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The population dynamics of converting properties from cattle to kangaroo production

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Abstract: With calls to replace some of Australia's domestic livestock production with native alternatives, we investigate a multi-species grazing scenario. As part of a portfolio optimisation analysis of the stocking options, a model is needed to determine the populations of the different species over time. A system of differential equations is used to simulate the interactions between cattle and kangaroos in Australian rangelands. They are used to explore the possibility of converting a property from one focussing on domestic stock, in this case cattle, to a native roving stock, kangaroos. Of particular interest is the income from commodities produced and the effects of the macropods breeding rate and migration on financial returns.

To this end, we show that using current pricing and preferences, the land holder could improve returns in theory by utilising native resources instead, or in conjunction with, domestic livestock. An important reason for this is the comparatively high reproduction rate for kangaroos and the arrival of extra stock from other properties and/or national parks. In particular three scenarios were investigated:

- Both properties continue a cattle enterprise considering kangaroos as pests.
- A property continues a cattle enterprise considering kangaroos as pests, while the other starts converting to a kangaroo enterprise (in effect a co-operative strategy).
- Both properties convert to kangaroo enterprises (a competitive strategy).

The results indicate:

- A competitive cattle enterprise strategy has equal returns given equivalent management practises.
- A co-operative strategy significantly improves returns for the kangaroo enterprise and marginally lower returns for the cattle enterprise.
- A competitive kangaroo enterprise strategy improves profits compared to the competitive cattle enterprise strategy but lower returns than the co-operative scenario given equivalent management practises.

In all scenarios, immigration from the national parks has a larger effect than between properties.

Keywords: *Differential equations, kangaroo harvesting, rangelands*

1. INTRODUCTION

For some time now, there have been calls for sustainable economic use of wildlife, particularly kangaroos in Australia (Pople et al. 1999, Grigg 2002 & Wilson et al. 2008). They are seen as a more environmentally friendly source of meat and leather than the introduced European species commonly found in Australia. The conservation benefits of kangaroo harvesting over the more traditional livestock enterprises could include reduced land degradation, increased biodiversity and reduced methane emissions as suggested in the Garnaut report (Garnaut, 2008). Currently pastoralists generally consider kangaroos a pest that needs to be eradicated from their properties. To this end in some states landholders can get permits for "damage mitigation" to reduce the numbers of kangaroos on their property, on the condition that the carcasses remain where they are shot. Several states allow for controlled harvesting of kangaroos (red, eastern grey & western grey kangaroos and euros, a type of wallaby) for both human and pet consumption as a proportion of the kangaroo population in that state. In general this harvesting is done by licenced harvesters, who have to tag and partially process the carcasses. Harvesters must be given permission to harvest kangaroos on the property, which most landholders see as a service (reducing their grazing pressure from kangaroos) and are therefore most willing to accept without economic compensation. The kangaroos that are harvested must be shot with a single bullet to the head, recorded and sold to processing factories, where the pelt is removed, and the meat processed. The pelts are then salted and sold to make leather products like professional football boots and high end car seats due to is durable, yet supple nature. The meat, once used mainly for pet food, is increasingly being used for human consumption, rising from 40% to 60% from 2002 to 2007, which has in turn increased the production value by over 15% in real terms over the same period (Garnaut, 2008).

For landholders to change their view of the kangaroos on their property, they need to know that diversifying into kangaroo "production" is economically viable amongst other issues. As part of an exploration into the economic advantages of a mixed-grazing strategy the interactions were modelled between cattle and kangaroos and appropriate harvest rates so as to encourage kangaroo numbers to increase on the property. Unlike domestic animals, which belong to the enterprise, and which can be readily bought and sold to control stocking rates, kangaroos are native fauna, and as such are "owned" by the federal government, and hence currently cannot be bought and sold. Therefore, controlling kangaroo numbers on a property can only be done via breeding and migration. While kangaroo proof fencing exits which overcomes their ability to jump long distances and great heights, it is much more expensive than standard fencing and therefore is currently not viable for large properties, like those typically found in Australian rangelands. Hence, kangaroos can be treated as a roving stock, moving from one area to the next, in search of grazing lands and therefore it is possible to encourage kangaroos onto your property from either surrounding properties or national parks (where harvesting is not allowed).

Differential models have been used for many years in biological systems with success in population modelling amongst other endeavours (Murray 1993 & Taubes 2001). The models we use have logistic growth and harvesting components for both species on the properties. Also included in this model are migration components due to the fact that cattle are limited to the property they originate from but kangaroos are free to cross borders between properties.

In this paper we examine the transition from one paradigm (cattle enterprises) to another (kangaroo enterprises in competition and in cooperation). To this end we focus on a scenario with two properties with adjoining fence lines surrounded by national park land. In particular we shall be looking at differential population models where the harvesting rate of the species affects their stable population numbers, and is therefore instrumental in any strategy to change paradigm. Of interest also is the income the landholders would receive.

2. TERMINOLOGY AND ASSUMPTIONS

The term carrying capacity can have different meaning to different people. In this paper we use the term to describe the maximum number of dry sheep equivalents that a property can maintain without harvesting. A dry sheep equivalent standardises the feed requirements of different animals across different species, using a 50kg, non-lactating Merino ewe as the standard for comparison. Hence, a *dse* of 3 equates to an animal that requires three times the feed of a standard ewe. We use the term density to refer to the proportion of the carrying capacity that is being utilised. The term migration refers to the net migration between two regions, as this is the only thing of interest to our research.

It is assumed that the number of kangaroos that leave properties do so at a rate that is proportional to the number of kangaroos in the property. It is also assumed that the kangaroo population in the national park is so large that migration has an insignificant effect on density in the national park. Also the interaction between cattle and kangaroos is such that the *dse* used by each species is sufficient to determine their interaction. This means that they compete for the same forage and there is no facilitation between species. The price/*dse* is estimated as $72.2 for cattle and $52.9 for kangaroo (using price data (unpublished data, P. Moloney) and 10 *dse*/cattle and 0.4 *dse*/kangaroo). The final assumption is that changing the production rate of cattle and kangaroo products does not affect the price of either.

3. FORMULATION

Differential equations were used to model the population where the harvesting rate of the species affects their stable population numbers, and the transition from one paradigm to another. To this end we focus on a scenario with two properties with adjoining fence lines surrounded by national park land. Whilst the cattle are limited to the property they originate from, kangaroos are free to cross borders between the three regions.

$$\frac{dx_1}{dt} = r_x x_1\left(1 - \frac{x_1 + y_1}{k_1}\right) - \gamma_{x_1} x_1 \tag{1}$$

$$\frac{dx_2}{dt} = r_x x_2\left(1 - \frac{x_2 + y_2}{k_2}\right) - \gamma_{x_2} x_2 \tag{2}$$

$$\frac{dy_1}{dt} = r_y y_1\left(1 - \frac{x_1 + y_1}{k_1}\right) - \gamma_{y_1} y_1 + \beta\left(\frac{x_2 + y_2}{k_2} - \frac{x_1 + y_1}{k_1}\right) f + \beta\left(D - \frac{x_1 + y_1}{k_1}\right) g_1 \tag{3}$$

$$\frac{dy_2}{dt} = r_y y_2\left(1 - \frac{x_2 + y_2}{k_2}\right) - \gamma_{y_2} y_2 + \beta\left(\frac{x_1 + y_1}{k_1} - \frac{x_2 + y_2}{k_2}\right) f + \beta\left(D - \frac{x_2 + y_2}{k_2}\right) g_2 \tag{4}$$

where $f = \begin{cases} y_1 & , \frac{x_2+y_2}{k_2} - \frac{x_1+y_1}{k_1} < 0 \\ y_2 & , otherwise \end{cases}$ and $g_i = \begin{cases} y_i & , D - \frac{x_i+y_i}{k_i} < 0 \\ Dk_i & , otherwise \end{cases}$, i = 1 or 2.

The model itself is made up of four differential equations relating to the population of animals on the properties. The equations (1) and (2) correspond to the rate of change in cattle numbers (x_i, i =1 ,2) and consist of a maximal growth rate (r_x) multiplied by a logistic term $(1 - (x_i - y_i)/k_i)$, and a harvesting rate (γ_{xi}, i = 1, 2) of cattle (see Table 1 for details).

Table 1. Definitions of notation used in the equations as well as their value and source.

Notation	Value	Definitions	Source
x_1, x_2	Variable	The number of cattle on property 1 and 2 in *dse*.	
y_1, y_2	Variable	The number of kangaroos on property 1 and 2 in *dse*.	
r_x, r_y	0.15, 0.50	The maximal growth rate for cattle and kangaroos respectively (growth rate given optimal conditions).	Caughley et al.
k_1, k_2	100, 100	The carrying capacity for the properties in *dse*, as a limit to what the property could maintain.	Arbitrary
γ_{x_1}, γ_{x_2}	0.08 or 0.15	The harvest rate for cattle on the properties (pro-cattle or pro-kangaroo).	Chosen so as to maintain or alter population numbers depending on scenario.
γ_{y_1}, γ_{y_2}	0.8 or 0.3	The harvest rate for kangaroos on the properties (pro-cattle or pro-kangaroo).	
β	0.1	The maximal rate of net migration per year.	Assumed common boarder of 10%.
D	0.5	The stocking density (proportion of carrying capacity used) of kangaroos in the national park.	Assumed nature at optimal density.

Equations (3) and (4) relate to the rate of change of the kangaroo populations includes the analogous terms to those just described for the cattle growth rates. In addition to this, terms to describe the migration between the two properties and the national park. For the sake of this model it is assumed that the number of kangaroos migrating at any given time is proportional to the number of kangaroos present in that area, and that the national park has an effectively continuous supply of kangaroos.

The migration rate between the two properties is affected by the maximal rate of migration per year (β), the number of kangaroos present on each property (y_i, i = 1, 2) and a function comparing the difference between the properties. The function we have chosen uses the difference between the stock densities on both properties and then multiplies it by β and the number of kangaroos on whichever property has the highest stocking rate. This is a linear relationship, where in the most extreme case (where one property is empty and the other is at capacity) the maximum migration rate will be in effect (from full to empty property) and if the properties are equally stocked (proportional to their carrying capacity) then there will be no net migration.

Using analogous reasoning to that used in the modelling migration between properties, the model for the migration rate to and from the national parks is governed by the system striving for parity with regards to the proportion of carrying capacity used in the national parks and the respective properties. Here D is used to signify density, the proportion of the carrying capacity used, in the national park. The difference between D and the property affect the kangaroo migration rate (again, think Newton's Law of Cooling). Conscious of the need to not only maintain consistent dimensions, but also the population from which some kangaroos may migrate is modelled using a piecewise function where the number of kangaroos is use if the property is over stocked with respect to the national park and the expected population of kangaroos (Dk_1 and Dk_2) if they are under stocked compared to the national park.

Together, this system of equations conveys the change in stocking rates over time and regions. It allows for movement of kangaroos between regions, competition for resources between species and the affect of harvesting kangaroos.

4. RESULTS AND DISCUSSION

The system of equations described in Section 3 was used to generate plots of the populations and income generated under different scenarios. The first scenario considered is the current situation, where both properties continue to remain cattle based. With initial conditions set so that each property had a nominal carrying capacity of 100, stocked with 45 *dse* of cattle and 5 *dse* of kangaroos and harvest rates of 0.08 and 0.3 for cattle and kangaroos respectively on each property. The other parameter values can be seen in Table 1. This resulted in cattle numbers increasing to plateau around 46.1 *dse* that dominated the kangaroo population, reduced to just over 0.5 *dse*.

When the scenario is changed to property 1 converting, over time, to a kangaroo enterprise it changes the outlook for that landholder significantly. As can be seen in Figure 1, the total *dse* for property 1 is less than that for property 2, with property 1 now dominated by kangaroos, while property 2 is relatively unaffected by the action of their neighbours decision. The yearly return for property 2 has decreased marginally (never greater than \$0.35 out of total in the \$200 to \$400s); however, property 1 has increased their return throughout compared to the cattle enterprise (see Figure 2).

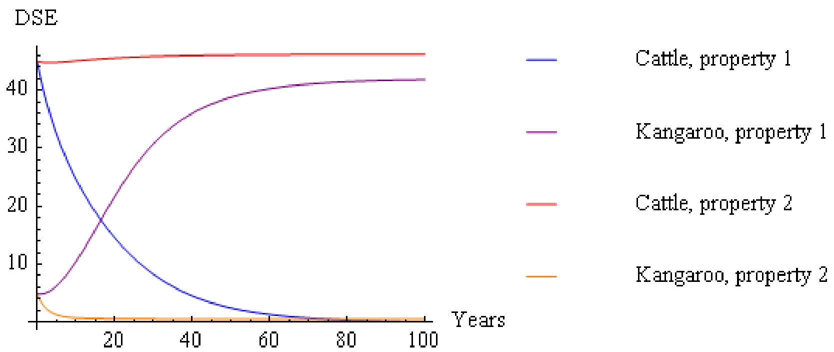

Figure 1. Population of cattle and kangaroos (in *dse*) on each property where property 1 is moving to a kangaroo based enterprise whilst property 2 is continuing to run a cattle-based enterprise.

The dramatic rise in income for the property converting to a kangaroo enterprise, may seem surprising given that cattle were more valuable per *dse* and the total number of *dse* were greater for the cattle property. The difference is due to the higher rate of reproduction for the kangaroos, and the ability to gain stock through immigration. The result is that property 1 can maintain a higher sustainable harvest rate, harvesting approximately three times more *dse* than a property using a higher proportion of its carrying capacity (stocking rate) as can be seen in Figure 3.

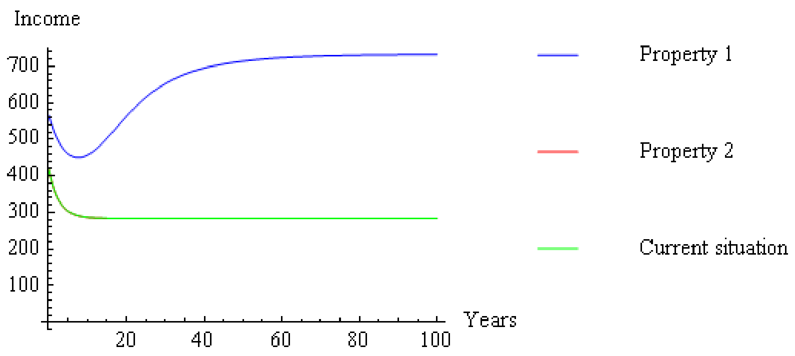

Figure 2. The income generated from the harvesting of cattle and kangaroos considering two scenarios. The first scenario is the current situation of cattle dominated properties; the second is where property one switches to a kangaroo enterprise while property 2 remains a cattle enterprise.

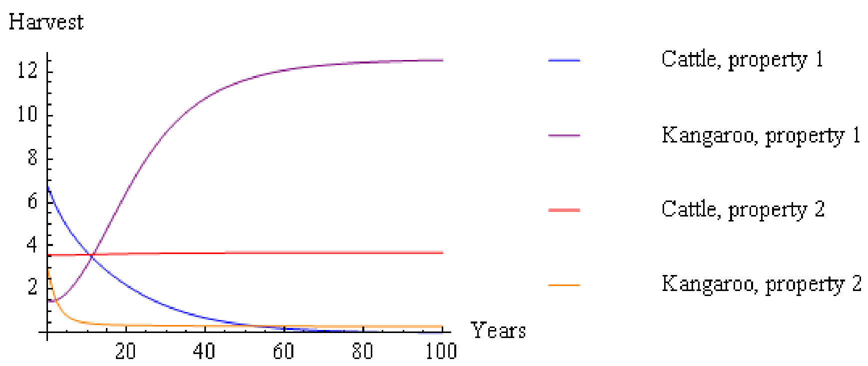

Figure 3. The harvest totals per property per species in *dse*.

Figure 4 shows that the main migration pressure is via the national parks in this scenario. This is partially due to the constant carrying capacities and national park density used and that whilst there is some migration from the property dominated by cattle to the property dominated by kangaroo, the population of kangaroos on the former is so low that even if all the kangaroos were to migrate, it would have little effect. Both properties receive an increase in the kangaroo population from the national park, with the property 1 taking the bulk of the migrants. Property 2 received enough immigration to stop the competitive exclusion you may expect from a simpler Lotka-Volterra competitive system.

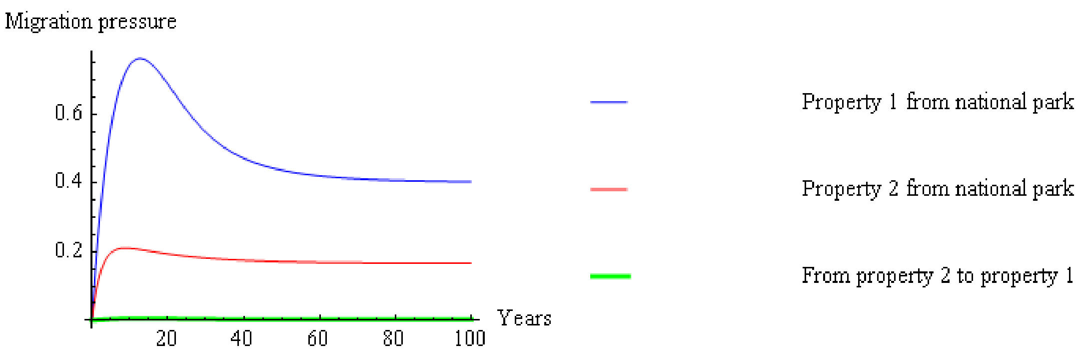

Figure 4. The pressure on kangaroo populations to migrate between the three regions. It includes migration to and from each property and the national park as well as from property 2 (dominated by cattle) to property 1 (dominated by kangaroos).

A third scenario, with both properties converting to kangaroo enterprises was also modelled. Not surprisingly, the result was that both properties were similar to those recorded for the kangaroo enterprise during the second scenario, just performing marginally worse, due to the lack of migration between properties.

5. CONCLUSION

The work carried out shows that by utilising the native species that are abundant, like macropods, landholders could create a viable enterprise. The modelling has shown that with an influx of kangaroos from outside the property, a greater harvest rate, and hence increased returns, can be maintained. This result compares favourably to some of the research we have performed looking at mixed-grazing strategies, where kangaroos or a combination of kangaroos and domestic livestock are the best option to maximise returns. We also see that migration between the properties seems to be negligible, with only a minimal transference between properties.

Inclusion of variable, even stochastic, carrying capacities and national park densities could allow the modelling to explore times of drought (or of plenty) as well as the effect of emigration to the national park. The true impact of migration from the national parks is also an area for further consideration, as this was a significant part of the ability to harvest kangaroos at such a high rate compared to cattle, or for cattle to succumb to competitive exclusion.

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