Bureau of Resource Sciences

Scientific, economic and social issues of commercial use of wild animals in Australia

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ISBN 0 642 28385 0

Copies available from:

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Internet: http://www.brs.gov.au

Preferred way to cite this publication:
Choquenot, D., Caughley, J. and McLeod, S. (1998) *Scientific, Economic and Social Issues of Commercial Use of Wild Animals in Australia.* Bureau of Resource Sciences, Canberra.

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FOREWORD

There are already well established harvesting industries involving native and non-native wildlife. There may be scope to increase the range of species used with a positive rather than negative outcome for conservation objectives. There is also scope for increased use of the species which are already harvested if existing markets can be expanded.

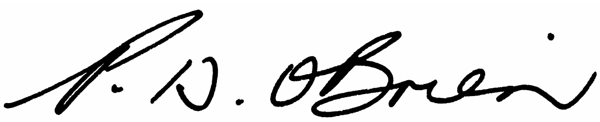
Animal production in Australia is currently based on a relatively small number of domesticated exotic species. Whilst these will continue to constitute the major form of production in the foreseeable future, there are a range of economic, environmental and social arguments for increasing the role of wildlife production.

It is argued that wildlife harvesting can provide greater incentive to conserve their habitats. The commercial use of wildlife also has the potential to enhance the economic viability of agricultural production through income diversification as well as providing a mechanism for more cost-effective management of pest animals for which there is a commercial market.

The commercial use of wild animals is a contentious issue. However, it is essential that policy development in this area is based on science rather than emotion, and at the same time reflects the uncertainty of current knowledge in being precautionary. Government authorities will have a critical regulatory role to play where commercial use involves native species.

The Bureau of Resource Sciences recognises the importance of providing accessible scientific information to feed into emerging policy issues and this has been the basis for developing this paper. Discussion of this issue is timely given the recent Senate Inquiry into the commercial use of Australian native wildlife.

This paper provides information on the ecological basis of wildlife use and associated economic and social considerations and represents an essential background text for scientists, policy makers and wildlife managers.



Peter O'Brien
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ACKNOWLEDGMENTS

This paper benefited from suggestions made by Jim Hone, Gerry Maynes, Gordon Grigg, Tony Pople and John Kelly, although some reviewers did not agree with some conclusions reached by the authors. Mary Bomford, Mike Braysher, Quentin Hart and Peter O'Brien were involved in the conception and management of the paper. Dana Bradford and Maureen Wright were responsible for editing and production and Brett Cullen redrew the figures.

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All $ values are in 1996–97 dollars unless otherwise stated in the text.

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ACRONYMS AND SYMBOLS

ANZECC	Australia and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council for Australia and New Zealand
ATSIC	Aboriginal and Torres Strait Islander Commission
ITQ	Individual transferable catch quota
IUCN	International Union for Conservation of Nature (now World Conservation Union)
KIAA	Kangaroo Industries Association of Australia
SCARM	Standing Committee for Agriculture and Resource Management
TAC	Total allowable catch quota
UN	United Nations
UNEP	United Nations Environment Program
US	United States
WWF	World Wildlife Fund

$C(x)$:	cost of obtaining each animal at population size x (overall harvesting costs)
c_h:	cost of handling each animal
$c_s(x)$:	cost of searching for animals to harvest
$c_t(x)$:	cost of travelling to the location where animals are obtained
CV%:	Coefficient of variation
D:	density
d:	discount rate
e_d:	elasticity of a demand curve
e_s:	elasticity of a supply curve
H:	instantaneous rate of harvest
H_{max}:	maximum rate of harvest
HN:	annual productivity
K:	ecological carrying capacity
MSY:	maximum sustainable yield
N:	abundance of an animal population
p:	price levels
P:	commodity price
P:	net revenue from each harvested animal
p_a:	minimum acceptable profit
PV:	present value
Q:	quantity of a commodity
r:	instantaneous rate of increase
R:	net revenue
$R(x)$:	net revenue from each harvested animal in a population
r_m:	intrinsic or maximum rate of increase
rN:	potential for increase
SY:	sustainable yield
t:	time
T:	lag between past abundance and current rate of increase
$v(x)$:	value of the saleable product obtained by harvesting each animal at population size x
x:	population size

SUMMARY

Scope of the paper

- The sustainable use of some species of wildlife is being promoted as a means of conserving natural environments and arresting land degradation on agricultural lands in Australia.

- Commercial use of wildlife potentially promotes conservation by providing landholders with the incentive and economic ability to maintain wildlife habitat and engage in more sustainable agricultural production.

- Commercial harvesting may also provide a cost-effective mechanism of reducing the impact of introduced wildlife and overabundant native wildlife.

- This paper reviews the suite of ecological and economic factors which influence the sustainability of wildlife harvesting and the capacity of wildlife harvesting to promote more sustainable land use.

Ecological factors influencing harvesting

1. (a) Ecological factors that influence the sustainability of wildlife harvests are those that affect prevailing and potential rates of increase in wildlife population abundance. The influence of these factors on the sustainability of wildlife harvests can be represented by a range of simple and complex predictive models. Simple models, such as those assuming logistic population growth, can provide accurate predictions about the sustainability of harvests for populations inhabiting stable environments.

   (b) Simple models will tend to overstate the sustainability of given harvest rates for populations inhabiting more variable environments. An additional complication is that information on rates of increase required for even simple harvesting models is lacking for most wildlife species in Australia. To overcome these problems, we suggest a general approach that will allow necessary information to be gathered in a harvest setting.

Economic factors influencing harvesting

2. Economic factors which affect the sustainability of harvests include:

   The discount rate applied to the economic return from harvesting — market forces will act to conserve a population of a commercially harvested species only when it has an intrinsic rate of increase considerably in excess of the commercial discount rate. Therefore species which have a high market value but a low rate of increase are susceptible to unsustainable harvesting.

The relationship between population density and the costs of harvesting — the need for harvesters to spend progressively more time searching for animals as population density falls will lead to an increase in harvest costs as population density declines.

Those factors that influence supply of and demand for harvested commodities — demand for harvested commodities will be a function of both economic and social factors influencing commodity supply and demand. Marketing can be used to increase demand at a given commodity price. However, in the absence of controls on harvesting rates, competition between harvesters for market share will convert any increase in demand into increased harvest rates rather than increased profit per harvested animal. Hence, the ability of marketing to increasing the attractiveness of wildlife harvesting as an alternative form of land use, will be restricted to systems where the number of animals harvested is regulated independently of market forces.

Other factors influencing harvesting

3. Wildlife 'ownership' largely determines to whom the economic benefits of a harvest accrue. Hence issues of 'ownership' have important implications for both the sustainability of wildlife harvests, and the extent to which the benefits of harvesting can be accounted against improved land management.

4. In law, native wildlife are owned by the people through the Crown, while introduced wildlife have no legal status beyond the capacity of landholders to nominate such animals stock wherever State legislation allows (that is, for species not specifically scheduled under noxious animals or other relevant Acts legislated by individual States).

5. In principle, native animals represent a common property resource, access for the purpose of harvesting being controlled by State legislation. Similarly, introduced animals are private property where they have been nominated as stock by the landholder on whose land they reside, or have no property status wherever they have not been nominated as stock.

6. (a) In practice, because landholders can invoke trespass law to control access to animals on their land, and in the case of kangaroos are issued with commercial harvesting tags, most wildlife in Australia has the potential to more closely resemble a private rather than a common or no property resource (that is, pseudo-ownership of the wildlife resource). The use of trespass law, reinforced in some cases by issue of commercial harvesting tags direct to landholders, appears adequate to give landholders sufficient property rights to control access to wildlife on their land.

(b) Pseudo-ownership appears a sufficient mechanism by which landholders can exercise discretionary use of wildlife on their land. Pseudo-ownership allows landholders to charge for access to wildlife or to commercial use tags, to allow free access to wildlife, or to undertake harvesting themselves. This allows them to balance direct and indirect economic benefits of wildlife harvesting with their perception of prevailing and future market conditions.

7. (a) Social attitudes to wildlife harvesting will always significantly affect the marketability of wildlife commodities and hence the capacity of wildlife harvesting to contribute to conservation objectives. In particular the perception of wildlife harvesting as a form of pest control, the conservation status of harvested species and the humaneness of harvesting, will remain important potential constraints on the acceptability of wildlife commodities by both the domestic and international markets.

   (b) The increased income from wildlife harvesting which should accompany development of markets for game meat, will be a major factor in changing the perception of wildlife from pest to resource in rural communities. However, urban and international markets will be at least as concerned with the sustainability and humaneness of harvests. Rigorous attention to animal welfare considerations and promotion of the careful management of harvests must be maintained in order to ensure ongoing market development.

8. (a) Regulations controlling the harvest of introduced wildlife are limited to codes of practice for shooting and meat handling and inspection. In contrast, the harvest of native wildlife is regulated by State and Territory wildlife agencies, and in some cases by overriding Commonwealth controls on the export of harvested commodities, operating through the *Wildlife Protection (Regulation of Exports and Imports) Act 1982*. For example, kangaroo harvesting is regulated by State legislation which is used as the basis for individual State and Territory management plans, applicable to each commercially harvested species. These management plans are periodically submitted to the relevant Commonwealth Department for approval, whereupon export licences are granted. In order to gain Commonwealth Government approval, the annual harvest within each State must be below a quota set by the relevant Commonwealth Department.

   (b) While kangaroo harvest quotas have not generally been met in recent years, the quota set for red kangaroos in Queensland has been regularly approached over recent years. Where quotas are not approached, the *rate* of harvest for kangaroos appears to be set by the low profitability of the harvest, rather than through legislative controls. However, if the trend for increasing commercial kangaroo harvests continues, such controls will become increasingly relevant to the operation of the industry.

9. (a) Regulation of kangaroo harvesting by quota requires independent monitoring of the harvested population's density, which is a significant cost to State and Territory management agencies. An alternative to monitoring which is used in other countries involves varying the number of harvesters licensed to operate in prescribed areas according to the effects of prevailing conditions on the harvested populations abundance, but allowing each harvester unlimited access to the wildlife population.

   (b) There is considerable disagreement concerning the effectiveness of quota and licencing systems for the regulation of wildlife harvests. For kangaroos, the ability of the quota system to regulate harvests at a national level will remain untested until the national quota for particular species is approached. However, for red kangaroos in Queensland, preliminary evidence suggests quotas are an adequate system of regulation. It is essential under any regulatory system that quota setting and monitoring remain completely independent of the harvesting and marketing components of the industry, providing a strong argument for the maintenance of government involvement in the management of any native wildlife harvest.

Wildlife harvesting and conservation on agricultural lands

10. Agricultural producers can become involved in wildlife harvesting as passive or facilitative participants in the harvest, as brokers of access to the harvest, or as active participants undertaking the harvest themselves. For a given harvest, the level of involvement a landholder has should reflect some balance between the costs of that involvement (including direct costs associated with any activity related to the harvest and indirect costs associated with maintaining the harvested species on their land), and its benefits (including the direct benefits of income derived from the harvest and indirect benefits of any increase in the profitability of their agricultural enterprise accruing from the reduction in the harvested population).

11. Contingent on the ecological and economic constraints which impinge on wildlife harvesting, commercial use of pest species has the potential to reduce pest densities below thresholds for acceptable levels of environmental and agricultural damage. The use of harvest subsidies to increase the value of harvested pests can potentially increase the effect of commercial harvesting on pest density, by elevating the return on pests taken from low density populations.

12. (a) Commercial use of wildlife can potentially promote conservation on agricultural lands by providing an economic yield from undeveloped lands which is competitive with less benign forms of land use, and by allowing diversification of income to agricultural enterprises. The potential for either process to realise conservation benefits is contingent upon the sustainability of the harvest proposed and the degree to which agricultural producers are prepared to substitute harvesting for traditional agricultural activities.

(b) If producers respond primarily to economic imperative, they will favour harvesting where they perceive a net economic gain in doing so, or at least believe harvesting to be a cost-neutral alternative to agricultural activities. Harvesting subsidies may represent a mechanism for promoting substitution of harvesting for less benign land uses. Such subsidies may represent an efficient use of conservation resources, particularly where habitats of high conservation value are involved.

13. For commercial harvesting to realise conservation benefits on agricultural lands, traditional agricultural activities must be curtailed or their intensity substantially reduced in order to participate in harvesting. Hence, agricultural activities must impact on the capacity of producers to participate in harvesting by constraining the sustainability of the harvest or the yield derived. Data unequivocally demonstrating the effect of agriculture on harvest sustainability and/or yield are currently unavailable.

14. (a) The popular thesis that kangaroo harvesting could induce rangelands graziers to reduce domestic stocking rates and/or reconsider clearance of undeveloped land serves to illustrate several of the issues impinging on the capacity of commercial wildlife harvesting to realise conservation benefits on agricultural lands. For example, while a range of economic factors will influence the level to which graziers will participate in kangaroo harvesting, additional factors will influence their propensity to lower domestic animal stocking rates even where participation in harvesting increases.

    (b) In the first instance, the interest graziers have in increasing their involvement in kangaroo harvesting will largely reflect the profit they can derive from each kangaroo harvested (as opposed to increased profit through an elevation in the number of kangaroos harvested). The per capita value of kangaroos harvested will reflect the interaction of supply and demand, and the effects of non-market influences such as quotas.

    (c) Substantial increases in per capita value would require an astonishingly successful marketing campaign to maintain demand for kangaroo products despite increasing prices, and a constraint on supply which inhibits harvesters converting elevated demand into elevated harvest rates, thereby allowing per capita price to rise. For the development of such an environment, the current quota system must be maintained in order to limit supply. However, the effect of quotas on market values for kangaroos would create conditions highly conducive to the development of 'symbiosis' between the agency setting quotas and the kangaroo industry. Links between these bodies must be assiduously avoided if conservation of harvested species is to be assured.

15. In addition, if conservation benefits are to be realised from increased participation of graziers in kangaroo harvesting, they must be convinced that profits from the harvest can be improved by reducing domestic animal stocking rates. Data linking stocking rates to kangaroo density are equivocal.

1. INTRODUCTION

Recent interest in wildlife harvesting has arisen for two different reasons. Firstly, a recognition has developed that the sustainable harvest of wildlife may lead to the conservation of the habitats that contain harvested species. If maintaining these areas provides a greater return to the economy and to society than do other forms of land use, then the exploited species and other species in these habitats will all be conserved (IUCN/UNEP/WWF 1980). This concept was progressed in the Bruntland Report (World Commission on Environment and Development 1987) and at the United Nations (UN) Conference on Environment and Development at Rio de Janeiro in 1992. Accordingly, the Species Survival Commission within the International Union for the Conservation of Nature (IUCN) has set up a Specialist Group on Sustainable Use of Wild Species with the task of developing a set of procedures that will be applicable worldwide for assessing the sustainability of use of wild species. An initial report on assessment procedures has been prepared (Prescott-Allen and Prescott-Allen 1996).

'There is increasing recognition that the sustainable harvest of wildlife may lead to the conservation of habitats that contain the harvested species.'

Within Australia, the National Strategy for the Conservation of Australia's Biological Diversity has similarly recognised the potential conservation benefits which can be obtained through the use of wild animals (see Box 1). In Australia, there is a second motivation for recent emergence of interest in wild animal harvesting. Because of the declining terms of trade for traditional agricultural products, Australian producers are looking to diversify their enterprises and broaden their income base. To this end, it has been suggested that commercial harvesting of wild animals on their properties may represent a significant alternative source of income (Ramsay 1994). Coincident with these developments has been the recent promotion of game meat as a 'healthy' alternative source of red meat, being low in cholesterol and free of chemical residues. This promotion has increased demand for game meat in Australia and overseas, although the major consumer in Australia remains the restaurant trade, and in particular those restaurants servicing the tourist trade. The market for game meat in overseas countries is also increasing as populations grow and affluence increases.

In addition to offering opportunities to broaden the income base of agricultural enterprises, wild animal harvesting in Australia may also directly address problems of land degradation (see papers in Grigg et al. 1995). It is generally considered that overgrazing by sheep and other herbivores has led to degradation of Australia's rangelands since European settlement (Graetz 1988). Degradation of the rangelands has seen the species composition of grasslands change 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). Both of these changes have led to an increase in soil erosion and a reduction in water recharge rates (Woods 1984). Involvement of agricultural enterprises in wildlife harvesting may represent a strategy whereby more benign forms of land use can be increasingly substituted for traditional agriculture, arresting or slowing the process of land degradation.

Wildlife harvesting may alleviate problems of land degradation for a number of reasons. Intrinsic attributes of native wildlife, including their co-evolution with native pasture resources, mobility, pattern of landscape usage and dietary preferences, may make them less likely to cause land degradation. Grigg (1988, 1989, 1995, 1996) has developed some of these ideas in association with his suggestion that the large species of kangaroos currently being harvested in Australia represent an undervalued potential source of income for rangeland graziers. While kangaroo farming per se is not a feasible option for many reasons (Shepherd 1983), the harvest of free-ranging kangaroos could occur with little modification to existing agricultural infrastructure. Grigg (1995) argues that income from kangaroo harvesting could potentially allow graziers to run fewer stock, thereby reducing total grazing pressure.

BOX 1:
NATIONAL STRATEGY FOR THE CONSERVATION OF AUSTRALIA'S BIOLOGICAL DIVERSITY

The National Strategy for the Conservation of Australia's Biological Diversity addresses the issue of native wildlife use in Australia (Section 2.7 in ANZECC 1996) as follows:

Objective:

- To achieve the conservation of biological diversity through the adoption of other ecologically sustainable wildlife management practices.

Actions:

- In accordance with the World Conservation Union's resolution on sustainable use, develop wildlife use programs that create economic and other incentives for the retention, rehabilitation, maintenance and management of natural habitats.

- Review the appropriateness and ecological sustainability of current management strategies involving the harvesting of native species by:

  (a) ensuring that coordinated research into and monitoring of exploited species is undertaken to determine ecological sustainability;

  (b) ensuring the development and regular review of management plans, for both domestic and export purposes;

  (c) ensuring that harvesting arrangements are based on the long-term viability of the species concerned; and

  (d) ensuring thorough public consultation and government accountability in the management, planning and implementation process.

Both ANZECC and ARMCANZ have placed the issue of sustainable use of wildlife on their respective agendas at recent council meetings. ANZECC has established a Sustainable Use of Wildlife Taskforce to examine existing programs for the sustainable use of wildlife in Australia and New Zealand, and to identify options for enhancing these programs. Discussion papers on these topics are being prepared. Another national initiative is the development of a National Strategy for

Rangeland Management (a joint project of ARMCANZ and ANZECC), which considers wildlife harvesting as one of its central issues.

'ANZECC and ARMCANZ have placed the issue of sustainable use of wildlife on their agendas.'

This paper has been prepared to complement these other papers. To avoid duplication, this paper does not deal in any detail with current harvesting programs nor, except where specific programs are used as examples, with strategies to enhance financial returns and other incentives to rural and other landholders. Similarly, we have not considered indigenous or traditional uses of wildlife, which have been reviewed recently elsewhere (Bomford and Caughley 1996). Instead this paper addresses scientific, technical and economic issues that will determine how commercial use of wild animals on agricultural land can be achieved sustainably. As such, our focus is almost exclusively on the harvest of free ranging species. We have not considered wildlife farming (defined as intensive farming by Hudson et al. 1989), because once wild animals are effectively enclosed (for example, as on buffalo, deer, emu and crocodile farms), issues impinging on their management are largely those of husbandry. From the point of view of this paper, our primary interest is that the number of animals taken from wild populations to stock such farms falls within acceptable offtake levels. The methods for determining acceptable levels are the same as those described herein for harvesting.

The paper only briefly considers the potential for other commercial uses of wildlife on agricultural land. For consumptive commercial use, such as safari hunting, the level of offtake and its regulation would be addressed in the same way as sustainable harvesting rates. Non-consumptive commercial use (namely tourism) does not remove animals so is not relevant here. While there may be some impact on the environment (dependent on the volume of tourism), direct impacts on animal species are likely to be very different from those associated with harvesting.

1.1 Current wildlife harvesting on agricultural land

1.1.1 The species

The native and introduced species of wildlife in Australia that are presently part of a commercial trade in harvested products are:

Native species

Red kangaroo (*Macropus rufus*)
Eastern grey kangaroo (*M. giganteus*)
Western grey kangaroo (*M. fuliginosus*)
Wallaroo or euro (*M. robustus*)
Whiptail wallaby (*M. parryi*)
Bennett's wallaby (*M. rufogriseus*)
Rufous wallaby (*Thylogale billardierii*)
Brushtail possum (*Trichosurus vulpecula*)
Emu (*Dromaius novaehollandiae*)
Saltwater crocodiles (*Crocodylus porosus*)
Freshwater crocodiles (*C. johnstoni*)
Magpie geese (*Anseranas semipalmata*)
Muttonbird (*Puffinus tenuirostris*)
Ducks (several species)

Introduced species

Feral goat (*Capra hircus*)	Feral camel (*Camelus dromedarius*)
Feral pig (*Sus scrofa*)	Feral buffalo (*Bubalus bubalis*)
Rabbit (*Oryctolagus cuniculus*)	Banteng (*Bos javanicus*)
Feral donkey (*Equus asinus*)	Fox (*Vulpes vulpes*)
Feral horse (*E. caballus*)	Feral cat (*Felis catus*)
Deer (several species)	Cane toad (*Bufo marinus*)

Some of the introduced species (for example, rabbits and foxes) were brought into Australia for hunting, while others (for example, goats, horses and pigs) were established as domestic stock before escaping to form feral populations (Wilson et al. 1992). Most species of wildlife that are commercially harvested in Australia are considered pests and their exploitation is typically viewed as a form of pest control. Some species are considered agricultural pests because they compete with stock for pasture, damage fences and watering points or prey upon domestic animals. Some species are considered environmental pests because they modify native pastures; prey upon native animals or compete with them for food, water or shelter; or because their hard hooves are believed to compact soil which may increase erosion.

1.1.2 The current system of harvesting

Most wildlife harvesting in Australia is done by professionals who do not pay fees to property owners for the wildlife removed from their land. However, it is increasingly common in South Australia for professional kangaroo harvesters and processors to pay kangaroo tag fees to landholders (Grigg 1995). Similarly, many recreational hunters pay landholders for access to populations of feral animals residing on their land. Because wildlife is, in principle, a common property resource belonging to no one (if introduced) or the Crown (if native), the commercial industry is largely free to operate within the bounds of access rights created by current regulations and trespass law (but see Section 2.3) (Collins and Menz 1986). Furthermore, since most harvested species are viewed as pests, the attitude that the harvester is doing the landowner a favour by removing unwanted animals from their property is common amongst both harvesters and landholders.

1.1.3 The product

The products of commercially harvested wildlife in Australia are primarily skins and meat. Most meat derived from wildlife in Australia is sold as pet meat, despite sizable markets for human consumption meat (game meat) overseas. Australia's contribution to overseas game meat markets has typically been small and sporadic, although relatively large quantities of particular game meats (primarily feral pig and goat) have been successfully marketed into specific countries on a reasonably consistent basis (Ramsay 1994). The inability of Australian game meat suppliers to find significant markets for many potential sources of game meat (including kangaroo meat) reflects to varying degrees fluctuations in supply and quality of product, the need for improved marketing and the influence of commercial and conservation interests on the governments of potential markets.

'The market for Australian wildlife products has not traditionally been lucrative.'

The market for Australian wildlife products has not traditionally been lucrative. To a large extent this reflects prevailing attitudes to the resource and its products. For example, wildlife resources in Australia are seen as abundant, reducing the price consumers are prepared to pay for products derived from the resource. Similarly, most animal species that are harvested commercially in Australia are considered pests, a negative perception that tends to cloud their perceived value as a resource. Finally, there is a limited cultural experience amongst Australians of game meat consumption. Collectively, these attitudes have mitigated against the widespread development of a domestic game meat industry based on human consumption.

1.2 Sustainability of wildlife harvesting on agricultural land

We define sustainable harvesting as harvesting which does not diminish the range and viability of populations of the species across their extant range. Harvesting will be sustainable if the rate of offtake is set at a level that can continue indefinitely into the future. In predicting whether a harvesting regime will be sustainable, the important factors are: the biological potential of the species being harvested; the technical limitations to its exploitation; the effectiveness of government regulations in controlling offtake; the effect of market demand and changing society expectations on economic viability; and the impact of harvesting on the natural environment.

'Sustainable harvesting is that which does not diminish the range and viability of a target species population across its range.'

Correspondingly, the following chapter will consider:

1. The ecological basis of harvesting (that is, how a population reacts to harvesting).
2. The economic factors affecting the profitability of harvesting.
3. The issue of wildlife ownership.
4. Other social and political constraints.
5. Achieving sustainable harvests within these interlacing strictures.

Following these assessments, we then explore the feasibility of sustainable harvesting in meeting the goals of agricultural diversification, pest management and conservation.

2. FACTORS AFFECTING WILDLIFE HARVESTS

2.1 The ecological basis of wildlife harvesting

2.1.1 Wildlife populations

When people refer to 'wildlife harvesting' they usually imply an offtake from an identifiable group of animals, the harvested population. Most people have several interpretations of what a population of wild animals is. When we talk about populations we will usually refer to a number of animals occupying an area where they are subject to the same broad set of environmental or management conditions. Hence, when we describe changes in the abundance of such a population according to factors representing environmental or management influences, we imply that these factors affect most of the animals in the population in a more-or-less similar way.

2.1.2 Harvesting models

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). For this reason, when a sustainable harvest of wild animals is contemplated, the ecological relationships which determine the population's rate of change in abundance should be understood so that the sustainability of given rates of harvest can be assessed. These relationships are generally represented as conceptual or mathematical models. Models which have been used to estimated sustainable yields for wildlife populations can be divided into those which represent the dynamics of: self-limited populations; populations limited by the availability of resources used consumptively (that is, food); and populations limited by the availability of resources used pre-emptively (for example, nest sites). Most harvesting models have been developed to predict yields of populations limited by resources used consumptively, although they have often been modified to consider harvests of the other two classes of population. Commonly used harvesting models fall into two categories; *single-species models* which assume some form of logistic population growth; and *multi-species models* which do not (Caughley 1976).

'Sustainable harvesting requires an understanding of the ecological relationships which determine a population's rate of change in abundance.'

Single-species models

One of the simplest mathematical models used to predict change in the abundance of an animal population (N) over time (t) is the logistic which has the form:

$$\frac{dN}{dt} = r_m N(1 - \frac{N}{K})$$

where r_m is the population's intrinsic rate of increase and K its abundance at ecological carrying capacity (Caughley 1976). The intrinsic rate of increase of a population is the natural logarithm of the rate at which the population will grow in a given environment when resources are not limiting (Caughley 1977). Ecological carrying capacity is either: the density of a population limited by renewable resources where these resources are sufficient only to allow replacement of each member of the population in subsequent generations; or the density of a self-limited population where crowding suppresses any further recruitment. In either case, *K* represents the population's maximum density. The trajectory of a population growing logistically is shown in Figure 1.

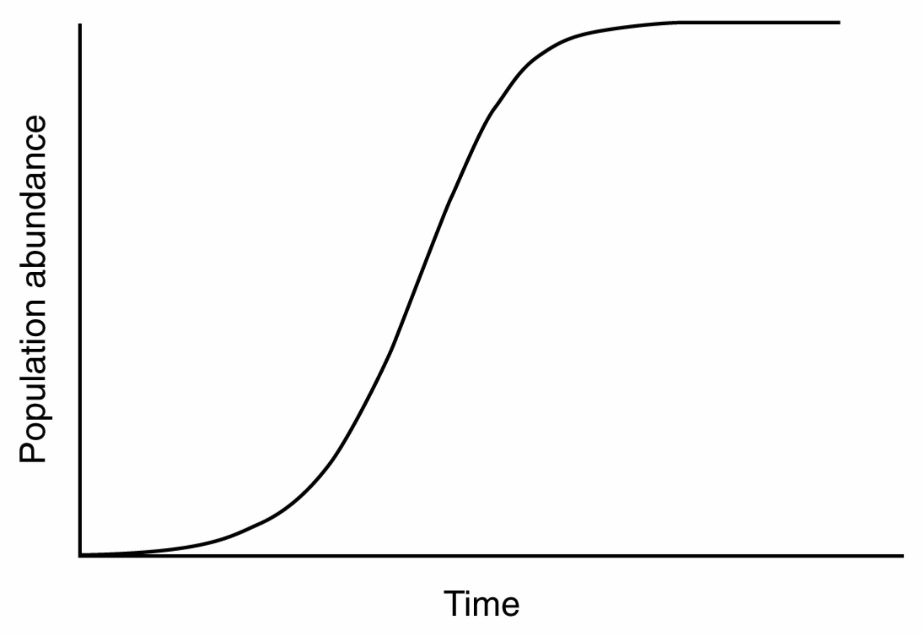

Figure 1: The trajectory of a population growing logistically.

When applied to an animal population limited by the availability of its food resources, the logistic population model implies that the population's per capita food availability (the amount of food available to each animal in the population) can be indexed by the abundance of the population itself and hence the population's instantaneous rate of increase (*r*) will decline linearly with increasing density until the abundance of resources is insufficient to generate a positive rate of population growth (Figure 2).

Such density dependence in *r* reflects the cumulative effects of density-dependent fecundity and/or mortality as per capita food availability declines. The linear decline in *r* with increasing population density assumes three important things about the relationship between the animal population and its food resources:

1. *The rate at which the population's food resources are renewed is independent of the density of the population.* An example would be mice in a cage to which a set amount of food is added daily, any uneaten residual being removed. In this case, the rate of renewal of the food resources is independent of the number of mice sharing the food.

2. *The effect of food availability on r is instantaneous.* For example, declining per capita availability of food to the caged mice as their abundance increases is immediately reflected in their fecundity and/or survival and hence prevailing *r*.

3. *The rate at which food is supplied to the population is constant.* For example, the same amount of food is added to the caged mice daily. This means that when the mouse population in the cage eventually attains a density where food resources allow only replacement of existing mice in subsequent generations, this density will be a constant (*K*).

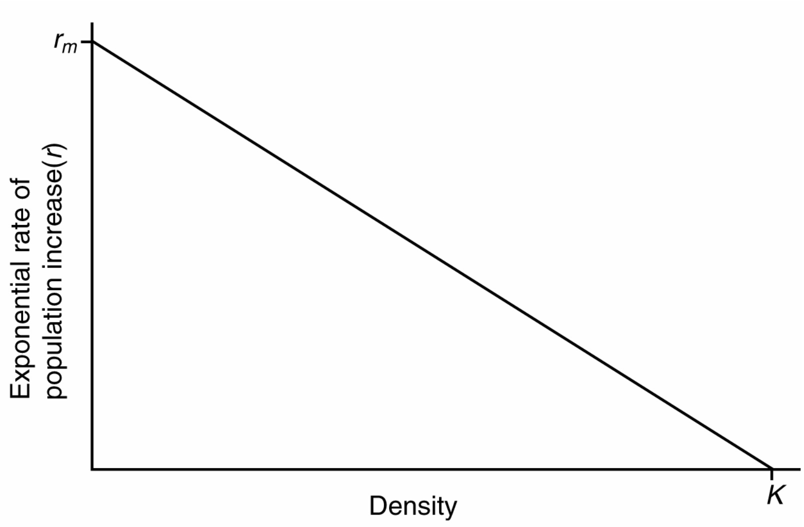

Figure 2: Density-dependent variation in the exponential rate of increase (*r*) of a population growing logistically.

Taken together, these assumptions explain why the logistic model implies that the prevailing density of the population provides a good index of its per capita food availability and hence *r*. These assumptions also explain why perturbation of the density of a population which grows logistically above or below *K* alternately decreases or increases per capita food availability, leading to negative or positive *r*, with the result that *N* moves back toward *K*. As such, a population which grows logistically is regulated at *K* by the density-dependent influence of intraspecific competition for food resources.

It is clear from Figures 1 and 2 that a population at any density (*N*) less than *K* will have positive *r*. If instead of allowing the population to grow at *r*, this potential growth were harvested each year, the population would remain at *N*, its potential for increase (*rN*) being removed as an annual harvest. Under these conditions, *r* will be equivalent to the population's instantaneous rate of harvest (*H*). The value of *H* required to hold a population at given *N* is the population's annual productivity (*HN*). Because *HN* represents the population's potential growth over that year, *HN* can be removed year-in year-out without affecting *N*. Hence *HN* is by definition a sustainable yield (SY). For a population growing logistically, *HN* for given *N* between 0 and *K* is calculated by:

$$HN = r_m N(1 - \frac{N}{K})$$

The resulting relationship between HN and N (density) is shown in Figure 3. HN peaks at $0.5K$ producing a maximum sustainable yield (MSY) of $HN = 0.25r_mK$ harvested at an instantaneous rate of $H = 0.5r_m$. As such, the logistic model predicts that a population reduced to half of its density at carrying capacity will produce its maximum net productivity and that this will provide its maximum potential rate of harvest which would be taken at half its intrinsic rate of increase. If the population is harvested at $H > r_m$, the harvest will be unsustainable, the population eventually being harvested to extinction.

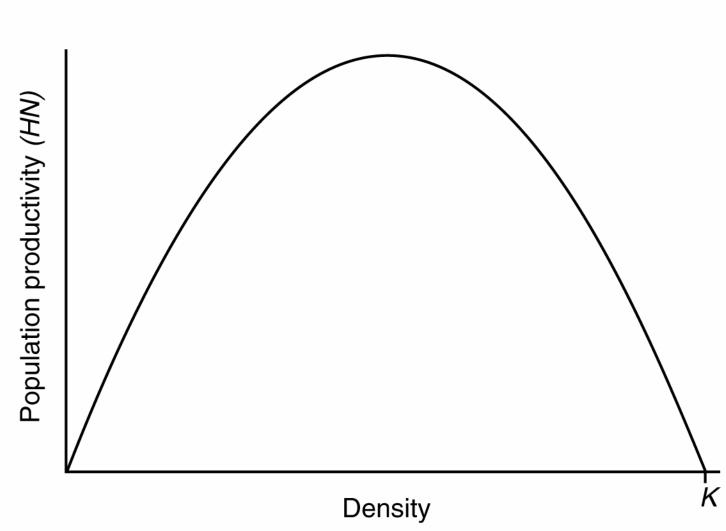

Figure 3: Productivity of a population growing logistically.

However, the three important assumptions of logistic population growth will not hold for many wildlife populations. Most wild animals influence both the immediate availability of their food resources and the rate at which those resources are renewed. Hence current food availability will be a function of past rather than current animal density. Hutchinson (1948, 1954) attempted to incorporate this effect by modifying the logistic model so that the influence of N on r is delayed by $t-T$, where T is the lag between past N and current r. Typically T would be related to gestation length and the period between parturition and recruitment. The delayed logistic model predicts HN from N_t by:

$$HN = r_m N_t (1 - \frac{N_{t-T}}{K})$$

When $T > 1$, maximum productivity occurs at higher densities than that predicted by the logistic model (that is, to the right of $0.5K$) (Figure 4). Density-dependent dynamics of many large mammal populations limited by food availability suggest that MSY peaks around $0.7K$ (Fowler 1981). However, while delaying density dependence in r modifies the assumptions of independence between N and rate of renewal in food supply and the immediate effects of food availability on r, the assumption that food supply is constant remains. This restricts the applicability of the delayed logistic model to wildlife populations inhabiting constant environments (Caughley 1976, 1977). Hence, while the delayed logistic model describes population growth trajectories that correspond more closely with those estimated for many wildlife populations (and for large mammals in particular) than that predicted by the logistic model, these populations almost invariably occur in demonstrably stable environments.

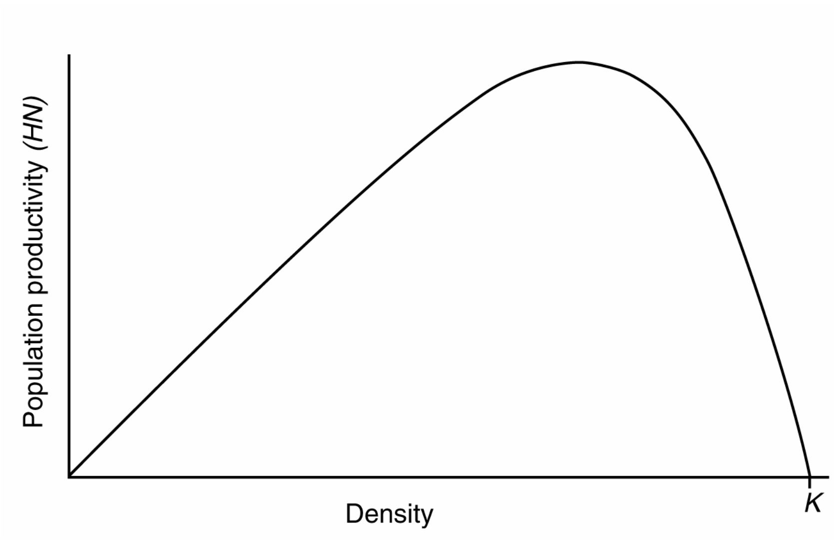

Figure 4: Productivity of a population growing according to the delayed logistic model.

In order to predict *r* (and hence *HN*) for wildlife populations inhabiting environments where food resources fluctuate independently of animal density, variation in the availability of food and the response of *r* to such variation, must be explicitly incorporated into predictive models. Because these models explicitly describe variation in the abundance of more than the wildlife species of interest, they are called multi-species models.

Multi-species models

Caughley (1976) developed an interactive plant–herbivore model which described coincident variation in the abundance of a herbivore population and its food resources through three functions:

1. The growth of ungrazed vegetation as a function of vegetation biomass. Because most plant populations grow logistically, a parabola (Figure 5) described this function.

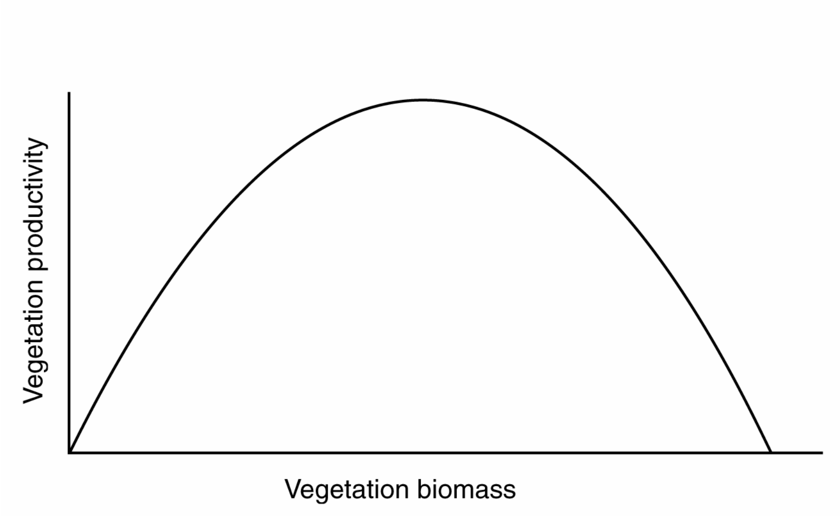

Figure 5: Productivity of ungrazed vegetation.

2. The functional response of herbivores that describes variation in their per capita rate of vegetation intake as a function of vegetation biomass. Holling (1959, 1965, 1966) proposed three general types of functional response. A Type I functional response is characteristic of a forager that consumes food in proportion to the forager's rate of encounter with food items (for example, a filter feeder), until saturation level is attained. Beyond saturation, the rate of food intake is a constant. A Type II functional response is characteristic of foragers that require some time to handle and ingest food. The 'cost' of handling and ingestion time leads to the functional response rising at a decreasing rate, to an asymptote equivalent to the rate associated with the forager's saturated feeding rate. Type III functional responses are characteristically sigmoidal, and result from either the consumer learning to avoid certain prey types when the prey are at low density (Holling 1966; Real 1977), or from the prey having a refuge from predation. Type II and III functional responses are typical of most herbivores (for example, Short 1986; Gross et al. 1993; Ginnett and Demment 1995). A Type II response for herbivores is shown in Figure 6.

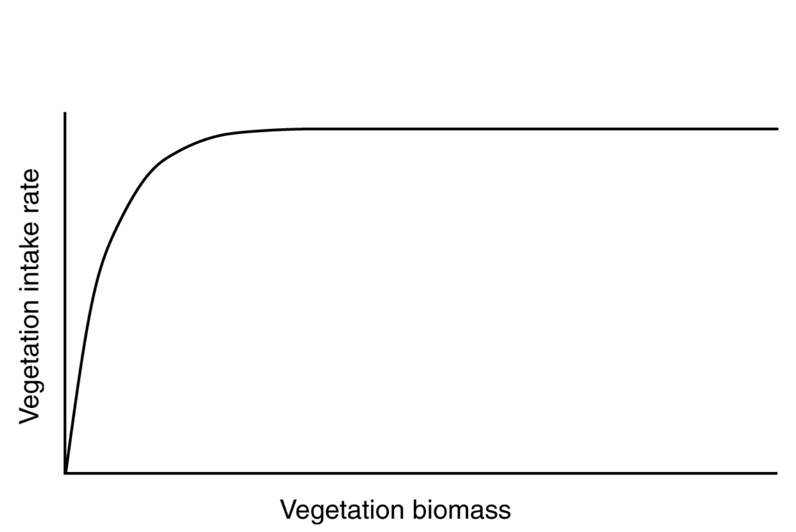

Figure 6: The Type II functional response of a herbivore to variation in vegetation biomass.

3. The numerical response of herbivores that describes variation in the exponential rate of increase (r) as a function of prevailing vegetation biomass. The numerical response usually takes the form of a saturation curve, with maximum r (that is, r_m) approached asymptotically at high vegetation biomass (Figure 7).

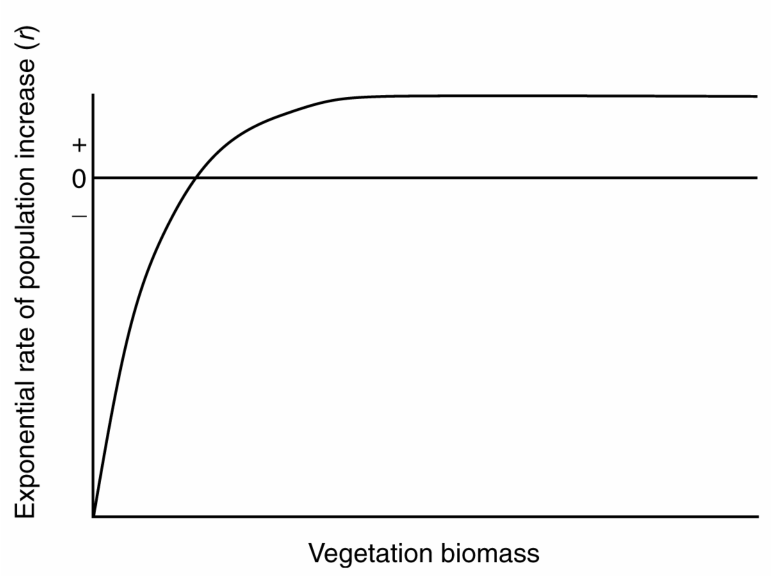

Figure 7: The numerical response of a herbivore population to variation in vegetation biomass.

These functions are linked in two simultaneous equations which predict reciprocal variation in the abundance of herbivores and the vegetation they feed upon. In contrast to the two logistic-based models described previously, the interactive model does not assume *K* to be constant. Hence *r* and *H* are not associated with any given *N*, but with prevailing vegetation biomass according to the numerical response. If, however, variation in vegetation biomass is primarily a function of the grazing activities of the herbivore population itself, there will be a tight relationship between herbivore density, vegetation biomass and hence *r*. In this case, the assumptions of the logistic-based models may be approached and these models might be used as a 'short-hand' method for approximating sustainable yields and the herbivore population density from which they may be taken.

The degree to which herbivores influence the availability of their food resources will depend on the variability of the environment in which ecosystem exists; and the relative efficiency of the reciprocal feedback between vegetation and herbivore abundance which is determined by the efficiency of the herbivore's numerical and functional responses to variation in food availability. Stocker and Walters (1984) used a hypothetical model of deer–vegetation interaction to identify optimal harvesting strategies for a deer population, and to examine the effect of stochastic variation in mortality rate and the form of density-dependent vegetation productivity on the optimality of different harvesting strategies.

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 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 (see Section 2.5). 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/km^2) (Figure 8). 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. The logistic model predicts MSY at $H = 0.5r_m$, which for red kangaroos is $H = 0.5(0.4) = 0.2$, 30% higher than $H = 0.14$ predicted from the interactive model.

'Harvesting a set proportion of a population balances offtake against variation in the availability of food resources.'

Fluctuating food availability depresses MSY because the numerical response of the harvested population is generally asymmetrical (that is, maximum exponential rates of decline are higher than the maximum exponential rate of increase), incremental decreases in food availability lowering r more than corresponding increases elevate it. Hence as variation in food availability increases, so does the amount of time the population spends decreasing as opposed to increasing. This means that as environmental variability increases and/or the efficiency of reciprocal feedback between food resources and population abundance decreases, MSY for the harvested population will decline from that predicted by logistic-based models (that is, logistic-based models overestimate MSY for populations inhabiting less than stable environments, the degree of overestimation increasing proportionally to the degree of intrinsic environmental variability).

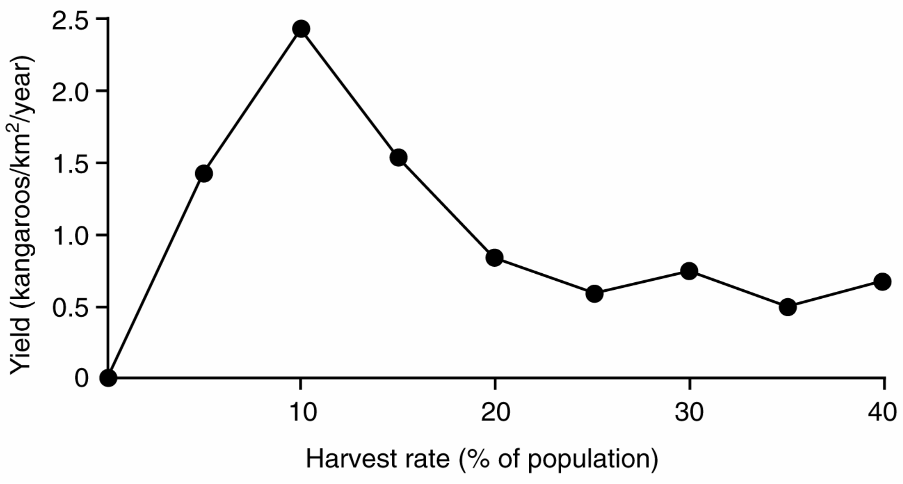

Figure 8: Variation in the average yield achieved by unselective harvesting of a modelled red kangaroo population as a function of harvest rate (after Caughley 1987b).

Harvesting models for populations limited by resources used pre-emptively

Many wildlife populations are limited by the availability of resources which they use pre-emptively, such as nesting holes, rather than resources used consumptively such as food availability. Beissinger and Bucher (1992) and Caughley and Sinclair (1994) argued that the growth trajectory of such a population would take the form of a ramp, representing exponential population growth until the limited availability of the resource truncates further growth. As such, yield increases with population size until the effects of the limiting resource begin to operate (Figure 9). The MSY for such a population will be MSY=$r_mK(r_m+1)$, taken from $N=K(r_m+1)$. Caughley and Sinclair (1994) point out that according to these relationships, MSY will correspond to a population size of $N<0.5K$ only when $r_m>1$ and as few vertebrate populations could generate such high rates of increase, MSY for these populations will generally correspond to $N>0.5K$.

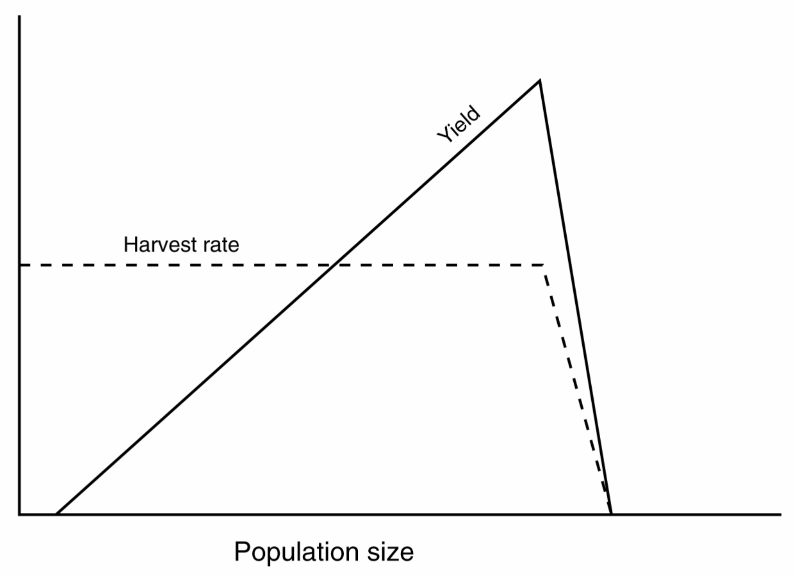

Figure 9: Relationships among population size, harvest rate and sustained yield for a population limited by a resource used pre-emptively (after Caughley and Sinclair 1994).

2.1.3 Complications to harvesting models

Age/sex biased harvesting

Caughley (1977) examined the consequences of age and sex biased harvesting for the size of sustainable yields which can be taken from wildlife populations. Prevailing r for a population is a product of the population's age-specific rates of fecundity and mortality, and hence will be influenced by the population's age-structure (particularly that of the female segment of the population). Caughley (1977) argued that the necessary compromise between taking as many females as possible from those age-classes that contribute least to the population's productivity while at the same time leaving an age-distribution that will provide enough females to enter these age-classes to provide the same yield in the following year, tends to cancel out any net benefit of age-selective harvesting in terms of increased r. Caughley (1977) concluded that with a few specific and generally trivial exceptions, age-specific harvesting affords no significant increase in yield over unselective harvesting.

Further, the additional costs associated with harvesting animals of specific ages may offset any marginal increase in yield afforded.

'Selective harvesting of males in a population may allow substantial increases in sustainable yield over that derived from non-selective harvesting.'

In contrast, selective harvesting of males in a population may allow substantial increases in sustainable yield over that derived from non-selective harvesting. Caughley (1977) pointed out that because many wildlife species are promiscuous, the ratio of males to females in a population will have little influence on the proportion of females fertilised until the ratio falls below some threshold where the ability of males to find all available females or the physical capacity of males to copulate with all available females, is compromised. As such, the proportion of males in a population will often have little influence on *r* until this threshold is reached, and for many populations this threshold will be well below that associated with the rate of harvest contemplated. For example, male-biased harvesting of red kangaroos allows populations to be harvested sustainably at rates substantially in excess of the 15% predicted as the maximum unselective rate by Caughley's (1987b) interactive model.

Effect of predation

The potential effect non-human predation may have on the size and/or sustainability of harvests has received little attention in the development of harvesting models. This is because the role of predation on the abundance of wildlife populations is not clearly understood (Skogland 1991; Boutin 1992; Messier 1994). Depending on whether all, some or no animals harvested from a population would otherwise have been doomed to predation, predation could represent a compensatory, partially compensatory or additional removal of animals from the harvested population. 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 that 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 how constant the effect of predation is.

'The extent of predation will have consequences for the sustainable size of a harvest.'

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 (adult survival and/or fecundity), resulting in no net gain in the size of the ungulate population available for harvesting.

2.1.4 The effect of competition

The abundance of some species may be determined wholly or partially through competition with other species for limiting resources. Competition can take the form of consumption by one species of a resource making it unavailable for another (laissez-faire competition), or by interference from one species affecting the ability of another to procure a limiting resource (interferential competition) (Caughley and Sinclair 1994). In either case, the actions of one species exacerbate any shortage of limiting resources that the other species would suffer in the absence of competition. While this may affect the yield derived from a given rate of harvest for populations limited by resources used consumptively, it will not influence the actual rate at which this yield will be optimal. For example, adding a competitor which eats the same proportion of available food as red kangaroos to the grazing model which Caughley (1987b) used to identify optimal unselective harvesting rates (see Section 2.1.2, Figure 8) indicates that the optimal harvest rate remains around 10% of prevailing population size but the yield at that rate is reduced by over 50% (Figure 10). This occurs because while competition operates through a reduction in the availability of the limiting resource (pasture), it does not affect the relationship between the harvested population's rate of increase and the availability of this resource (the numerical response).

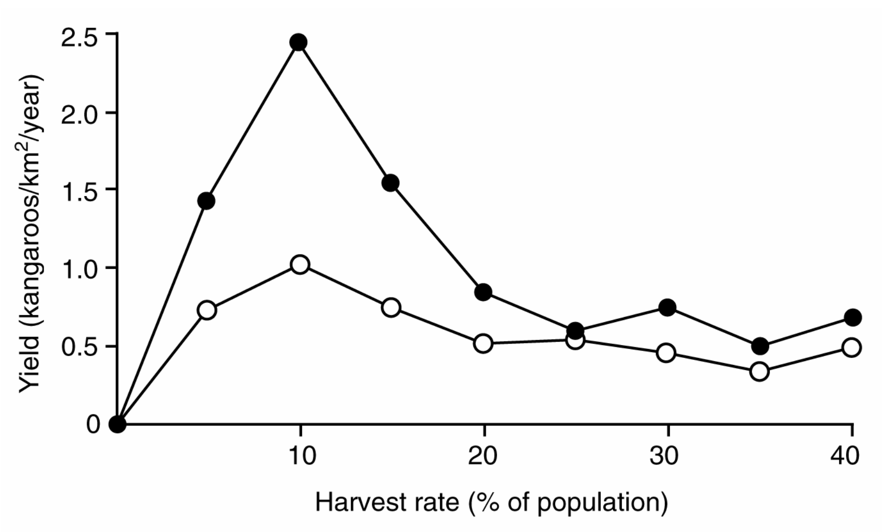

Figure 10: Variation in the average yield achieved by unselective harvesting of a modelled red kangaroo population as a function of harvest rate in the absence (dots) and presence (open circles) of a population of competing herbivores (after Caughley 1987b).

The rate of change in a populations whose abundance is limited by resources used pre-emptively (for example, nest sites) remains at a constant maximum (r_m) until the limiting resource is completely utilised (see Section 2.1.2). Hence the harvesting rate will also be a constant maximum up to this point, producing a yield that increases until the shortage of the resource forces the rate of increase to decline. Competition for the limiting resource will reduce the size of the population where rate of increase declines from its maximum rate to 0 and hence the size of the maximum yield. For example, the abundance of cockatoos in an area may be limited by the number of nest holes available. Hence, an unharvested population will increase at its maximum rate until all nest holes are used. The maximum yield obtainable from this population would be taken as the equivalent of the population's intrinsic rate of increase from a population held just below the density at which nest holes become limiting. If a second non-harvestable species of bird that competed successfully with cockatoos were present it might reduce the availability of holes to cockatoos by 50%. While the optimum harvest rate for the cockatoo population would remain equivalent to the population's intrinsic rate of increase, the yield would be halved because the size of the population from which the harvest can be taken has been halved. Hence, competition for limiting resources used either consumptively or pre-emptively will not affect the optimum rate at which a population can be harvested, but will reduce the yield that is obtained by reducing the size of the harvested population.

'The abundance of some species is partly determined by competition with other species for limiting resources, such as food.'

2.1.5 Practical implications for sustainable harvests of wildlife

In summary, theoretical and empirical studies of harvesting in relation to the dynamics of wildlife populations indicate the following points:

- In general, a harvest will be sustainable if the average rate of offtake does not exceed the rate at which the harvested population would otherwise increase. Hence, sustainable rates of harvest can be obtained from a wide range of population densities, although the actual rate will depend on a number of factors.

- For populations limited by the availability of resources used consumptively (for example, food), the maximum rate of harvest at any point in time will be determined by the availability of these resources. Where a close association between population size and per capita resource availability exists (that is, where the environment is relatively constant and/or there is a tight reciprocal influence of animal density and resource availability), harvestable yield will tend to be consistently related to population density. For such populations, an MSY of $0.5r_m$ can be taken from a density of around $0.5K$ where the association between population density and r operates instantaneously, and from densities approaching $0.7–0.8K$ where that association is delayed. Where the relationship between population size and per capita resource availability is less systematic (that is, where the environment fluctuates more widely and/or the reciprocal influence of animals and resource availability is loose), the association between population density and harvestable yield will be less direct or non-existent. For these populations maximum harvest rate will not represent a constant number of animals, nor will there be a consistent density from which the maximum harvest rate is taken.

- For populations limited by the availability of resources used pre-emptively (for example, nest sites), the maximum rate of harvest will also be determined by the per capita availability of these resources. Hence, as long as the availability of these resources remains constant, there will be a consistent relationship between population density and yield and a predictable density from which MSY can be taken.

- While age-biased harvesting will not generally prove more efficient than a non-selective harvest, for many species selective harvesting of males may allow populations to be harvested at rates substantially in excess of MSY. 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.

'Harvest rates need to be adjusted for factors such as predation, competition and sex or age-biased hunting.'

Collectively, these points suggest that in order to initiate a harvest of a wildlife population which approaches its maximum sustainable yield we need to know:

1. the population's intrinsic rate of increase[1] (r_m);
2. the primary factors affecting variation in a population's rate of increase;
3. where these factors are resources used consumptively, the degree of variability in their availability and the strength of reciprocal influences of animal and resource abundance;
4. where these factors are resources used pre-emptively, what factors determine their availability over time;
5. the influence of predation on the population and whether predation is compensatory, partially compensatory or additive to harvesting; and
6. where a selective harvest of males is contemplated, the relationship between male/female ratio and the proportion of available females fertilised.

In practice, what will usually be known is an estimate or 'guesstimate' of r_m, perhaps some idea of whether the population to be harvested is limited by resources used consumptively or pre-emptively, and in some cases whether predation is having an influence on the population's dynamics. To begin harvesting a population on the basis of this type of information would require identification of an appropriate (safe) initial rate of harvest; and information that should be collected to further refine this estimate by moving the rate of harvest toward its maximum sustainable rate. Section 2.1.2 describes how a maximum rate of harvest can be estimated from the logistic growth model using the population's intrinsic rate of increase (r_m), which for some species has been estimated directly (for example, feral donkeys (Choquenot 1990), red and western grey kangaroos (Bayliss 1985), feral pigs (Giles 1980; Choquenot 1994)), or for certain taxa can be approximated from body weight (for example, Caughley and Krebs 1983).

However, because the assumptions of logistic population growth restrict its applicability, estimates of maximum harvest rate calculated from r_m using the logistic model should never be used as an initial rate of harvest. Rather, they should represent a starting point for arriving at an appropriate initial harvest rate, based on what is and is not known about factors affecting variation in *r* for the population. For example, Section 2.1.2 describes how increasing environmental variation and/or decreasing efficiency in the reciprocal influence between vegetation and herbivore abundance leads to a reduction in maximum sustainable harvest rate for the herbivore population below that estimated by the logistic model. In order to integrate these influences, relative measures of environmental

[1] The intrinsic rate of increase (r_m) is defined as the exponential rate at which a population with a stable age distribution will grow when no resources are in short supply (Caughley 1977). However, in highly variable environments, such as Australia's arid and semiarid zones, stable age distributions are unlikely to occur. Under these circumstances maximum *r* can be higher or lower than r_m, and can best be described as $\bar{r}_m$, the maximum exponential rate of growth when limiting resources are not in short supply. In order to estimate this parameter, the numerical response of a population to its limiting factor/s must be estimated and variation in asymptotic values of *r* (that is, those above the level where *r* appears to saturate) averaged.

variation and the strength of reciprocal influence between resource and animal abundance should be obtained, and the maximum rate of harvest derived from the logistic model adjusted accordingly.

'Greater margins of error need to be allowed for in determining the sustainable yield of populations in variable environments.'

Caughley and Sinclair (1994) offer some useful rules of thumb regarding the setting of sustainable harvesting rates. They suggest that a harvest rate about 25% below the maximum sustainable yield should leave a sufficient margin of error so that a population is not overharvested. However, they also caution that the difference between the maximum sustainable yield and this 'safe' harvesting rate should be increased for animals living in highly variable environments.

Table 1 suggests multiplicative factors to correct estimates of H_{max} estimated from the logistic model for the effects of four levels of environmental variation (measured as the CV% in year-to-year rainfall), and reciprocal feedback between resource and animal abundance (measured as the CV% in a sequence of abundance estimates for an unharvested population inhabiting the same environment to that of the population for which harvesting is contemplated, collected over an appropriate time scale).

While rainfall will represent a suitable measure of environmental variation for many species, more appropriate measures may be apparent for particular cases (for example, variation in the frequency of flooding for some water birds). Similarly, if direct measures of the strength of reciprocal feedback between resources and animals are available (for example, the functional and numerical responses of herbivores to variation in pasture biomass), these will represent a better relative measure of the ability of a population to respond to environmental stochasticity than will variation in abundance alone.

Table 1: Suggested correction factors to discount initial harvest rates (calculated from $H = 0.5r_m$) according to the intrinsic variability of the environment (here indexed by CV% rainfall) and the apparent ability of the population to respond to this variation (here indexed by CV% N over an appropriate length of time).

		CV% rainfall			
		0–20	***20–50***	***50–75***	***>75***
CV% *N*	***0–20***	0.8	0.7	*	*
	20–50	0.7	0.6	0.5	0
	50–75	0.6	0.5	0	0
	>75	0	0	0	0

* Indicates combinations of environmental variability and population stability that are biologically improbable, suggesting indices are either inappropriate or inaccurate.

0 Indicates combinations of environmental variability and population stability that suggest that additional information is needed about the population to be harvested and those factors which affect variation in its abundance before an initial harvest rate can be set.

For example, if a harvest of red kangaroos at Menindee near Broken Hill in western New South Wales were contemplated and the only information available about the population was an r_m estimate of 0.4, we could use the logistic model to estimate MSY at $H=0.5r_m=0.5(0.4)=0.2$. We could then calculate the CV% of rainfall for Menindee (47%) and of kangaroo numbers derived from aerial surveys over 10 years in this region (62%). Applying these values to Table 1 yields a multiplicative correction factor of 0.5 suggesting an initial harvest rate of $0.5(0.2)=0.1$. According to Caughley's (1987b) model, the optimum unselective harvest rate for this population is around 0.10–0.15, suggesting that this first approximation is sufficiently conservative not to threaten the population. As the harvest progressed, additional information on the specific interaction between kangaroos and the resources that determine variation in their abundance should be collected to adjust the harvest rate where appropriate. If survey data had indicated CV% in the abundance of an unharvested kangaroo populations in excess of 50% for the Menindee district, Table 1 would have suggested no harvesting occur until additional data were available by which to determine its sustainability.

The values given in Table 1 should be used only as a guide. If a population to be harvested were subject to predation or intermittent mortalities due to abiotic processes (such as floods), or the harvest contemplated was strongly sex or age biased, initial harvest rates would need to be reduced to some degree, or the harvest halted until an appreciation of the effects of these factors on r was established.

2.2 The economic basis of wildlife harvesting

While a range of economic and socio-economic factors potentially impinge on various aspects of wildlife harvesting, three related issues directly affect harvest sustainability: (1) the discount rate applied to the harvested resource relative to the harvested population's intrinsic rate of increase; (2) the relationship between population density and the cost of harvesting individual animals; and (3) the relationship between the value of harvested commodities and their supply and demand.

2.2.1 Discount rates and rates of increase

Where a harvest is unregulated, a harvester will generally harvest at a rate (H) that maximises the present value (PV) of the net revenue generated from the harvest (the value of the harvested commodity less harvesting costs), discounted into the future at some rate (d) (Clark 1973; May 1976). Discounting is used so that the value of revenue generated by the alternative strategies open to the harvester for taking animals in the future can be compared according to their present value. Discounting can be applied formally or may simply represent an intuitive judgement on the part of individual harvesters. For a harvester operating in an economically rational way, the appropriate discount rate to apply to estimate present value of future revenue will be the prevailing bank interest rate. This approach encompasses the consideration of short and long-term economic benefits a harvester will typically make in deciding the appropriate level at which to harvest a population.

'Species which have a high market value but a low rate of increase are susceptible to unsustainable harvesting.'

May (1976) used this line of argument to generalise that maximisation of PV will allow harvests to be sustainable only when $r_m>d$. Where $d>r_m$, economic imperative will dictate that $H>r_m$, and the harvest will be unsustainable. Hence, H will depend on the perceived or estimated PV of the net revenue of future harvests, which in turn depends on the ratio of d to r_m. If d is considered a constant, the sustainability of harvesting a population of animals will depend upon r_m. If the current bank interest rate were 5%, r_m for the harvested population would need to exceed 0.051 for the harvest to be sustainable.

Resource access and property rights (see Section 2.3) will also influence the *PV* of the future resource and therefore decisions about the rate at which to harvest wildlife populations. For example, if access to the harvested population is open, animals left behind to ensure the sustainability of a harvest will likely be removed by other harvesters. In such a system, harvesters operating optimally will take all animals that can be obtained, as long as the cost of harvesting these animals does not compromise the harvester's minimum revenue requirements. In this sense, a harvester operating optimally should stabilise *H* at a value which maximises the net revenue accruing from each animal harvested, regardless of whether or not *H* leads to a sustainable harvest (Clark 1990).

Harvesters will operate at levels dictated entirely by economic imperative where they are permitted to do so. All native wildlife populations are publicly owned (see Section 2.3), giving the public an important stake in decisions about whether these populations are harvested at all, and if so at what rate. Public interest in native wildlife harvests essentially takes two forms: whether the harvest is sustainable (that is, is harvesting at a rate dictated exclusively by economic factors sustainable?); and whether the harvest compromises an alternative use for the population (that is, does harvesting at an economically optimal rate compromise the availability of the population for uses such as viewing, recreational hunting, or preserving an intact natural ecosystem?). In the first case, public interest may take the form of a publicly held discount rate on the harvested resource which is lower (in some cases, 0) than that employed by the harvester, while in the second case the alternative use of the population may increase the value of the resource itself. Either factor will require harvesters to operate at rates below that dictated solely by economic considerations.

'Public interests and resultant government regulation will require harvesters to operate at rates below that dictated solely by economic considerations.'

Even where economic factors do not operate to restrain harvesting operations, rates of harvest may be restricted by regulation or legislation. The interests of society in wildlife harvesting are usually embodied in the government agencies empowered to oversee wildlife harvests. Caughley and Sinclair (1994) warn against the development of 'symbiotic' relationships between these regulating agencies and industries based on harvests, which could lead to actions on the part of the management agency that support the wellbeing of the industry rather than the interests of the public. The development of such relationships impinges on any system of regulation which seeks to balance economic returns accruing to individuals from the exploitation of resources in which the public retains some significant interest.

2.2.2 Profit in wildlife harvesting

Net revenue from each harvested animal ($R(x)$) can be calculated as:

$$R(x) = v(x) - C(x)$$

where $v(x)$ is the value of the saleable product obtained by harvesting each animal at population size x, and $C(x)$ is the cost of obtaining each animal at population size x. Factors such as sex, weight and the interaction of supply and demand (see Section 2.2.4) determine v, which determines the actual profit accruing to the harvester (the commodity value less the costs of obtaining it). However, most harvesters will have a minimum acceptable profit (p_a) based on their income expectations, below which they will not allow the average profit derived from each animal harvested to fall. Hence, $R(x)$ must be greater than p_a, or alternatively, $v(x) - C(x) - p_a$ must be greater than 0. Given this, p_a should be relatively constant through time (subject to inflation), and any change in circumstance which decreases $v(x)$ or increases $C(x)$ such that $v(x) - C(x) - p_a < 0$ will mean that the harvester's minimum revenue requirements will not be met. Under such conditions, a harvester has the option of curtailing the harvesting operation or switching to a more profitable location or species.

2.2.3 The cost of harvesting animals

The cost of obtaining each animal to harvest ($C(x)$) will vary according to:

$$C(x) = c_h + c_s(x) + c_t(x)$$

where c_h is the cost of handling each animal (that is, ammunition, time taken to field dress and similar costs), $c_s(x)$ is the cost of searching for animals to harvest, and $c_t(x)$ is the cost of travelling to the location where animals are obtained and returning to the base of the harvesting operation (that is, the chiller or shooting camp). Handling cost (c_h) is assumed to be independent of population size (x), while searching (c_s) and travelling (c_t) costs will depend upon the population size of the harvested animal. If the harvested population is at a high density, search and travelling time will be relatively small. However, as the density of the harvested species decreases, more time must be spent searching and travelling to find animals to harvest.

'As the density of a harvested species decreases, more time must be spent searching and travelling to find animals to harvest.'

Some understanding of how the constituent costs of harvesting vary with animal density can be obtained from classical predator–prey (Holling 1959) and optimal foraging theory (Stephens and Krebs 1986). The Type II functional response of predator–prey theory suggests that the rate at which prey are consumed by a predator rises to an asymptote at a decreasing rate (Figure 11a) (Holling 1959). For a harvester, the rate at which animals are harvested is a function of the average time required to locate each animal (search time) and that involved in dispatching and field-dressing each (handling time). As prey density increases, the search time required to locate individual animals to harvest decreases but handling time remains constant. At very high densities, the harvester may spend very little time searching for animals to harvest allowing harvest rate to saturate at a level that corresponds with the time taken simply to handle each harvested animal.

If the time taken to consume prey represents a cost to the predator, then the cost of predation will be the inverse of the functional response (Figure 11b). For a harvester, the cost of harvesting each animal is the value of the time and resources expended in finding each animal, then dispatching, field-dressing and transporting it back to their base of operations. This cost decreases curvilinearly from a theoretical maximum at low animal density, reflecting the decreasing time required to find animals as their density increases, and the reduced distance from the base of operations harvesters have to travel to find animals to harvest. Above some threshold animal density, cost approaches a constant minimum representing handling time alone. Beyond this threshold, animal density is such that the time taken to locate animals to harvest and transport them back to base is negligible or constant.

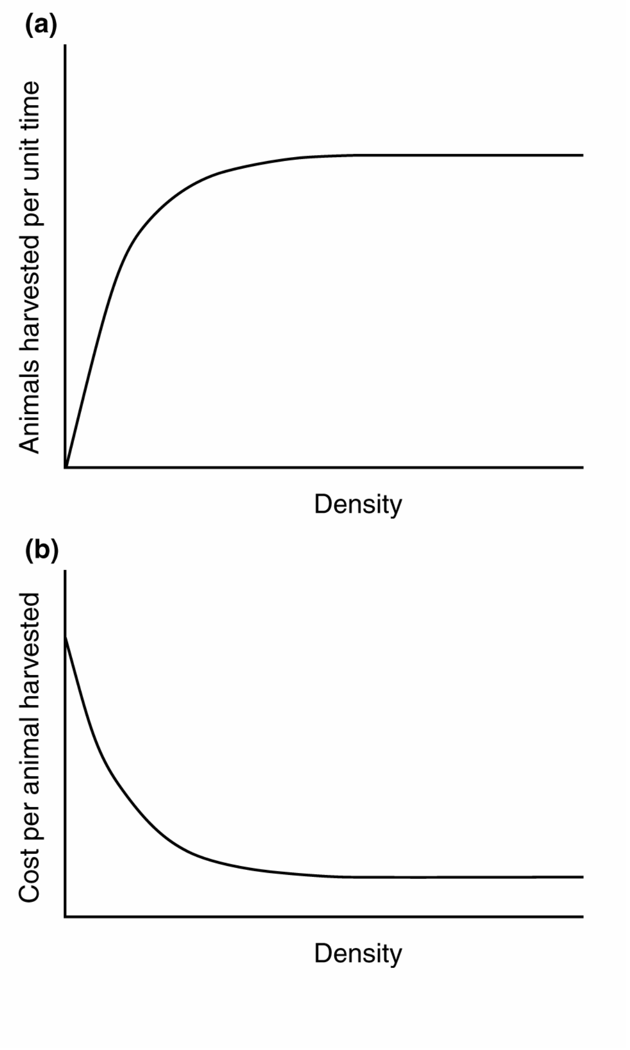

Figure 11: Variation in **(a)** harvest rate and **(b)** its reciprocal time per animal harvested (cost), as a function of population density.

2.2.4 Demand and supply, density and harvest rate

In purely economic terms, the relationships between price and demand; and price and supply, will dictate how the density of the harvested population influences harvest rate.

Demand curves define the total quantity of a given commodity (*Q*) that consumers will purchase per unit time, at each price level *p* (Clark 1990) (Figure 12). The elasticity of a demand curve (e_d) describes how sensitive demand is to price, its value reflecting the percentage decline in demand for every 1% increase in commodity price (Clark 1990). If $e_d >> 1$, a small change in price results in a large change in demand, and demand is said to be *highly elastic*. Commodities for which there are readily available substitutes usually have highly elastic demand curves, because if price increases, consumers simply switch to an alternative product. Alternatively, if $e_d << 1$, demand is said to be *highly inelastic* in which case a change in price has little effect on demand. Essential commodities with no substitutes typically have inelastic demand curves, especially if they represent a small proportion of total consumer expenditure (Samuelson et al. 1970; Clark 1990).

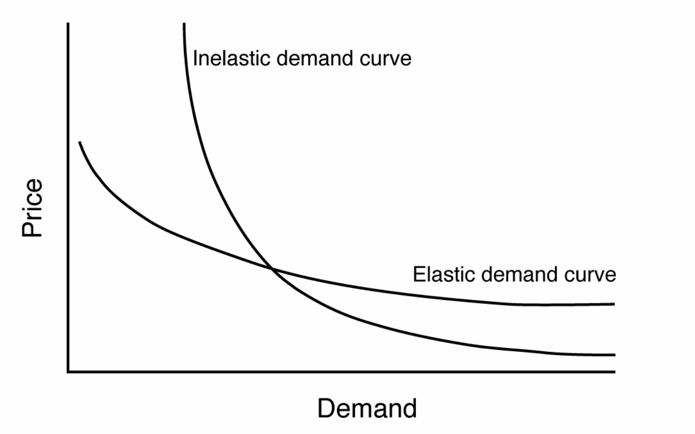

Figure 12: Elastic and inelastic demand curves (after Clark 1990).

Supply curves relate the quantity (*Q*) of a commodity that producers will supply at certain price levels (*p*) (Clark 1990) (Figure 13). As with demand curves, supply curves can display elasticity (e_s), increasing price having a greater or lesser effect on supply. In a competitive supply environment, the intersection of the supply and demand curve will determine the demand, supply and price of a commodity.

These relationships can be used to determine the effect of economic factors on harvest (supply) rate for wild animal commodities. The three important factors examined here are the effects of:

- marketing to increase commodity price;
- a supply limitation such as a quota system; and
- setting supply independent of demand (minimum pricing).

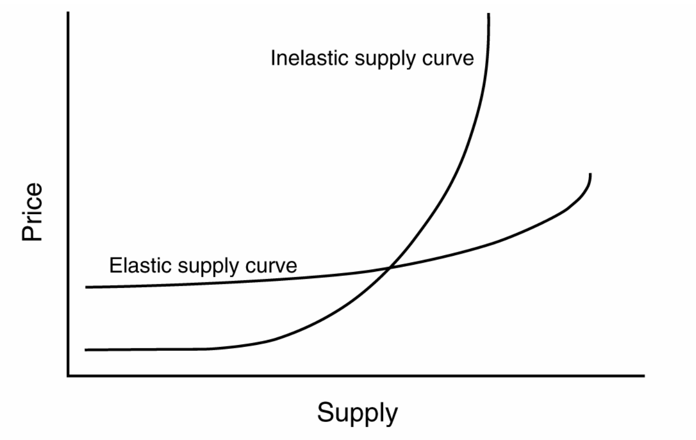

Figure 13: Elastic and inelastic supply curves (after Clark 1990).

2.2.4.1 Marketing

Increasing the value of native animal commodities through marketing has been advocated as a way of achieving conservation objectives by making exploitation of natural ecosystems economically competitive with less benign land uses (McNeely 1988; and see Section 3.3). The degree to which marketing can increase the value of each animal harvested depends on the ratio of supply to demand, the degree of competition between harvesters, and the operation of any limitation to the size of the harvest such as that imposed by a quota system. Marketing seeks to decrease the elasticity of the demand curve (e_d), leading to maintenance of high demand despite increasing prices, and/or increase the base level of demand (the demand for the product if it were free).

'Marketing seeks to decrease the elasticity of the demand curve.'

In an open-access harvesting system where harvesters work to supply demand, competition will operate to restrain the price per animal at a minimum set by the cost of harvesting ($C(x)$) and the harvesters' minimum acceptable profit (p_a), despite any increase in the level of demand. As long as supply outstrips demand the price per animal will remain at this constant minimum, only the harvesting rate rising to meet any increase in the base level of demand. Increasing demand may eventually lead to harvest rates which reduce the density of the harvested population to the point where search time ($c_s(x)$) increases, leading to concomitant increases in overall harvesting costs ($C(x)$). Under such circumstances, if minimum acceptable profit (p_a) remains constant, the harvester would have no choice but to either increase the price charged for the animal or product ($V(x)$) such that $V(x)$-$C(x)$-p_a=0 or to cease harvesting. If the harvester increases $V(x)$, then depending on the prevailing shape of the demand curve, demand will decline to some degree, reducing harvesting rates.

Increasing price and decreasing demand will eventually lead to a rate of harvest which will stabilise the population at a density where $c_s(x)$ is such that again $V(x)$-$C(x)$-p_a=0, and the cost of supplying product equals the value of product demand. Because any increase in price associated with arrival at this equilibrium is accounted for by increased costs, the profit per animal accruing to the harvester remains constant despite the increase in demand. Depending on whether or not harvesters were operating at 100% of their capacity, any increase in demand arising from marketing would be a reason for harvesters to increase the number of harvested animals, or simply allow more harvesters to enter the industry.

BOX 2:
AN EXAMPLE — KANGAROO HARVESTING TO ACHIEVE CONSERVATION BENEFITS

Grigg (1987, 1988, 1989, 1995, 1996) has suggested that increasing the value of commercially harvested kangaroos would allow rangeland graziers to supplement their income and diversify their enterprise. This could prompt graziers to reduce densities at which they stock domestic animals, leading to improvements in range condition that would have conservation benefits. In an economic analysis of a hypothetical grazing property, Young and Wilson (1995) concluded that the value of kangaroo meat would have to increase to at least the present value of beef or lamb for kangaroos for graziers to contemplate kangaroos as a viable alternative to domestic stock. To achieve such increases in the value of harvested kangaroos, Grigg (1995) advocates that kangaroo meat be sold as a specialty meat rather than as a substitute in competition with traditional sources of red meat such as beef or lamb.

Demand curves for exported kangaroo products over recent years indicate that demand for most kangaroo products including game meat is highly elastic (Appendix 1; Ramsay 1994). This suggests that an increase in demand or supply will not increase market price paid for harvested kangaroos. Given that promotion of kangaroo meat for human consumption seeks to place kangaroo meat in a market where ready substitutes exist, marketing would have to be exceptionally successful if it is to make demand curves inelastic to the point where the effect of price on demand is substantially reduced (Clark 1990).

Interestingly, the export kangaroo product for which the demand curve already appears to be inelastic, raw fur skins, does not feature prominently in Grigg's (1995) strategy to enhance the value of harvested kangaroos. A likely reason for the inelastic demand curve is that kangaroo skins are a preferred product for high quality sports shoes for which there appears a limited number of substitutes. For example, data presented in Ramsay (1994) (and summarised in Appendix 1) indicate that an increase in price paid per skin from $7.80 in 1987–88 to $12.20 in 1990–91 elicited little change in apparent demand. Some consideration of the capacity of marketing to increase base-level demand for this ostensibly valuable use of harvested kangaroos would seem a sensible adjunct to any moves to increase the demand for kangaroo game meat.

2.2.4.2 Quotas

A different circumstance arises where a limit such as a quota is placed on the maximum number of animals that can be harvested. If the prevailing level of demand is below the upper harvest limit set by the quota, the quota will have no effect on the relationship between demand and price. However, if the level of demand exceeds the permissible quota, the elasticity of the demand curve is reduced (Figure 14).

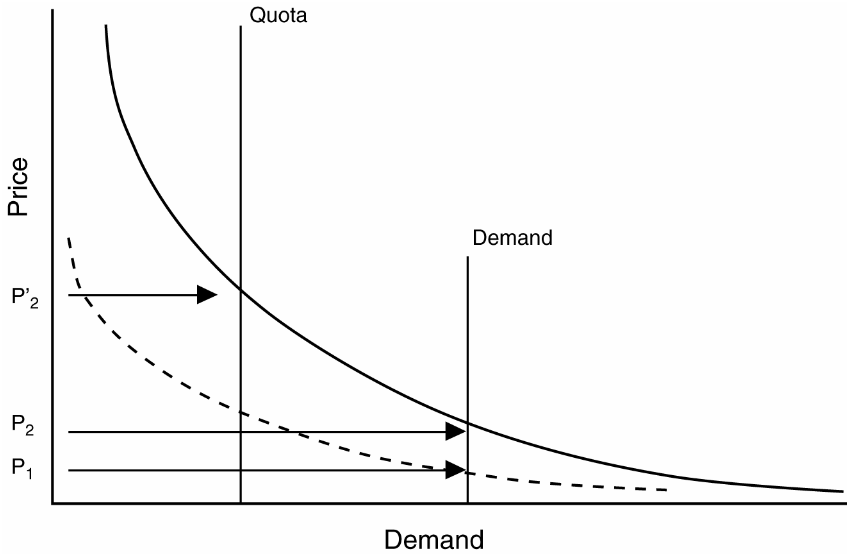

Figure 14: The effect of a quota on commodity price (P) where the quota limits supply below demand. The price increase from P_1 to P_2 is due to marketing effects on the elasticity of the demand curve. The price increase from P_2 to P'_2 is due to the quota limiting supply.

For kangaroo harvesting, increasing demand while maintaining a quota appears the only realistic way of generating sufficient income from kangaroos to allow graziers to consider reduction of domestic stocking rates (Grigg 1987, 1988, 1989, 1995, 1996). However, the sensitivity of profit derived from harvesting to the size of the quota would provide an environment highly conducive to the evolution of a symbiotic relationship between the harvesting industry and the agency responsible for setting quota (see Section 2.2.1). This may compromise the usefulness of the quota for achieving the very thing it is designed to do, namely ensuring the persistence of commercially harvested kangaroo species across their extant range. Any such link must be vigorously avoided.

'If demand exceeds the quota, the elasticity of the demand curve is reduced.'

At a national level, offtakes of all harvested kangaroo species have consistently been well below quota, although there is a trend for harvests to more closely approach quota over recent years (Figure 15). With the exception of red kangaroos in Queensland, the failure of the kangaroo industry to consistently meet quota in any Australian State demonstrates that potential supply of kangaroo products consistently outstrips demand (Appendix 2). Perhaps the only other exception occurs in New South Wales where the quota of red kangaroos has been closely approached or taken since 1995. However, it is not clear if this situation will continue in the longer term. For red kangaroos in Queensland, the annual quota has been reached or closely approached in most years since 1984, while harvests of eastern grey kangaroos and wallaroos have less consistently approached quota (Appendix 2). Assuming products are readily interchangeable between species of large kangaroo, quotas should not have a major influence on the relationship between price and demand for kangaroo products until quotas for all species are approached in all States. However, if a specific market niches for product of a particular species or from a particular location exists, the relevant demand curve will be affected if quota for that species and/or location alone is approached.

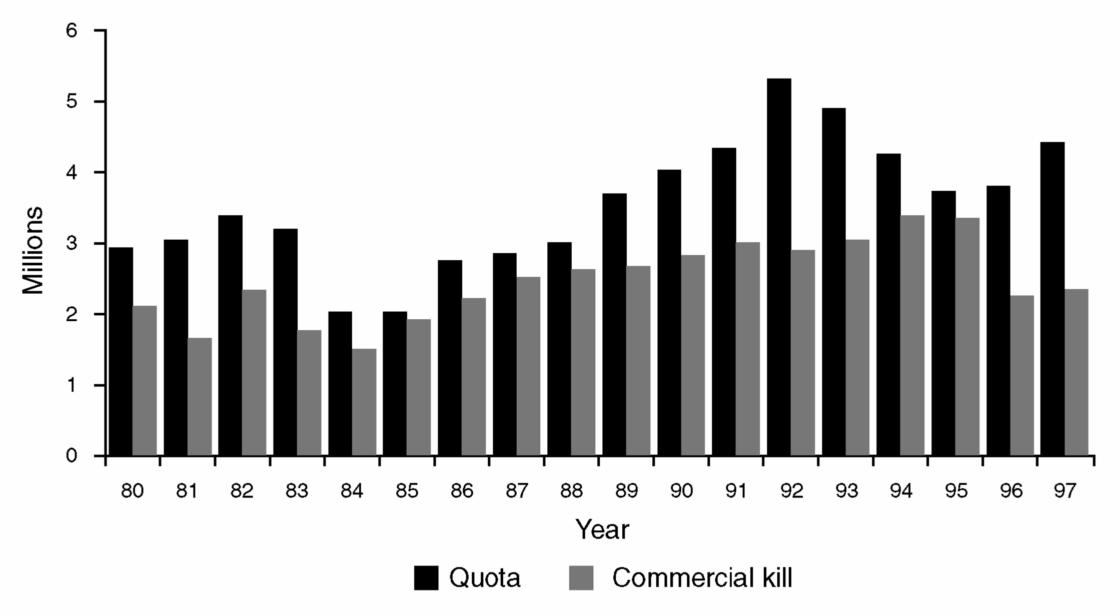

Figure 15: Total quota and commercial kill for all species of harvested macropods in Australia (data from Environment Australia).

2.2.4.3 Minimum pricing

Some consumptive uses of wildlife (such as trophy hunting) have much greater potential value than the supply of meat or hides. The value of such commodities stems as much from the exclusivity of their availability as from the material value of the product. In order to maintain this exclusivity, the demand curve can be artificially truncated by setting some minimum price (Figure 16). This constrains the association between price and demand to the high price end of the curve which will typically be relatively inelastic (that is, significant increases in price lead to only minor reductions in demand).

'The value of wildlife may be increased by artificially constraining supply.'

The price obtained for each animal taken may be further increased by artificially constraining supply. By making few opportunities to take animals, and auctioning these opportunities to the highest bidders, supply can effectively service only the highest price end of the demand curve. An example of this system would be the harvest of trophy banteng bulls (*Bos javanicus*) from Cobourg Peninsula in northern Australia where fewer than 30 bulls per year are licensed for safari hunting despite many more being available. This maintains the very high price trophy hunters are willing to pay for each animal taken. Within the constraint of harvesting trophy animals at a sustainable rate, managers of such harvests seek to maximise economic gain by optimising the product of the rate at which such animals are supplied and the price the market will tolerate.

Another example of minimum pricing would probably develop out of the proposal to permit hunting of large saltwater crocodiles (*Crocodylus porosus*) under licence in northern Australia. It is anticipated that licences to take animals would attract large royalty fees, a proportion of which would return to the landholder from whose property the animal was taken. It is argued that the potential for significant financial gain by landholders with sufficient numbers of crocodiles for a sustainable harvest will associate a tangible benefit with conservation of the wetlands upon which the continued supply of crocodiles is dependent (see also Section 3.3).

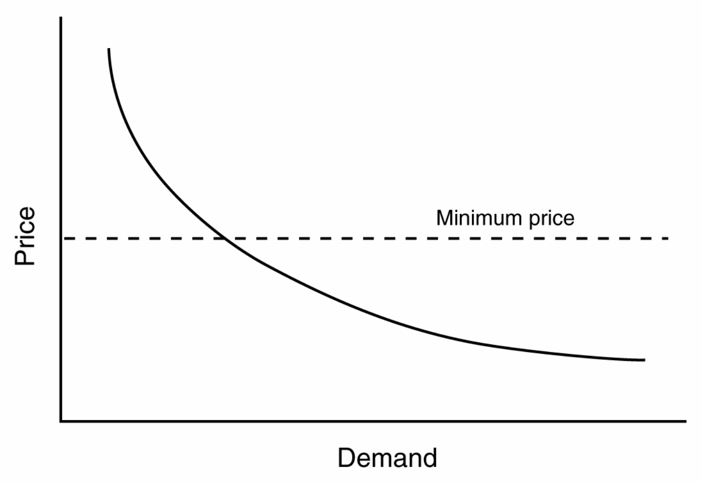

Figure 16: The effect of fixing a minimum price at a point on the demand curve where elasticity becomes low or non-existent.

The rate at which large crocodiles to hunt could be supplied would depend ultimately on the rate at which wild populations could produce them, but more proximally on the propensity of management agencies, landholders and safari operators to license and facilitate their harvest. Within the constraints of the ability of the wild populations to sustain any given harvest, interest groups would seek to maximise the economic gain from harvesting by optimising rate of offtake and the price obtained per crocodile, by setting an appropriate rate of harvest. These factors do not operate independently; harvest rate affects availability (exclusivity) which affects price which affects demand which affects harvest rate. Hence, neither the strategy which maximises price nor that which maximises offtake may necessarily afford the best economic return from the harvest.

2.2.5 The economic basis of overexploitation

Any resource can be overexploited. In biological terms, a resource is overexploited when its rate of harvest is greater than its rate of increase (see Section 2.1.2). In economic terms, a variety of factors will influence if, and to what extent, a resource will be overexploited. Interestingly, the very nature of biological resources predisposes them to overexploitation when their use is dominated by economic, rather than ecological imperatives. This Section deals with some of the economic factors that can lead to overexploitation of biological resources.

'Biological resources are susceptible to overexploitation where their use is dominated by economic, rather than ecological imperatives.'

McNeely (1988) describes six main factors that influence the economic basis of overexploitation:

1. Biological resources are often not appropriately priced in the marketplace. The intangible costs of depleting biological diversity usually provides ineffectual justification for conserving biological resources. This is especially so when the projected monetary benefits of exploitation can be more easily and tangibly demonstrated.

2. The social benefits of conserving biological resources are often socially widespread, making them difficult to account for directly in the marketplace. Taken together, these two factors mean that the benefits which accrue from the preservation of natural systems cannot be easily quantified (especially in monetary terms). As such, benefit–cost analyses contrasting exploitation with preservation of natural resources will often be based on gross underestimates of the real costs of exploitation to society.

3. The costs to society of resource exploitation are transferred to a greater or lesser degree from the individual/s who profit from exploitation, to society as a whole.

4. The species and ecosystems which tend to be most overexploited also tend to be those whose ownership is weakest. For example, many overexploited resources represent open-access systems which are unable to support the combined demands of developing economies and increasing populations.

5. Discount rates applied to capital investment required to undertake exploitation favour depletion rather than conservation of biological resources (see Section 2.2.1).

6. Conventional measures of national income, such as per capita gross domestic product, do not account for the depletion of natural resources as a loss in terms of national wealth or capital. This means that depletion of biological resources through their unsustainable exploitation is usually not considered in relation to national welfare economics.

Most of the issues associated with the economic rationalism underlying overexploitation of biological resources stem from society's inability to objectively assign a meaningful 'value' to biological resources. The intangible nature of biological resource value has received increasing attention (for example, Stoll and Johnson 1984; Pearce et al. 1989; Cocks 1992), with some authors developing techniques (for example, contingent valuation) which seek to convert non-market values to monetary equivalents. Caughley and Gunn (1996) point out that while economists need to reduce all values to monetary equivalents, the analyses and subsequent comparisons of market versus non-market values do not tend to arrive at unequivocal conclusions. It appears that currently, the lack of any adequate method for quantifying the intangible value of biological resources represents a severe constraint on society's ability or propensity to fully account for the costs associated with loss of biodiversity.

'The inability to quantify the intangible value of biological resources constrains society's ability to account for the costs associated with loss of biodiversity.'

In terms of wildlife harvesting, the current conservative approach to native animal use appears sufficient to ensure that these resources are not overtly threatened by inadequacies in our capacity to appropriately value them. However, as interest in wildlife exploitation develops, it is inevitable that the harvesting industry will place increasing pressure on whatever regulatory mechanisms are put in place to limit the influence of purely economic factors on permissible levels of offtake. The views of groups with entirely economic interests in wildlife exploitation should be tempered by the knowledge that such groups may place quite different values on wildlife resources than does society as a whole. Similarly, the capacity of such groups to more readily convert these values to tangible monetary benefits should be considered carefully. The more abstract values other groups in society place on wildlife resources may be no less valid, despite the fact that they are less easily entered into benefit–cost equations.

2.3 Wildlife ownership

There are three issues which impinge on the concept and operational reality of ownership of wildlife resources in Australia: (1) the legal status of the resource which determines *in law* who owns it; (2) the 'property' status of the resource which determines *in principle* who owns it; and (3) the reality of 'pseudo-ownership' of the resource which determines *in practice* who can harvest it. As all of these issues have implications for how the animal resource can be managed and to whom any profit derived from its harvest might accrue, all will have consequences for potential commercial use of wild animals resources.

'Native wildlife belongs to the people through the Crown and harvesting is controlled by State government regulations.'

Under the laws of each Australian State, native wildlife belongs to the people through the Crown and harvesting is controlled by State government regulations (for example, quotas, licences, see Section 2.5). This basic concept of legal ownership has arisen from the Ancient Roman rule that since game belonged to no specific person (*res nullius*), only the Emperor could decide if, when, where and by whom it could be harvested (Bubeník 1989). That view persisted through much of European history with the right of harvest vested with the Head of State and enforced by relevant government agencies. Ironically, this system of legal ownership did not characterise that applied to wildlife resources in Britain, where, in keeping with strong Norman monarchical tradition, game were privately owned by royalty and nobles (see Caughley (1983) for a full discussion of the evolution of legislation controlling wild animal harvests in Britain and its colonies).

Despite having its colonial roots in Britain, legislative controls on wildlife ownership in Australia (and in most other British colonies) adopted the more European approach of vesting ownership of wildlife in the people. Caughley (1983) details how vesting ownership in the nominate 'Crown' (which was represented by the colonial Governor, whose imperative was to safeguard British interests in the colony by safeguarding the rights of British colonial subjects), accomplished this. The adoption of the European model of wildlife ownership no doubt reflected the unique experience of British settlers being confronted with a rare abundance of 'unowned' land containing wildlife which was consequently 'unownable' (Caughley 1983).

In contrast to native wildlife, feral animals were introduced into Australia as domestic stock or as a private or public hunting resource. Hence, as feral animals became less a resource and more a pest, their legal status devolved from being private property to having no legal status beyond the statutory responsibility of landholders for their control under various State noxious animals Acts. Manifestations of this devolution can be seen in the landholder view of feral horses, cattle and goats as pests or resources depending on prevailing commodity prices, and the resistance that moves to have such species covered by noxious animals legislation meets from many landholders. As such, for the purposes of this discussion, as long as an introduced animal is viewed as 'feral' it has no legal status, being owned by neither the Crown or by the landholder on whose land it resides. If an animal is considered by a landholder to belong to them, as long as it is not listed in relevant noxious animals legislation, we will considered it stock and not further contemplate issues of its legal, property or practical ownership.

Any resource can be classified as common or private property, or can represent no property at all. The property rights of a *common property* resource are distributed amongst a number of owners who are co-equal in their rights to use the resource, and do not lose that right through non-use (Ciriacy-Wantrup and Bishop 1975). Potential users of common property resources who are not members of the group of co-equal owners are excluded from use of the resource. In contrast the property rights of a *private property* resource are vested in an individual, while a *no property* resource allows free and unregulated access to any potential user (Ciriacy-Wantrup and Bishop 1975; Aguliera-Klink 1994).

In principle, because ownership of Australian native wildlife is vested in the Crown and its use is regulated by State legislation, potential resources derived from its harvest are examples of common property resources. For example, kangaroos belong to the people through the Crown, with their harvest regulated through State legislation. As such, all Australians are co-equal in their right to harvest kangaroos as long as they subscribe to the regulations imposed by the State in which they wish to conduct their harvest. In practice, a variety of regulations impinge on the ability of an individual to participate in the harvest of kangaroos, which make important aspects of the harvest appear more like that of a private than a common property resource (pseudo-ownership). These regulations include trespass laws and the issue of commercial kangaroo harvest tags (which must be attached to carcasses entering the commercial trade) to landholders (in Queensland, commercial tags can also be issued directly to harvesters). These constraints collectively allow landholders complete discretion in who can undertake harvesting on their property. This discretion, which make access to common property resources more closely resemble access to private property resources, has important consequences for where profits derived from the harvest of those resources can accrue. As such, constraints on access to kangaroo harvesting potentially provide mechanisms by which profits can be directed to landholders. This is an important component of Grigg's (1995) proposal to direct profits derived from kangaroo harvesting to rangelands graziers as an incentive to reduce stocking rates on their land (see below).

'While the harvest of feral animals is not subject to the same legislative controls as that of native wildlife, landholders can use trespass law to control access to the resource.'

While the harvest of feral animals is not subject to similar legislative controls as is that of native wildlife, landholders can still use trespass law to control access to the resource. In this case, rather than pseudo-ownership providing a mechanism which changes access to a common property resource to be more like that to private property, it provides a mechanism whereby a resource that in principle is no property, appears more like private property.

2.3.1 Other systems of ownership

In Europe, two other systems of wildlife ownership operate. One is a relic of the French Revolution which, not surprisingly, terminated royal hunting rights. In France and countries occupied by France during Napoleon’s rule, *Codex Napoleon* replaced *res nullius* and game became a no property resource, with free and unregulated access by all people. Unfortunately, game was hunted mercilessly to almost total annihilation until licensing was introduced, shifting wildlife from a no property to a common property resource (Bubeník 1989). It is important to note that the introduction of a licensing system (that is, changing the status of the resource from a no property to a common property) does not necessarily preclude overexploitation of a natural resource (Aguilera-Klink 1994).

The other system evident in Europe evolved from the Roman view of *res nullius,* but the law now acknowledges that landowners have the right to control hunting on their property, provided: (1) the property (or part thereof) is specifically managed for game; and (2) it is registered as a hunting area or ‘revier’ with the appropriate government department (Bubeník 1989). The revier owners are legally accountable for management of the game, and to be registered have to pass an accreditation course. Game inventories are filed annually with the appropriate government department which sets the level of offtake. The revier owner may lease the area to registered hunters but carcasses of hunted animals remain the property of the owner and may be sold as game. Liability insurance is mandatory. A similar system operates in southern Africa where trophy hunting is permitted on private land. The hunts are organised by licensed safari operators who negotiate with the property owner for hunting rights (Cumming 1989). Ownership of game and hunting rights is a workable system in both these situations because the animals are constrained either through their strong association with particular habitats or by fencing.

2.3.2 Pseudo-ownership and harvesting income

Pseudo-ownership of native and feral wildlife in Australia gives landholders the capacity to charge a fee for access to harvestable wildlife. For kangaroos, fees could be charged for access to the property and/or provision of tags which allow carcasses to enter the commercial trade. For feral animals, fees could be charged for access to the property and/or for animals harvested on the property.

In New Zealand the use of trespass law to give pseudo-ownership of red deer (*Cervus elaphus*) to landholders was sufficient to control offtake on private lands until the processor price of venison increased dramatically in the late 1970s. The increase in resource value led to landholders demanding escalating hunting fees from shooters and complaining stridently about the level of deer ‘poaching’. Shooters complained that farmers were selling what they did not own (Caughley 1983). The crux of these changes was the shift in the status of deer from being largely a pest, with a realised no property resource value, to a valuable resource that landholders attempted to treat as private property by invoking trespass law to create pseudo-ownership. The solution adopted in New Zealand was to attach a much stronger series of trespass laws to the legislation that regulated deer hunting. This made pseudo-ownership of red deer by landholders so strong that individual wild deer became in effect entirely the private property of a landholder, as long as the deer resided on their land.

A similar situation could very easily develop in Australia in relation to feral animal harvests. For example, an increase in the value of feral goats could prompt landholders who had previously allowed free access to commercial harvesters or recreational hunters, to impose fees for access to their property or for each animal taken. It is likely that harvesters and hunters would resent having to pay fees for access to a resource that had previously been free. However, if the value of goats became sufficiently high so as to counteract whatever fees landholders imposed, harvesters or hunters may perceive that paying fees was acceptable. In the parlance of Section 2.2.2, fees charged by landholders would become an additional cost of harvesting, which would reduce the net revenue (R) derived from the harvest. Whether they would continue harvesting under a fee regime would then depend on whether they were still able to obtain their minimum acceptable profit (p_a) from the harvest which would largely depend on the prevailing value (v) of the saleable product of the harvest.

A similar situation is unlikely to develop in relation to kangaroo harvesting as in addition to property access, harvesters must procure commercial harvest tags which are issued to the landholder. Market forces will dictate the fees that landholders can charge for access and/or tags and still have harvesters interested in taking up the harvesting opportunity on offer.

In the United States, landholders are able to sell property access rights (called 'trespass fees') as long as they carry public liability insurance (Payne 1989). This arrangement allows hunters with valid licences to purchase access to hunting resources while maintaining the principle of public wildlife ownership, under which (as in Australia) US wildlife legislation operates.

'Pseudo-ownership of native and feral wildlife in Australia gives landholders the capacity to charge a fee for access to harvestable wildlife.'

The use of pseudo-ownership of wildlife by landholders to derive income from wildlife harvesting already occurs in Australia for recreational and commercial hunting of some wildlife resources. For example, many landholders charge access fees for recreational hunters exploiting feral animal resources. In this case pseudo-ownership of harvested wildlife (imparted through trespass law) passes from the landholder to the hunter following a successful hunt. Similarly, some landholders in South Australia were selling commercial kangaroo harvesting tags to processors for $2 to $3 per tag in 1995 (Grigg 1995; G. Grigg, University of Queensland, Queensland, pers. comm. 1995). Ownership of a harvested kangaroo passes from the Crown to the harvester when a commercial harvest tag is attached to a carcass. In this way, pseudo-ownership provides a mechanism by which landholders can potentially share in the profits of kangaroo harvesting. Alternative ways that landholders can derive income from the harvest of kangaroos on their property include vertical integration and catchment based independent businesses operating harvesting enterprises (J. Kelly, KIAA, Tasmania, pers. comm. 1998). Alternative ways for stakeholders to participate in the commercial harvest of wildlife are discussed in greater detail in Section 3.1. Grigg (1995) considers the engagement of graziers in the kangaroo harvesting industry an important mechanism for reduction of stocking rates in rangelands areas.

However, the extent to which the use of pseudo-ownership could be used by landholders to derive income from wildlife is limited by two important factors: (1) the profit hunters or harvesters obtain from the harvest; and (2) the ratio of income derived by the landholder to the costs associated with maintaining the harvest (that is, the cost associated with maintaining the abundance of wildlife resources at a level necessary to facilitate harvesting activities).

Harvesters obtain profit from selling harvested commodities for more money than it costs to obtain them. In contrast, hunters 'profit' through the extent to which their experiential expectations are met by a given hunting experience (Tisdell 1973). In the first case, any fee charged by a landholder for access to property or to tags will diminish the profit to the harvester. Faced with the prospect of a diminished profit, the harvester can elect to harvest elsewhere (if other more profitable opportunities are available), to harvest at the diminished level of profit, or not to harvest at all. The harvester's decision will reflect their minimum acceptable profit, the prevailing commodity price, the availability of cheaper harvesting options and any additional costs involved in exploiting cheaper harvesting options (Section 2.2.2). A recreational hunter will face essentially the same decisions as a harvester when confronted with a cost to undertake a hunt, except that rather than equating costs of various options with a monetary profit, they will equate costs with their expected experiential satisfaction.

In terms of the difference between income derived by the landholder and costs associated with maintaining the harvest, landholders will be aware that by charging access to property or tags, they risk forgoing the reduction in pest density commensurate with the level of harvesting that would otherwise occur. Harvesters and hunters are also aware of this potential cost to the landholder. For example, a survey conducted by Gibson and Young (1987) found that on average, landholders perceived each kangaroo to cost them between $5.10 and $27.10 annually, depending on the nature of their agricultural enterprise (Table 2). A landholder must balance the potential income derived from exploiting their pseudo-ownership of wildlife, with the value of losses incurred if in deriving that income they forgo some or all of the reduction in pest density they would have been afforded were they to allow access to the wildlife on their land. Because there will be some uncertainty inherent in the effect of the level of fees charged on the level of harvesting or hunting which subsequently occurs, landholders will also explicitly or implicitly include some consideration of risk when determining the appropriate level of access and/or tag fees to levy.

Table 2: Landholder's perceived annual loss in production due to kangaroos (from Gibson and Young 1987).

Enterprise type	No. regions	Loss in production /kangaroo
Established cropping	3	$27.10
Marginal cropping	2	$14.10
Grazing only	5	$5.10

Another issue that will probably influence the propensity of landholders to use pseudo-ownership to derive income from wildlife, is the effect of seasonal conditions on the capacity of pests to affect agricultural production. Landholders generally, but graziers in particular, tend to be most concerned about the effect of pests on agricultural production when pest numbers are high and/or pasture is declining (for example, during a drought). When pasture is abundant, any harvesting of wildlife is usually at the instigation of the harvester. However, during a prolonged dry spell, when wildlife compete with stock for scarce feed, landholders will often contact harvesters to undertake harvesting on their land. If the wildlife is abundant and the dry conditions widespread, a landholder may not then be in a position to invoke fees for either access or tags. The effect of seasonal conditions on the ability of landholders to exploit pseudo-ownership will mostly influence harvests of competitors with stock for feed (for example, kangaroos, goats, rabbits). For harvestable wildlife that has impacts on agricultural production less influenced by prevailing seasonal conditions (for example, foxes or feral pigs), the potential for landholders to derive income will arguably be more constant.

2.4 Other issues

According to Ramsay (1994), the major impediments to the development of wild animals industries are 'public perceptions, parochial attitudes, administrative and legislative structures, the variable operating environment, current (low) product values, newness of product, small size of industries, lack of information and poor information transfer, animal welfare, and pest control activities which conflict with commercial harvesting'.

2.4.1 The problem of perception

The debate about whether commercially harvested species are pests or resources has already been discussed. The general attitude throughout Australia that wildlife species are harvested because they are pests affects the commercial harvest at several levels of the trade; from the landholder on whose land the harvest takes place, through to the harvester and processor, and ultimately influencing consumer attitudes to wildlife products. This attitude accounts for some of the variation in the size of the market, the standards applied to product handling and the consequent prices consumers are prepared to pay. The perception that wildlife products are derived predominantly from pest control activities is reflected in legislation regulating wildlife harvests in some States and is manifest in the approach State agencies have typically taken to administering harvests in all States. It is by far the most significant factor influencing the nature of the wildlife harvesting industry in Australia and its potential to become an instrument for agricultural diversification and conservation.

The perception of introduced species as pests means that the preferred community goal for their management is total eradication. Yet eradication is virtually impossible without the expenditure of vast resources of time and money, probably far in excess of the cost of the damage these animals cause (Bomford and O'Brien 1995). Even if eradication is achieved on a local scale, re-invasion from surrounding areas will eventually occur. The community needs to accept that eradication is an unobtainable goal. It would be more realistic to aim for a level of control that achieves an acceptable level of damage mitigation, and to ask whether that level of control can be achieved by commercial harvesting (see Section 3.2).

Not surprisingly, the perception of wildlife as pests affects consumers. Most game meat is sold on the domestic market as pet food. As Shepherd and Caughley (1987) note, even as pet meat, 'kangaroo meat is generally less acceptable to the public ... than beef or lamb, which means that the product has to be offered at a lower price to counter this resistance. When cattle and sheep prices fall, then less kangaroo meat is sold'. The comment applies equally to other wildlife that are used in the pet food trade.

'The domestic and export markets for game meat are gradually increasing.'

Human consumption of game meat is limited within Australia, constituting less than 1% of total meat consumption (Ramsay 1994). However, the market is gradually increasing and the export market is also growing. These markets will be invaluable in facilitating a shift in perception of harvested species from that of a pest to that of a valuable resource.

2.4.2 The problem of scale

Until recently, many game meat processors have operated as small, independent businesses, each handling the processing, marketing and sale of single species or, in the case of kangaroos, a group of species. However rationalisation in these industries has led to consolidation of enterprises, such that today fewer large companies handle processing and sale of several species, constituting a wide and diverse range of wild animal products. This change has been desirable from an industry point of view, as it has enhanced the capacity of the industry as a whole to manage fluctuations in supply and demand for product and to meet changes in domestic and international regulations and requirements. This more consolidated industry has also been better able to lobby governments and consumers to enhance recognition of wild animal populations as renewable resources, and wild animal industries as important components of many wildlife management programs.

2.4.3 Problems of marketing

Through effective consolidation, marketing and promotion, game meats are growing in popularity. However, Hudson and Dezhkin (1989) caution that field-slaughtered game may increasingly lose its share of the game meat market. They point out firstly, that game farming enterprises are able to supply a more consistent product; secondly, markets are placing increasingly sophisticated hygiene requirements on game meats, making it more and more difficult for field-shot animals to satisfy statutory standards of meat inspection[2]. Already, a market shift has occurred away from field-shot animals with venison (Hudson and Dezhkin 1989). Should similar issues lead to adoption of widespread requirements for animals processed for human consumption be transported to abattoirs for slaughter, feral animal harvesting would have to change from field shooting operations to mustering or trapping operations. While such a change would be operationally feasible for species such as pigs or goats (in fact the majority of goats harvested are already mustered for transportation to abbatoirs or for live export), it would effectively exclude kangaroos from game meat markets. Interestingly, the largest market for wild pig meat exported from Australia (Germany) actually attaches a premium to the product specifically because animals are field shot and dressed. This is because the German demand for wild-harvested meat reflects a cultural association many Germans have with their tradition of hunting and consumption of the products of the hunt.

[2] However, a review of the public health aspects of consuming field shot kangaroo meat concluded that it posed little or no human health risk (Andrew 1988).

2.4.4 Ethical issues

Perception and hygiene are not the only sociological issues that continue to influence the development of commercial harvesting in Australia. Issues of ethics associated with wildlife harvesting are often equally important. For example, the broad opposition animal rights groups have to the use of wildlife for consumptive purposes and the concern of many conservationists that economic imperative may jeopardise the sustainability of harvests, both have the potential to inhibit the development of markets for wildlife products. Similarly, animal welfare groups almost universally condemn wildlife harvesting because of concerns that animals may not be harvested humanely. Strict adherence to harvesting regulations and to established 'codes of practice' for shooting or handling live animals are essential safeguards if negative images of the industry are to be avoided.

Ethical deliberations will not of themselves exclude an evaluation of alternative options for managing wildlife on agricultural land. When Gibson and Young (1987) asked landholders what action they would take if a commercial kangaroo shooter was unavailable, 80% said they would undertake the shooting themselves. Others indicated they would seek cheaper control methods, such as inviting amateur shooters onto the property or poisoning water supplies. These methods have serious ethical disadvantages. 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 carcase 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.

2.4.5 The problem of regulation

At present, beyond the constraints of various State noxious animal Acts, the management of introduced species harvests is in the hands of landholders and the harvesters themselves. In contrast, the harvest of native species is controlled by State wildlife agencies (see Section 2.5.1). For example, a variable quota system determines the potential number of kangaroos that can be harvested in any one year. This quota is derived and enforced by National and State wildlife regulatory authorities. These authorities operate independently from the kangaroo industry (but see Section 2.2.4.2). These issues are discussed further in Section 2.5.

2.5 Managing wildlife harvests

2.5.1 Alternative regulatory systems

Clark (1990) describes four methods for regulating the exploitation of common property renewable resources: (1) limited entry (licensing); (2) resource (harvest) taxes; (3) transferable allocated quotas (or individual transferable quotas, ITQs); and (4) total allowable catch quotas (TACs).

1. A *licensing system*, which limits the entry of harvesters to the industry would reduce competition between harvesters, leading to increased individual incomes. Under conditions of reduced competition, licensed harvesters would be motivated to maximise their harvest rate by investment in technologies which increase their harvesting efficiency (for example, larger chiller boxes, chiller boxes closer to harvesting area, Finlayson troughs to concentrate kangaroo density within smaller areas). This type of regulation can lead to a cycle of increased regulation by management

agencies seeking to limit individual harvester offtake, prompting harvesters to attempt to overcome this increased regulation by investment in new or improved technologies. An example of such a cycle is the rapid development of technologies among New Zealand deer harvesters to overcome indirect restrictions imposed on their capacity to exploit red deer in the early 1970s (Caughley 1983). This type of cycle reflects the fact that licensing systems do not consider the economic incentives that dominate the exploitation of common property renewable resources (Walters 1986; Clark 1990).

2. A *resource tax* (applied per harvested unit) would, in theory, prompt otherwise unregulated harvesters to exert an optimal level of effort to maximise their net revenue. Such a tax has the additional benefit of decentralising the need for decision making, since operational decisions (in view of the level of taxation) remain under the control of individual harvesters. In practice there are significant difficulties associated with such a taxation scheme (Clark 1990). Harvesters are often unanimously opposed to harvest taxes because they perceive them to be unfair. Furthermore, it is difficult to calculate a tax level which will have the desired effect on harvester offtake without detailed knowledge of the cost structure of individual harvesters and of the biological characteristics of the harvested population. These problems are compounded in unpredictable environments such as Australia's rangelands, where a taxation level commensurate with the desired level of harvesting would need to be recalculated and legislatively imposed at least annually (Clark 1990).

3. *Individual transferable catch quotas* (ITQs) allow each landholder (or co-owner of the resource) a given quota, which can be transferred (in whole or in part) in whichever way a landholder sees fit (Clark 1990). Similarly, harvesters or processors who procure quotas from landholders have the option of on-selling them to other potential exploiters of the resource. Because ITQs involve a harvest quota set independently of the harvesting industry, it counteracts problems of overexploitation by individual harvesters and of excessive entry of new harvesters into the industry, both of which affect regulatory systems based on licensing or harvest taxation. However, there are management difficulties inherent in any quota-based system. These include the allocation and enforcement of quotas, and monitoring the ongoing harvest (Clark 1990).

   Clark (1990) suggests that a combination of a resource tax and ITQs may provide the best solution in terms of economic efficiency and sustainable management of common property resources. By combining these forms of regulation, a management agency can potentially: derive income sufficient to administer the harvest; allow landholders to derive income from the harvest; and maintain control of the level of harvest.

4. A non-allocated *total allowable catch quota* (TAC) differs from ITQs in that harvesters must compete for a share of the total set quota. Because there is no constraint on participation in the harvest (neither a license nor access to a transferable quota being necessary), problems with a TAC system will parallel those associated with all open-access systems (that is, overinvestment of effort by individual harvesters to maximise offtake and too many harvesters entering the industry). Furthermore, because set quotas are invariably met, competition between harvesters means entire annual quotas will tend to be taken over a short period of time. This will lead to sharp fluctuations in the density of the harvested resource between the commencement of the harvest and attainment

of the set quota. While such a system may ensure the sustainability of a harvested resource, the resultant performance of the harvesting industry will be suboptimal (Clark 1990).

Kangaroo harvests in Australia are theoretically regulated by a TAC set by each State; in practice these quotas are rarely reached. Hence, the system operates more like an open-access harvest (McCallum 1995), modified in some instances by the effect of pseudo-ownership of kangaroos by landholders has on resource access (see Section 2.3). However, if the current trend in kangaroo harvesting continues (Figure 15), and marketing successfully increases the demand for kangaroo game meat, in the future quotas in some States may be reached more regularly. Under such conditions, the kangaroo harvest may be regulated by TAC in reality as well as in theory.

If, as seems likely, landholders respond to increased demand for kangaroo product by actively exploiting their pseudo-ownership of the resource by charging access and/or tag fees (Section 2.3), the regulatory system imposed through the setting of State quotas will evolve into a system that more closely resembles an ITQ than a TAC. Given the pros and cons of the various regulatory alternatives available, movement toward an ITQ system as kangaroo quotas are approached would seem the most useful way of ensuring both the viability of the harvesting industry and some return to landholders. Whether that return is sufficient to encourage landholders to reduce domestic stock densities on their properties will be largely determined by issues of price, demand and supply (Section 2.2).

'Whether the return from wildlife harvesting is sufficient to encourage landholders to reduce domestic stock densities will be largely determined by issues of price, demand and supply.'

However, it appears that the mechanisms which currently give landholders pseudo-ownership of the resource (recourse to trespass law and allocation of commercial tags to landholders) are sufficient to ensure that they can engage the harvesting industry and share in its profits at whatever level they deem appropriate. Consideration should be given to imposition of some form of harvest tax to cover the costs of resource monitoring and harvest administration. Such a mechanism already exists in some States through fees paid for royalty tags. Given the change in the emphasis from pest control to renewable resource exploitation, some assessment of whether or not such a system represents the most equitable method of taxing the industry should be made.

2.5.2 Regulation of the harvest of introduced species

Licensing does not regulate the harvest of introduced species. State and Territory Governments generally view the harvest as a positive benefit to rural communities. Each State has codes of practice for shooters and meat handling and inspection standards to meet market requirements, and maintains a watching brief on the size of the harvest by collating data from levies collected at abattoirs and monitoring the export trade (W. Hedley, BRS, Canberra, pers. comm. 1994).

2.5.3 Regulation of native wildlife harvests

Because in law, ownership of native wildlife in Australia is vested in the Crown (see Section 2.3), its management is administered by State and Territory wildlife authorities. Under the Commonwealth *Wildlife Protection (Regulation of Exports and Imports) Act 1982*, export of harvested native wildlife products is permitted only where the relevant State or Territory wildlife authority has a Commonwealth-approved management program.

Kangaroo management plans

In all States and Territories, culling of kangaroos is permitted under licence where the animals are considered to be causing agricultural damage. Under conditions prescribed in approved plans of management, kangaroos culled for agricultural damage mitigation in Queensland, New South Wales, South Australia, Western Australia, and Tasmania can be sold into the commercial trade for domestic use and export. In addition, in Queensland, New South Wales and Western Australia, kangaroos harvested purely as a renewable resource can also be sold into the commercial trade.

Plans for the management of kangaroos vary in their detail from State to State, but essentially each aims to ensure the persistence of viable populations of all harvested species over their extant range, and contain the deleterious effects of kangaroos and wallabies on agricultural and pastoral production.

Generally, when a licence is granted to shoot kangaroos for damage mitigation or harvest as a renewable resource, the relevant State authorities issue some form of royalty tag that must be attached to each carcass entering the commercial trade, or a licence tag if carcasses are shot to waste. For each species in each State, the total number of tags issued annually corresponds to a more-or-less constant proportion of the estimated State population for that species. The proportional offtake used to determine quotas is nominated in the management plans which must be approved by the Commonwealth if an export licence for the products of the harvest is to be granted. The other major components of management plans are the specifications for surveys used to estimate variation in the abundance of harvested species (the monitoring program) and the mechanism by which tags are issued and licences granted to shooters, chillers and wholesalers and their records accounted.

'For each species in each State, the total number of tags issued annually corresponds to a more-or-less constant proportion of the estimated State population for that species.'

How quotas are set varies from State to State. In Western Australia, quotas are determined from the difference between an estimate of the density of kangaroos and a minimum acceptable density (Anon 1984). The density estimate used in this calculation has typically been based on aerial surveys conducted every three years since 1981. In Queensland quotas have been set at a known long-term sustainable harvest rates, and fixed-wing aerial surveys conducted over much of the harvest area from 1984 to 1991. Since 1990 annual helicopter surveys of a series of representative blocks have replaced broad-scale fixed-wing surveys (T. Pople, University of Queensland, Queensland, pers. comm. 1995). In South Australia and New South Wales, quotas are dependent on population estimates derived from annual fixed-wing surveys. In both States quotas are generally set around 17% of population estimates, although as stated in the South Australian kangaroo management program, quotas take into consideration 'the annual aerial survey results, past trends in the population numbers and the expected climatic conditions in the forthcoming year' (DENR cited in Anon 1984) (Figure 17).

In New South Wales and South Australia annual quotas apply to the commercial cull of kangaroos only. Kangaroos culled non-commercially are not accounted against the quota, nor is the size of this cull limited by the quota. Hence, there are essentially two harvests operating more-or-less independently: the commercial harvest regulated by license and quota (with the combined objectives of damage mitigation and sustainable use); and the non-commercial harvest regulated by license only (with the sole objective of damage mitigation). In the event of quotas being approached and significant numbers of kangaroos being culled non-commercially, the total cull would eventually exceed the level of sustainable use. With the trend toward increasing commercial offtake in both of these States, the disparate objectives of the two management systems should be resolved. Ensuring that both commercial and non-commercial harvests were regulated under a common quota would be a logical first step. In New South Wales at least, there has been a increase in the size of the non-commercial cull since 1992 (Everleigh 1995).

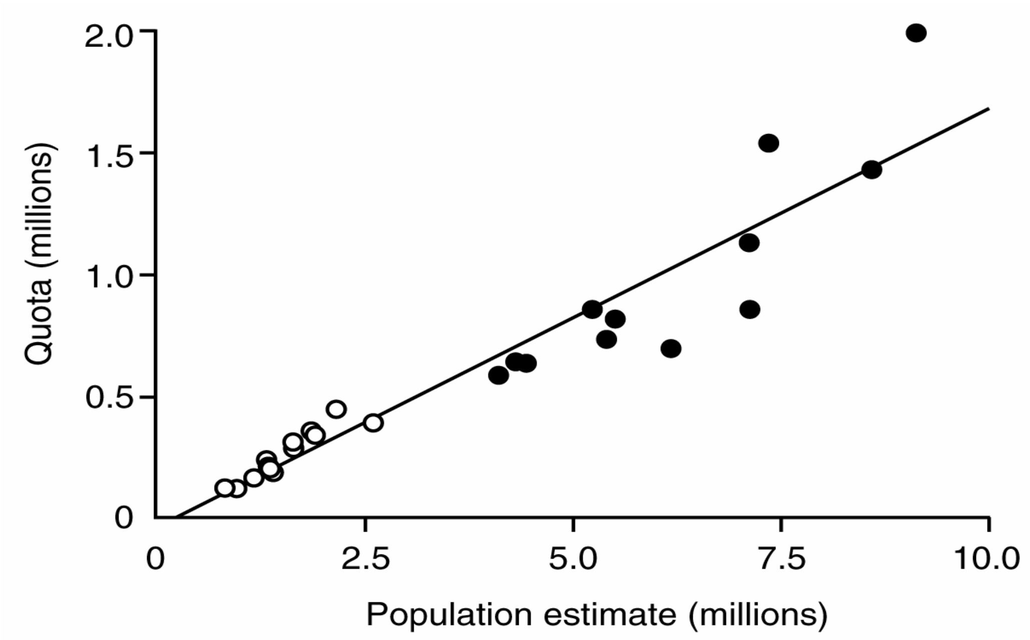

Figure 17: Relationship (y = 0.17x – 30,950; r^2 = 0.79) between the annual quota for red and grey kangaroos in South Australia (open circles) and New South Wales (closed circles) and the previous year's population estimate based on aerial surveys (data from Environment Australia).

Other regulations affecting kangaroo harvesting

The State and Commonwealth Governments also have a code of practice for shooters and regulations controlling the handling and inspection of carcasses.

2.5.4 Do quotas regulate kangaroo harvesting?

The number of kangaroos harvested in any year is closely related to their abundance (Figure 18). The harvest rate in New South Wales and South Australia has been around 9% irrespective of density. Since the set quota in each State is around 17% of prevailing population density, the quota has rarely been taken and has rarely limited the size of the harvest (Figure 19). This does not mean that the quota would not regulate harvesting if proportional offtake of kangaroos approached that set by quota. However, until quotas are reached on some sort of regular basis and demands from landholders to increase the size of the quota are rejected by the wildlife agencies that determine the quota, the capacity of the current system of regulation in these States to effectively limit commercial offtake of kangaroos will not be seriously tested.

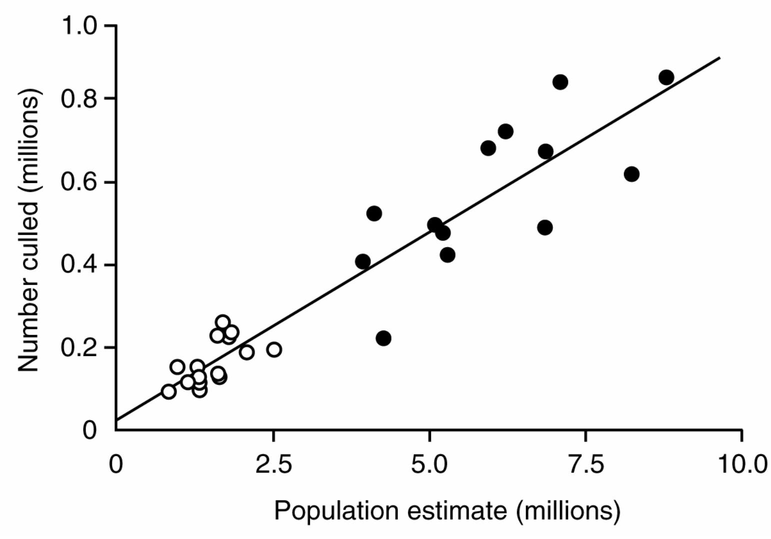

Figure 18: Relationship (y = 0.09x + 26,300; r^2 = 0.88) between the annual harvest of red and grey kangaroos in South Australia (open circles) and New South Wales (closed circles) and the population estimate for that year based on aerial surveys (data from Environment Australia).

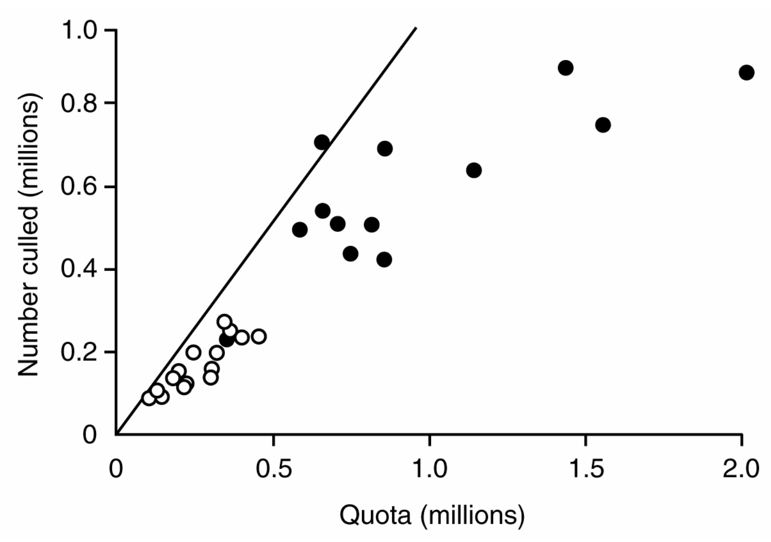

Figure 19: Number of kangaroos harvested in South Australia (open circles) and New South Wales (closed circles) against the respective annual State quotas. The line indicates where cull = quota (data from Environment Australia).

It appears that instead of reflecting a limit imposed by quotas, the harvest in South Australia and New South Wales simply tracks kangaroo density. The number of kangaroos harvested is most likely some function of the number of licensed shooters (and/or chillers), while the rate of harvest reflects the profitability of harvesting. As such, at a national level, kangaroo harvesting appears to operate as an open-access harvest (McCallum 1995). For example, Figure 18 indicates that historically the number of commercially harvested kangaroos in New South Wales and South Australia is typically well below the quota. This suggests that neither market demand, nor the regulatory effect licensing shooters and/or chillers has on harvest rate, currently limits the size of the harvest.

At a national level the commercial harvest quota for kangaroos has never been reached. Therefore, the common perception that quotas limit the size of the kangaroo harvest remains untested. Until the quotas are consistently filled, their effectiveness as a regulatory control on kangaroo harvests at a national level cannot be assessed. However, in Queensland the red kangaroo quota has been attained in most years since 1984. In at least three of these years, the Commonwealth has rejected applications by the management agency in Queensland for extensions to their nominated quota (G. Maynes, Environment Australia, Canberra, pers. comm. 1995). This provides qualified though encouraging support for the notion that the current system of monitoring, quotas and licensing provides an adequate process for regulating the commercial kangaroo harvest.

In contrast, Shepherd and Caughley (1987) suggest that the quota method was a potentially dangerous way of regulating harvests if quotas were set close to a harvested population's maximum sustainable yield. They warn that small environmental perturbations may trigger slides in the density of the harvested population. These concerns are justified where the quota is set as a fixed number of animals. However, if the quota is set as a proportion of the population size (that is, as a harvest rate), as long as that proportion is at or below that corresponding to the population's MSY, the population cannot be harvested to extinction. A process for iteratively moving toward such a rate in a conservative harvest setting is described in Section 2.1.5.

Caughley and Sinclair (1994) suggest that limiting the number of harvesters, but not limiting an individual harvester's offtake, was an inherently superior method of harvest regulation than the use of quotas. They suggest that a fixed effort system (that is, a constant number of harvesters) will tend to harvest the same proportion of the population at high and low density. This removes the need to regularly monitor the size of the harvested population, which would realise significant savings in the cost of harvest administration. However, if a constant number of harvesters are to remove a constant proportion of a population, the relationship between the density of the harvested population and offtake must be linear (Mangel 1982). While the data for kangaroo harvesters in New South Wales and South Australia operating below quota support this assumption (Figure 18), it would be unwise to conclude that the relationship will remain linear if kangaroo harvesting becomes more lucrative to harvesters. For example, if harvesters responded to declining yields by increasing their effort or by using new technologies to enhance their harvesting efficiency, they may be able to sustain high levels of kangaroo offtake despite declining availability.

Harvesters would be able to increase harvesting effort without compromising their minimum acceptable profit if the commodity price was sufficiently high to elevate the net revenue generated by the harvest (Section 2.2.2). Elevating harvesting efficiency at low kangaroo availability would result in the functional response of harvesters to kangaroo density shifting from the linear response shown in Figure 18 to a curvilinear response (see Section 2.2.3). Whether such increases in harvesting efficiency would be sufficient for kangaroo populations to be severely overexploited is unknown.

However, the point remains that despite its operational appeal, a licensing system alone may guarantee neither resource conservation nor its optimal use (see also the arguments against similar catch-effort statistics for managing harvested systems by Walters (1986)).

'Independent population monitoring and the setting of quotas should continue as fundamental components of any harvest regulation scheme.'

Given that there is no clear consensus on the most appropriate system for harvest regulation, a general system applicable to harvests of all native animal resources is difficult to identify. However, whichever method of regulation is adopted to manage specific wildlife harvests, it appears essential that population monitoring and the setting of quotas continue as important checks on the size of harvests. It is also important that conservation agencies do not lose administrative control of the regulation of harvests, or of the monitoring and regulation programs on which harvest systems should be based.

3. HARVESTING WILDLIFE IN DIFFERENT SETTINGS

3.1 Wildlife harvesting and agriculture

Consideration of wildlife harvesting in an agricultural setting touches on three areas of relevance to agricultural production, the role of wildlife harvesting in:

1. enterprise diversification;
2. control of agricultural pests; and
3. off-reserve conservation and sustainable agricultural development through substitution for less benign land management practices.

These issues are considered in the following Sections.

3.1.1 Agricultural diversification through wildlife harvesting

Deriving income from a combination of domestic animal production and wildlife harvesting is not a new concept. It has been argued that a mix of domestic and wild species would result in better use of vegetation, and that wild animals would be more disease resistant and require less husbandry than domestic animals. However, despite the enthusiasm for harvesting wild species for their meat and/or hides, Caughley (1976) pointed out that few of these enterprises have met with spectacular commercial success. Reasons for the lower than expected productivity of wild species include: (1) the adaptation of native plants to herbivory by native animals which has led to the evolution of chemical and physical plant defences that specifically target native herbivores; (2) much higher dietary overlap between domestic and wild herbivores than had been anticipated; (3) overestimation of potential offtakes of wild herbivores arising from the use of single-species models inappropriate to the environments considered (see Section 2.1); and (4) underestimation of the costs and level of expertise required to harvest wild species efficiently.

'It has been argued that a mix of domestic and wild species would result in better use of vegetation.'

In South Africa, integration of domestic animal production and wildlife harvesting has persisted, increasing steadily since the 1960s with now over 8,000 ranches conducting at least some wildlife harvesting (Skinner 1989). The income from wildlife on these ranches does not match that of domestic stock (Skinner places the ratio at around 1:10) but the costs of managing wildlife (for example, husbandry and infrastructure) are considerably lower. Skinner estimated that for wildlife, management costs accounted for 31% of average gross income, while for sheep the figure was 51%. Skinner also presented data for a mixed cattle/impala ranch where gross income from game was 50% of that from cattle, but the costs were only 10% because all infrastructure costs (for example, maintenance of water, fencing and roads) were assigned to cattle whereas a proportional distribution would have been more appropriate.

Harvest for trophy animals or for the experience of game hunting generally has a much higher intrinsic value than the yield afforded through most meat or skin products, although trophy hunting is obviously applicable to far fewer species. In the United States, for example, far more emphasis is placed on income derived from recreational hunting than from the sale of meat or hides (Yorks 1989). The estimated value of recreational hunting in the sparsely populated State of Wyoming exceeds $300 million annually. Similarly, Yorks quotes figures from a ranch in Texas where the net annual return from domestic cattle was $60,000 compared with that from lease hunting deer, quail and javelina of over $150,000.

In Australia, managers of agricultural enterprises may participate to some degree in the harvest of kangaroos and crocodile eggs, or a variety of introduced species including pigs, goats, foxes, rabbits, hares, buffalo, horses and donkeys (Ramsay 1994). Managers involved in wildlife harvesting may act as:

Passive participants — giving permission to undertake harvesting on their land, but obtaining no financial gain from the harvest. An example would be where graziers give commercial rabbit shooters permission to hunt on their land free of charge.

Facilitators — undertaking some service that allows or enhances the harvest of wildlife on their land, but obtaining no financial gain from that harvest or from the provision of the service. Examples would be farmers obtaining tags for commercial kangaroo shooting and passing these on to harvesters free of charge, or a farmer providing free accommodation to commercial pig shooters.

Brokers — undertaking some service that allows or enhances the harvest of wildlife on their land, and obtaining a direct financial gain from the harvest and/or provision of the service. Examples would be farmers who take a proportion of the income derived by a contract goat musterer, or charge commercial or recreational pig hunters for access to their land.

Active participants — actively participating in a commercial harvest leading to direct financial gain. Examples would be farmers who obtain a wildlife traders licence and conduct commercial kangaroo shooting on their properties, or harvest feral goats or pigs for the commercial industry from their properties.

The type of participation which a manager of an agricultural enterprise has with wildlife harvesting will determine the potential financial contribution harvesting can make to the cash flow of the enterprise. This will in turn determine whether or not wildlife harvesting can contribute to enterprise diversification.

3.1.2 Indirect benefits of wildlife harvesting

Passive and facilitative participation afford no direct financial gain to the enterprise, with the latter often imposing a cost. However, both forms of participation can contribute indirectly to the value of an enterprise if they result in lower densities of animals that constrain the profitability of the enterprise. For example, passive or facilitative participation in kangaroo, feral goat, rabbit, hare, horse or donkey harvesting may increase wool or meat production or reduce crop damage, while participation in feral pig harvesting may also reduce crop damage or, along with fox harvesting, reduce predation of new-born lambs. Passive or facilitative participation in wildlife harvesting may further contribute to enterprise profitability where it reduces the need to conduct conventional control programs to sufficiently mitigate these impacts (see Section 3.2).

In addition to the indirect contribution that passive and facilitative participation in harvesting can make to enterprise profitability, *brokering or active participation* in harvesting have the potential to contribute directly to enterprise cash flow. The direct contribution of these forms of participation in wildlife harvesting will depend on the ratio of the direct costs they impose on the enterprise and the direct financial gains they afford. The direct costs to an agricultural enterprise of brokering will be consistently minor, although the density of wildlife which may be necessary to maintain to provide harvesting opportunities may impose significant indirect costs (see Section 2.1).

The financial gains afforded by brokering will represent either some proportion of the income generated by the activities of commercial harvesters, or money forthcoming from recreational or commercial hunters as fees for access and/or provision of services such as accommodation. In the former case, the proportion of income which the manager can claim will probably be contingent on marginal value of the harvest to the harvester. In the latter case, the willingness of hunters to pay for access and/or provision of services will depend on the real or perceived value of access, which for commercial hunters will be the profits to be made and for the recreational hunter the quality of the hunting experience. In either case, the direct benefit of brokering the harvest will decline with decreasing densities of harvestable animals, disappearing completely at a density where commercial and recreational hunters have no interest in paying to hunt on that property. Managers may consider constraining offtake to ensure some level of sustainable yield from the harvest depending on: the ratio of the harvested population's intrinsic rate of increase to the discount rate applied to income from brokering the harvest (see Section 2.2.1); volatility in the value of the harvested species; and the degree to which the harvested population affects profitability of the agricultural enterprise (see Section 3.2).

The total net benefit of brokering the harvest will be the sum of the income from the brokering, which depends on the prevailing density of the population, and the value of the saving on control costs afforded by the harvest (that is, the cost of controlling the population from its unharvested to its harvested density), less the value of the impact of the harvested species at its harvested density and the costs of the brokering activities. This total net benefit will vary with the density of the harvested population according to the form of functions describing density-dependent variation in brokering income, the cost of controlling the population in the absence of harvesting and the value of the harvested species' impact on the agricultural enterprise. Contrasting the net benefit of brokering harvests with those of conventional control or active participation in harvesting, would allow the economically optimal management of a wild population to be identified.

Active participation in wildlife harvesting will usually involve much higher direct costs than will simply brokering the harvest. Direct costs will include any infrastructural costs associated with participation in the harvest (for example, vehicles, firearms and ammunition, traps, knives, yards and wildlife trader's licence), and the value of the time required to conduct the harvest. Net direct benefits accruing to the enterprise will depend on the value of the harvested commodity, less the costs associated with finding and harvesting animals, and (where appropriate), the costs of transporting product to chillers or processors. Because these costs include the time taken to locate animals to harvest, overall costs will tend to rise as the density of animals to harvest declines (see Section 2.2). As with brokered harvests, total net benefit from full participation in harvesting will vary with the density of the harvested population according to the form of functions describing density-dependent variation in harvest income, the cost of controlling the population in the absence of harvesting and the value of the harvested species' impact on the agricultural enterprise. However, active participation in harvesting will not usually be associated with recreational hunting, and hence the densities to which wild populations are harvested will usually be lower.

3.1.3 Some examples

Passive participation

A woolgrower in the rangelands may consider that rabbit control affords them no net benefit in terms of enhanced enterprise profitability. However, if approached by a commercial rabbit harvester to allow free access to their property, it will be in the woolgrower's interest to agree. While conventional control may yield no net benefit to the enterprise, harvesting occurs at no cost to the woolgrower. Hence any benefit accruing in terms of increased wool production represents a direct financial advantage to the enterprise.

Facilitative participation

A woolgrower in western New South Wales approached by a commercial kangaroo harvester to procure tags for the commercial offtake of kangaroos on his/her property must weigh up the costs of obtaining the tags (phone calls, time and royalties) with any increase in enterprise profitability associated with lower kangaroo densities on their properties. If the woolgrower perceives a net gain or perhaps even a break-even margin, it will be in their interest to facilitate the harvest.

Brokering

A woolgrower in the rangelands interested in charging recreational hunters to harvest feral pigs on his/her property would need to consider the total net benefit of brokering the harvest. This would involve determining: the costs and value of the brokerage activities (net direct income) and how these varied with pig density; the effect of hunting on pig density; the cost of achieving the same reduction in density using conventional control; and the value of any decrease in lamb predation afforded by the reduction in pig density.

In order to contrast the total net benefit of the brokerage option with other management alternatives, the woolgrower would need to estimate the costs and benefits of conventional control and, perhaps, the costs and benefits associated with active participation in a commercial feral pig harvesting program. The role of harvesting (if any) within the context of the profitability of the total enterprise could then be determined.

Depending on the current value of pigs, the discount rate applied to revenue generated from their harvest, the capacity of pig populations to increase, and the density-dependent impact of pigs on wool production, the woolgrower may determine that harvesting pigs at some sustainable rate (that is, less than their intrinsic rate of increase) may represent an economically optimal strategy for their use. However, because sustainable offtake requires the harvested population to be maintained at higher densities than an unsustainable offtake, this option will lead to higher indirect costs where the harvested species reduces agricultural profitability on a per capita basis (see Section 3.2.1).

Active participation

A woolgrower in the rangelands interested in harvesting feral goats would need to consider the total net benefit of conducting the harvest. This would involve determining: the value of the harvest (the product of the number of goats which could be obtained and the price paid per head) less the direct costs of undertaking the harvest including the value of the time required; the effect of the reduction in goat density achieved on the profitability of the woolgrowing enterprise; and the cost of achieving the same reduction in goat density using other means of control.

The woolgrower may determine that harvesting goats at some sustainable rate (that is, less than their maximum capacity to increase) may represent an economically optimal strategy. However, because sustainable offtake requires the harvested population to be maintained at higher densities than an unsustainable offtake, this option will lead to higher indirect costs where the harvested species reduces agricultural profitability on a per capita basis (see Section 3.2.1).

3.1.4 Implications of enterprise diversification

While managers of agricultural enterprises have traditionally participated in wildlife harvesting as a cost neutral or low cost form of pest control, recent reductions in the terms of trade for traditional agricultural products has forced many managers to reconsider the potential of wildlife harvesting for diversification of income for their enterprise. In the case of kangaroo harvesting, some conservationists have encouraged this reappraisal, viewing such a harvest as a more benign alternative to domestic animal production (see Section 2.2). In contrast, some interest groups have identified any move toward financial reliance on commercial offtake of introduced species as a potential impediment to their control, either by conventional methods or new biological control technologies (Braysher 1993).

'Recent reductions in the terms of trade for traditional agricultural products has forced many managers to reconsider the potential for enterprise diversification through wildlife harvesting.'

Increasing the value of harvested species to enhance the revenue generated from their offtake is complex in a competitive, free-market environment. Without quotas or minimum pricing, elevating demand at given price would be expected to increase offtake rates rather than increase per capita profit (see Section 2.2). While quotas for kangaroo harvesting currently operate in most States where they could serve to increase per capita profitability in the face of rising demand, and minimum pricing would likely be an important part of a highly regulated crocodile hunting industry in northern Australia, either option would be viewed as an anathema if applied to introduced animal populations typically considered pests to be controlled to low densities. As such, increasing the value of introduced animal harvesting would require not only identification of high value markets, but also a fundamental shift in the view agricultural managers have of these species.

Another less tangible impediment to use of wildlife harvesting for enterprise diversification on agricultural lands is the degree to which a manager will shift his or her traditional lifestyle to exploit harvesting opportunities. In the rangelands, feral goats are currently worth enough money that some managers who would previously have mustered all goats on their property and shot anything which the abattoir would not accept are considering factors which may affect longer-term offtake (that is, releasing pregnant does). If the value of harvested goats continues to increase, more intensive husbandry may result. This may prove a dilemma for some managers and management agencies who have advocated high level control or eradication as the only option for goat management in the rangelands. In contrast, feral pigs, which are of significantly higher value than are goats, have not attracted the same interest in active participation in harvesting, although many managers broker their harvest by commercial and/or recreational hunters. It is likely that managers are more comfortable with activities associated with goat harvesting than pig harvesting, and that this contributes to their reluctance to involve themselves actively in the latter. Whether more interest in active participation in wildlife harvesting will require a generational change in managers or simply further declines in the terms of trade for traditional agricultural products remains to be seen.

3.2 Wildlife harvesting and pest control

Many wild introduced animals in Australia are harvested for the commercial value of products they provide. Most of these animals are perceived to damage species or habitats upon which we place important conservation value (environmental impacts) or affect the value of agricultural products either directly or by increasing costs (agricultural impacts) (Tisdell 1982). Pest control programs aimed at mitigating environmental or agricultural impacts implicitly or explicitly assume that reducing the abundance of pests will lead to commensurate declines in the magnitude of these impacts (Hone 1994). If this assumption is valid, it follows that reducing pest density through commercial harvesting will contribute to pest control objectives. However, placing an economic value on pests through commercial harvesting may encourage maintenance of a pest density sufficient to meet harvesting needs, and/or discourage future attempts at high level control or eradication (Tisdell 1982; Ramsay 1994). If realised, these factors could offset the potential contribution of pest harvesting to achieving pest control objectives.

‘Reducing pest density through commercial harvesting may contribute to pest control objectives.’

Whether or not commercial harvesting of pests can reduce their environmental or agricultural impact will depend upon:

- the density of pests as a result of commercial harvesting;
- the relationship between the density of the pest and their environmental or agricultural impact; and
- how commercial harvesting and conventional control interact where they occur together.

In this Section we address these issues by briefly drawing on aspects of harvesting dynamics which will influence the density of commercially harvested pest populations, and examining the relationship between pest density and environmental and agricultural impacts. We then develop a conceptual model of pest harvesting and impact, and give an hypothetical example based on the commercial harvest of wild pigs. Finally we use the outcomes of the conceptual model to explore the likely interaction of commercial harvesting and conventional control, and to assess the efficiency of alternative strategies for expending public resources to reduce the environmental and agricultural impacts of harvested pests[3].

3.2.1 Pest density and impact

The ecological and economic bases of harvesting are discussed in Sections 2.1 and 2.2. Consumptive impacts of pests (impacts caused by consumption of some resource upon which we place a value) may be related to pest density by one of the curves shown in Figure 20 (Izac and O'Brien 1991; Hone 1994). Curve (a) in Figure 20 suggests direct facilitation between pests that increases per capita damage as pest density rises (Headley 1972), curve (b) suggests no such facilitation, while curve (c) suggests that competition among pests for the damaged resource leads to a decline in per capita damage at high pest densities (Southwood and Norton 1973). Curves (b) and (c) are considered the most likely form of relationship between pest abundance and damage for most types of consumptive impact, the presence of the asymptote implied by (c) depending on the density of pests and the distribution of the susceptible resource in space and time (Hone 1994). More complex relationships between pest density and impact may result where factors other than pest density affect the propensity of pests to inflict damage (for example, Hone 1988). Figure 21 shows the relationship between feral pig density and an index of lamb predation rate for the semi-arid rangelands of eastern Australia (Choquenot et al. 1997). The relationship is approximately linear up to a density of around 4 pigs/km^2, beyond which competition for new-born lambs slows the rate at which predation increases with increasing pig density. Hone (1994) describes other relationships between pest density and impact.

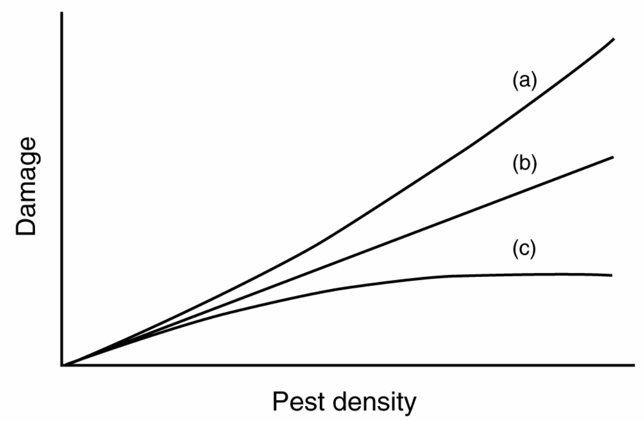

Figure 20: Possible relationships between pest density and per capita impact: (a) pest density facilitates impact; (b) pests not in competition for resource; and (c) competition between pests for resource.

[3] Much of this material is drawn from Choquenot et al. (1995).

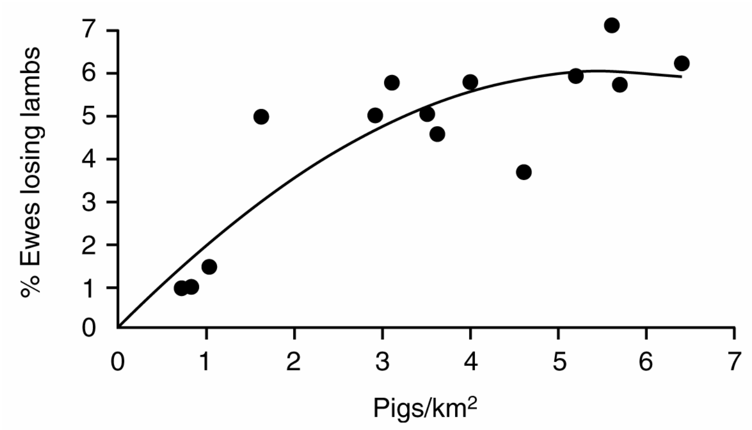

Figure 21: The relationship between pig density and percentage of ewes that lost lambs (after Choquenot et al. 1997).

If a relationship between pest density and impact can be established, it could be used to predict the reduction in impact associated with incremental reductions in pest abundance. This information could be used to identify a density of pests below which impacts are considered acceptable. Establishing such an acceptable 'target' density for a harvested pest population would allow the area over which harvesting affords effective protection from impacts to be estimated (Figure 22).

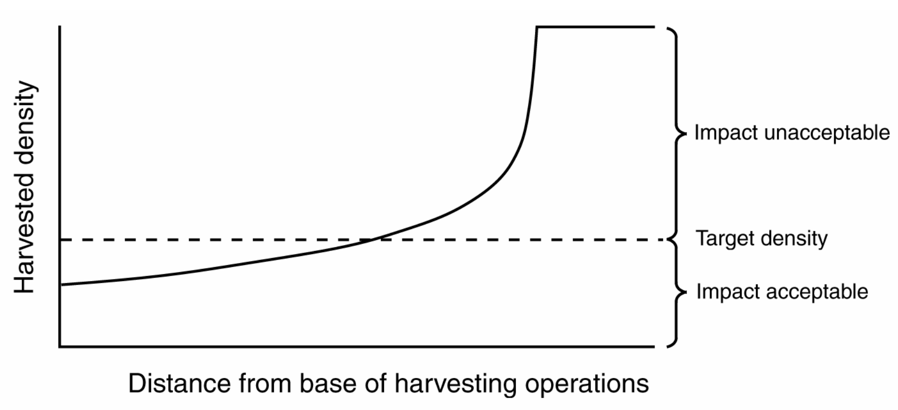

Figure 22: The relationship between distance from the base of harvesting operations and the density of the population harvested to $P=0$, with an arbitrary target density indicated. Where harvesting reduces the population below this target density, impacts are considered acceptable (Choquenot et al. 1995).

3.2.2 An example: harvesting feral pigs

Feral pigs are a commercial resource in many parts of eastern and northern Australia, where they are harvested for game meat that is exported primarily to Europe (Tisdell 1982; Choquenot and O'Brien 1989; Ramsay 1994). Pigs are harvested in the field mostly by spotlight shooting at night. Harvesting is essentially unregulated, although property access may be restricted in some locations. Carcasses are dressed where they are shot and delivered to stationary refrigeration units where they are inspected and purchased, actual value varying with weight and current demand. During 1992, chillers were typically paying $1.10/kg for carcasses of over 80 kg, $0.80/kg for carcasses between 50 and 80 kg and $0.60 for carcasses of 30 to 50 kg (Ramsay 1994). The cost of obtaining carcasses is more difficult to ascertain. There are no data on the relationship between pig density and search time for spotlight shooting of wild pigs and the number of pigs obtained during a foray is highly variable.

In order to simplify their construction of a spatial model of wild pig harvesting along the conceptual lines described above, Choquenot et al. (1995) assumed the following values:

- all pigs harvested field dress to 40 kg ($24.00);
- ten pigs are obtained on each foray (that is, $v = \$240.00$);
- cost of handling each pig is $2 (ammunition) + $2.50 (time) (that is, $c_h = \$45.00$ for the 10 pigs obtained on each foray);
- the cost of finding 10 pigs per foray (c_s) at a labour cost of $10/hr varies with density (D) according to the hypothetical relationship $c_s = 600(e^{(-D/2.9)})$. According to this relationship (Figure 23), the time taken to find 10 pigs when $D = 15$ pigs/km^2 is 0.28 hrs (equivalent to $c_s = \$2.80$) while when $D = 1$ pigs/km^2 it requires 35 hours (equivalent to $c_s = \$350.00$) to find 10 pigs to harvest;
- cost of travel is $1.00/km;
- minimum acceptable profit to the harvester is $50.00/foray ($p_a = \$50.00$); and
- the population has an unharvested density of $K = 15$ pigs/km^2.

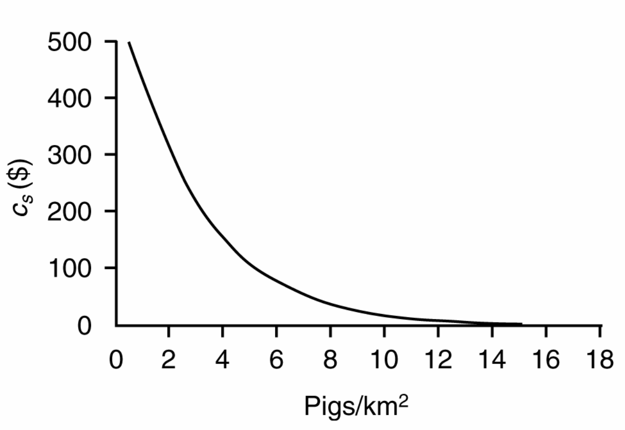

Figure 23: Assumed relationship between the cost of finding 10 pigs per harvesting foray (c_S) and pig density.

The distance-density relationship for a pig population harvested to densities where $P=0$, and conforming to the above assumptions is shown in Figure 24. Harvesting the population is economically viable out to 72 km from the chiller location. Beyond this distance, harvesters must reduce their minimum acceptable profit (p_a) in order to continue harvesting. The distance-density relationship will persist through time where $r_m>d$, and will represent that prevailing when harvesters move to other locations or species where $r_m<d$ (see Section 2.2.1). Giles (1980) estimated r_m for wild pig populations in western New South Wales to be around 0.62 (86% per annum). Harvesting wild pigs would be unsustainable only when d exceeded this level. If harvesters discount their investment in pig harvesting at a rate approximating the prevailing bank interest rate, it is unlikely that wild pig populations will often be harvested unsustainably.

If a relationship between pig density and impact was used to identify a density below which the incidence or frequency of the impact was 'acceptable', then the area over which the harvesting operation reduced pig density to a level where impact was acceptable could be estimated from the relationship shown in Figure 24. For example, an empirical relationship between the occurrence of seedlings of a species integral to an endangered plant association and pig density might suggest that at densities less than 6 pigs/km^2 the occurrence of seedlings was such that the plant association would persist. For an homogenous population of pigs harvested as described above, pig density would be below this target for a distance of 41 km from the chiller. This would effectively mitigate the impact of pigs on the plant association over an area of 5,281 km^2. If the target density were lower than 6 pigs/km^2, then the area over which impact mitigation was achieved would contract. Figure 25 shows the relationship between target density and area protected for the harvesting example illustrated in Figure 24.

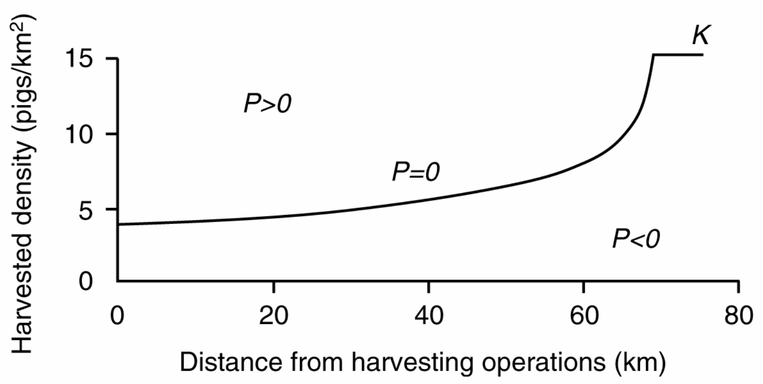

Figure 24: The relationship between distance from the base of harvesting operations and pig density for a pig population harvested to $P = 0$. Beyond a certain distance the population persists at its unharvested density K (Choquenot et al. 1995).

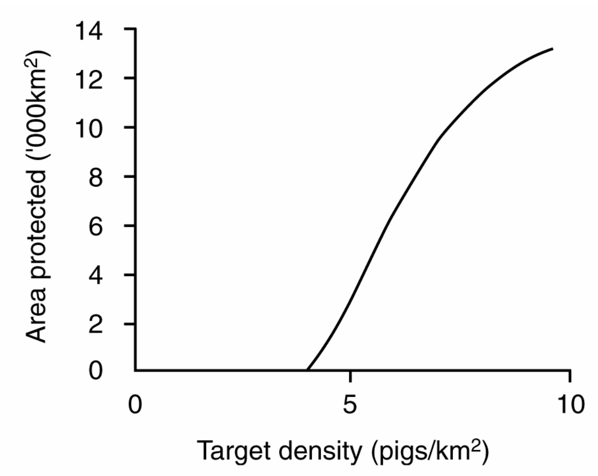

Figure 25: The relationship between the target density for pigs, below which impact is acceptable, and the area over which the harvest illustrated in Figure 24 reduces density below this target.

3.2.3 Harvesting and conventional control

The above example suggests that commercial harvesting can lead to reduced pest densities, often over considerable areas. However, the question of whether harvesting can coexist with conventional control of pests remains. Notwithstanding costs, control will reduce pest impacts more than harvesting: (1) where control achieves a higher reduction in pest density than does harvesting; and (2) when control is used to further reduce pest abundance following completion of an unsustained harvest (for example, where feral goat control is conducted after harvesters have reduced goat abundance to economic extinction).

Where harvesting achieves a greater reduction in pest density than achievable by any control that would otherwise be undertaken, harvesting will lead to more effective mitigation of pest impacts than control. In such a case, implementation of conventional control will reduce the economic viability of the harvest by removing animals which would have been harvested in any case. In extreme cases, control may affect the viability of a harvest to the point where harvesting ceases and any associated conservation benefits are lost. If, as is usual, pest control to reduce environmental or agricultural impacts is publicly funded, removal of pests that would otherwise be taken by harvesters represents a questionable use of finite resources. Where control leads to cessation of harvesting, the cost of achieving environmental or agricultural protection through pest control, commensurate with that achieved at no public cost through harvesting, will have to be indefinitely borne by public resources. Such unnecessary expenditure reduces the opportunity for reduction of environmental impacts through pest control in areas where harvesting is not viable or has less effect on pest density.

Where harvesting does not reduce pest density to levels where impacts are considered acceptable, or where the area over which harvesting achieves appropriate reductions in pest density is considered too small, options for expenditure of public resources are not limited to substituting conventional control. Increasing the value of harvested animals will reduce the population density at which $P = 0$, increasing both the reduction in density associated with the harvest at any distance from the base of harvesting operations, and the area over which harvesting occurs. Subsidising the commercial harvest of pest animals to increase their value may represent the most efficient use of public resources to achieve effective reduction in impact. Figure 26 demonstrates the effect of increasing the value of harvested pigs by 15%, on the distance-density relationship for the wild pig harvest illustrated in Figure 24. The area over which density has been reduced below that affording acceptable mitigation of impact (<6/km^2) increases by 52% to 10,935 km^2.

Subsidised harvesting will only increase the reduction in pest density achieved by harvesting if the harvester's minimum acceptable profit is unaffected by the value of the harvested commodity. Figure 27 shows the relationship between the value of fox skins and the number of skins exported from Australia between 1980 and 1992 (Ramsay 1994). Assuming that no stockpiling of skins occurred, either: hunters increased harvesting rates in response to higher prices; or high harvest rates reduced fox abundance and skin supply relative to demand, leading to increased skin value. If higher harvesting rates led to elevated demand, years in which harvesting was high would tend to be followed by years where value was high. Figure 28 shows the value of fox skins in year t subtracted from the value in year t_{-1} (that is, negative values indicate an increase in value) plotted against the number of skins exported in year t. There was no overall pattern suggesting that harvests responded to commodity value rather than the other way around, although small increases in skin value occurred in the years following the three highest exports of skins, suggesting that where harvest rate is very high it may have some effect on supply in relation to demand and consequent skin value. The effect of increasing commodity value on the minimum profit acceptable to harvesters is unknown, but competition should suppress any tendency for acceptable profits to rise.

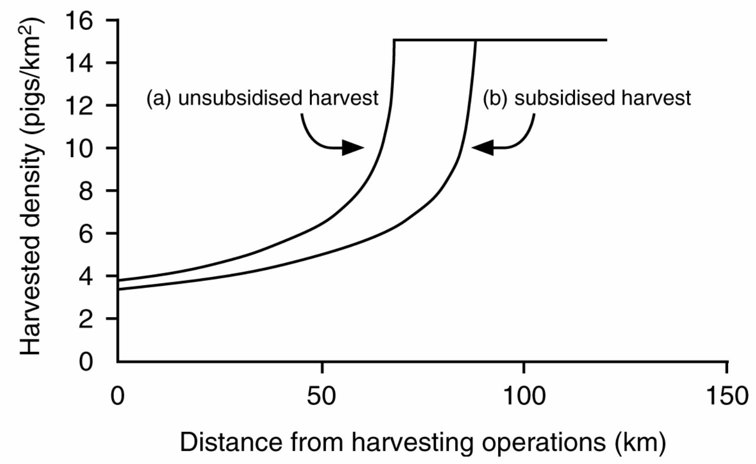

Figure 26: The relationship between distance from the base of harvesting operations and pig density where (a) harvesting corresponds to conditions detailed in the text, and (b) the value of pigs is increased by provision of a 15% subsidy.

Indirect effects of harvesting on control and vice versa can complicate the degree to which harvesting and control can be interchanged to achieve pest control objectives. For example: (1) harvesters might exert political pressure on control agencies not to conduct conventional control they would otherwise undertake; (2) harvesting activities could reduce the effectiveness of techniques used for control (for example, ground shooting by harvesters may make animals less likely to enter traps used for conventional control); and (3) control might affect the ability of harvesters to exploit animals surviving control (that is, helicopter shooting of wild pigs and goats may make survivors difficult or impossible to harvest). Indirect consequences of harvesting for the effectiveness of control, and of control for harvesting, will often depend on the particular circumstances of given pests, impacts and harvests.

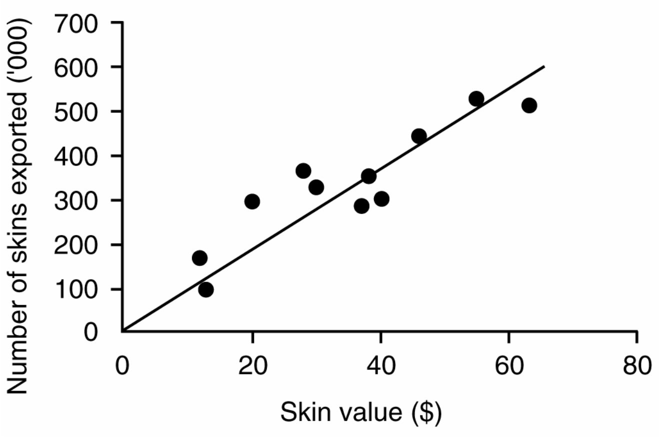

Figure 27: The relationship between the value and numbers of fox skins exported from Australia between 1979 and 1990 (Ramsay 1994).

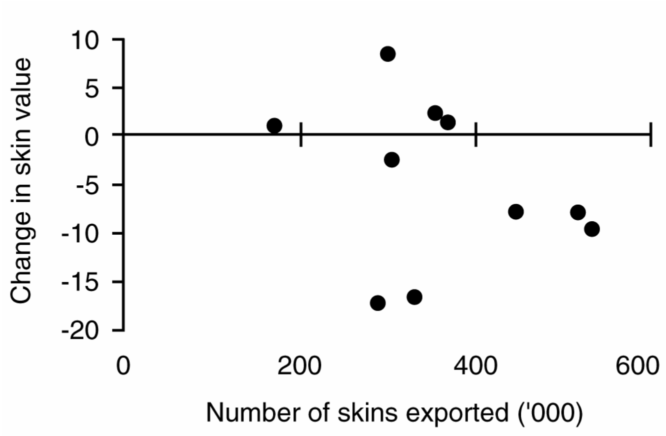

Figure 28: The relationship between change in the value of fox skins ($\$t - \$t_{-1}$) and the number of fox skins exported in year t_{-1}.

3.2.4 Conclusion

Many factors influence the effect of commercial harvesting on the density of pest populations and the economic sustainability of such harvests. These include the value of the harvested commodity, the costs associated with the harvest (which will usually be a function of pest density), the minimum profit acceptable to the harvester, the pest population's intrinsic capacity for increase, and the discount rate applied to investment in harvesting. The extent of reduction in environmental or agricultural impact associated with pest harvesting will depend largely on the area over which the harvest reduces pest density to levels where damage is deemed acceptable. Determining pest densities at which environmental or agricultural impact is acceptable requires information on the relationship between pest density and damage. While there are theoretical models of this relationship, empirical data are rare. Opportunities to integrate conventional control and commercial harvesting of pests appear to be common, particularly where commercial harvests are unsustainable. Where commercial harvesting is sustainable, conventional control is rational only when it meets a specific damage control objective by maintaining control of pest populations at densities lower than that achievable through commercial harvesting. Pest harvesting has the potential to contribute to pest control objectives under a range of conditions. Insufficient information on the relationship between pest abundance and environmental and/or agricultural impact currently limits our ability to connect the two.

3.3 Wildlife harvesting and conservation

Sustainable wildlife harvesting has the potential to contribute to conservation objectives related to land management in two ways:

1. use of wildlife may impart economic value to land which supports habitats necessary for the sustainability of the harvest (conservation of habitats); and/or

2. substitution of wildlife harvesting for existing forms of land use may results in a more conservative use of biological resources (enterprise diversification).

However, the sustainability of the wildlife harvesting itself has important implications for wildlife conservation. In this Section we address the question of whether or not wildlife harvesting on agricultural land can be sustainable. Assuming that wildlife harvesting can be conducted in a sustainable fashion, we then go on to discuss issues which determine whether harvesting can contribute to conservation objectives by providing an alternative use of undeveloped land, or allowing enterprise diversification.

3.3.1 Sustainability of harvests

Factors influencing the sustainability of wildlife harvesting have been described in previous Sections of this paper. There is no doubt that harvesting has contributed to or independently caused both local and continental extinction of many species (Cassels 1983; Caughley 1987a). Many more species have been brought to the verge of extinction or suffered severe range contraction as a result of commercial overexploitation (Clark 1973). Unfortunately, while some overexploited species have recovered following the cessation of harvesting or intervention of strict controls on use (for example, crocodiles (*Crocodylus* spp.) in Australia, and deer (Family Cervidae) in Russia), many others have not (for example, koalas (*Phascolarctos cinereus*) and yellow-footed rock wallabies (*Petrogale xanthopus*) in Australia). The clear potential that commercial wildlife exploitation has for impact on species range and/or persistence reinforces the concern that harvesting may have direct conservation implications for the species concerned.

Kangaroos

The commercially exploited species of kangaroos have sustained a combined harvest in Australia of around two million annually for decades without any apparent diminution of their range or their ability to recover from harvesting (Collins and Menz 1986).This demonstrates that State and Territory kangaroo management programs have been successful in meeting their the conservation objectives (Poole 1978). 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.

'The quota system has yet to be tested nationally or for any significant period of sustained industry pressure.'

If marketing successfully elevates demand for kangaroo products, would existing regulatory systems continue to successfully meet their conservation objectives? Evidence from Queensland suggests that the quota system has been an effective constraint on the desire of the industry to harvest more red kangaroos in that State over recent years (see Section 2.5.3). However, the quota system has yet to be tested nationally or for any significant period of sustained industry pressure. Such a test will occur if increasing demand results in quotas for all species being reached in all States. Under such conditions, the ratio of quotas to monitored kangaroo densities will have to be carefully scrutinised to guard against any systematic shift toward higher proportional harvests that cannot be unequivocally justified on biological grounds (a phenomenon Graeme Caughley christened 'quota creep'). Such a shift would indicate development of a symbiotic relationship between the harvesting industry and the agency responsible for regulation of the harvest. At present, the allocation of quotas, licensing and the monitoring of species abundance is managed by the State wildlife agencies, with additional support through the control of exports by the Commonwealth Government. This system must remain in place.

Other species

Most other species harvested on agricultural land are introduced (for example, goats, pigs, horses, donkeys, camels and rabbits). Offtake levels of these species are not subject to government regulation because these animals are considered pests warranting removal by any means. As such, the sustainability of their harvests is not considered an issue of concern for government or by conservation organisations. Indeed, the converse is often the case with arguments mounted that commercial exploitation may lead to maintenance of higher densities of these species than would occur if they had no commercial value (Braysher 1993). Section 3.2 considers these arguments in the context of commercial harvesting, conventional control, and combinations of the two.

3.3.2 Conservation through changes in land management

Perceived benefits to conservation through improved land management are often put forward as arguments in favour of sustainable wildlife harvesting. The general benefits to conservation which are perceived to flow from the sustainable exploitation of wildlife are: (1) conservation of habitats necessary for the sustainable offtake of harvested species; and (2) diversification of land use through integration of agriculture and wildlife harvesting.

Conservation of habitats

If harvested wild animals have a value exceeding that of other forms of land use, then conservation of their natural habitat to ensure ongoing harvests will represent an economically rational decision. In addition, where land use decisions favour habitat conservation in order to harvest species, a wider conservation benefit is often achieved through the conservation of species which, although not harvested, also rely on the conserved habitat. In most situations, but especially on agricultural land, conservation of natural habitats is not the motivation behind harvesting programs. However this does not mean that wildlife harvesting has no conservation benefits in these areas.

'If harvested wild animals have a value exceeding that of other forms of land use, then conservation of their natural habitat to ensure ongoing harvests will represent an economically rational decision.'

For example, it has been suggested that saltwater crocodiles have the potential to be harvested as a high-value species for trophy hunting. It is likely that the capacity of a crocodile population to supply trophy-grade individuals will at some level reflect the availability of wetlands which represent prime breeding habitat. Such wetlands can be rapidly degraded by the effects of cattle grazing, limiting the capacity of resident crocodile populations to produce trophy-grade individuals. A landholder who owns property containing such wetlands may decide to protect them from cattle grazing in order to participate in crocodile trophy hunting activities. While conservation may not represent the primary motivation of the landholder, in protecting wetlands on their property they not only safeguard their access to sustainable income from the crocodile hunting trade, but conserve the myriad other species which inhabit wetlands.

In making such land use decisions, landholders responding solely to economic imperative will select the land use that maximises the present value of current and future income (Section 2.2 considered the range of factors which impinge on the present value of various forms of income in the long and short-term). Where a landholder elects, on an economic basis, not to undertake wildlife harvesting, society may forgo conservation benefits upon which it places considerable value. In these circumstances subsidy of wildlife harvesting to make it a more economically attractive option than less benign land uses may represent a sensible expenditure of resources available for conservation (Section 3.2.3 described how a similar subsidy system could potentially increase the capacity of commercial pest harvesting to limit environmental impacts).

In order to consider policy options which seek to realise the potential conservation benefit wildlife harvesting may have through habitat conservation, the full range of ecological and economic factors which impinge on the sustainability of harvesting need to be considered. These factors are outlined in some detail in Sections 2.1 and 2.2. In addition, the interplay of economic and social factors that will influence landholder decisions about the most appropriate use of unimproved lands must be explored in order to identify where government intervention may enhance conservation benefits accruing to society as a whole. These factors are considered in Section 2.2 and 2.3. There appears particular value in examining the potential for harvest subsidy where this promotes long-term protection of undeveloped land of specific conservation value.

Enterprise diversification

Land degradation is a serious conservation problem in Australia, particularly in the arid and semi-arid rangelands. The specific mechanisms by which degradation was historically initiated and continues today are debatable, but there is little disagreement that overgrazing, particularly during droughts, is a primary cause of pasture modification and soil compaction (Noble 1986). 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). It is broadly accepted that management of total grazing pressure is necessary if continuing degradation of the rangelands is to be slowed, halted or reversed (Ludwig et al. 1997).

Grigg (1988, 1989, 1995) has proposed that the rate of land degradation could be ameliorated if landholders used income derived from participation in kangaroo harvesting to reduce domestic animal stocking rates (see Box 2). For this proposal to work, landholders must realise either a net economic gain in their participation in kangaroo harvesting and an associated reduction in domestic animal densities, or at least view this change as a cost-neutral alternative to current grazing activities. Economic gains to landholders will be the direct income they receive from some level of participation in kangaroo harvesting (see Section 3.1 for a discussion of the various levels at which landholders can participate in wildlife harvesting), and any increase in the value of their property commensurate with its improved condition as a consequence of more conservative stocking practices. Economic losses will be the forfeited income from domestic stock, forgone through any reduction in stocking rate associated with their participation in kangaroo harvesting. In addition, where graziers have an altruistic concern for the welfare of future generations, they may to some degree discount any negative balance in the ratio of losses to gains associated with participation in kangaroo harvesting.

Under this proposal, landholders seeking to maximise their net income from the combination of participation in kangaroo harvesting and traditional grazing activities must reduce domestic animal stocking rates. If net income is maximised without any such reduction, there will be no economic incentive for landholders to reduce domestic animal stocking rates, and hence no mechanism associating kangaroo harvesting with conservation gains through reduced total grazing pressure. Reducing domestic animal stocking rates will increase net income accruing to landholders *only* where the forfeited income from domestic stock (that is, income forgone from the sale of stock or their product equivalent to the size of the reduction in stocking rate), is more than offset by the sum of increased income resulting from higher yields of kangaroos and higher capital value of property achieved through improved land management. It is important to note that in the absence of any increase in the *yield* of kangaroos, increases in the value of kangaroos alone will not provide an economic incentive for landholders to reduce domestic animal stocking rates. However, if reductions in domestic stocking rates result in an increase in the density and consequently the harvestable yield of kangaroos, then increasing the value of any kangaroo harvesting will increase the degree to which income forgone through reduced domestic animal density can be offset.

Data supporting the contention that reducing domestic animal stocking rates increases kangaroo density (and hence yield) are equivocal. 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, Denny (unpubl. data cited in Edwards 1989) could demonstrate 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 29). However, beyond a correlation between sheep and kangaroo density, their study does not demonstrate any reduction in kangaroo density commensurate with increasing domestic stocking rate. Hence, it is far from certain that a reduction in domestic animal density would increase kangaroo density. In the absence of any such increase, it is difficult to understand why any graziers (assuming that they are motivated by economic considerations) would reduce domestic animal densities even if the value of harvested kangaroo products increased.

Unless large increases in the value of kangaroos and an increase in kangaroo density in response to reduced stocking rates was realised, it would be economically optimal for a grazier to derive *additional* income from kangaroo harvesting, rather than *substituting* harvesting income for that derived from traditional grazing activities. It appears that a clear demonstration of a relationship between stock densities and kangaroo densities (or rate of increase) is critical to the further development of Grigg's (1988, 1989, 1995, 1996) thesis.

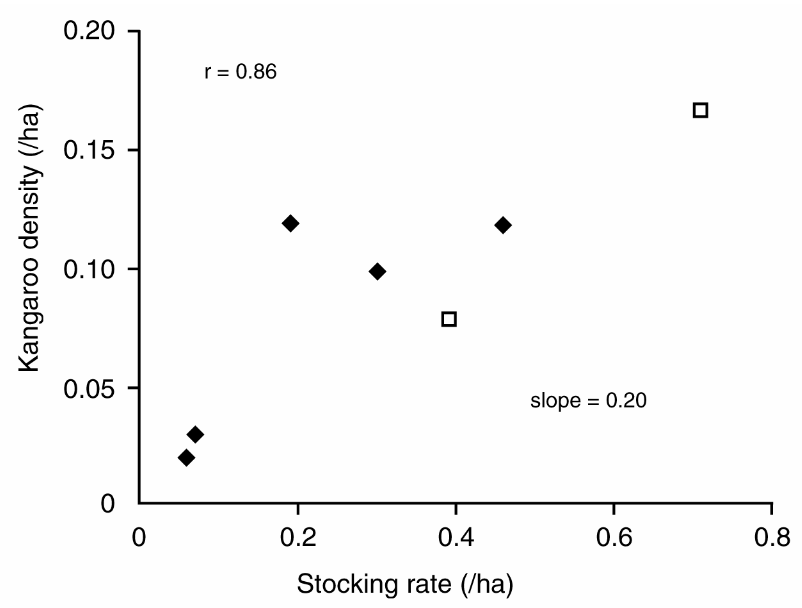

Figure 29: Relationship between stocking rate and kangaroo density across rangelands in Australia. Dots are areas used only for grazing; squares are marginal cropping areas (data from Gibson and Young 1987).

Of course, kangaroos are only one of a number of potentially harvestable resources in the rangelands. The same conservation gains associated with substitution of kangaroo harvesting for traditional grazing activities could be applied to these other harvestable resources. Similarly, the same factors that constrain the capacity of kangaroo harvesting to achieve reductions in domestic animal stocking rates will apply to conservation gains derived through the exploitation of these other resources. These constraints include the sustainability of the harvest itself, and the ratio of the income derived from the harvest with that equivalent to the reduction in grazing activities necessary to participate in the harvest. However, perhaps of more importance is the need to establish a clear link between the size of wildlife harvests (and hence their value to the landholder) and domestic animal stocking rates. In the absence of such information, the potential for wildlife harvesting to contribute to improved land management in the rangelands will remain equivocal. Until these issues are resolved the development and extension of sensible policy in this area will be difficult or impossible.

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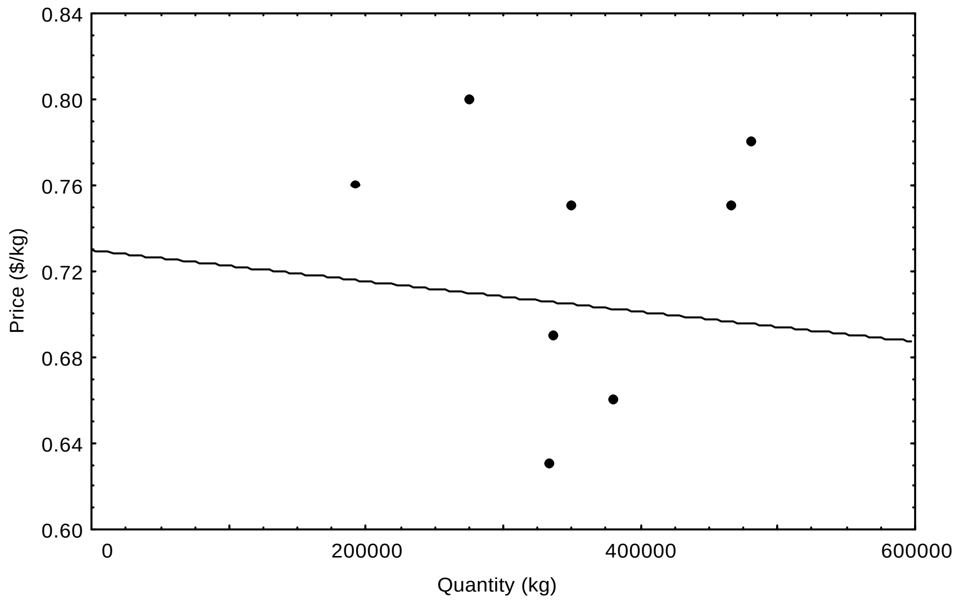
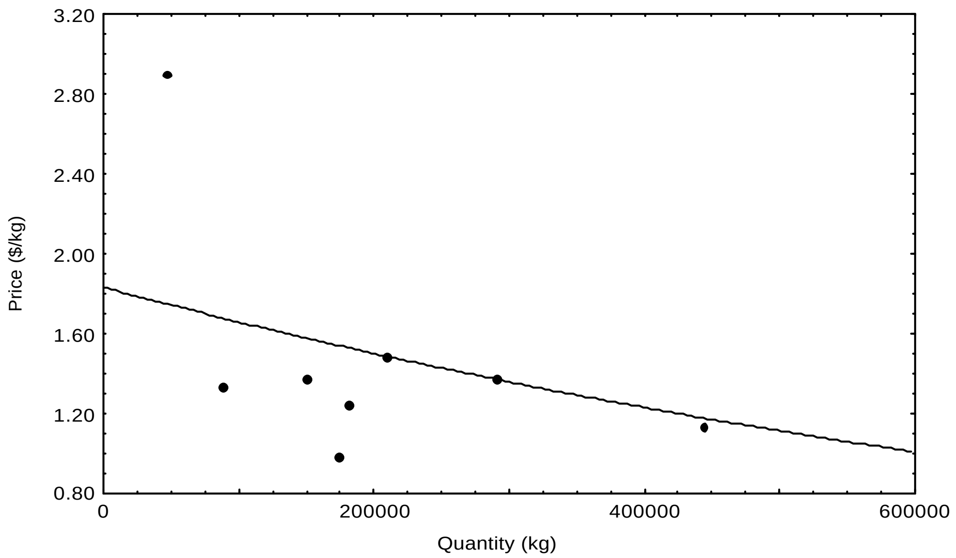
Appendix 1: Demand curves for exports of kangaroo products

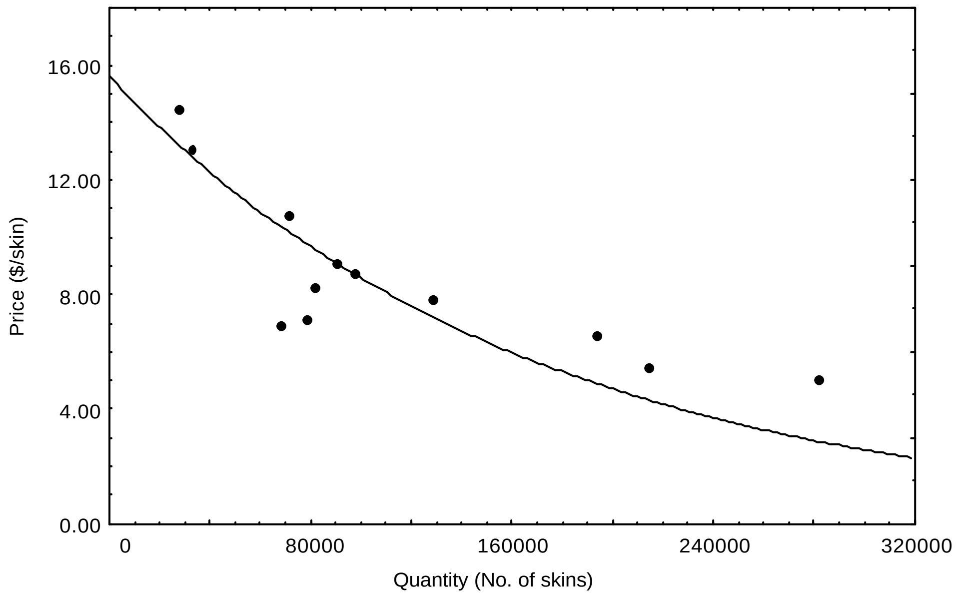
The demand curves for annual exports of kangaroo products, a) pet meat (1984–1992), b) game meat (1984–1992), c) raw fur skins (1980–1992), and d) pickled skins (1980–1992). The lines of best-fit follow an exponential decay model (that is, $y = A(B)^{-x}$, where A and B are constants). Raw fur skin was the only commodity for which there was a significant relationship between demand and price. (Data from the Australian Bureau of Statistics, in Ramsay 1994. All values in 1994 dollars.) The data were analysed by linear regression after the variable 'Price' was linearised by $\log_e$ transformation (Snedecor and Cochran 1989).



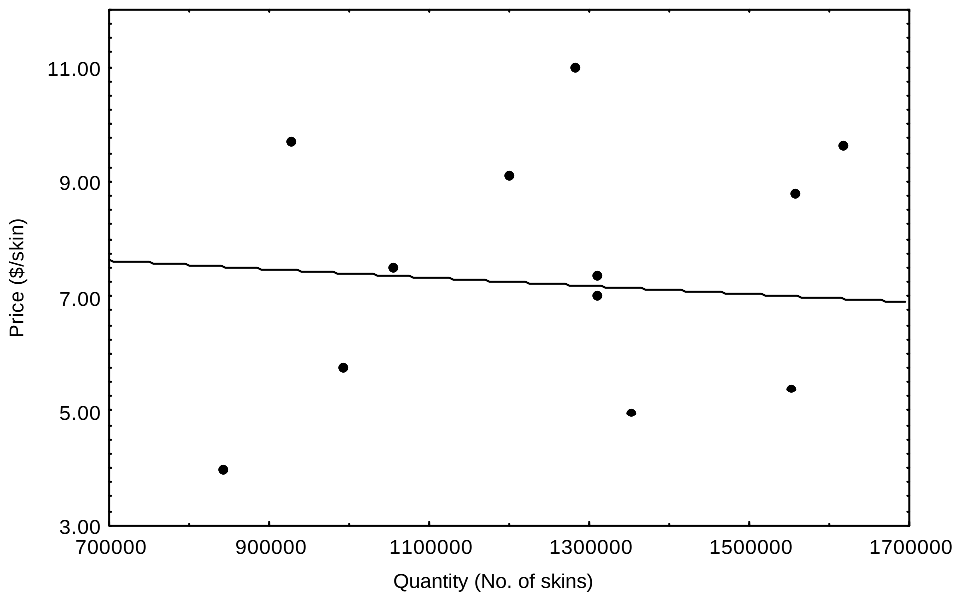
a) Pet meat (1984–1992) $F_{1,6} = 0.00224$, $P > 0.9$, $r = 0.019$



b) Game meat (1984–1992) $F_{1,6} = 2.32$, $P > 0.15$, $r = 0.528$



c) Raw fur skins (1980–1992) $F_{1,6} = 14.6$, $P < 0.01$, $r = 0.842$

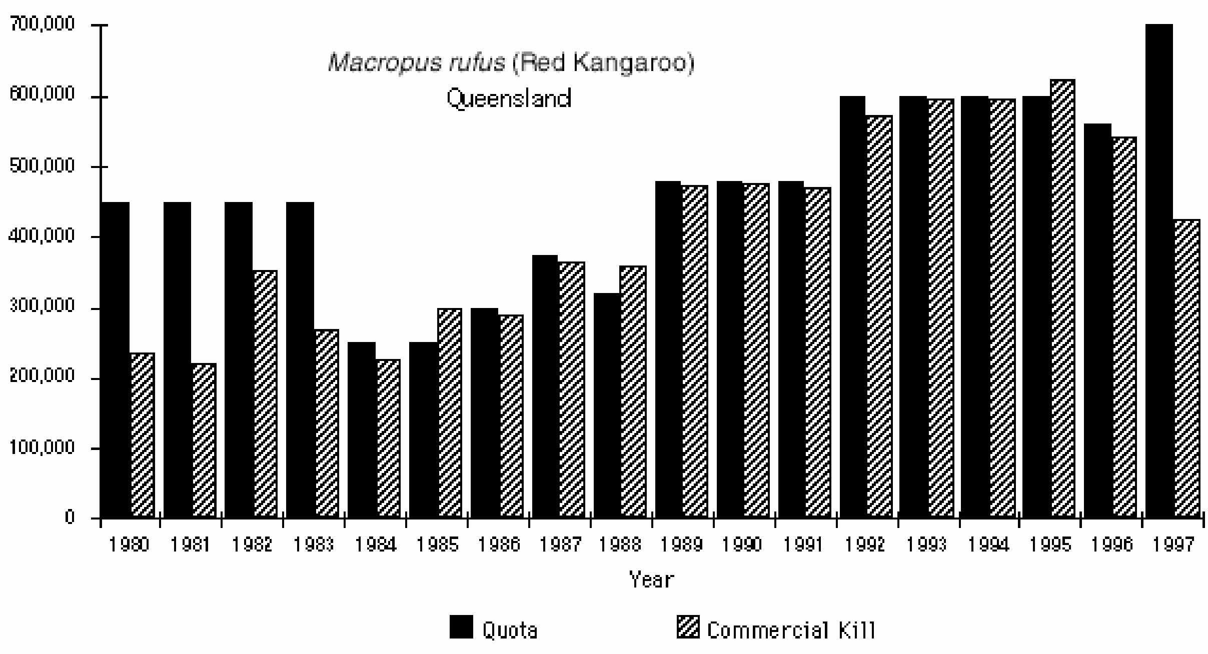


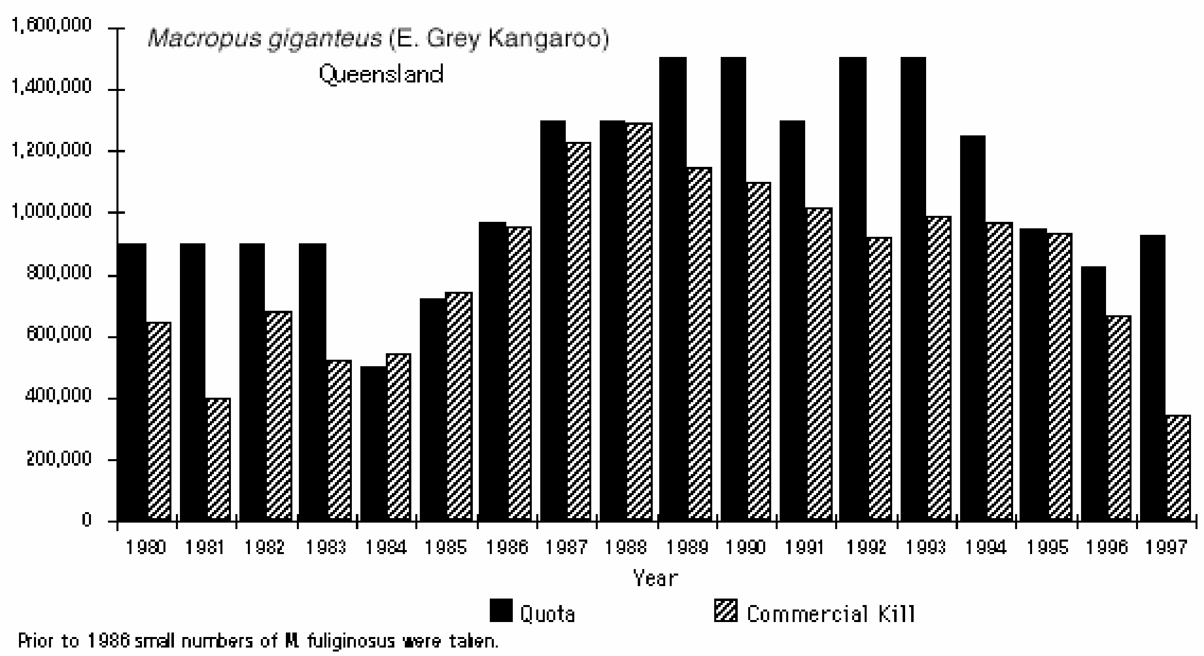
d) Pickled skins (1980–1992) $F_{1,6} = 0.0244$, $P > 0.8$, $r = 0.064$

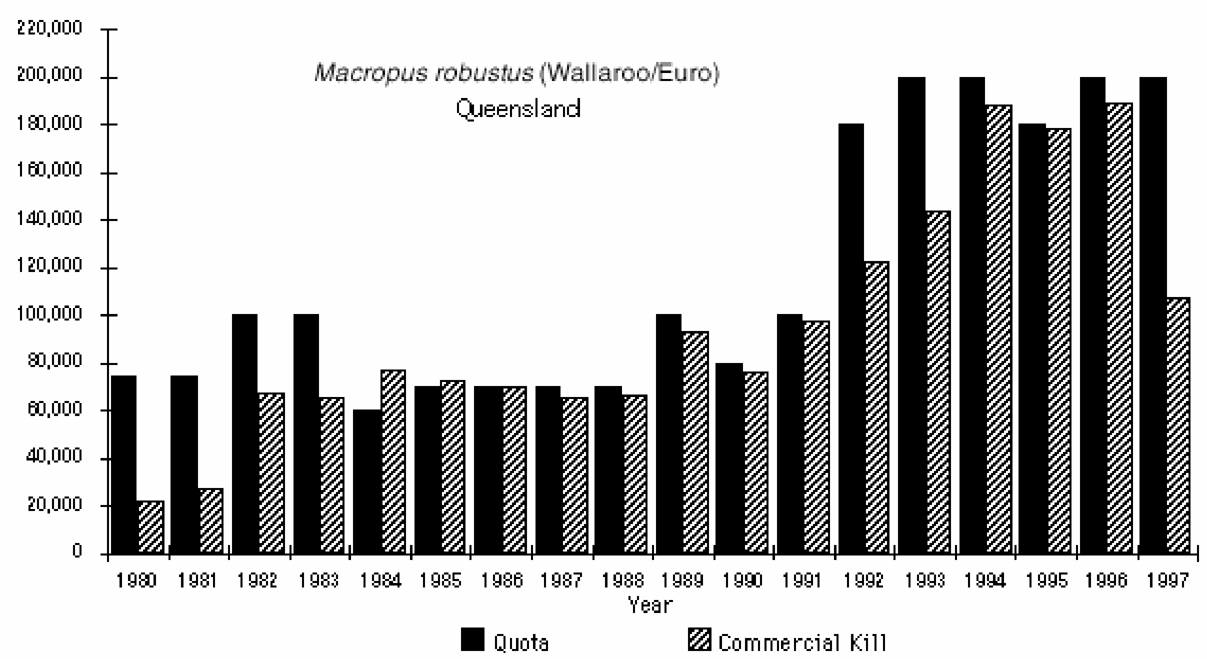
Appendix 2: Quotas and harvests of kangaroos

The commercial quota and harvest of red kangaroos, eastern and western grey kangaroos and wallaroos (euros) from Queensland, New South Wales, South Australia and Western Australia from 1980 to 1997 (data from Environment Australia).

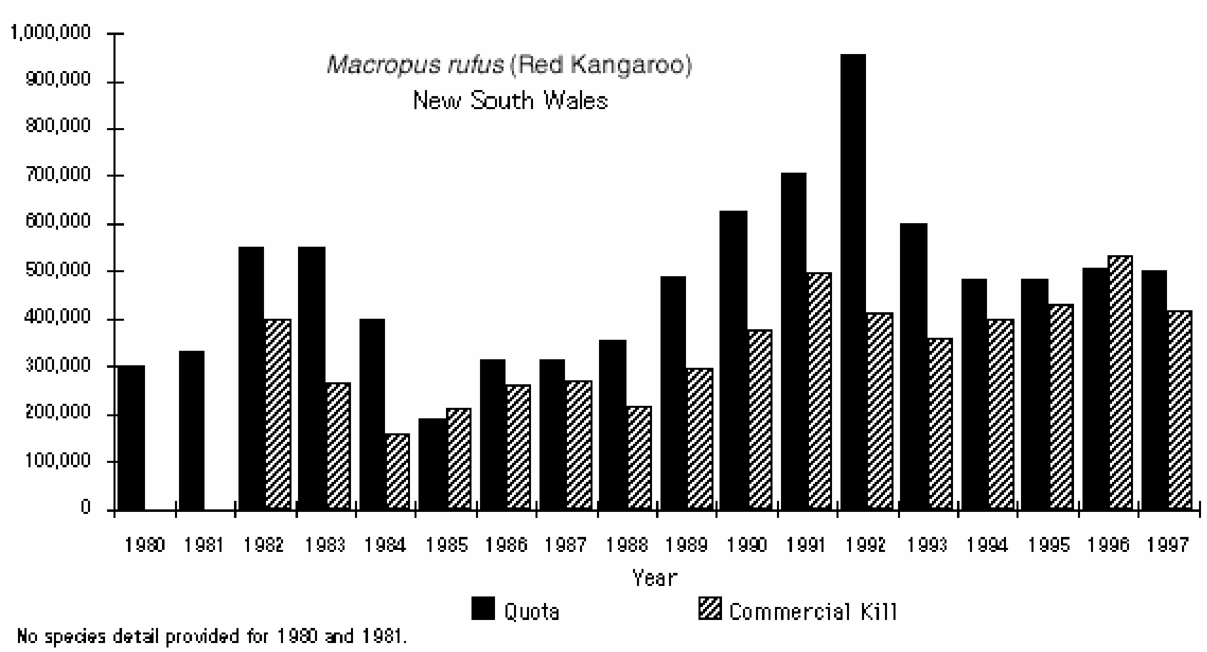
Queensland



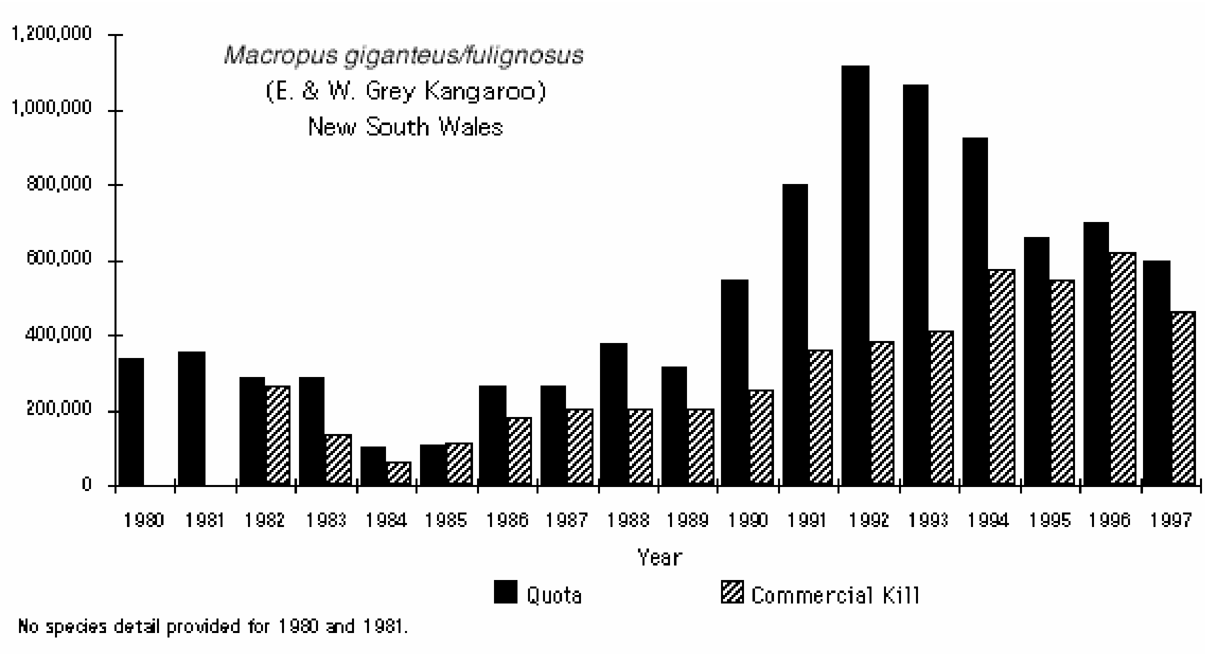


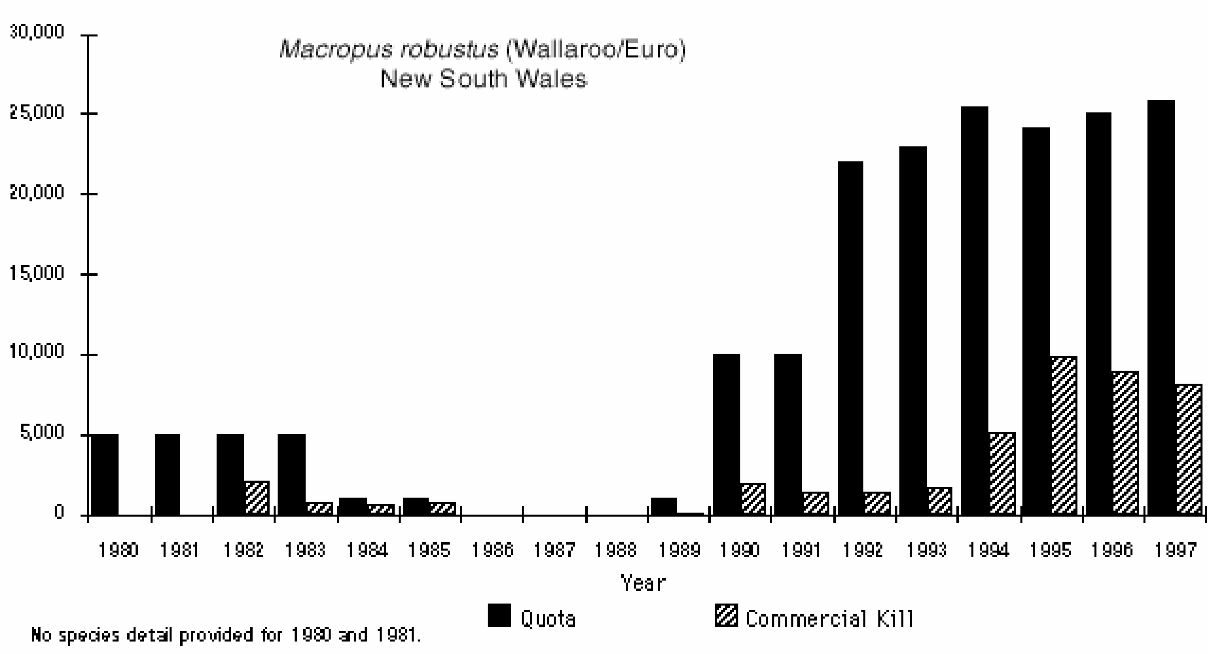


New South Wales

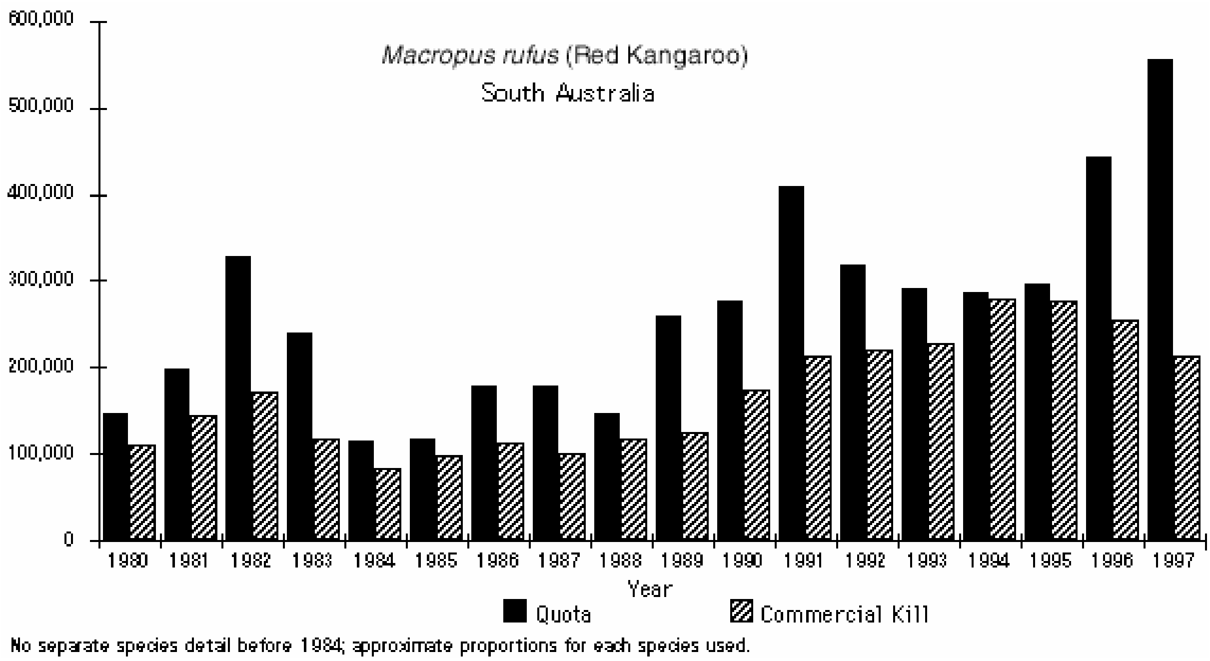


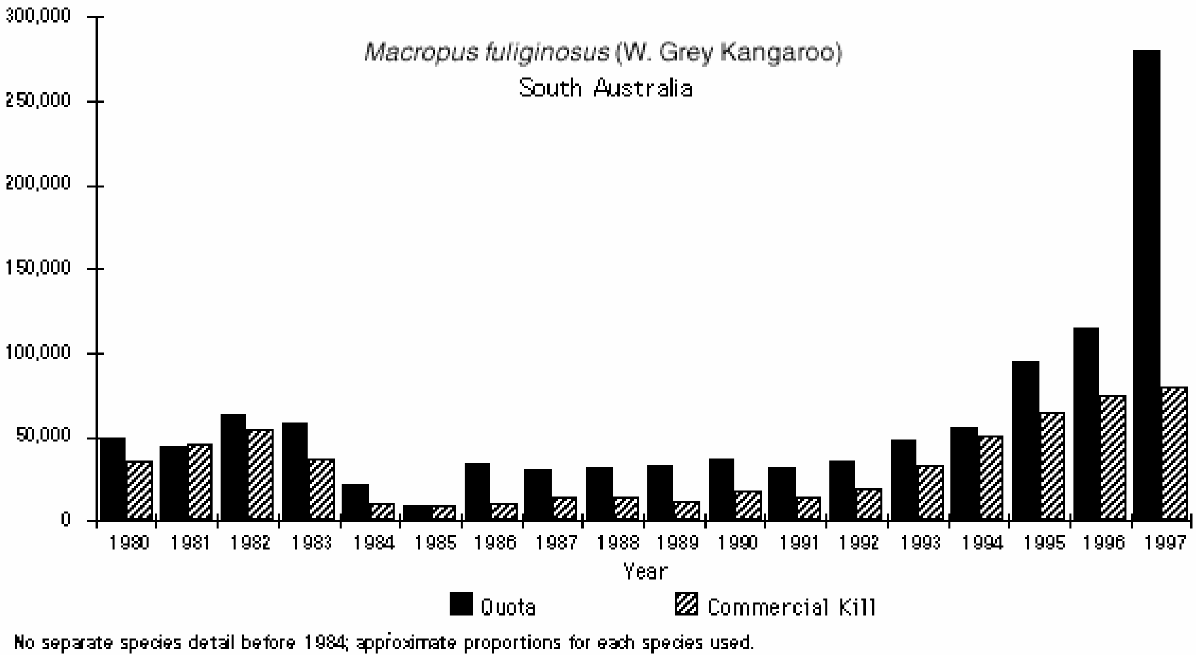
No species detail provided for 1980 and 1981.

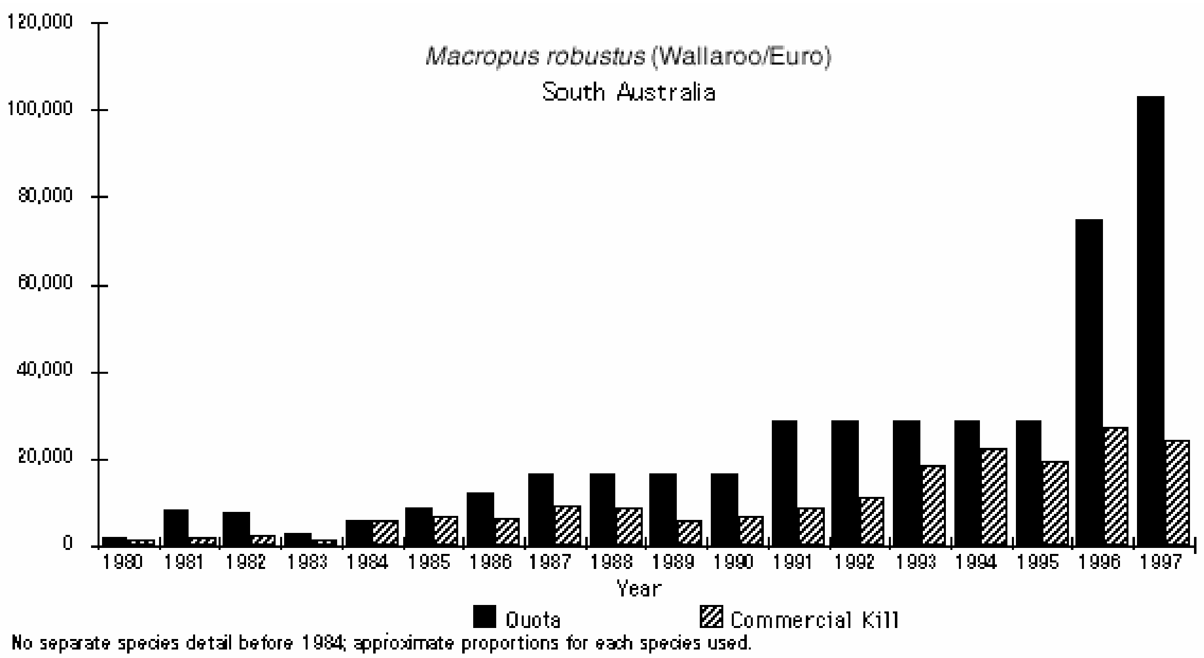

Macropus giganteus/fulignosus
(E. & W. Grey Kangaroo)
New South Wales
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Year
Quota
Commercial Kill
No species detail provided for 1980 and 1981.


Macropus robustus (Wallaroo/Euro)
New South Wales
30,000
25,000
20,000
15,000
10,000
5,000
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Year
Quota
Commercial Kill
No species detail provided for 1980 and 1981.

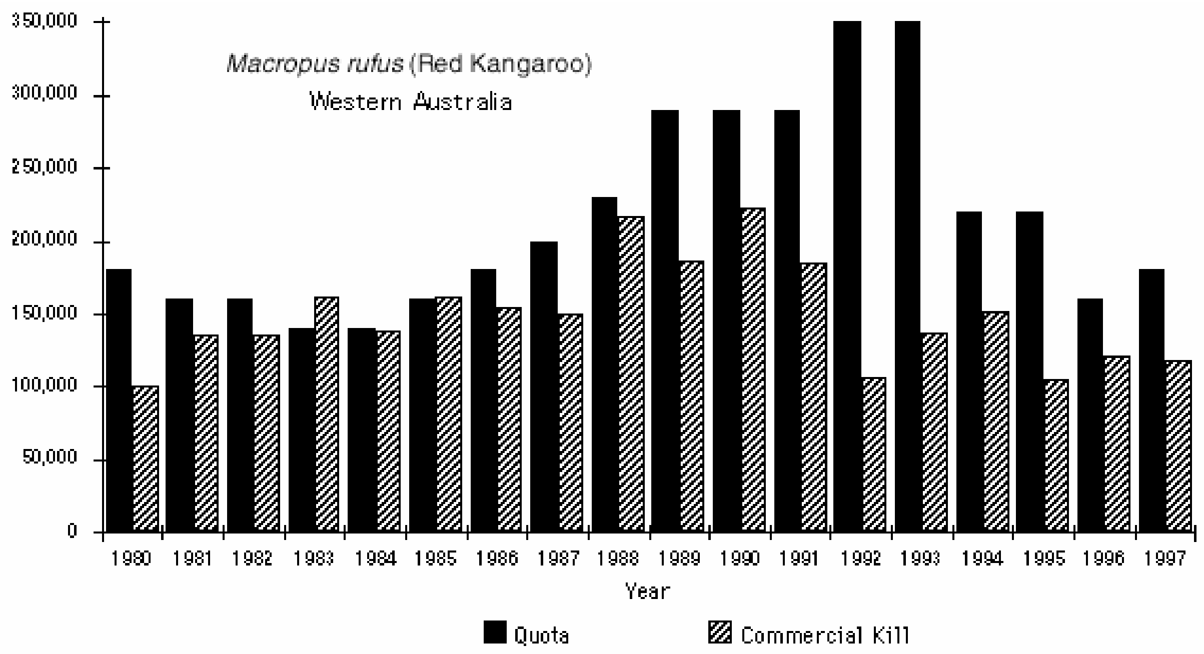
South Australia

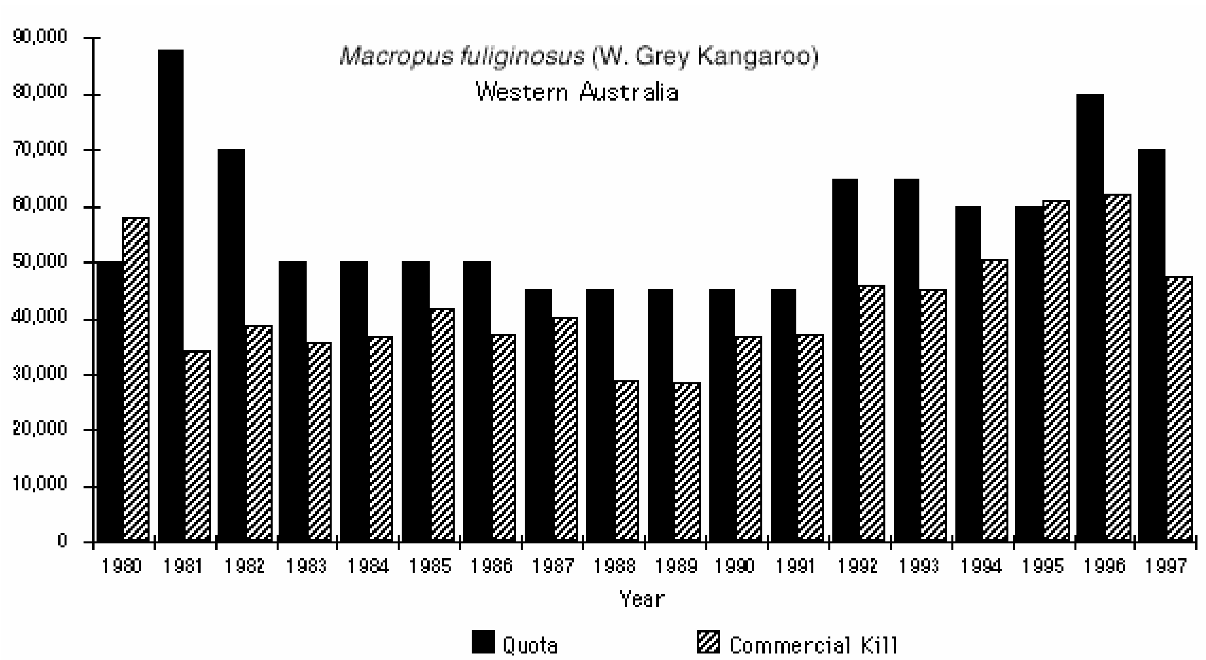


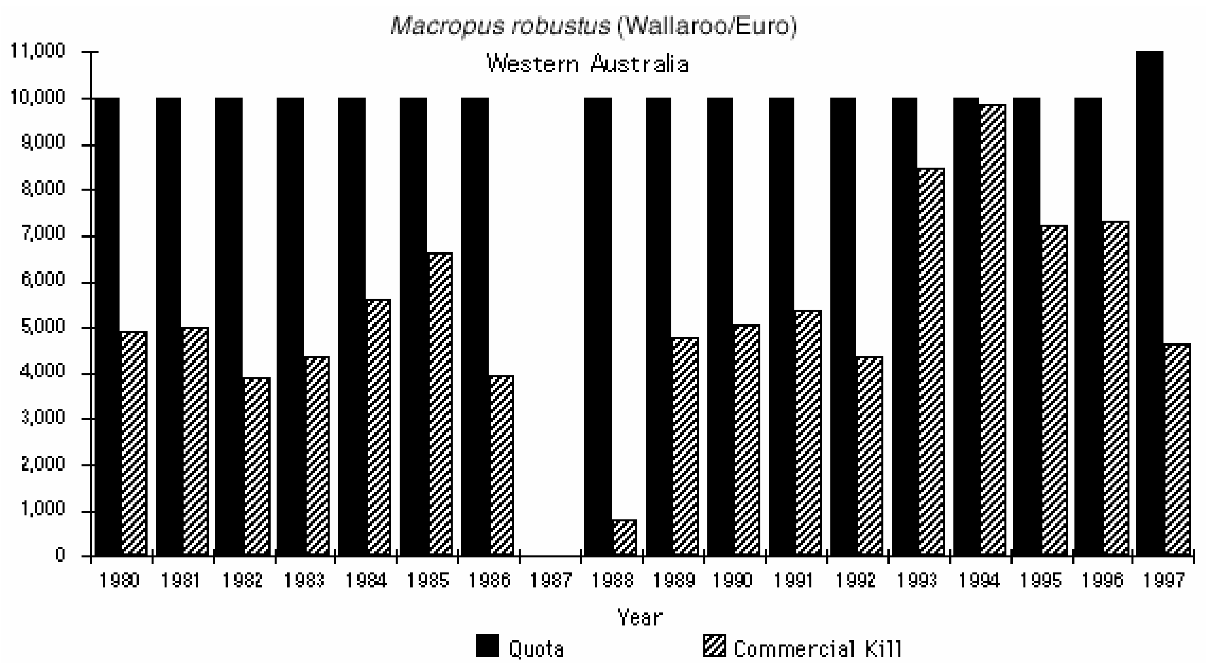




Western Australia




Macropus fuliginosus (W. Grey Kangaroo)
Western Australia
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Year
Quota
Commercial Kill


Macropus robustus (Wallaroo/Euro)
Western Australia
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Year
Quota
Commercial Kill

GLOSSARY

Asymptote: Where a curvilinear line flattens out and approaches a constant value.
Forbs: Broad-leafed (non-grass) herbaceous plants.
Instantaneous birth rate: The number of individuals born over a short period of time (usually in the order of days or weeks).
Instantaneous death rate: The number of individuals that die over a short period of time (usually in the order of days or weeks).
Instantaneous rate of increase: The rate defined by the difference between the instantaneous birth and death rates of a population. Note that this rate may be negative in value (that is, a decrease) and is referred to as a rate of 'increase' by convention.
Intrinsic rate of increase (r_m): The exponential rate at which a population with a stable age distribution grows when no resource is in short supply.
Lability: Instability.
Population: Group of animals occupying an area where they are subject to the same broad set of environmental or management conditions.
Stochastic: Incorporating some degree of random variation.
Total grazing pressure: The sum impact of stock, native herbivores and introduced species on pastures.
Vegetation biomass: Weight of above-ground vegetation available per unit area of ground.
Wildlife or wild animals: Unmanaged, free-ranging native and/or introduced animal species.