of sheep density, irrespective of stocking rate (Figure 1). This correlation between sheep and kangaroo density may suggest that some sort have dynamic balance has developed between sheep and kangaroos. Indeed, Caughley (1987a) suggested that many grazing systems in Australia reached a new dynamic equilibrium after the introduction of sheep in the late 1700s, initial increase in numbers, then a steep reduction in sheep numbers in the late 1890s accompanied by an increase in kangaroos. Further, land grazed by a cattle-kangaroo mix is more productive on most pastures than it is when grazed by either species alone (Lavery 1985).

Edwards (1989) suggested that:

- Rangelands may be better used by mixed grazing, given that kangaroos and sheep often eat different plants; and
- Pastures may be maintained at a more desirable ecological equilibrium under mixed grazing than in the presence of sheep alone.

He recommended that further studies were required to test the usefulness of mixed-grazing.

Overview

Simplistic removal of kangaroos will not necessarily allow replacement with the equivalent in stock or improvement of productivity (e.g., wool production). Limited evidence suggests that mixed grazing regimes are more productive and ecologically sound.

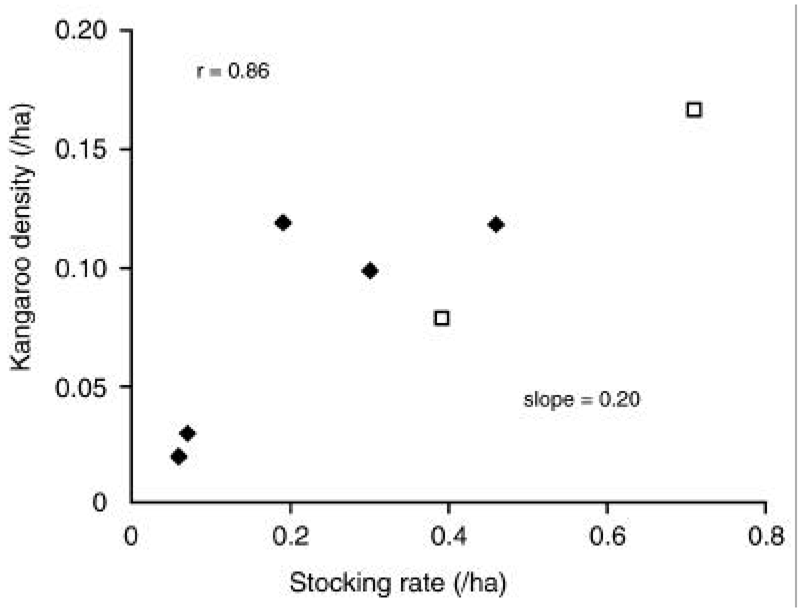

Figure 1. Relationship between stocking rate and kangaroo density across rangelands in Australia. Diamonds are areas used only for grazing; squares are marginal cropping areas (Choquenot et al. 1998, data from Gibson and Young 1987).

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).

Sheep compared with kangaroos

The numbers of sheep in Australia are estimated at approximately 150 million, compared with 25-35 million kangaroos (ABS; Pople and Grigg 1999). There is little doubt that under certain conditions kangaroos compete with stock for water and food (Shepherd and Caughley 1987).

The large macropods are grass eaters; sheep have a much more varied diet (Dawson 1989). There is great variability but some general patterns (Edwards 1989). These include: between kangaroos and sheep diet overlap is greatest during drought (Barker 1987; Dawson 1989) but even then diets differ (Wiens 1977). Kangaroo diets always contain mostly grass (Dawson 1989; Edwards 1989; Jarman and Phillips 1989); in sheep, grass is only occasionally the main component of diet (Dawson 1989; Jarman and Phillips 1989); kangaroos select low fibre portions of plants (Dawson 1989). Of necessity, Red Kangaroos may be less selective than the other large kangaroos (Dawson 1989) and overlap between them and sheep may be greater than with other large kangaroos (Griffiths and Barker 1966), with a similar range of plants eaten. Even though kangaroos prefer to graze in certain areas, such as where pasture is succulent (Hill in Lavery 1985), within them they take plants in similar proportions to which they occur in the pasture; sheep are generally more selective (Lavery 1985).

Sheep vs kangaroos

Caughley (1987b) surmised that, in semi-arid areas, sheep and kangaroos competed when pasture biomass fell below 300 kg/ha. He postulated that sheep impact upon kangaroo more than the reverse, and ran a simulation model that suggested that sheep can suppress kangaroo population by 42% in the longterm. However, he cautioned about his assumption of shared food resources.

McLeod (1996) reviewed studies of sheep-kangaroo grazing interaction. Wilson (1991a) and Edwards et al. (1995, 1996) attempted experimental studies of competition. At Fowler's Gap, Edwards et al. found little evidence of competition in the rangelands at pasture biomasses above 50-60 g/m^2 (500-600 kg/ha). For the same study area, McLeod (1996) concluded that competition occurred only in unusual circumstances, when kangaroo numbers were high and pastures poor. He further reported that sheep prevailed under such conditions and that kangaroos avoided pasture species grazed by sheep. In semi-arid woodlands near Louth, Wilson (1991a) reported competitive effects but used unrealistically high numbers of sheep and fences unnaturally confined the kangaroos, which makes the results questionable. However, he recognised that the important issue was whether there was economic harm, not competition per se.

Impact on native vegetation and pastures

Sheep grazing has a major impact on vegetation communities, both in spatial scale and in the degree of change (Ealey 1967; Newman and Condon 1969; Leigh 1974; Wilson and Graetz 1979; Robertson et al. 1987). It causes changes in soil and vegetation, particularly in the low shrublands (Newman and Condon 1969). Continued heavy sheep grazing creates sub-climax communities dominated by ephemerals and grasses (Moore 1962; Newman and Condon 1969). In semi-arid areas, replacement of palatable species by woody weeds, spiney and otherwise unpalatable species is a particular problem (Moore 1962; Leigh 1977; Harrington et al. 1979).

The creation of sub-climax communities by sheep has actually favoured kangaroos, allowing them to increase in numbers (Newsome 1971b; Frith 1973; Denny 1980). In more arid areas, Newsome (1971 a, b, 1975) believed that sheep (and cattle) crop the dry perennials allowing a flush of green when conditions are suitable, providing preferred grazing for Red Kangaroos. A similar effect has been reported for mesic (moderate) areas, where Grey Kangaroos are the beneficiaries (Moore 1962; Kaufmann 1974; Poole 1983).

Where dingoes are controlled kangaroos can become a pest and contribute to over-grazing (Norbury et al. 1993; Freudenberger 1995). Kangaroo impact on pastures is greatest in average years, and they may suppress recruitment and survival of perennial grasses and chenopod sub-shrubs and promote the spread of woody weeds (Gardiner 1986 a, b). Their impact is not as severe as that of sheep but they may help to maintaining sub-climax communities (Newsome 1975), perhaps to the disadvantage of sheep. By contrast, Freudenberger (1995) made the preliminary conclusion that at equivalent stocking densities (i.e. adjusted for the greater energy efficiency of kangaroos) kangaroos and sheep had a similar impact on standing forage and projected ground cover. However, the latter study was flawed experimentally, as he admitted, and because kangaroos were fenced into the study site rather than being able to roam naturally.

When conditions are dry herbivores must subsist on the standing dry plant biomass because plant growth is suspended. Kangaroos can move in search of better pasture (Pridell 1987), sheep are restrained by fences and hence can cause more pasture damage.

In the presence of overgrazing, sheep are unable to maintain themselves and numbers fall. Whereas kangaroos, that are better adapted to dynamic Australian systems (about twice as energy efficient as a same-size placental – Fanning and Dawson 1989), are able to survive and increase as conditions improve (Ealey 1967 for Euros). However, kangaroos starve to death before they can damage the shrub stratum, while sheep can survive on such a diet and cause irreversible damage; pasture species withdraw to the seed bank until conditions improve (Shepherd and Caughley 1987).

Long-term studies are important but rarely conducted. For example, in an experimental exclosure of degraded pasture in South Australia, sheep were removed in 1925 (Sinclair 1996). Rehabilitation was slow but accelerated after the removal of rabbits in the early 1970s even though kangaroos remained uncontrolled.

Table 3. Examples of the damage kangaroos may cause to pastoralism and agriculture. From Archer et al. (1985).

Western Grey Kangaroo	damage to grain crops, fences, pasture
Eastern Grey Kangaroo	damage to forest plantations, fences, pasture
Common Wallaroo	damage to pasture
Red Kangaroo	damage to field crops, fences, pasture

Economic impact

- McLeod (1996) reported decreased productivity of sheep in rare conditions, when kangaroo numbers were high and pasture biomass low. Kangaroos reduce wool production only during drought.
- Clarke and Cottam (1995) reported that culling of kangaroos and reduction of stock resulted in more efficient production per animal and other benefits. However, it is not possible to know whether removal of kangaroos and/or reduction of stock produced this outcome.

- In the semi-arid mulga woodlands, sheep body weight is affected more than wool production by increase kangaroo density (Wilson and McLeod cited in Edwards 1989; Wilson 1991b).
- In the arid shrublands at Fowler's Gap, removal experiments compared animals grazed in areas with sheep only with those with kangaroos only and both species combined (Edwards 1989). Only under poor conditions did sheep affect kangaroo body condition, rather than the reverse. Caughley's (1987) model lends support to this notion of an asymmetrical relationship.

Kangaroos occasionally cause significant damage to crops (e.g., 0.3% of the Queensland sugar cane crop, Lavery 1985; Archer et al. 1985), however, they are often scarce in intensively farmed areas (Short and Grigg). Travelling in search of green pick, they may graze pastures pastoralists are attempting to spell (Edwards 1989; Norbury and Norbury 1993).

Gibson and Young's 1988 analysis of the economics of culling, by survey of farmers in NSW and elsewhere, showed that landholder's perceived losses reached a total value of $113 million, equivalent to 3% of gross agricultural production in the commercial zone. This could be broken down into: fodder loss which accounted for 51%, crop production 27%, fence repairs 14% and water use 8%. The equivalent percentages for NSW alone were: fodder 43%; crops 36%; fences 11%; water 8%. This may have been more an index of the extent to which kangaroos were viewed as pests rather than a realistic estimate of costs (Pople and Grigg 1999). Although Gibson and Young estimated maximum possible losses to agriculture using the scientific literature and concluded that the farm survey results were not unreasonable.

Overview

Although studies are few, kangaroos do not appear to impact greatly on wool production and compelling evidence of competition between kangaroos and sheep is lacking. Evidence suggests that kangaroos cause far less damage to natural vegetation and pastures than do sheep, and then when conditions are poor due to drought or overstocking. By pastoralists' estimates, which might be expected to be somewhat exaggerated, the total of all perceived losses to kangaroos was equivalent to 3% of gross agricultural production in the commercial zone.

<u>Specific issue</u> – Other herbivores including invertebrates and their role in the ecological processes impacted by grazing.

Sheep and the four large macropods are the dominant vertebrate herbivores across most of southern Australia (Edwards 1989). However, in certain areas and conditions, other grazers can become important.

The combined impact of invertebrate grazers, such as some termites (order Isoptera), ants (family Formicidae) and grasshoppers (family Acrididae) is probably of greater significance to Australian grasslands than the combined effects of the vertebrate herbivores (Lee and Wood 1971, 1977). Caughley (1987) noted a sporadic but important effect of insects on pasture biomass. The invertebrates also have physical effects on the soil, both positive and negative, such as the denudation and cementing of termites. Termites are predominant invertebrate grazers in some areas, particularly cleared areas (Lavery 1985). Locusts and grasshoppers can denude vast areas but their effects are sporadic (Lee 1977). Wood and Lee (1971) concluded that competition between colonies of grass- and organic-feeding termites is greater on native pastures heavily grazed by stock than on unrgrazed or lightly grazed pasture. Where stock denude mulga, termites thrive until they have eaten it out (Wood and Gay 1970).

Goats can be as numerous as sheep in areas in northern NSW (Freudenberger 1993; Landsberg and Stol 1996). They damage pasture in a similar way to sheep but differ slightly in the vegetation preferences (Landsberg and Stohl 1996). Kangaroos and goats are responsible for more than half the total grazing pressure in some southern rangeland areas (Dawson et al. 1975; Landsberg et al. 1992). Rabbits can alter species composition, prevent growth of seedlings and help to promote the growth of exotics

(Williams et al. 1995). Newsome (1965), suggested that cattle alter the vegetation structure which in turn favours kangaroos.

In an exclosure experiment in the mulga, rabbits cropped seedlings before larger herbivores could eat them and trees died in the absence of goats (Henzell 1991). Hence, effective management for mulga protection needed to include all species.

It is important to note that, despite the number of herbivores, much of the time pasture systems produce more feed than grazing animals can eat. As an example, in western New South Wales, it is not until the pasture biomass falls below about 250 kilograms per hectare that there is significant competition for pasture between sheep and other grazers such as rabbits, feral goats and kangaroos (Short 1985).

Overview

There are a number of important grazers, both vertebrate and invertebrate, that occur with kangaroos. Studies are lacking on their combined effects and their interactions, yet effective management for habitat conservation depends on such knowledge. Pastoralists need to maintain ecologically and economically viable enterprises and manage total grazing impact from sheep, rabbits, kangaroo, feral goats and other grazers in the context of market and climatic risks (e.g., Parkes et al. 1996).

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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 NSW.

<u>Specific issue</u> – Accuracy of kangaroo population estimation methods currently used in the NSW KMP.

Estimates of density are required for setting quotas as a proportion of population size (Caughley and Sinclair 1994). Comprehensive reviews of macropod survey techniques have been carried out by Southwell (1989) and Pople (1999). Direct monitoring can be undertaken by foot or vehicle survey and aerial survey. Indirect monitoring includes counts of scats (e.g., Hill 1981; Perry and Braysher 1986; Bulinski and McArthur 2000) and the use of harvest statistics, but such measures are limited in application (Southwell 1989).

Direct monitoring

Line transect sampling is a well accepted way to estimate abundance, particularly of large, observable animals (e.g., Pollock and Kendall 1987; Pollock 1995). Ground counts from vehicles tend to be unreliable (Pople et al. 1998) but foot transects have proven accurate and useful for more detailed, intensive analyses of macropod distribution (Southwell 1989, 1994). In general, line transect surveys, on foot or by helicopter, are the most repeatable, least biased estimates of kangaroo density (Pople et al. 1998). However, the former is useful on the small to medium scale (Southwell 1989, 1994, 1995b) and the latter is prohibitively costly and labour intensive for broad scale survey (Pollock 1995; Pople et al. 1998). Survey from fixed-wing aircraft is the most cost-effective platform for broad-scale survey (Pople et al. 1998), Southwell (1989) concluded that aerial counts compared favourably with corresponding ground counts, confirmed by Clancy et al. (1997), but warned of the need of correction factors to allow for overlooked individuals. Thus, aerial survey using fixed-wing aircraft is the most repeatable and cost-effective way to survey large areas for the harvestable species, which occur in relatively flat, open habitat and are active around sunrise and sunset (e.g., Pople et al. 1998; Grigg and Pople 2000). Considerable effort has gone into development and application of aerial survey (Caughley et al. 1976, 1977: Caughley and Grigg 1981, 1982; Short et al. 1983).

Aerial survey by fixed wing aircraft has been the accepted practice for obtaining estimates of abundance of kangaroos in NSW, and Australia in general, for some years (e.g., Frith 1964; Newsome 1965c). The methodology is described in Pople and Grigg (1999). In NSW, aerial survey have been carried out since 1975-76 and since 1984 the western plains, totalling 500 000 km2, have been surveyed at a sampling intensity of about 0.8%. To a limited extent, helicopters are also used in Queensland and in NSW they have been used to survey Wallaroos in more rugged regions such as the Barrier, Mt Darling and Coonabaralba Ranges since 1993 (Pople and Grigg 1999).

Not all animals are seen from the aircraft so that correction factors must be applied to convert counts to estimates abundance; these were first estimated and applied by Caughley et al. (1976, 1977). Aerial counts are precise for any observable animals (Caughley et al. 1976) but correction factors are less reliable, varying according to habitat, in particular, and erring towards underestimates (Bayliss and Giles 1984; Pollock and Kendell 1987; Pople et al. 1998). Studies have established that sampling intensity of 1.5-2.5% per block (1:250 000 map square) over seven randomly-selected blocks gives a standard error of 5-8% of the estimate of Red Kangaroo numbers and 6-11% of Grey Kangaroo numbers for the whole area (NPWS 1984). The survey area represents the whole of the habitat of the Red and Western Grey Kangaroos. For Eastern Grey Kangaroos the survey area takes in only 55% of habitat, but covers 91% of the species' commercial harvest area. Censuses are carried out annually on winter mornings and evenings, when kangaroos are likely to be most visible. Large fluctuations in numbers can occur but often changes in behaviour resulting in changes in observability account for differences between repeated counts.

Population estimates for Western NSW, made by aerial survey, show standard errors of 10% for Grey Kangaroos (range 6-17%) and 7% for Red Kangaroos (4-10%)(Appendix 2). These would suggest a fair degree of repeatability.

So that actual densities (also to improve accuracy and repeatability and monitor population trends; Pollock and Kendall 1987), and hence quotas, can be estimated, considerable effort has gone into calculating and improving correction factors to allow for visibility problems from aircraft (Southwell 1989) with the emphasis on repeatability as distinguished from precision (e.g., Southwell 1989). Several methods of estimating habitat correction factors have been tested but the comparison of estimates from aerial survey with those from the ground have proven most reliable and generally applicable (Pople and Grigg 1999). Correction factors from Caughley et al. (1976) were used until recently, but are known to be underestimates and have been reassessed in most States (Pople and Grigg 1999). Since 1998, the correction factor for Grey Kangaroos in NSW has been increased to 3.5 (Pople and Grigg 1999). Stuart Cairns is currently analysing the results of a three year study of aerial survey conducted with the aim of improving species-specific correction factors for NSW (Cairns pers. comm.).

In NSW, for the zone of overlap of Eastern and Western Grey Kangaroos, which are inseparable from the air, the numbers of each are estimated according to the proportions of these two species determined for every one degree block in the overlap zone (KMP 1992-2002). Numbers have been apportioned approximately 70:30 Eastern:Western (based on Caughley et al. 1984 and harvest records). For the 2001 survey a reappraisal, based on the study by Stuart Cairns, will have established improved ratios (Gilroy, KMAC, March 1999).

Pople et al. (1998) compared four variations of fixed wing survey. As a result, they calculated revised (increased) correction factors for Eastern Grey Kangaroos and Common Wallaroos, and concluded that current estimates for Red Kangaroos were adequate (see Table 4). They suggested that a 100m strip transect offered improved visibility and therefore likely improved accuracy and repeatability. Correction factors for 100m strip transect were: 2.1-3.6 for Eastern Grey Kangaroos; 1.7-2.1 for Common Wallaroos; and 1.0-1.8 for Red Kangaroos. They recommended that the advantages of the narrower transect be weighed against the historical collection of data from 200m strips. If the 100m strip method was adopted then the relationship between the two methods would need to be well established so that the record remained comparable.

Pople et al. (1998) point out that kangaroo behaviour and habitat use, which are known to influence visibility (Hill et al. 1985; Short and Hone 1988), are themselves influenced by temperature, which has been shown to affect aerial survey reliability (Bayliss and Giles 1985). Hence, they suggest that a temperature correction factor may improve these sources of variability. For increased accuracy, they suggest that broad-based regional habitat correction factors could also be tested.

Table 4. Correction factors for 200m strip transects from fixed wing aircraft using the same methodology (Pople and Grigg 1999). Open refers to grassland and scrubland and wooded refers to vegetation ranging from low open woodland to woodland.

Source	Habitat	Red Kangaroo	Eastern Grey Kangaroo	Western Grey Kangaroo	Common Wallaroo
Bailey 1971	open	1.8			
Caughley et al. 1976	open	2.3			
Caughley et al. 1976	wooded	2.4			
Short and Bayliss 1985	open	1.8		4.8	
Short and Bayliss 1985	wooded	2.8		16.7	
Short and Hone 1988	open	2.5		5.9	11.1
Southwell 1989	open	1.8			3.9
Southwell 1989	wooded	4.2			23.3
Grice et al. 1990	wooded	3.8	3.5		
Southwell 1993	open	2.3			
Pople et al. 1993 (Windorah)	open	3.1	9.5		
Pople et al. 1993 (Bollon)	wooded	1.8	4.0		
Pople et al. 1993 (Roma)	wooded	0.7	3.4		
Pople et al. 1993 (Goondiwindi)	wooded		7.6		
Pople et al. 1998 (Longreach)	open	1.7	10.1		3.8
Pople et al. 1998 (Blackall)	open/wooded	2.6	5.0		4.1
Pople et al. 1998 (Charleville)	wooded	2.7*	3.7*		*

*given as 3.1, 5.1 and 4.8, respectively in Pople and Grigg (1999).

Indirect monitoring

Potentially, kangaroos can be monitored on a broadscale using characteristics of the harvested animals such as sex, age and average weight. Harvest characteristics have been used in Western Australia and Queensland, and has the benefit of continuous monitoring and wide coverage, but the technique has not been validated (Pople and Grigg 1999). Southwell (1989) discusses the technique. To be a useful population monitoring device a number of assumptions would have to be met and factors such as harvesting effort, market prices, weather etc., must be standardised. Despite these confounding factors, Nance (1985) developed an age-structured model to identify potential harvest monitoring methods and de la Mare (1988) built a model based on size-selective harvesting model. Neither model has been tested, and both must be amended, particularly so that they allow for a variable environment (Cairns 1989). Pople (1996) suggested that carcass weight, skin size and sex ratio might be useful indicators of harvest rate for Grey Kangaroos, but in Red Kangaroos only skin size had potential. In Queensland a range of harvesting parameters, supplemented by samples from harvested and unharvested populations, has been used in a model relating harvest regimes to offtake (Kirkpatrick and Nance 1985). At least at present, such models, indeed indirect monitoring using harvest statistics, remain unvalidated and of unknown value.

In the New England region of NSW, direct monitoring of Wallaroo populations by aerial survey from fixed winged aircraft is impossible because of the animals' preferred habitat of hilly, rocky and commonly forested areas, its similarity to Grey Kangaroos, and its discontinuous distribution. Recent demand for damage mitigation in the Western Slopes, Tablelands region and the ranges in the far west of NSW has indicated the need to reintroduce a quota for this species (KMP 1992-2002). Monitoring of this harvest will occur through shooter and dealer returns.

Overview

The current survey system in NSW is mainly based on aerial survey from fixed wing aircraft, which provides repeatable estimates and is suitable for use over most of the commercial zone. It has been developed over many years and, as a basis for setting quotas, has stood the test of time. The technique gives underestimates, particularly for Grey Kangaroos, on which quotas are based, and therefore provides conservative management. It is likely to remain the main survey method, especially in the absence of an economic and reliable alternative. Helicopter survey is more accurate because of improved visibility but because of cost is likely to be used only in rugged and heavily treed areas, where fixed wing survey is difficult. Indirect methods of monitoring, such as the use of harvest statistics for Wallaroos, remain to be developed and tested.

Although past estimates have proven adequate, the rigour of broadscale survey techniques is still being improved. For broadscale survey from fixed wing aircraft, correction factors continue to be refined to improve repeatability. Stuart Cairns is currently analysing the results of a three year study of aerial surveys aimed at producing species-specific correction factors for NSW. Potential ways to further lessen variability in estimates include the development and testing of temperature and/or habitat correction factors and the use of 100m as opposed to the standard 200m transect.

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<u>Specific issue</u> – 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.

Some landholders have called for a property by property assessment, so that if numbers are high on their property, they can remove more than allowed based on a regional assessment.

Kangaroos are relatively mobile. For example, in the rangelands, kangaroos travel approximately 20 km to reach preferred grazing areas (James et al. 1999). They may rely on some areas in times of stress or for other reasons, but spread more evenly over the region at others. Counts carried out on a property one day may be quite different the next day. Hence, the need for a regional perspective.

Abundance estimates by aerial surveys are corrected based on ground counts (see previous section). Hence, it is unlikely a paddock density estimate for all or a proportion of properties in an area would improve on the estimate for the region. Further, it would be difficult to make property by property assessments. Spot-light surveys are unreliable and would need to be repeated to determine reliability. Pellet counts would need to be quantified for the break-down rate of the pellet (which will vary with season and area). Total grazing impact from goats, rabbits and stock as well as kangaroos may also be a concern. However, assessing this adds greatly to the task. Monitoring and regulating a property-based system would be highly resource intensive.

Harvesting quotas are so rarely filled (see section 3.6) that in general they must be more than adequate to meet commercial harvesters' needs. Gibson and Young (1987) asked landholders what action they would take if a commercial kangaroo shooter was unavailable and 80% said they would undertake the shooting themselves, which would be costly and time consuming. Others indicated they would seek cheaper control methods, such as encouraging amateur shooters onto the property or poisoning water supplies. However, these are farmers perceptions, and for individual farmers to take the time and expense of additional removal would doubtfully be justified in terms of the return and in the light of general property needs. Until the prices of kangaroo meat match those of dressed beef and lamb (Young and Wilson 1995), or the kangaroo skin market is better developed sufficiently, intensive monitoring and control is uneconomical. The promotion of kangaroo skins is a promising option given the skin markets apparent inelasticity, that is, demand is not tied to price (Choquenot et al. 1998).

One solution might be via property Management Agreements that take into account property use by kangaroos in a regional context, so that some adjustment might be made to the regional estimates. However, landholders can already achieve this within the current system via section 1.8 of the KMP, vis: 'Control of kangaroo culling is exercised through the taking of kangaroos by licensed landholders or other licensed shooters. The carcasses of kangaroos so taken may be sold if the appropriate license has been obtained, and the property is within the Commercial Zone. Applications to take kangaroos must be justified on the basis that the numbers of kangaroos are such that significant damage to crops or pastoral production or rangeland is occurring or likely to occur. Landholders thus have no prima facie right to take kangaroos independently of this need to protect their rangelands, agricultural lands or pastoral production.' Hence, the main casualty of a property-based assessment process is likely to be the State regulators of commercial offtake faced with the impracticalities and expense of such a resource intensive system.

Overview

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.

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3.6 HARVESTING CONCERNS

<u>Specific issue</u> – 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 four major aims of the NSW Kangaroo Management program are to:

a) maintain viable populations of Red Kangaroos, Western Grey Kangaroos, Eastern Grey Kangaroos and Wallaroos throughout their natural range;

b) minimise the adverse effects that certain densities of these four species may have on rangelands, on pastoral and agricultural production and other land uses;

c) to maintain populations in these areas at levels which will not, in the long term, adversely affect these habitats; and

d) where possible, manage the species as a renewable resource, providing conservation of the species is not compromised.

There is little doubt that viable populations of the four harvested species have been maintained across their natural range (see section ‘Habitat loss and modification’). Since settlement, Eastern and Western Grey and Red Kangaroos have increased in numbers and perhaps range. Common Wallaroos populations and distribution show little change (Calaby and Grigg 1989). Despite 20 years of intensive harvesting, this situation has not changed (Pople and Grigg 1999; Grigg and Pople 2000). If anything, the range of one species, the Eastern Grey Kangaroo, may still be expanding westwards (Cairns and Coombs 1992). This is despite an increasing harvest offtake both absolutely and relatively (see Figures 1 and 2, respectively). The harvest industry is estimated to be worth about $100 million annually to Australia (Pople and Grigg 1999). Kangaroos’ intrinsic, environmental and tourism values are harder to quantify. Nevertheless, there is little doubt that kangaroos are a resource, and that the resource is clearly renewable at current harvest rates.

The KMP's aim relating to habitat damage (c) is more problematic and overall, given that kangaroo numbers have been maintained, their contribution to damage has probably also been maintained. However, kangaroos are just one many factors impacting on habitat (see section 3.4).

As Choquenot et al. (1998) stated: "Gibson and Young (1987) similarly concluded that 'the (national) kangaroo management program has been effective in simultaneously ensuring the survival of a viable population of all the harvested species over their natural range; and also containing the deleterious effects of kangaroos on agricultural and pastoral production'. While kangaroo harvesting has been concentrated in areas where kangaroos species are most abundant (Sinclair 1977), this strategy is both efficient from a commercial perspective, and safe in terms of conservation."

Simplistic analysis of the impact of harvest on kangaroo densities

The overall trend in the kangaroo population has been stable (Figure 2) with marked fluctuations mainly associated with rainfall. Fletcher et al. (1990) explained national trends, which apply to NSW trends, as increasing through the late 1970s following years of above average rainfall, declining following the drought in the early 1980s, then recovery by 1990. During the early 1990s there was a decline associated with drier than normal conditions, especially in the Grey Kangaroo population, followed by recovery in the late 1900s. The pattern suggests a dynamic situation with population crashes, some more sudden than others, followed by a gradual build up of numbers approximately every decade.

Quotas have been filled in only one year (Figure 4) and few Wallaroos are harvested (Appendix 4). In the past three years the percentage of the quota met in NSW has fallen (Figure 4), as it has nationally (Pople and Grigg 1999). Inspite of this the quota has been increased. The numbers of kangaroos culled levels off at about 800 000-900 000 after populations have reached about 8+ million, regardless of increases in the population, suggesting some ceiling to the cull (Figures 1 and 5). Similarly, ‘yield’ also levels off at about 800 000-900 000, regardless of the percentage of the population removed, perhaps indicating a maximum yield resulting from quotas set (Figure 6).

For many species selective harvesting of males, as happens with kangaroos (e.g., Pople and Grigg 1999), may allow populations to be harvested at rates substantially in excess of MSY (maximum sustainable yield; Choquenot et al. 1998). This is because lowering the ratio of males to females in a population will not generally reduce the proportion of females fertilised until some usually low threshold ratio is reached. This effect of sex biased harvesting is likely to hold with Red and Grey Kangaroos.

Caughley (1987b) modelled unselective harvesting that suggested 14% maximised offtake (Figure 7) which in the longterm would lower populations by 30-40%. Over the past 20 years harvest rates have averaged only 10.3%. Nevertheless, Figure 6 could indicate that maximum offtakes have not yet been reached and might be a few percent higher than Caughley’s estimate (perhaps 17%). Further, eyeballing Figure 2 suggests that equilibrium abundance of the Red and Grey Kangaroo populations combined might be about 8-9 million.

Cull rates are highest in years of increase (generally wet years) at 10.6% (range 2.9-18.5) and lowest in drought 9.5% (range 7.9-13.7). The reverse pattern would approach

Stocker and Walter's (1984) optimal harvesting strategy, which is based on Caughley's (1976) interactive model.

Although the percentage of the quota taken up varied quite widely (Figures 4), the relationship between kangaroo numbers and numbers culled was strong (Figure 5), suggesting that ease of culling (kangaroo accessibility) or number of harvesters might have been a factor in the harvest size. It also suggests that instead of reflecting a limit imposed by quotas, the harvest simply tracks kangaroo density.

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). Figure 8 indicates no relationship between 'harvest rate' and rate of increase in the population. There was a negative relationship between population size and rate of increase (Figure 9). Together, these results might indicate that harvesting at current rates have no impact on the population, which at present is driven by other forces.

Indeed, food supply (measured as pasture biomass or rainfall) has proven to be more strongly correlated with rate of increase (Caughley et al. 1984; Bayliss 1985a, 1987; Cairns and Grigg 1993), especially for Red Kangaroos, and, more importantly, is causal (Shepherd 1987). The current mosaic of harvesting zones interspersed with conservation reserves, non-commercial areas etc. (Pople and Grigg 1999) inadvertently conforms to the patchwork harvesting strategy recommended by McCullough (1996), and would appear to be successful for conservation and sustainment of the resource.

See Appendix 5 for assessment of trends in the zones, which are useful for determining local harvest impacts. The main findings are:

- There was some indication that Grey Kangaroo populations in zones 1, 2, 6, and 11 may have increased (from historically low levels in 1982/3) and may be continuing to do so in zones 6 and, especially, 11.
- There was a positive relationship between Grey and Red Kangaroo numbers in most zones except those in which Grey Kangaroos were increasing.
- This suggests some sort of equilibrium in numbers between Reds and Grey Kangaroos, that has been disrupted in the zones of increase and that the species should not be managed in isolation.
- There was some indication that harvesting might be enhancing rates in increase in some populations, but this requires more thorough investigation and analysis.

Overview

The evidence suggests that current rates of harvesting have no impact on the overall density of kangaroos, hence aims a, b and d of the KMP are not compromised. Consideration could be given to increasing average harvest rates, after a species-specific reassessment, although quotas are rarely filled at lower rates.

Information is insufficient to assess whether habitat damage aims (c) are being met. However, (Norbury and Norbury 1993) concluded that, at current rates, commercial shooting may be ineffective in reducing kangaroo numbers to preserve pasture and soil. Damage monitoring in relation to kangaroo and other herbivore numbers is recommended, to define the relationship between damage and numbers in a more comprehensive range of habitats and taking into account the major grazers. As kangaroos are just one of a suite of compensatory or partially compensatory grazers (see section on Total Grazing Management), until a more holistic approach to management than simply targeting kangaroos is taken then gains in this area are likely to be small. Unless pastoral production or other land use in the commercial and non-commercial zones is profitable (and this is affected by many factors including commodity prices, debt servicing and infrastructure) then killing kangaroos is tinkering at the edges. As with the management of any pest, kangaroo management is best approached as part of the whole system of land management (see Australasian Wildlife Management Society's position statement on the sustainable commercial use of wildlife, in Grigg and Pople 2000).

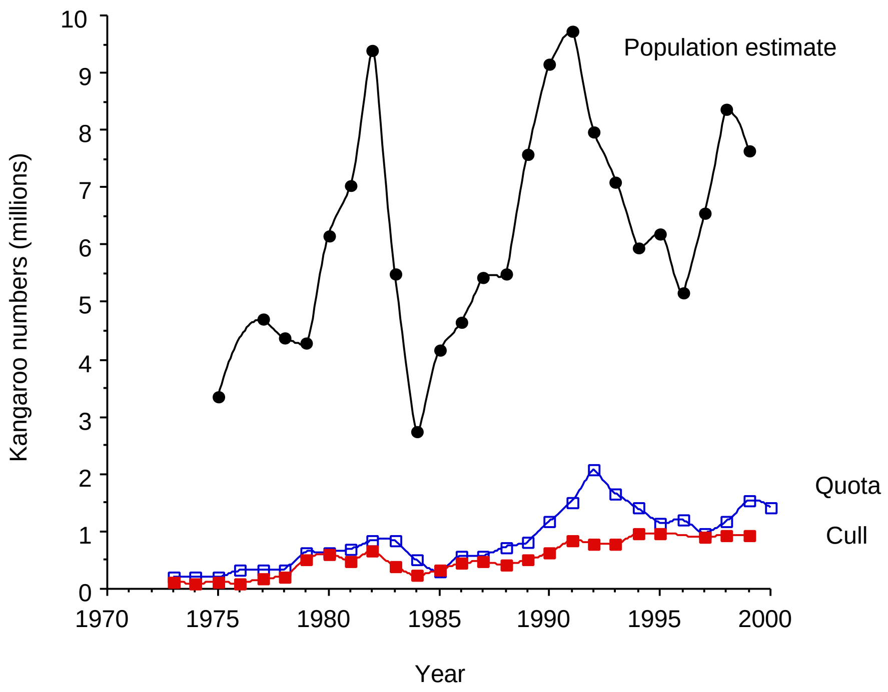

Figure 2. Population estimates, quotas and culls of Red and Grey Kangaroos combined in NSW. Based on data in Appendix 3. The trends are similar for all species. 1973-1983 – based on survey of seven 1:250 000 monitor blocks; 1984-1998 – based on survey of virtually all the western plains of New South Wales; and from 1989 – based on survey of virtually all the western plains of New South Wales plus ground survey of tablelands.

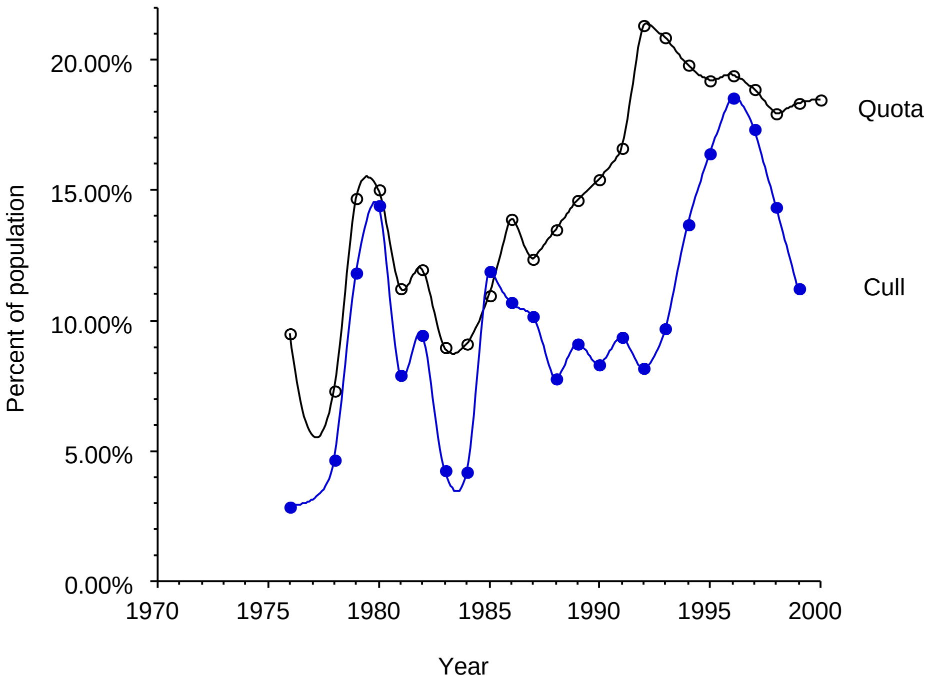

Figure 3. The quota and subsequent cull as a percentage of the population for Red and Grey Kangaroos combined. Based on data in Appendix 3. The trends are similar for all species.

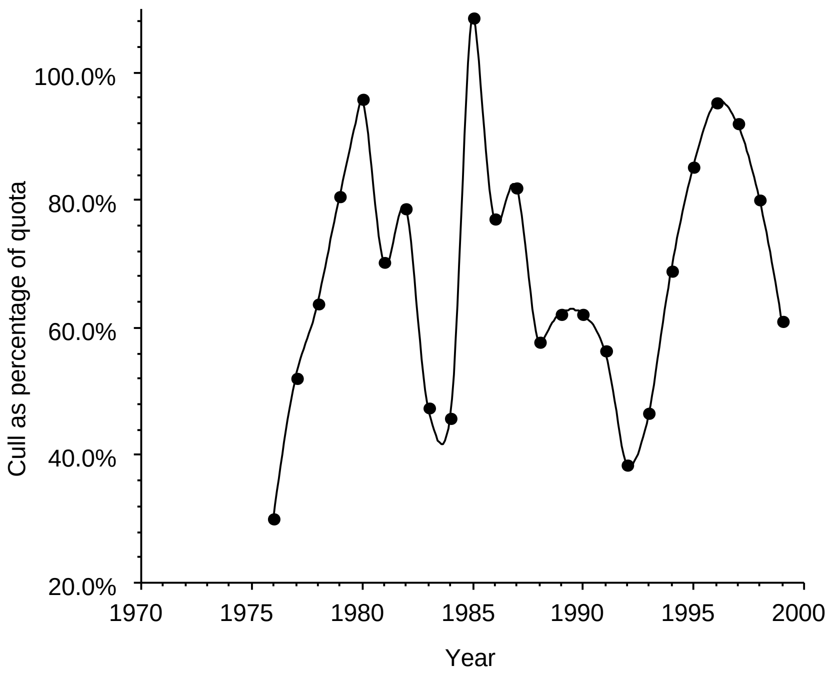

Figure 4. The percentage of the kangaroo quota taken up for Red and Grey Kangaroos combined. Based on data in Appendix 3. A slightly higher percentage of the quota for Red Kangaroos is taken up than it is for Grey Kangaroos.

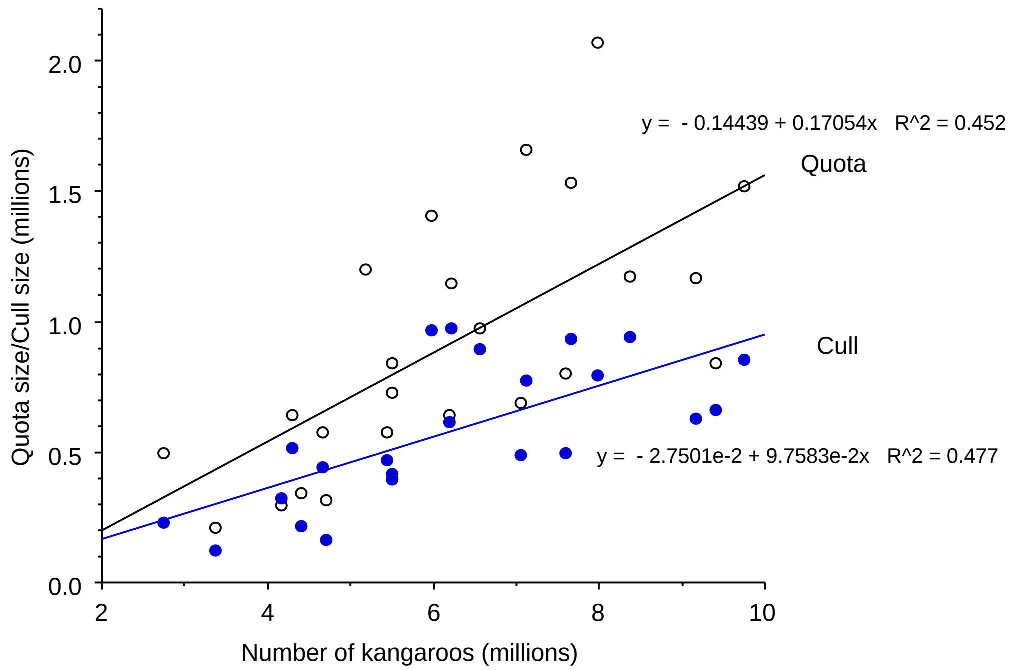

Figure 5. The relationship between population size and a. number culled and b. quota set (both P < 0.05; n = 23). Based on data in Appendix 3.

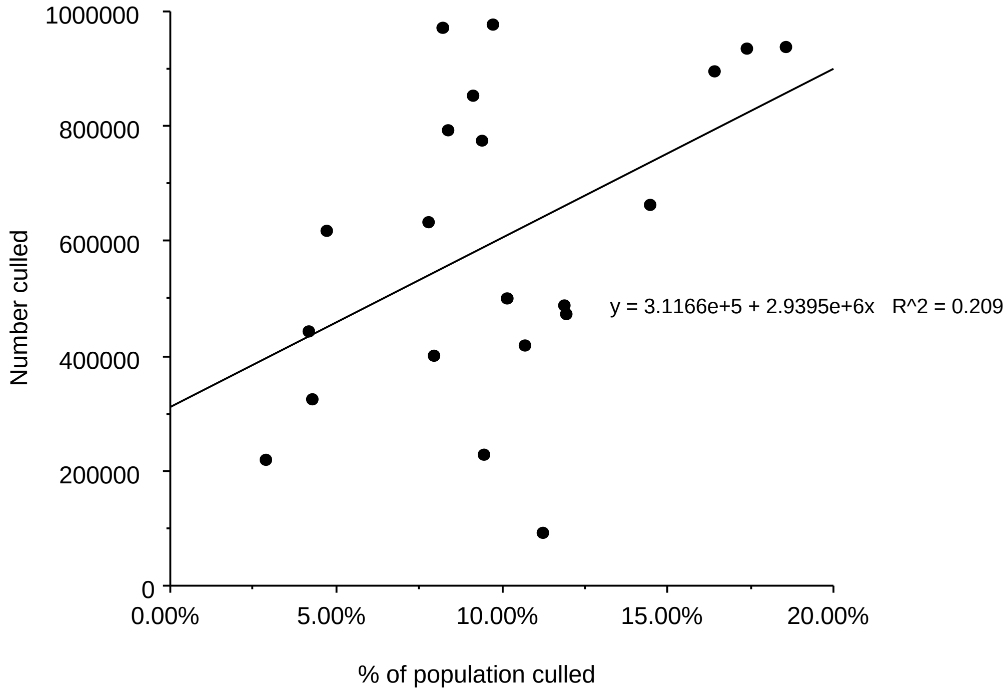

Figure 6. The relationship between 'harvest rate' (% of population culled) and 'yield' (number culled).(P = 0.03; n = 21). Based on data in Appendix 3.

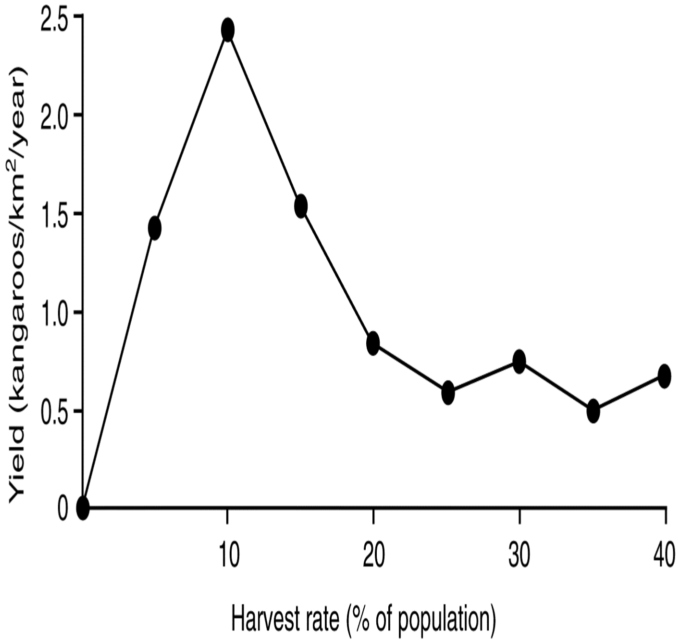

Figure 7: Variation in the average yield achieved by unselective harvesting of a modelled Red Kangaroo population as a function of harvest rate (Choquenot et al. 1998, after Caughley 1987b).

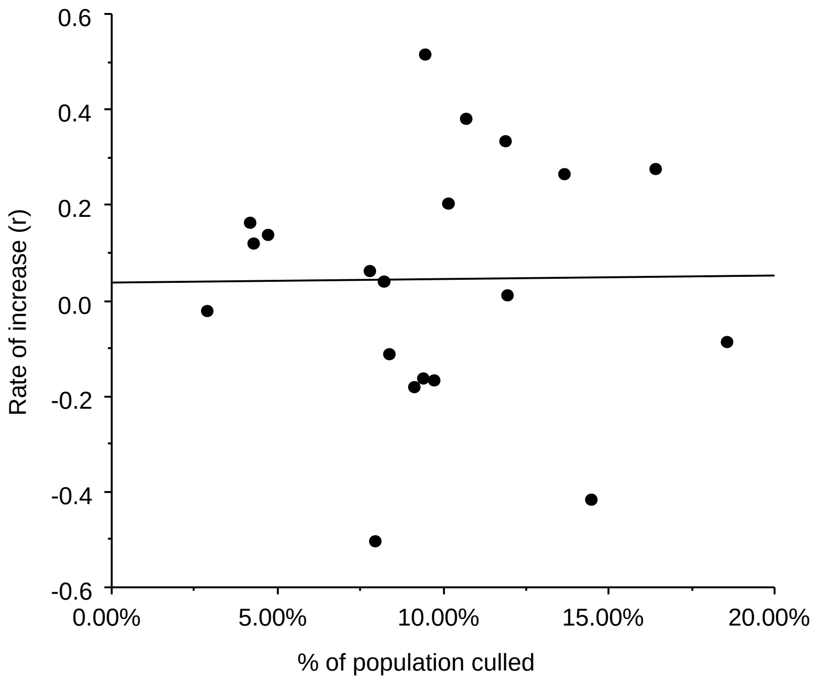

Figure 8. Relationship between the percentage of the population culled and the rate of increase in the population. When years of increasing population were separated from years of increase (see Figure 9), neither displayed any trend. Based on data in Appendix 3.

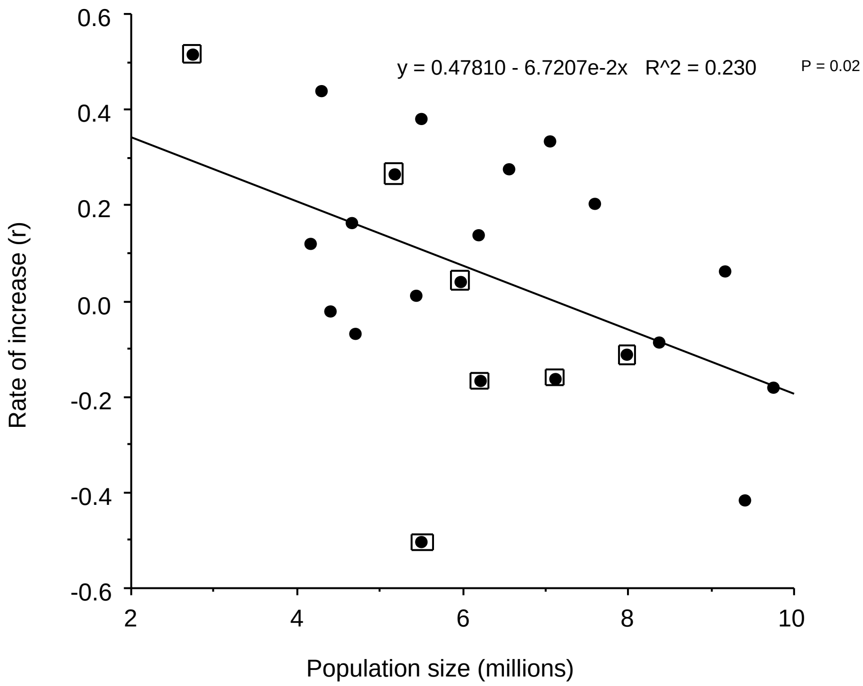

Figure 9. Relationship between population numbers and rate of increase (r); boxed circles are for years of population decline, (1983-4, 1992-6), unboxed circles are for years of increasing population (1978-82, 1985-91, 1997-98). Based on data in Appendix 3.

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APPENDIX 1 – CONSULTANCY BRIEF

Aim

To provide the current state of scientific knowledge on specific issues and theories relating to kangaroo management in NSW. This will be completed primarily by a comprehensive review of the available literature.

Outline

There are five major themes or subject areas that must be assessed, based on a comprehensive review of the current literature. The impact of kangaroos on the vegetation/habitat/land resource/biodiversity and the impact of harvesting on the kangaroo population are of primary concern to stakeholders. For this reason the report should frequently refer to these concerns. The major subject areas are:

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.
2. The effect of other impacts on kangaroo populations including disease and habitat loss or habitat modification.
3. The genetic impact of kangaroo culling.
4. 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.
5. Assessment of the direct and indirect methods used to monitor kangaroo populations in NSW.

In addition there are specific issues, identified by the KMAC and NPWS, that must be addressed in the report.

1. Sheep compared to kangaroos & sheep and 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).

   This should include an analysis of the combined effects of sheep and kangaroos and also the nature of the herbivore-herbivore interaction between sheep and kangaroos.
2. Ecological and economic benefits of fewer kangaroo where domestic sheep, cattle or goats continue to graze.
3. 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.
4. Other herbivores including invertebrates and their role in the ecological processes impacted by grazing.
5. An analysis of watering points (AWP), kangaroos, domestic grazing animals and biodiversity. Kangaroo population response to variations in AWP's.
6. Predation of kangaroos by Dingoes or any other predator, historical and current.
7. Genetics – likely impact of harvesting, including an assessment of the 'worst case scenario', i.e., 20% of reds over 100 years (no unharvested areas).
8. Total Grazing Pressure theory and practice for domestic grazing animals and application in kangaroo management, e.g. manage kangaroos as one component of TGP.
9. 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.

10. Accuracy of kangaroo population estimation methods currently used in the NSW KMP.
11. 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.
12. 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.

Desired outcomes

The final report should address all of the required subjects and issues listed in the brief. The report must be based on a comprehensive review of the available literature and prepared in a style and to standards that would be required for a paper in a scientific journal. Wherever possible any conclusions in the report must be based on references from the literature.

In addition the report should include an attachment that enables quick reference from issues to relevant sections or pages within the report. This could be an index style topic/page numbers, or a matrix with issues, page numbers and brief comment or some other alternative as agreed. The consultant should discuss the format and content of this section with NPWS.

APPENDIX 2 – ANNUAL POPULATION ESTIMATES

Trends in the estimated numbers of Red Kangaroos and Grey Kangaroos on the Western Plains of New South Wales from aerial survey (Source: NSW NPWS).

	Grey Kangaroo			Red Kangaroo		
Year	Mean	Minimum	Maximum	Mean	Minimum	Maximum
1973	no survey	1973	no survey			
1974	no survey	1974	no survey			
1975	1580000			2073000		
1976	no survey	1976	no survey			
1977	2030000			2669000		
1978	2314000			2069000		
1979	1933000			2355000		
1980	2797000			3377000		
1981	2420000			4626000		
1982	3700000			5700000		
1983	2100000			3400000		
1984	1088000	903000	1273000	1650000	1514700	1785300
1985	1792000	1601400	1982600	2363000	2152300	2573700
1986	2088000	1893100	2282900	2574000	2318900	2829100
1987	2648000	2426900	2869100	2777000	2587600	2966400
1988	2058000	1895800	2220200	3440000	3223000	3657000
1989	2992500	2699500	3194500	4101000	3777800	4424200
1990	4051000	3759000	4343000	4499000	4244800	4753200
1991	4349000	3978300	4719700	4755000	4465500	5044500
1992	4003000	3672600	4333400	3348900	3085600	3684200
1993	3690600	3459100	3922100	2759800	2578000	2941400
1994	2832000	2624000	3041000	2568000	2441000	2695000
1995	2945800	2701300	3190300	2672000	2552200	2791800
1996	2276000	1926700	2625300	2438000	2248500	2627500
1997	2578600	2264400	2892800	3456100	3234700	3677500
1998	4207050	3855550	4558550	3595850	3329950	3861750
1999	4147028	3842528	4451528	2952442	2711742	3193142

APPENDIX 3 – POPULATION ESTIMATES AND HARVEST DETAILS FOR RED KANGAROOS AND GREY KANGAROOS IN NSW

Year	Population	Quota	% Population	Cull	% Population	% Quota
1973	no estim.	213,000	-	132,000	-	61.97%
1974	no estim.	216,000	-	95,000	-	43.98%
1975	3,365,300	212,000	-	123,000	-	58.02%
1976	no estim.	319,400	9.49%	96,000	2.85%	30.06%
1977	4,699,000	321,000	-	167,200	-	52.09%
1978	4,383,000	345,000	7.34%	220,000	4.68%	63.77%
1979	4,288,000	645,000	14.72%	520,000	11.86%	80.62%
1980	6,174,000	645,000	15.04%	619,023	14.44%	95.97%
1981	7,046,000	694,500	11.25%	488,647	7.91%	70.36%
1982	9,400,000	843,000	11.96%	664,342	9.43%	78.81%
1983	5,500,000	843,000	8.97%	400,477	4.26%	47.51%
1984	2,738,000	500,000	9.09%	229,484	4.17%	45.90%
1985	4,155,000	300,000	10.96%	326,028	11.91%	108.68%
1986	4,662,100	577,000	13.89%	444,509	10.70%	77.04%
1987	5,425,000	577,000	12.38%	473,454	10.16%	82.05%
1988	5,498,000	730,000	13.46%	421,200	7.76%	57.70%
1989	7,593,500	804,000	14.62%	500,355	9.10%	62.23%
1990	9,150,000	1,172,000	15.43%	633,000	8.34%	62.23%
1991	9,734,000	1,520,000	16.61%	856,406	9.36%	56.34%
1992	7,981,900	2,074,000	21.31%	796,007	8.18%	38.38%
1993	7,112,000	1,663,600	20.84%	775,220	9.71%	46.60%
1994	5,962,800	1,409,100	19.81%	971,694	13.66%	68.96%
1995	6,202,200	1,146,626	19.23%	977,459	16.39%	85.25%
1996	5,170,000	1,206,000	19.44%	######	18.54%	95.35%
1997	6,549,800	976,000	18.88%	897,937	17.37%	92.00%
1998	8,362,800	1,175,140	17.94%	940,789	14.36%	80.06%
1999	7,653,775	1,532,916	18.33%	937,642	11.21%	61.17%
2000		1,416,285	18.50%			

Source: NSW NPWS. 1973-1983 – based on survey of seven 1:250 000 monitor blocks; 1984-1998 – based on survey of virtually all the western plains of New South Wales; and from 1989 – based on survey of virtually all the western plains of New South Wales plus ground survey of tablelands.

APPENDIX 4 – KANGAROOS KILLED UNDER COMMERCIAL HARVEST QUOTAS – NEW SOUTH WALES

Year	Red Kangaroo	Eastern Grey	and	Western Grey	Euro/ Wallaroo	Total
1975						123,000
1976						96,700
1977						167,200
1978		No species detail provided for 1975-1981				220,000
1979						520,000
1980						619,023
1981						488,647
1982	399,108	-	263,168	-	2,066	664,342
1983	264,863	-	134,900	-	714	400,477
1984	157,629	-	63,754	-	632	222,015
1985	213,297	-	111,968	-	763	326,028
1986	263,046	-	181,463	-	-	444,509
1987	270,467	140,061	-	62,926	-	473,454
1988	218,086	130,335	-	72,786	-	421,207
1989	297,029	136,073	-	67,253	97	500,452
1990	377,155	170,766	-	83,708	1,967	633,596
1991	495,986	253,791	-	106,629	1,378	857,784
1992	412,189	264,447	-	117,994	1,377	796,007
1993	359,820	284,344	-	129,378	1,678	775,220
1994	397,791	363,659	-	210,244	5,036	976,730
1995	431,663	370,757	-	175,039	9,917	987,376
1996	531,370	402,356	-	216,191	8,941	1,158,858
1997	415,395	333,426	-	141,167	7,949	897,937
1998	495,100	314,328	-	123,826	7,535	940,789
1999	450,020	355,845	-	122,481	9,296	937,642

Source: Environment Australia. Last updated 16 June 2000

APPENDIX 5 – SIMPLE ASSESSMENT OF HARVESTING IMPACT IN THE ZONES

Population and harvest data were available for eight zones: zone 1 Tibooburra; zone 2 Broken Hill; zone 4 Lower Darling; zone 6 Cobar; zone 7 Broken Hill; zone 8 Narrabri; zone 10 Coonabarabran; and zone 11 Griffith. Population estimates were available for 1985-1999 and harvest figures from 1992-1999. Simple plots and regressions were used to test for trends.

Red Kangaroo populations fluctuated around an equilibrium in all of the zones, that is, there were no trends in population size or density (see Appendix figures). The exception might be zone 8 where in 1998/1999 there seemed to be a sharp increase in the population (NB, this may have been an error in the data).

Grey Kangaroo populations appear to have increased in zone 2 and may be continuing to increase in zones 6,11 and perhaps 1 (Appendix figure a). However, it should be borne in mind that kangaroo populations are dynamic and that they reached historically low numbers during the severe drought of the early 1980s, which corresponded with the beginning of the current monitoring program. Furthermore, there is no general trend either towards increase or decrease in overall kangaroo numbers in NSW (Figure 2).

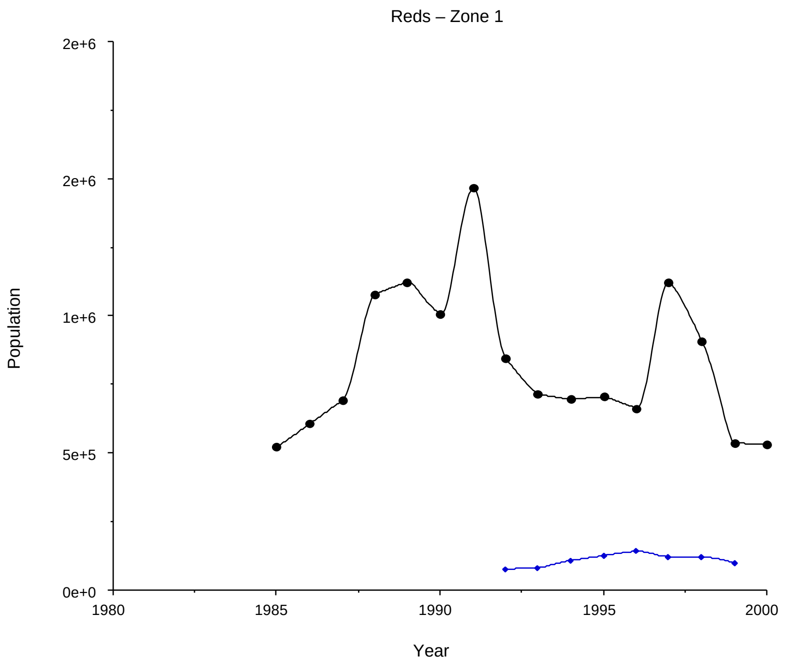
In general, the possible increases in the four zones did not appear to be due to any differential increase in either Eastern or Western Grey Kangaroos.

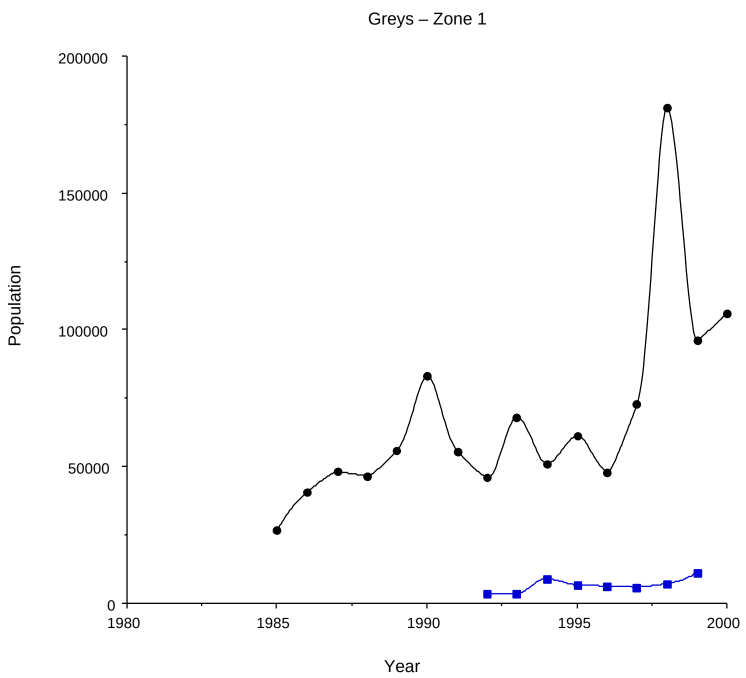
Overall harvest figures have remained more or less steady or with a very slight trend towards decrease in recent years for both Grey and Red Kangaroos in many zones, and zone 2 showed an increasing trend for Greys, none of which were statistically significant.

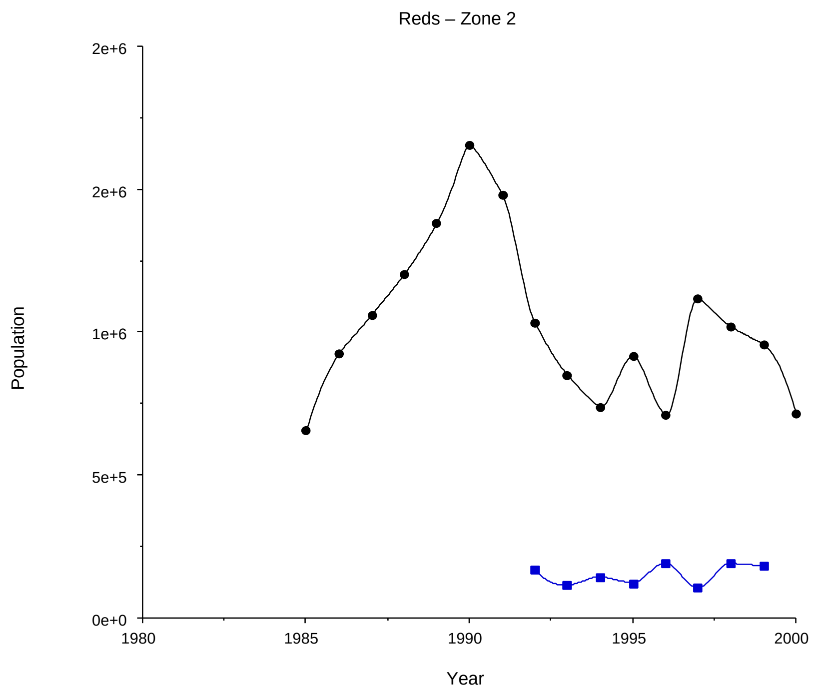
The percentage change in the population (Appendix figure b) was plotted against the percentage of the population harvested. This was a gross test of whether the harvest was regulating growth in the population. In fact, if anything, there tended to be a positive relationship between harvest rate and rate of increase, which could be interpreted to indicate that culling at recent/present levels enhances the growth rate of the population. This result does not necessarily mean that harvesting has a causal effect on population increase. However, harvesting does mimic some of the conditions produced by natural perturbations, such as die-off of males in drought, from which the kangaroo population is adapted to recover quickly by enhancing its rate of increase.

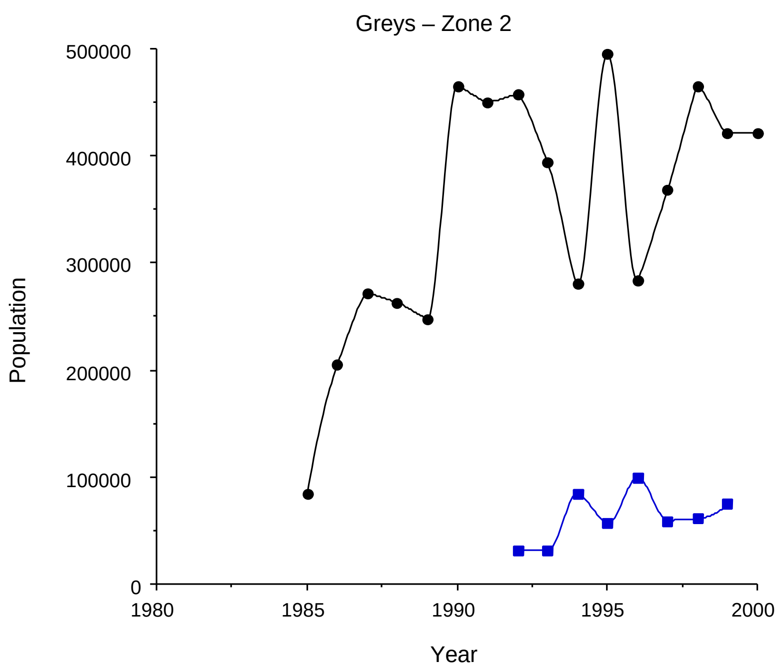
The ratio of Red Kangaroos to Grey Kangaroos was generally positively correlated, significantly so in zones 2 and 5 and highly significantly in zones 4, 7, 8 and 10 (Appendix figure c). In the zones where Grey Kangaroos have increased greatly in numbers the relationship was weaker, perhaps indicating a breakdown in equilibrium between them. This general relationship in numbers between the species suggests that they should not be managed in isolation.

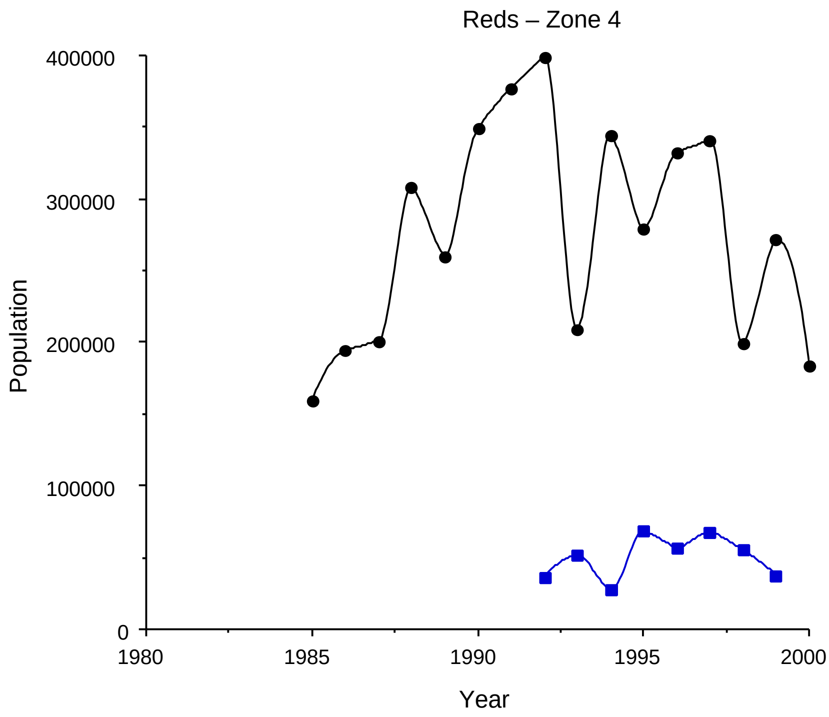
Appendix 5 figure (a). Population numbers (proportional to density) and harvest data for Red and Grey Kangaroos (both species combined) in each zone since 1985. Circles represent population estimates and squares harvest figures. (Source: tabulated data supplied by Joshua Gilroy).

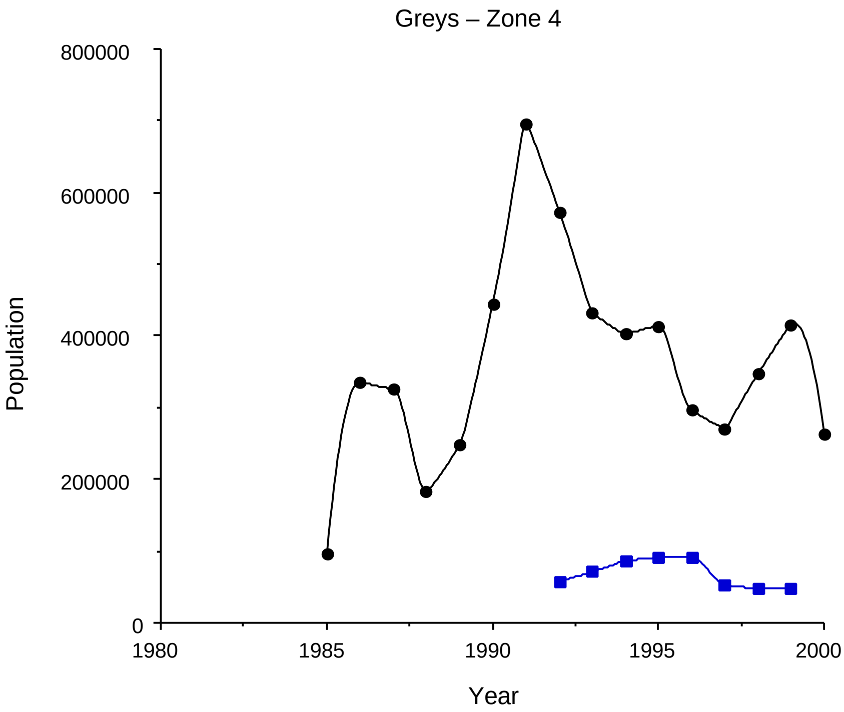

Reds – Zone 1
2e+6
2e+6
1e+6
5e+5
0e+0
Population
1980
1985
1990
1995
2000
Year

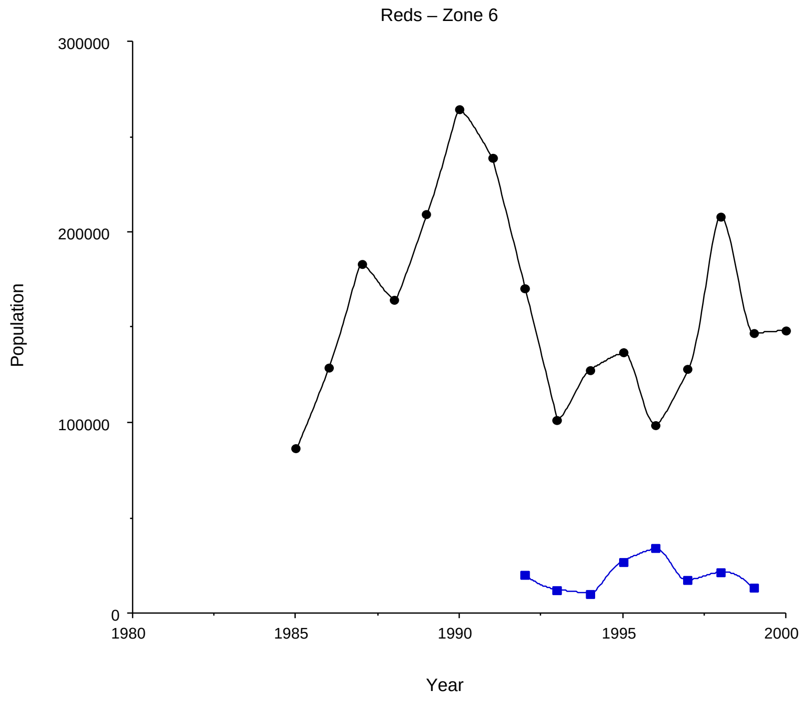

Greys – Zone 1
200000
150000
100000
50000
0
Population
1980
1985
1990
1995
2000
Year


Reds – Zone 2
2e+6
2e+6
1e+6
5e+5
0e+0
Population
1980
1985
1990
1995
2000
Year

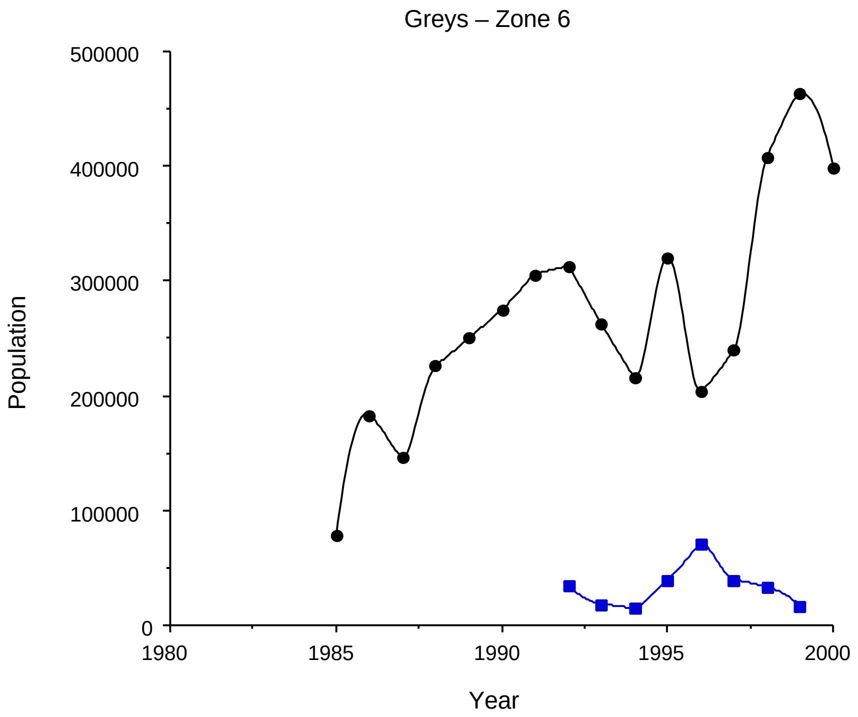

Greys – Zone 2
500000
400000
300000
200000
100000
0
Population
1980
1985
1990
1995
2000
Year


Reds – Zone 4
400000
300000
200000
100000
0
Population
1980
1985
1990
1995
2000
Year

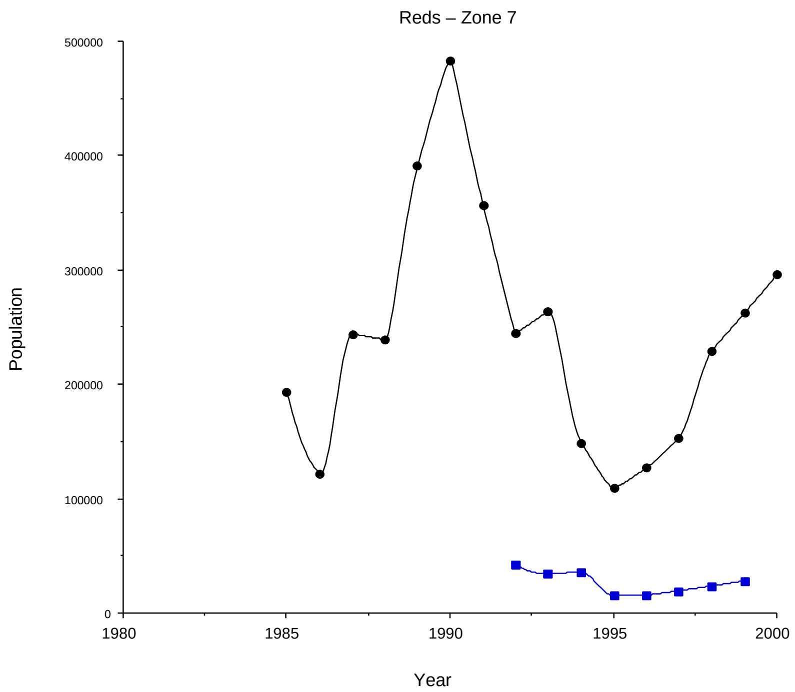

Greys – Zone 4
800000
600000
400000
200000
0
Population
1980
1985
1990
1995
2000
Year

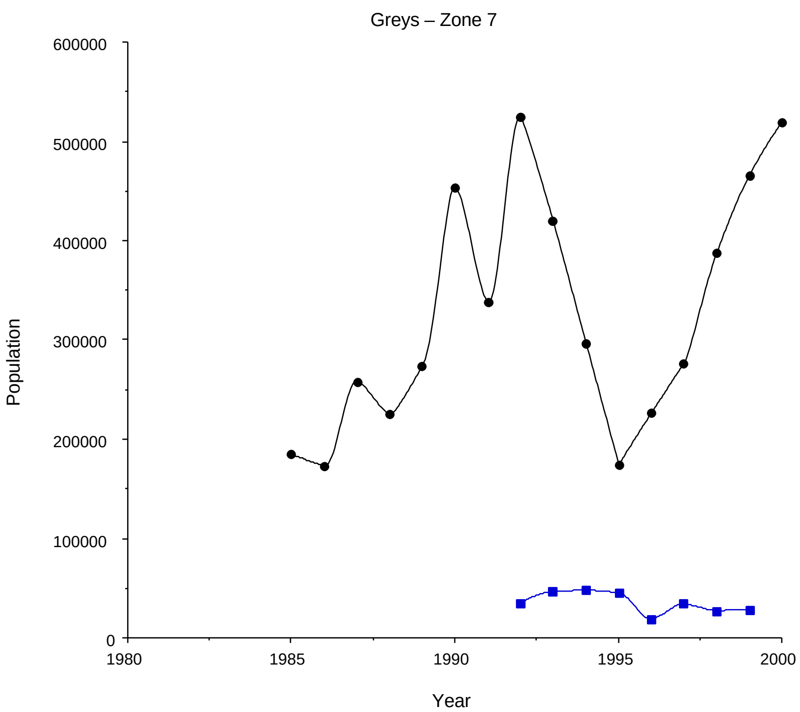


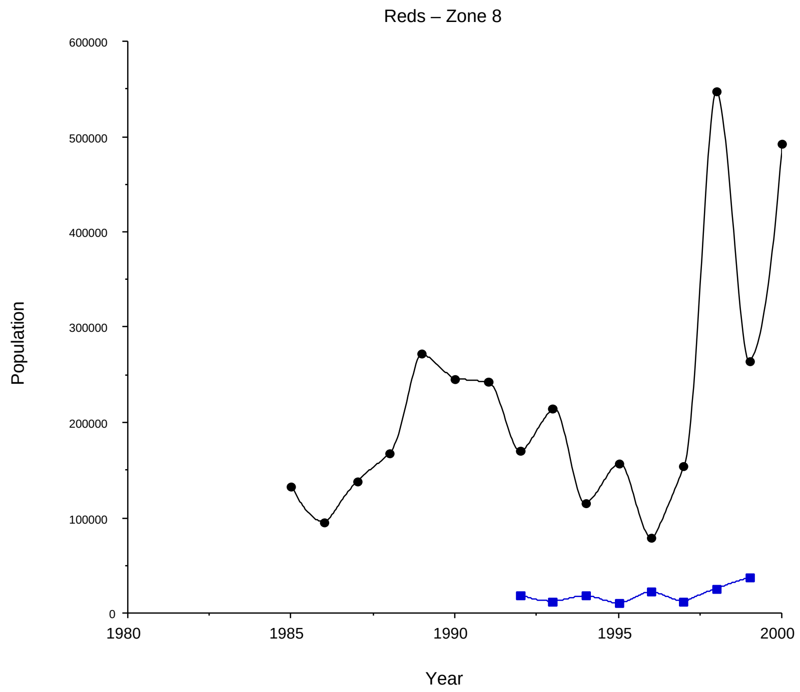
Reds – Zone 6
300000
200000
100000
0
Population
1980
1985
1990
1995
2000
Year

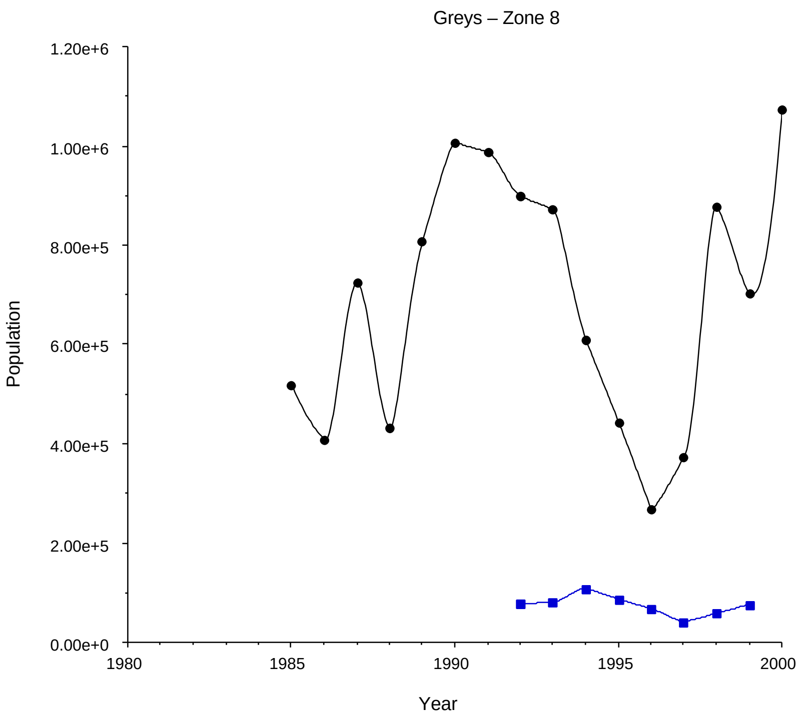


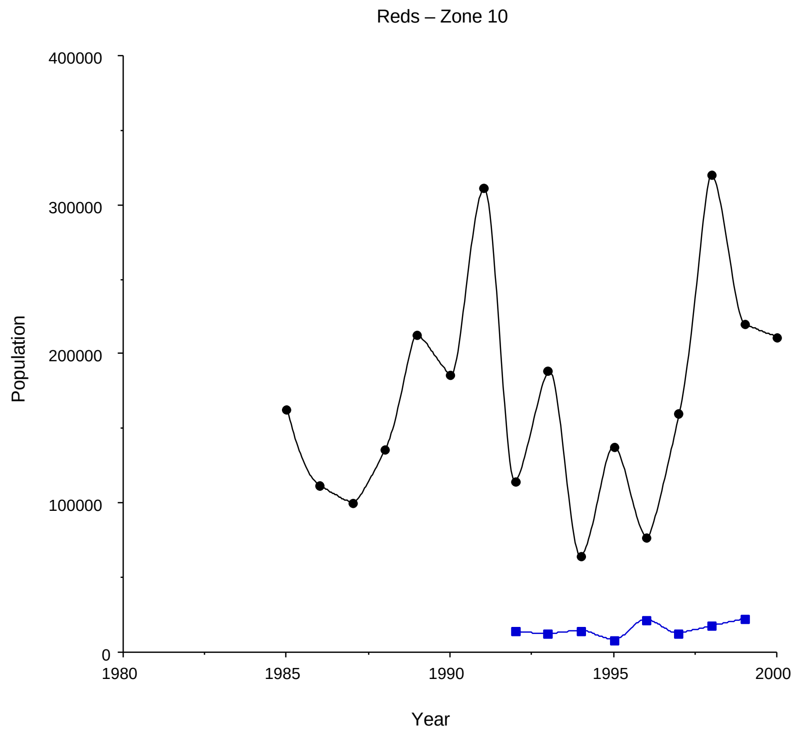
Greys – Zone 6
500000
400000
300000
200000
100000
0
Population
1980
1985
1990
1995
2000
Year

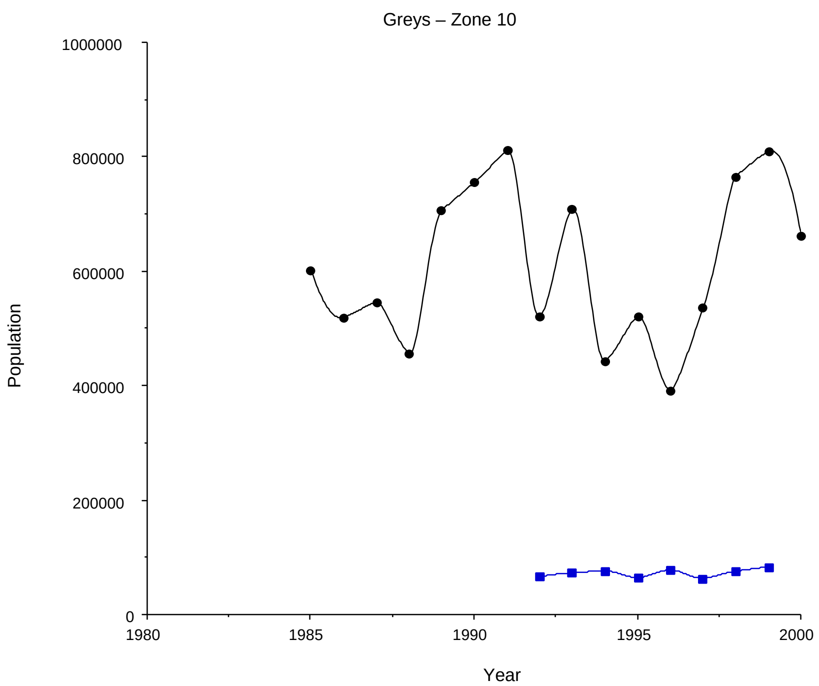

Reds – Zone 7
Population
500000
400000
300000
200000
100000
0
1980
1985
1990
1995
2000
Year

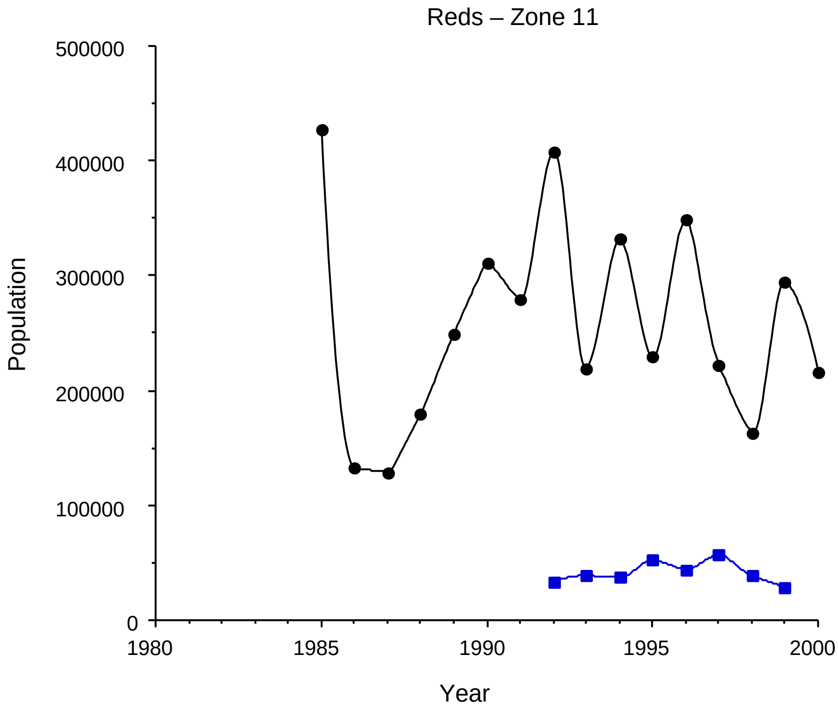

Greys – Zone 7
Population
600000
500000
400000
300000
200000
100000
0
1980
1985
1990
1995
2000
Year

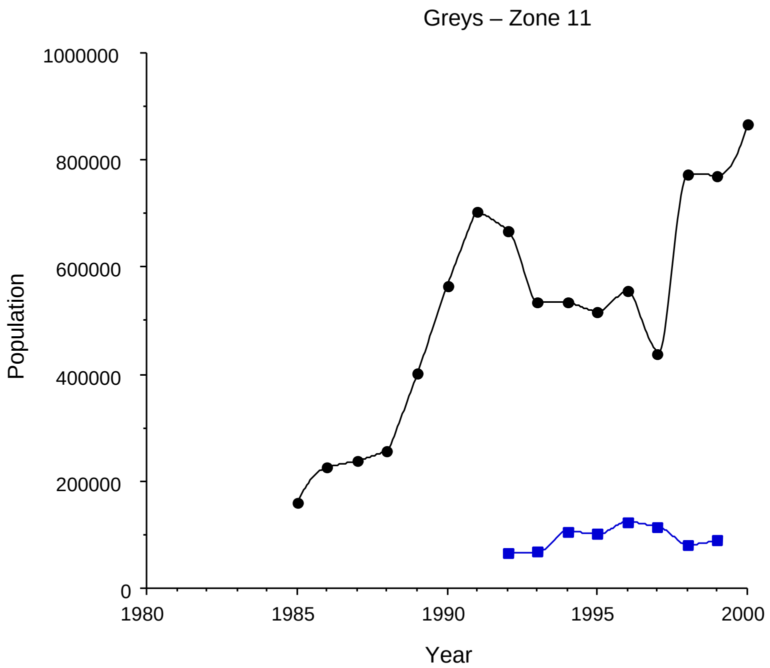

Reds – Zone 8
Population
Year
600000
500000
400000
300000
200000
100000
0
1980
1985
1990
1995
2000


Greys – Zone 8
Population
Year
1.20e+6
1.00e+6
8.00e+5
6.00e+5
4.00e+5
2.00e+5
0.00e+0
1980
1985
1990
1995
2000

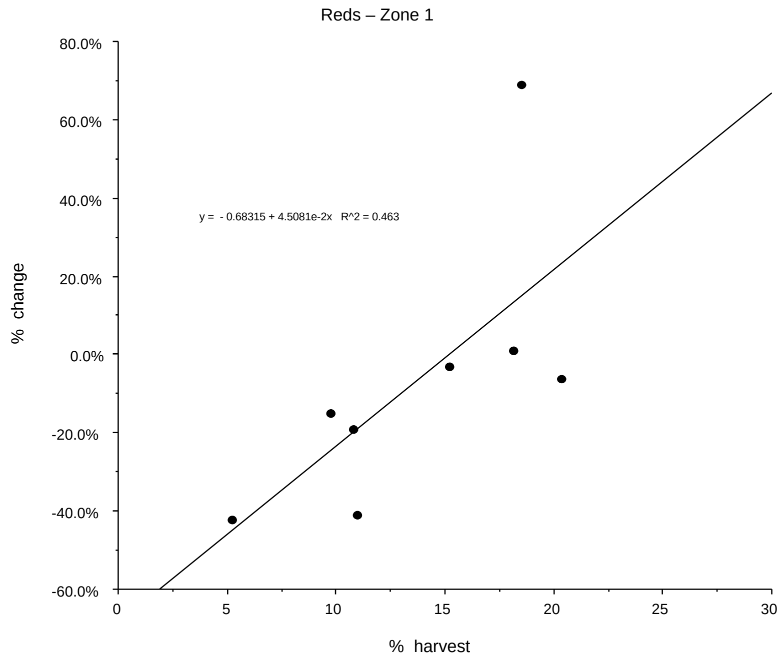

Reds – Zone 10
400000
300000
200000
100000
0
Population
1980
1985
1990
1995
2000
Year

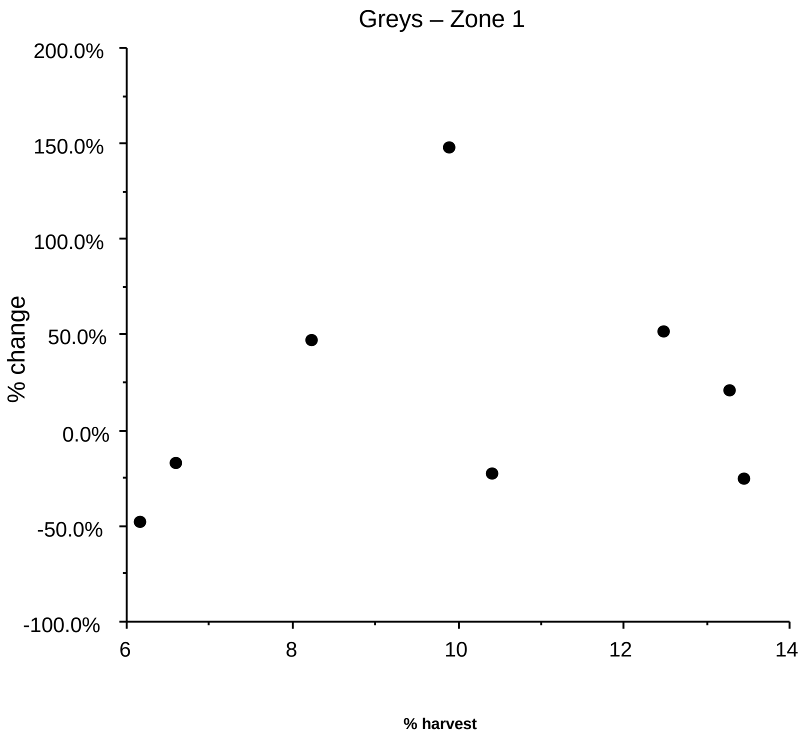

Greys – Zone 10
1000000
800000
600000
400000
200000
0
Population
1980
1985
1990
1995
2000
Year

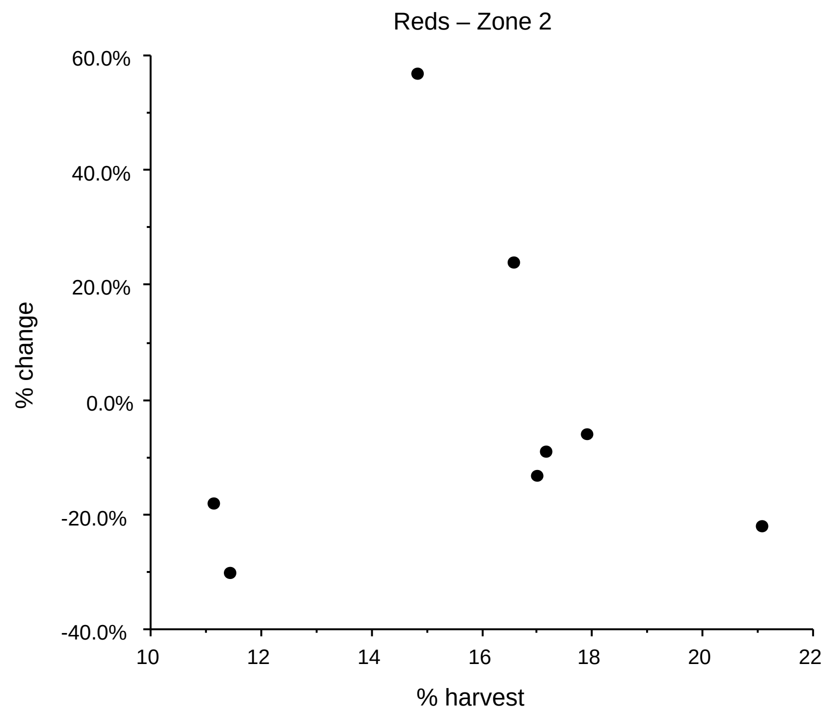

Reds – Zone 11
Population
500000
400000
300000
200000
100000
0
1980
1985
1990
1995
2000
Year

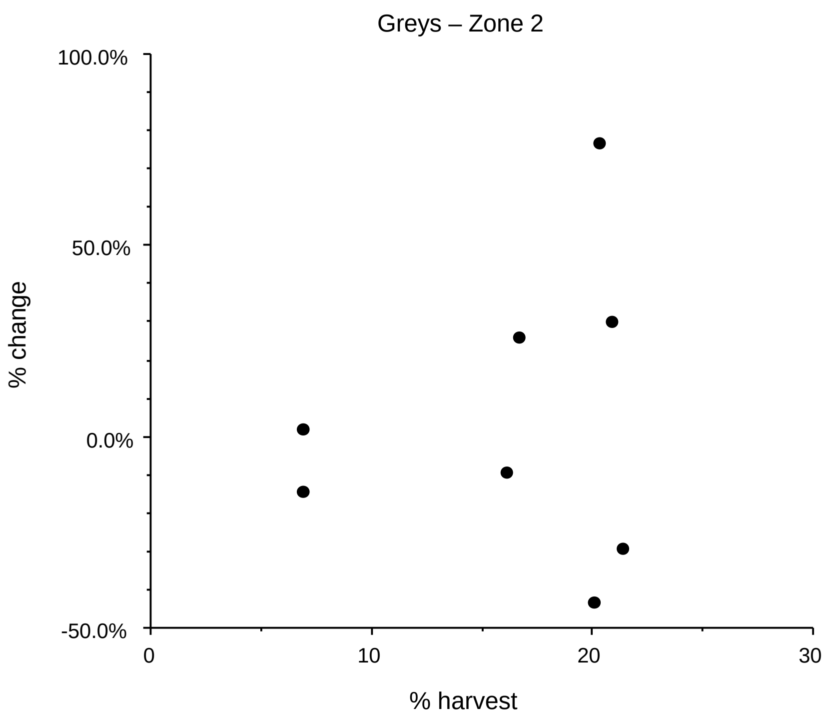

Greys – Zone 11
Population
1000000
800000
600000
400000
200000
0
1980
1985
1990
1995
2000
Year

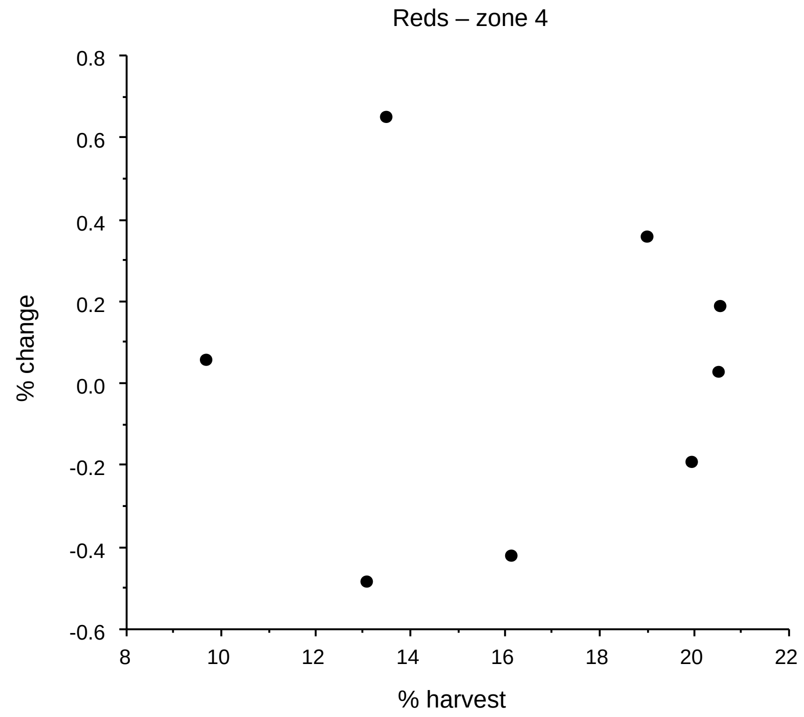
Appendix 5 figure (b). For the same data as in (a), the relationship between the percentage of the population culled and the percentage change in the population (equivalent to r). Regression lines are shown only where relationships were significant, at least $P < 0.05$). (Source: tabulated data supplied by Joshua Gilroy).


Reds – Zone 1
80.0%
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
-60.0%
% change
y = - 0.68315 + 4.5081e-2x R^2 = 0.463
0
5
10
15
20
25
30
% harvest

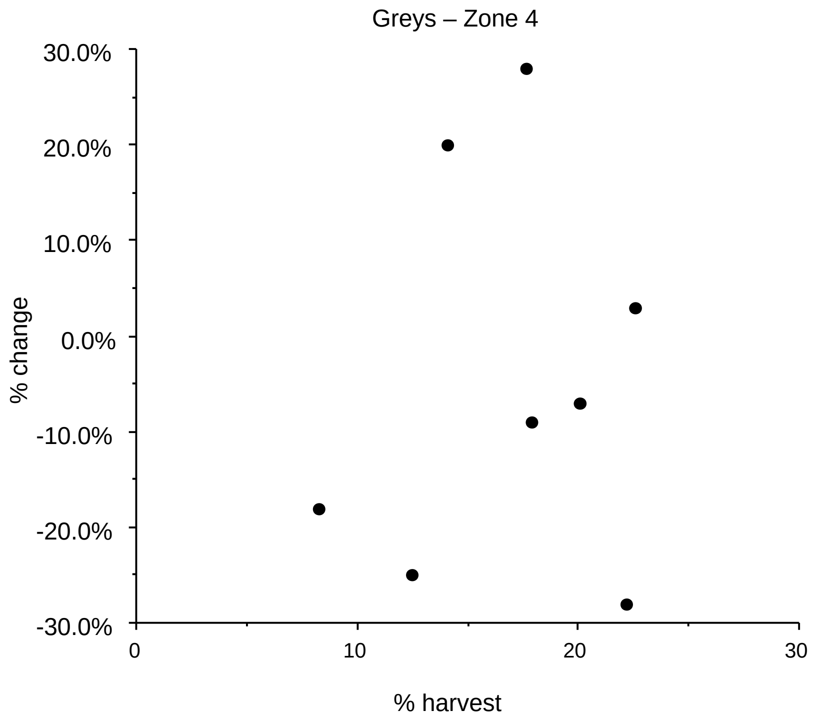

Greys – Zone 1
200.0%
150.0%
100.0%
50.0%
0.0%
-50.0%
-100.0%
% change
6
8
10
12
14
% harvest


Reds – Zone 2
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
% change
10
12
14
16
18
20
22
% harvest

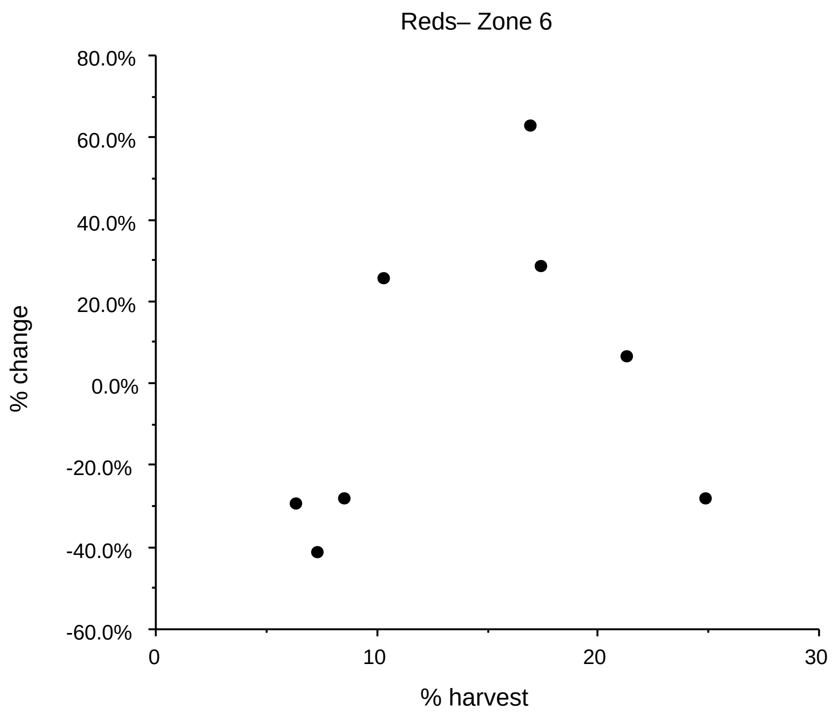

Greys – Zone 2
100.0%
50.0%
0.0%
-50.0%
% change
0
10
20
30
% harvest

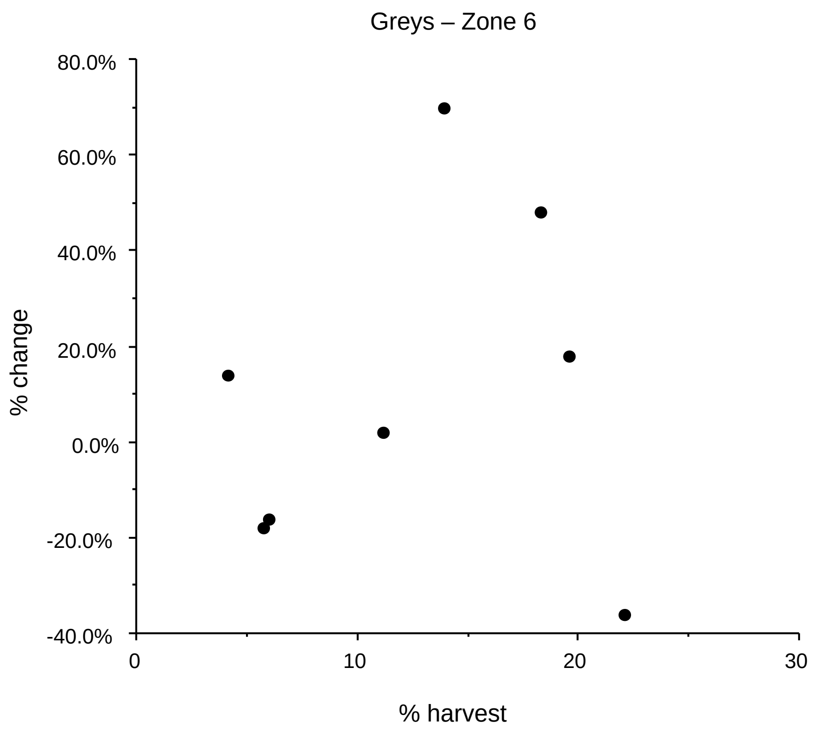


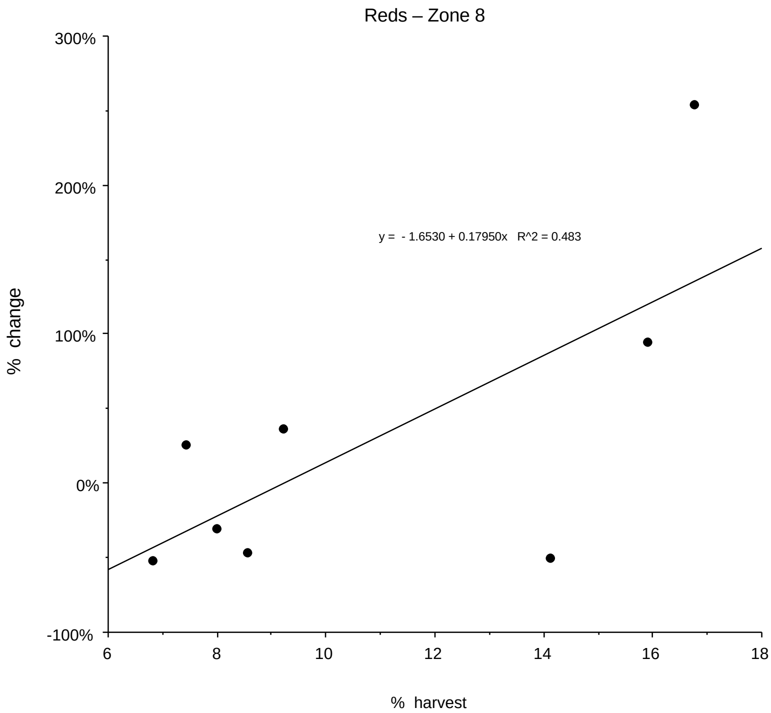
Reds – zone 4
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
% change
8
10
12
14
16
18
20
22
% harvest

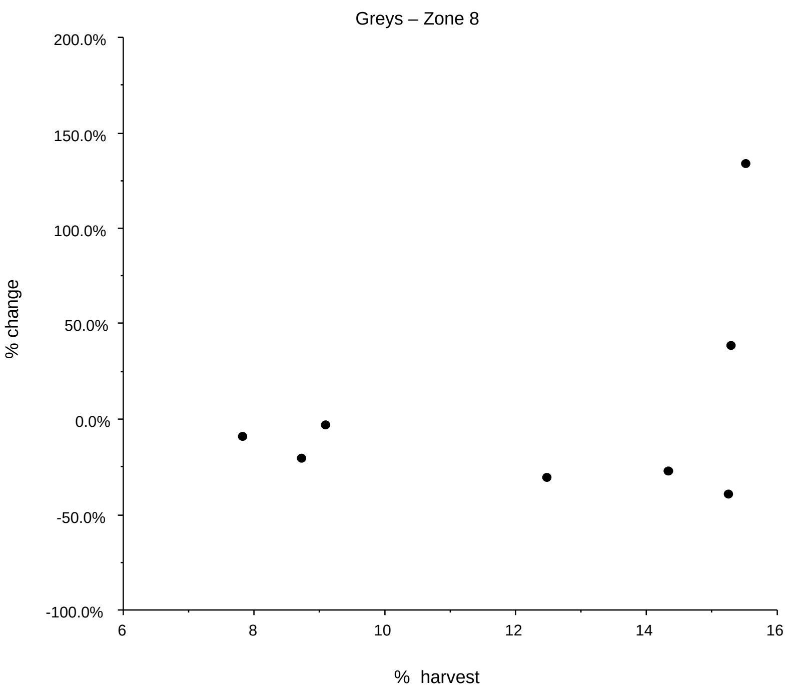


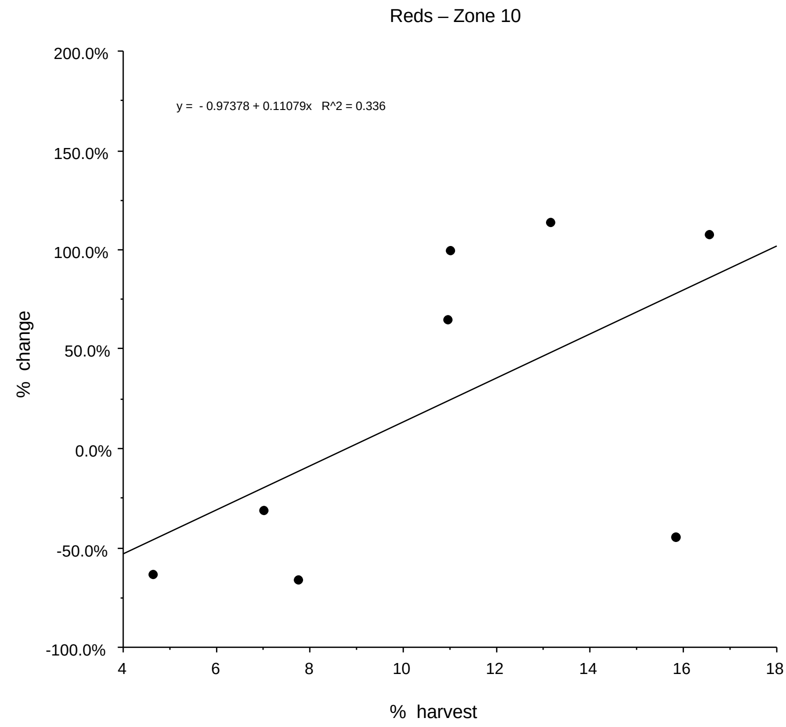
Greys – Zone 4
30.0%
20.0%
10.0%
0.0%
-10.0%
-20.0%
-30.0%
% change
0
10
20
30
% harvest

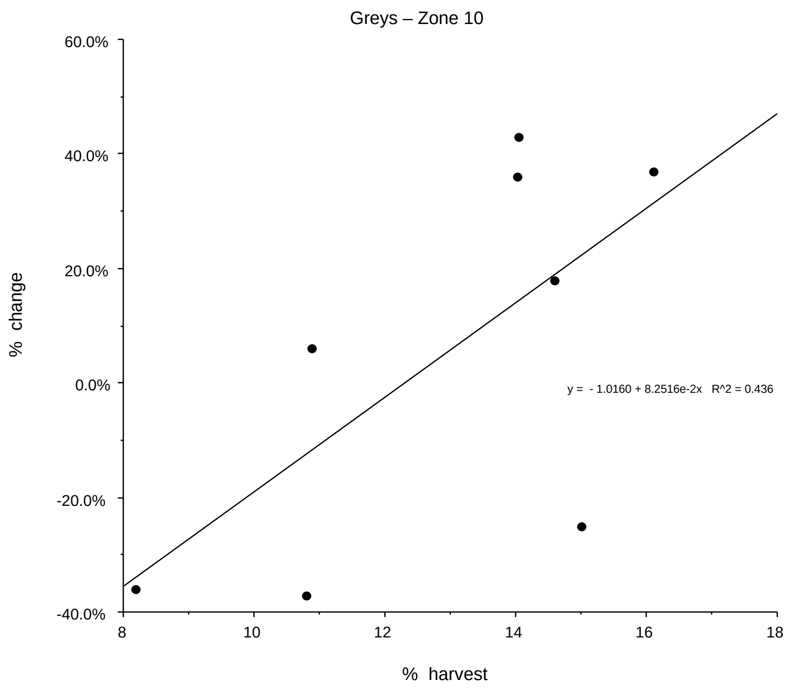

Reds– Zone 6
80.0%
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
-60.0%
% change
0
10
20
30
% harvest

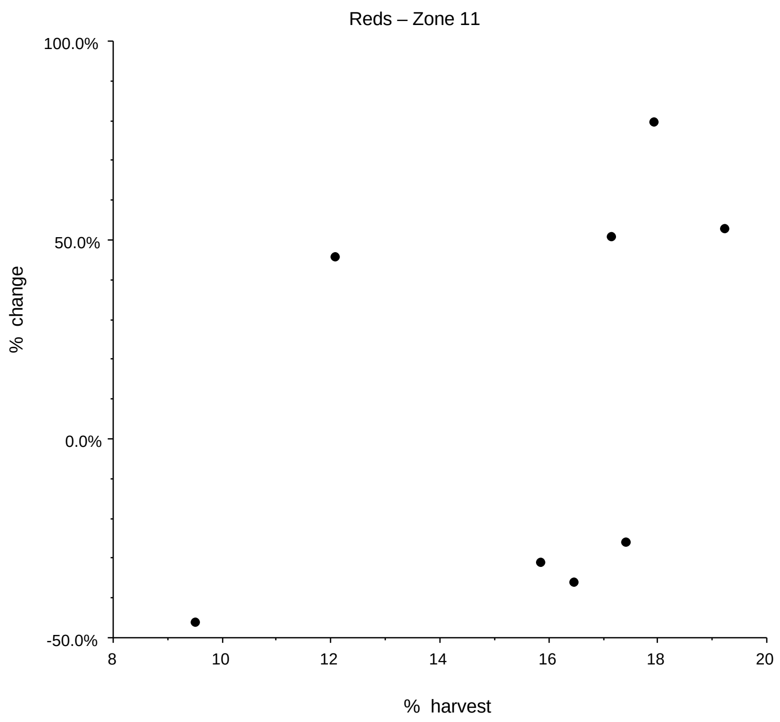

Greys – Zone 6
80.0%
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
% change
0
10
20
30
% harvest

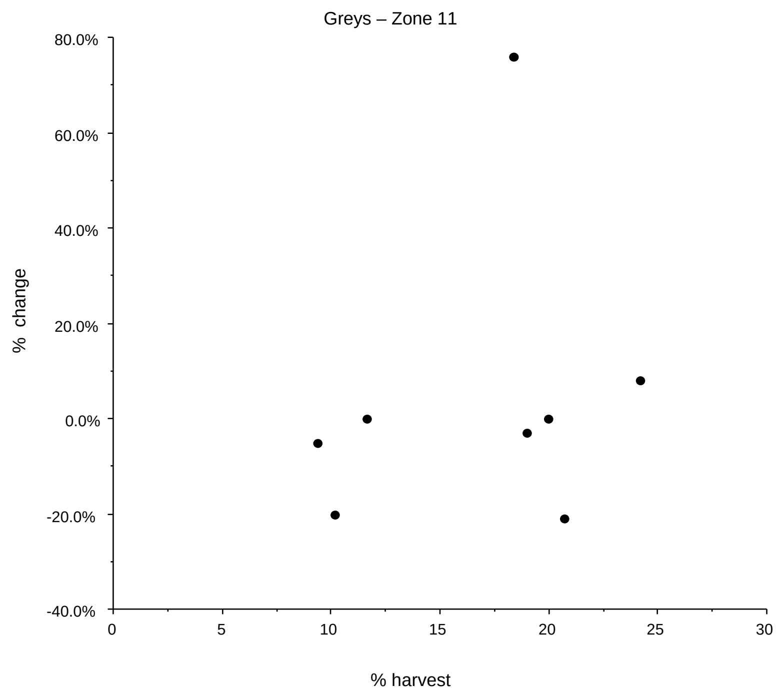

Reds – Zone 8
300%
200%
100%
0%
-100%
% change
y = - 1.6530 + 0.17950x R^2 = 0.483
6
8
10
12
14
16
18
% harvest


Greys – Zone 8
200.0%
150.0%
100.0%
50.0%
0.0%
-50.0%
-100.0%
% change
6
8
10
12
14
16
% harvest

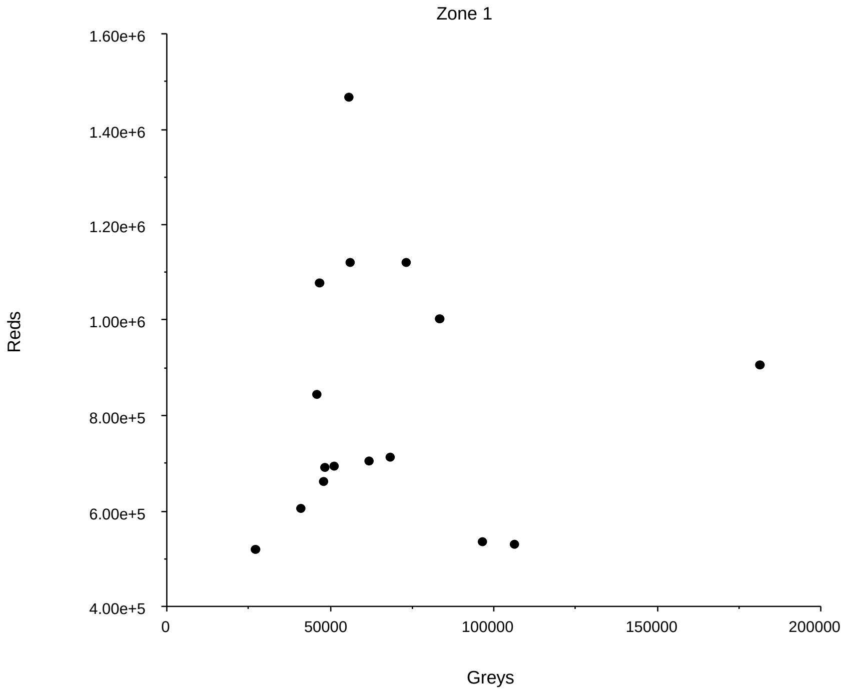

Reds – Zone 10
y = - 0.97378 + 0.11079x R^2 = 0.336
200.0%
150.0%
100.0%
50.0%
0.0%
-50.0%
-100.0%
% change
4
6
8
10
12
14
16
18
% harvest

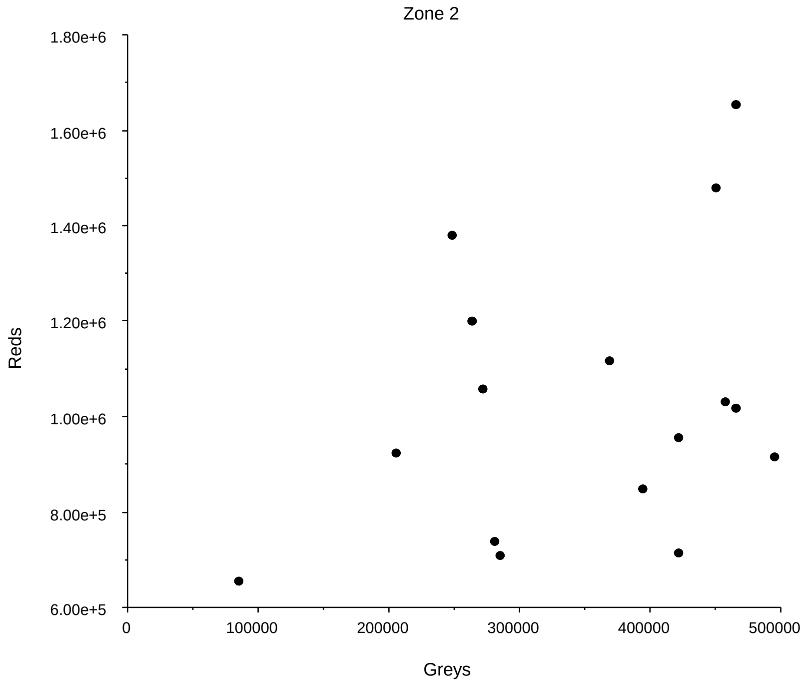

Greys – Zone 10
y = - 1.0160 + 8.2516e-2x R^2 = 0.436
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
% change
8
10
12
14
16
18
% harvest

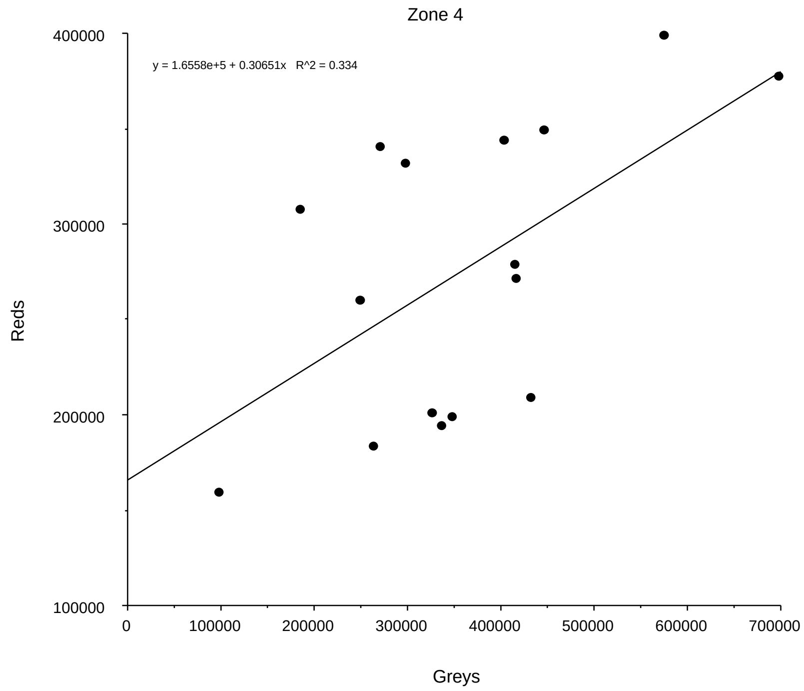

Reds – Zone 11
100.0%
50.0%
0.0%
-50.0%
% change
8
10
12
14
16
18
20
% harvest

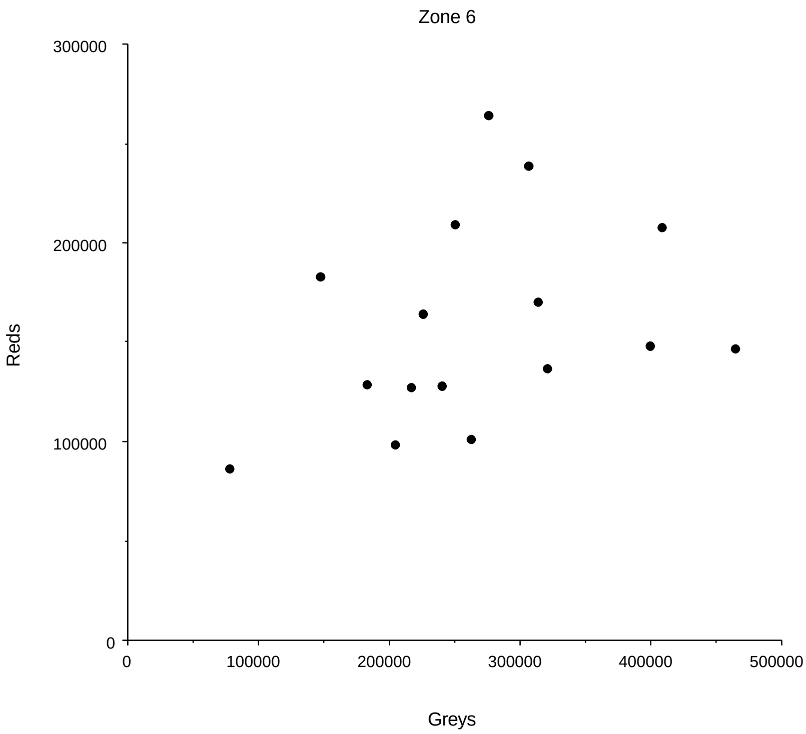

Greys – Zone 11
80.0%
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
% change
0
5
10
15
20
25
30
% harvest

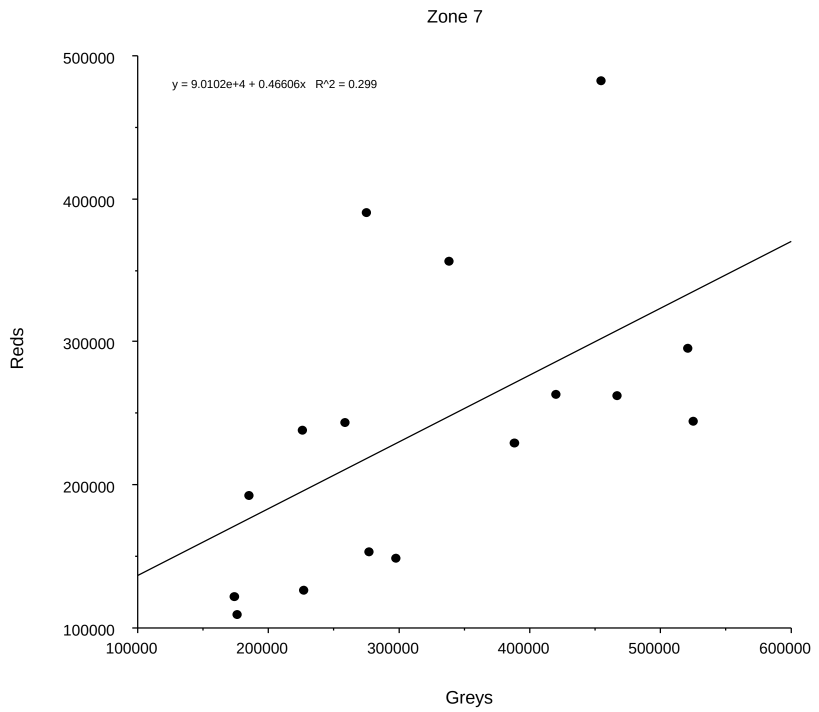
Appendix 5 figure (c). For the same data as in (a), the relationship between numbers of Grey Kangaroos (both species combined) and numbers of Red Kangaroos. Regression lines are shown only where relationships were significant, at least $P < 0.05$). (Source: tabulated data supplied by Joshua Gilroy).

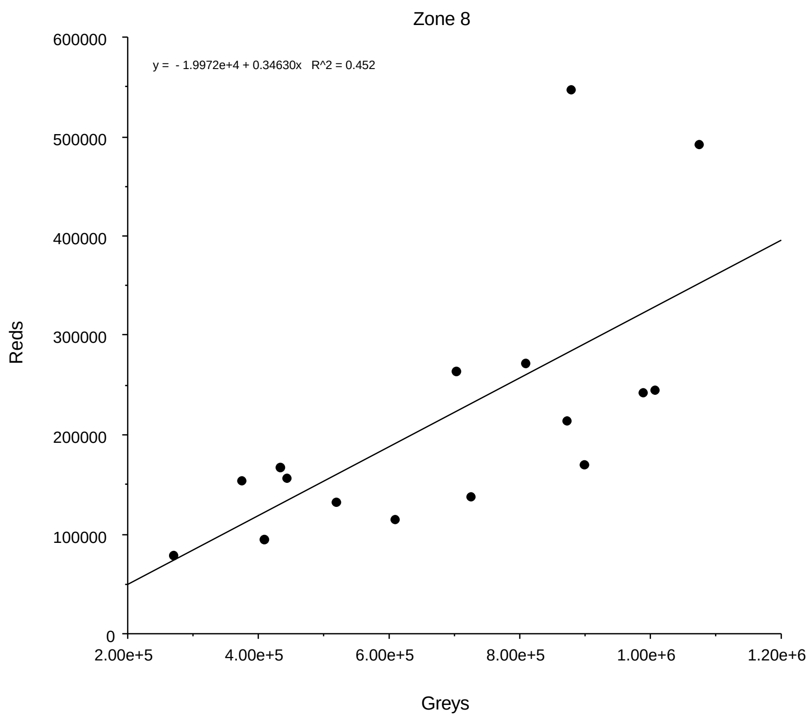

Zone 1
1.60e+6
1.40e+6
1.20e+6
1.00e+6
8.00e+5
6.00e+5
4.00e+5
Reds
0
50000
100000
150000
200000
Greys

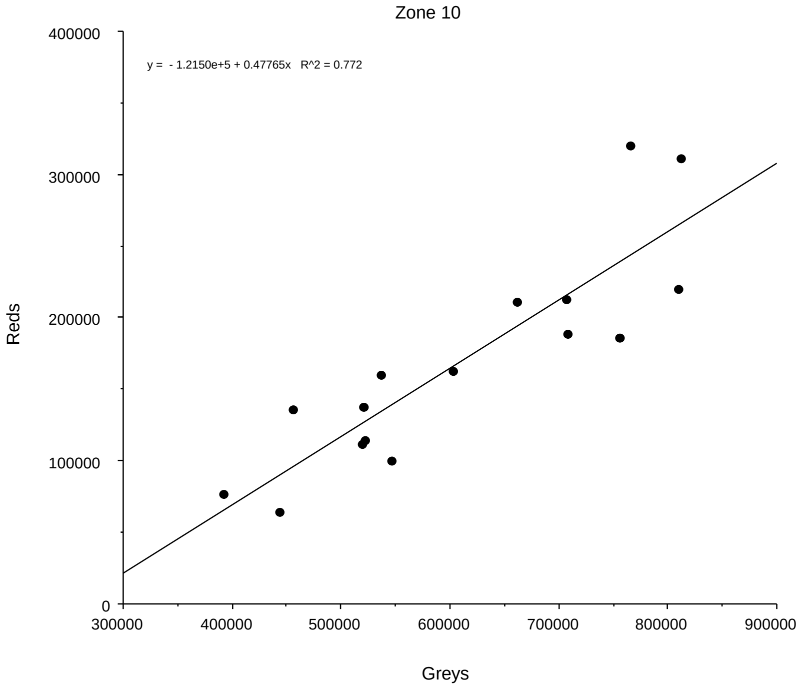

Zone 2
1.80e+6
1.60e+6
1.40e+6
1.20e+6
1.00e+6
8.00e+5
6.00e+5
Reds
0
100000
200000
300000
400000
500000
Greys

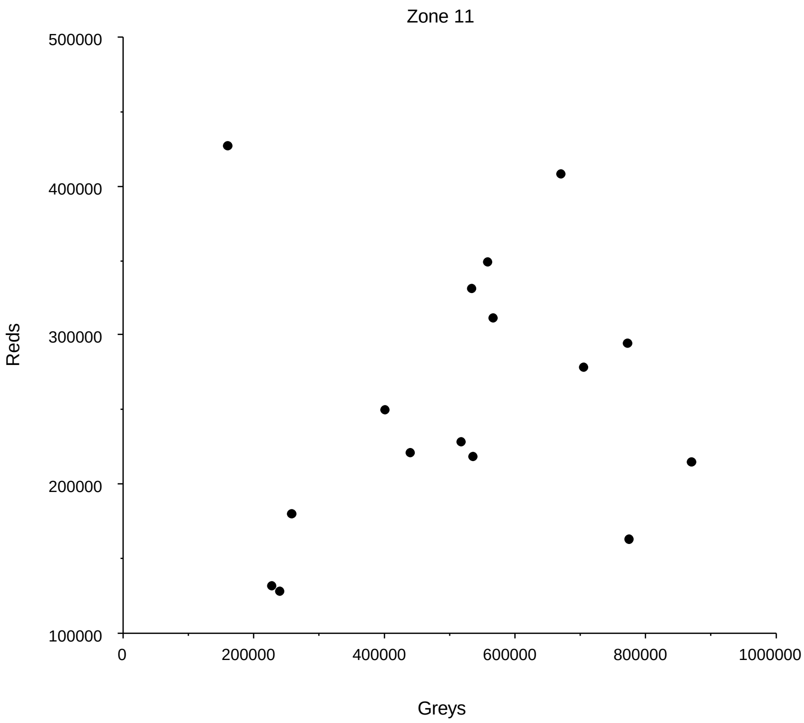

Zone 4
y = 1.6558e+5 + 0.30651x R^2 = 0.334
400000
300000
200000
100000
Reds
0
100000
200000
300000
400000
500000
600000
700000
Greys


Zone 6
300000
200000
100000
0
Reds
0
100000
200000
300000
400000
500000
Greys


Zone 7
y = 9.0102e+4 + 0.46606x   R^2 = 0.299
500000
400000
300000
200000
100000
Reds
100000
200000
300000
400000
500000
600000
Greys


Zone 8
y = - 1.9972e+4 + 0.34630x   R^2 = 0.452
600000
500000
400000
300000
200000
100000
0
Reds
2.00e+5
4.00e+5
6.00e+5
8.00e+5
1.00e+6
1.20e+6
Greys


Zone 10
y = - 1.2150e+5 + 0.47765x R^2 = 0.772
Reds
Greys
400000
300000
200000
100000
0
300000
400000
500000
600000
700000
800000
900000


Zone 11
Reds
Greys
500000
400000
300000
200000
100000
0
200000
400000
600000
800000
1000000