CENTRE FOR
INVASIVE SPECIES SOLUTIONS

ASSESSMENT OF THE BIODIVERSITY, ECONOMIC AND PRODUCTIVITY GAINS FROM EXCLUSION FENCING

IMPLICATIONS OF EXCLUSION FENCING FOR LIVESTOCK PRODUCTION

TECHNICAL REPORT FOR
PROJECT P01-L-005

AUTHOR

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We acknowledge the Traditional Custodians of the lands on which we meet and work and pay our respects to Elders — past, present and emerging.

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Cover image: Queensland Exclusion Fence.

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ABSTRACT

Two main types of fencing are now common on livestock properties in South West Queensland. Traditional fencing, mostly consisting of barbed wire, has been used for many decades and is still in wide use today. Exclusion fencing, which has become widespread within the past 10 years, consists of tall mesh fences that prevent wild dogs, feral goats, large macropods and livestock from passing under, through or over them.

The study reported here investigated potential sheep and cattle productivity gains arising from the use of exclusion fencing to reduce predation by wild dogs and competition with macropods. Livestock productivity on exclusion-fenced properties was compared with that of traditionally fenced (barbed wire) properties using a combination of producer-provided livestock records and on-ground monitoring of pasture, cattle, macropods, wild dogs and foxes. Records of livestock productivity were collated for 11 properties – three exclusion-fenced sheep properties, three exclusion-fenced cattle properties and five traditionally fenced cattle properties.

Wild dog activity in exclusion-fenced properties was much less than that in traditionally fenced properties, but large variation in annual lamb-marking, ewe-mortality and calf-weaning rates between years masked differences between fence types. Differences between years were mainly due to climate and management variability and extreme weather events. Even so, years with a 67% mortality rate of ewes and a 13% lamb-marking rate, both predominantly due to wild dog attacks prior to erection of exclusion fencing, demonstrated the incompatibility of small ruminants (sheep and goats) and wild dogs. In a landscape where wild dogs have become common, small-ruminant enterprises are only viable if they are exclusion-fenced and wild dogs are continuously culled. Foxes would also need to be culled regularly.

Wild dogs appeared to have little impact on the beef-cattle enterprises monitored during this study, including properties that were not exclusion-fenced and on which wild dogs were common. While two beef-cattle producers reported a few calves with wild dog bite marks in a few years, no cattle producers were aware of any losses due to wild dog attacks. It is possible that a few calves were killed by wild dogs, but these were not discernible among the larger annual variation in calf-weaning rates due to differences in climate, reproductive disease and management.

Macropod populations were at historically low densities during this study due to recent droughts, but some exclusion-fenced properties still had high densities compared with regional averages. Exclusion-fenced properties had higher macropod densities and they tended to have lower cattle stocking-rates compared with traditionally fenced properties. Also, exclusion-fenced properties generally had more pasture biomass available per adult equivalent (AE) cattle than traditionally fenced properties. This may act as a buffer to the higher macropod grazing pressure that increases as pasture biomass declines during drier seasons.

While differences between exclusion-fenced and traditionally fenced properties were often large with regard to pasture biomass, cattle stocking-rates and the amount of pasture available per AE, they were mostly not statistically significantly different. This is not unexpected, regardless of fencing types, given the relatively small number of properties examined, the short time period of the study, and the large spatial and temporal variability that occurs between properties.

Macropod population densities of 50 head/km^2 recorded during this study had the potential to reduce the number of weaners sold annually by 52% and annual income by $231,000. In comparison, annual income is only reduced by $30,800 if wild dogs prey on seven per cent of the calves, which is at the higher end of beef-producer estimates of calf losses arising from wild dogs. While the results of this simplistic comparison favours tolerance of wild dogs that in turn suppress macropod populations, it is likely that the impacts of wild dogs have been underestimated in this study. A better understanding of the long-term costs (e.g. calf loss, injured cattle, disease transmission) and benefits (fewer macropods and feral pests) of wild dogs is needed before conclusions can be drawn about the value of exclusion fencing for beef-cattle production.

INTRODUCTION

A large and rapidly increasing number of sheep and cattle properties in southern and Central West Queensland (Figure 1) have been exclusion-fenced during the past 10 years for the purpose of reducing predation by wild dogs and competition with macropods. This report contains the results of an investigation into the potential livestock productivity gains arising from exclusion fencing of sheep and cattle properties in South West Queensland. This is a component of the Biosecurity Queensland Department of Agriculture and Fisheries project ‘Assessment of the biodiversity, economic and productivity gains from exclusion fencing’.

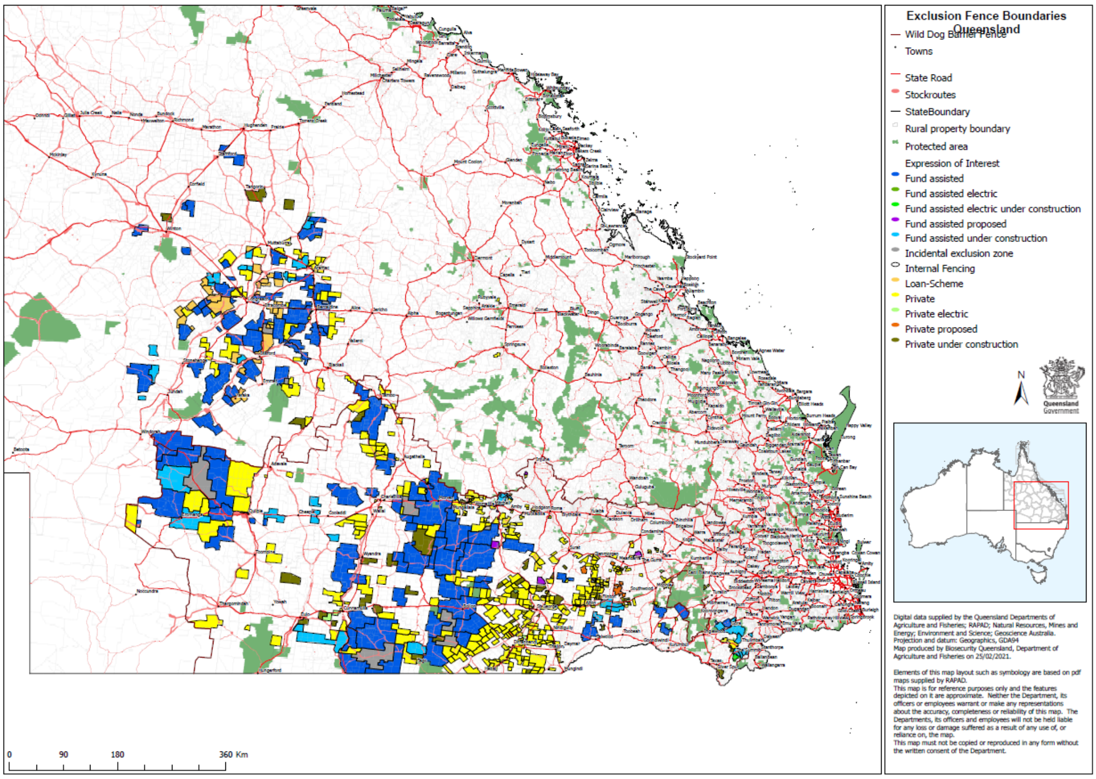


Figure 1. Map of exclusion fence boundaries in southern, South West and Central West Queensland. Source: Cameron Wilson, Biosecurity Queensland, Department of Agriculture and Fisheries

The extent that competing macropods reduce livestock productivity has been disputed for many years. Initially, based on the lower basal metabolic rates of marsupials compared with eutherian mammals (‘placental’ mammals) (Dawson and Hulbert 1970), the grazing pressure of a kangaroo was thought to be 0.7 that of a merino sheep (Linton and Greenfield 1999; Gutteridge et al. 2001). Further comparisons of metabolic rates by Munn et al. (2009; 2013; 2016) concluded that the grazing pressure of red and western grey kangaroos was only 0.35–0.46 than that of similar-sized merino sheep. Furthermore, Grigg (2002) argued that the grazing pressure of a kangaroo could be as low as 0.15 that of a 45-kg sheep, given the low average body weight of kangaroos in commercially harvested populations. In addition to lower energy requirements, Olsen and Braysher (2000) and Olsen and Low (2006) concluded that macropods mostly do not reduce livestock productivity because they have different diets and forage in different areas.

This is in contrast to the widely held views of pastoralists that kangaroos are a major constraint to the productivity of sheep and cattle (Collins and Menz 1986; Gibson and Young 1987; Sloane et al. 1988). Pastoralists also complained that grazing by kangaroos nullified their attempts to maintain or improve pasture condition by reducing numbers of sheep or cattle during dry years, or in more extreme events, destocking entire properties or paddocks. These views were supported by the research of Wilson (1991) who found that the forage consumed by macropods was 0.75 that of a similar-sized sheep, and Norbury et al. (1993) reported that grazing by red kangaroos reduced grass biomass in degraded and recovering pastures where livestock had been removed. More recently, Pahl (2020a; 2020b) reported that the mass-specific forage intakes, diet composition and foraging areas of red, eastern and western grey kangaroos, wallaroos, sheep and cattle were broadly equivalent. Given that the average size of these macropods is around 25 kg, including all age classes on the ground, each animal is equivalent to 0.5 of a 50-kg dry sheep, known as a dry sheep equivalent (DSE), or 0.06 of a 450-kg steer, known as an adult equivalent (AE).

The impact of wild dogs on livestock productivity is less obvious. On one hand, their predation can substantially reduce the productivity and financial viability of sheep and goat enterprises (Thomson 1984; Allen and West 2013), but on the other hand, they can benefit livestock enterprises by suppressing competitive macropod populations (Caughley et al. 1980; Allen 2015; Pople et al. 2000). While the direct financial cost of wild dogs to livestock industries is substantial, Smith and Appleby (2018) reported considerable disparity in estimates of this. For example, they noted that for Australia, estimates varied between $48 million and $66 million per year (McLeod 2004; Gong et al. 2009; Allen and West 2013), and just for Queensland the cost has been estimated at over $67 million (Hewitt 2009). Even though estimated financial costs are variable, there is no doubt that some sheep producers experience very high financial and emotional costs (Smith and Appleby 2018) to the point they may decide to exit the industry (Thomson 1984; Allen and West 2013).

However, the major cause of contractions in the sheep and wool sectors tend to be declining market conditions rather than predation by wild dogs (Smith and Appleby 2018). This was certainly the case for the very large decline in numbers of merino sheep enterprises in Queensland during the late 1990s and early 2000s. The recent expansion in numbers of sheep enterprises in southern and western Queensland has predominantly occurred with dorper sheep, driven by high prices for meat sheep. Similarly, high prices for goat meat have been mainly responsible for a large increase in the number of domestic-goat enterprises in these regions. While both small ruminants are well adapted to rangeland environments, they are as susceptible to wild dog attack as merino sheep.

Beef-cattle producers are often less concerned about losses due to wild dogs (Allen and Sparkes 2001; Allen 2014; van Eeden et al. 2021). Even so, reported costs in the beef-cattle industry due to the direct impacts of wild dogs are considerable. Of the $67 million cost of wild dogs to Queensland in 2008/09 (Hewitt 2009), $40 million occurred in the beef-cattle industry due to loss of calves by predation ($22.8 million), product loss from dingo-bitten livestock ($2.0 million), parasite transmission (*Neospora caninum* and *Echinococcus granulosus*) ($5.2 million) and wild dog management costs ($11.2 million) (Allen 2014). While mortality of calves due to wild dog attacks is believed to be the major cost for beef-cattle enterprises (Fleming et al. 2012), this is often difficult to verify on extensive properties that, for several reasons, typically experience high variation in calf losses between years and properties (Allen 2014).

While foetal and calf wastage losses between pregnancy diagnosis and weaning in beef herds of northern Australia can vary between two per cent and 40% annually, the causes are often unknown (Allen 2014). Even so, Allan (2014) reported that most studies did not list wild dogs as a major cause of calf loss (Hasker 2000; Schatz and Hearnden 2008; Burns et al. 2010). This suggests that in many studies losses of calves due to wild dog attacks were relatively low compared with losses due to other causes. For example, in a large cattle herd on a station in central Australia, losses of calves due to wild dog predation was less than 1.5% annually (Wallach et al. 2017). As reported by Edwards et al. (2021), this is consistent with survey results of cattle producers who estimated annual calf losses due to wild dog predation to be between one and seven per cent (Eldridge and Bryan 1995; Hewitt 2009; McGowan et al. 2014; Binks et al. 2015).

Allen (2014) noted that Rankine and Donaldson (1968) and Allen and Fleming (2004) reported higher calf losses due to wild dog attacks of nine per cent and 15% respectively, and that cattle producers in some regions believed wild dog predation to be a common cause of calf loss (Gibson 1987). Fleming et al. (2012) and Fleming et al. (2014) reported much higher calf losses due to wild dog predation. These authors identified two studies where annual calf losses were 32% (Allen 2005) and 33% (Allen 2010). According to Allen (2010), these very high rates of calf loss due to wild dog predation are more likely to occur during drought when the availability of alternative prey is scarce.

As per the project description, investigation of the potential livestock productivity gains due to exclusion fencing requires an assessment – relative to unfenced areas – of the effectiveness of pest control that landholders do, improvements in pasture production and, ultimately, improvements to livestock production. Specifically: Seven years after exclusion fencing of the Morven cluster was completed in January 2015, has exclusion fencing been responsible for an increase in livestock productivity?

BACKGROUND

Exclusion fencing – modern mesh fences of a type and height that prevent wild dogs, feral goats, macropods and livestock from passing under, through or over them – is now commonplace in southern, South West and Central West Queensland (Figure 2).

Figure 2. Exclusion fence in the Morven cluster

A more detailed map of the locations of exclusion fencing and the sources of funding for them for the Murweh Shire Council area are shown in Figure 3.

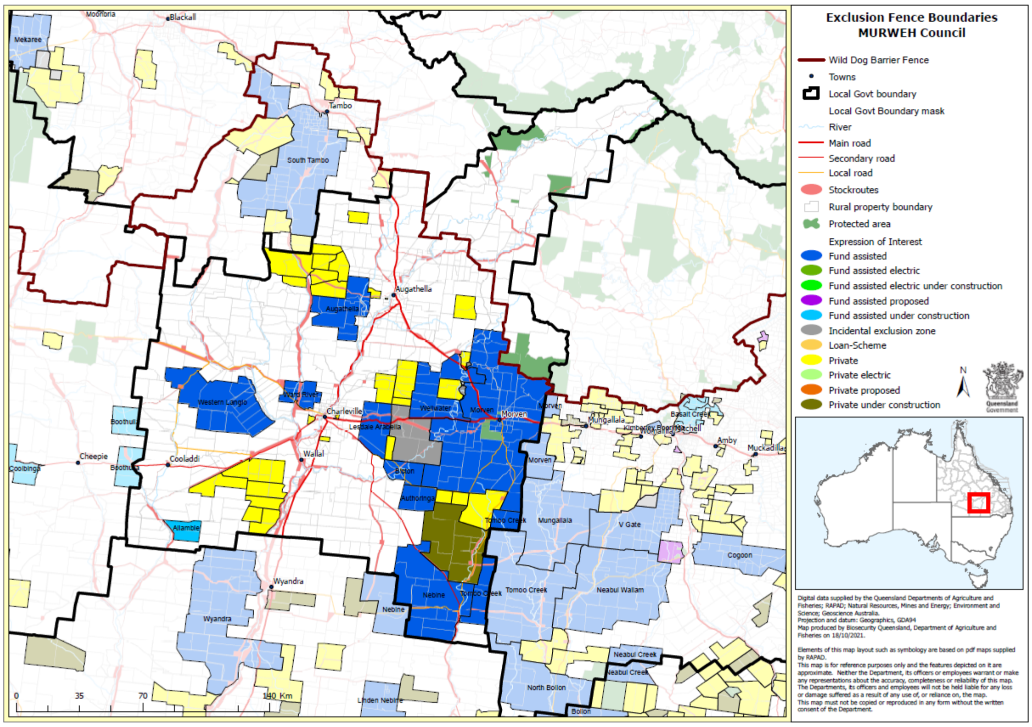


Figure 3. Murweh Shire Council exclusion-fence boundaries. Source: Cameron Wilson, Biosecurity Queensland, Department of Agriculture and Fisheries

The livestock properties investigated in this study are mostly located within or near the Morven cluster (the large, dark-blue block of properties surrounding Morven in Figure 3). An additional property is located in the grey cluster called South Tambo, immediately south of Tambo, near the top of Figure 3.

Exclusion fences are not new. Similar fences, called vermin fences (Figure 4), were mandatory (state government legislation) for controlling the spread of rabbits and wild dogs on leasehold grazing properties in many parts of Queensland during the late 19th and early 20th century.

Figure 4. An old vermin fence located on the boundary of the Morven Conservation Park

The locations of many historical vermin fences are shown in Figure 5. Interestingly, the distribution of these vermin fences is quite similar to that of the present-day exclusion fencing (Figure 1).

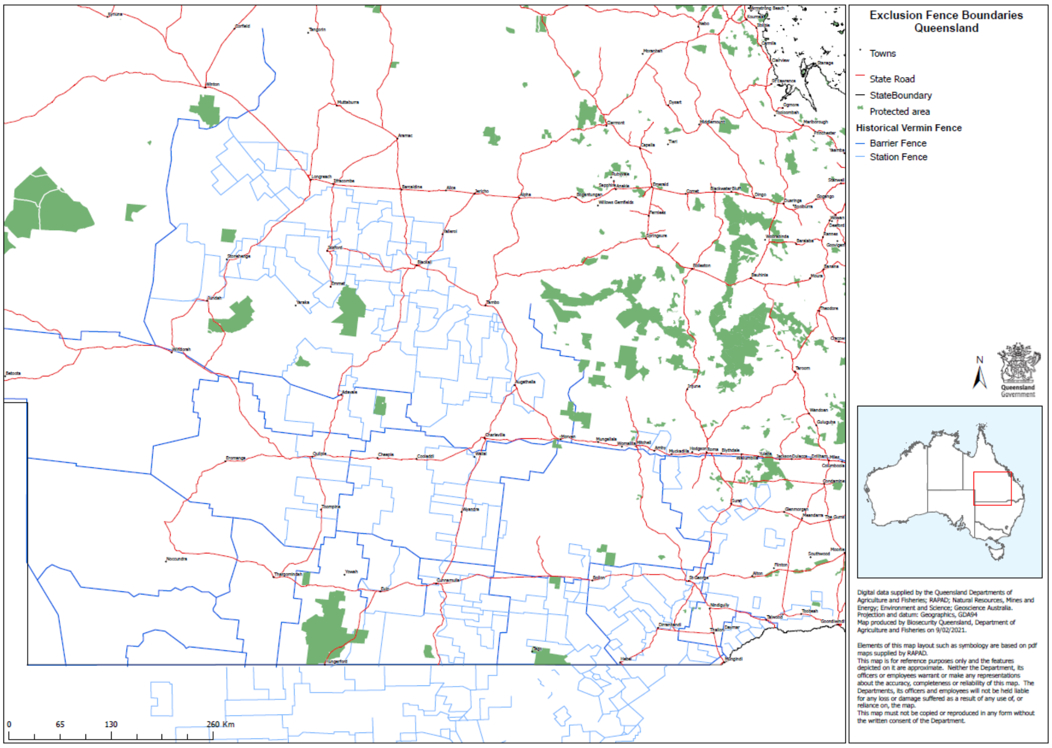


Figure 5. Map of vermin-fence boundaries in southern, South West and Central West Queensland. Source: Cameron Wilson, Biosecurity Queensland, Department of Agriculture and Fisheries

While the map in Figure 5 shows the locations of many stations' vermin fences, it is likely that many more have not been mapped. For example, vermin fences such as in Figure 4 were observed on several properties north-east of Morven, none of which are shown on the map in Figure 5.

Over time, other methods of controlling wild dogs were considered more effective and cost-efficient, and thus these netting fences fell into disrepair (Figure 6).

Figure 6. Vermin fence in disrepair at Morven, with holes large enough for easy passage of sheep, goats, macropods and wild dogs

The maintenance of these vermin fences declined as regulations were relaxed and as their function was replaced by coordinated, large-scale baiting programs in conjunction with the wild dog barrier fence (solid brown line in Figure 3). Hence, property-scale exclusion fencing was no longer necessary.

With the demise of the wool sector due to market collapse during the 1990s, many properties in southern and western Queensland changed from merino sheep to beef cattle. As cattle production and profitability are less impacted by wild dog predation than sheep, many cattle producers stopped baiting wild dogs. Over two decades, densities of wild dogs increased to levels that were making small-ruminant production unviable.

A small number of the few remaining merino sheep producers started to erect exclusion fencing during the 2000s at their own expense as a tool for controlling wild dogs and the grazing pressure of macropods. While little factual evidence was available as to the cost-effectiveness of these fences, they quickly became popular in South West Queensland. Popularity was aided by a number of organisations which distributed funding from state governments and the Australian Government to groups of livestock producers for the purchase of exclusion-fencing materials. Livestock producers then provided the labour required to erect these fences. It was envisaged that public funding for these fences would be recouped in the form of increased regional employment and income associated with an expanded wool industry, as well as the public benefit of improved land condition arising from increased control of total grazing pressure (largely macropods, wallabies and feral goats).

An example of an early (if not the first) group of livestock producers to receive funding for exclusion fencing is the Morven cluster (Figure 7).

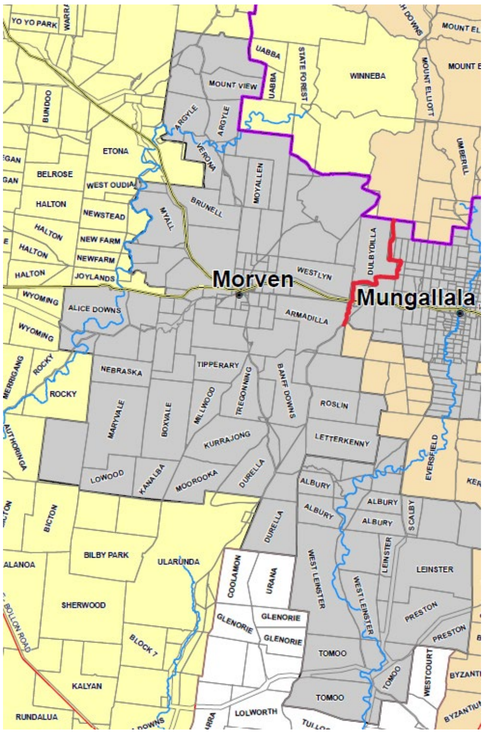


Figure 7. The Morven exclusion fencing cluster (grey-shaded) properties north and south of Morven

The Morven cluster is a coalition of around 50 adjoining properties circling Morven in South West Queensland. The grant to this group was for the purchase of fence materials sufficient to fence the outer boundary of the 50 combined properties. Erection of this fence commenced in 2013 and was completed in January 2015. Since then, at least half of the participating livestock producers have, at their own expense, exclusion-fenced the boundary of their individual property, creating a honeycomb of exclusion fencing within the Morven cluster.

The wide and rapid adoption of exclusion fencing has been driven by a number of factors. Initially, it was high densities of wild dogs that were making sheep production unviable. Also, macropod population densities increased markedly from 2010 to a peak in 2013 due to favourable climatic conditions (Figure 8). At this time, properties with suitable habitat for macropods experienced high macropod grazing pressure.

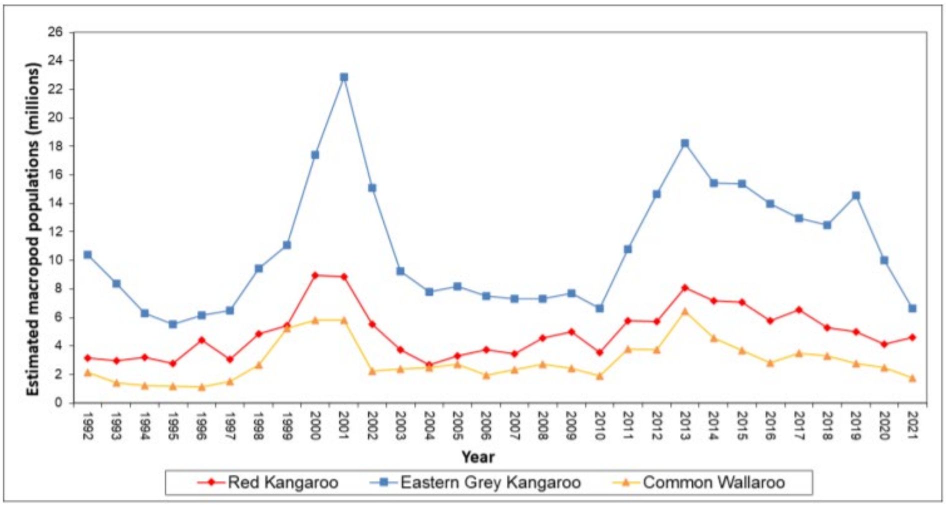


Figure 8. Estimated size of red kangaroo, eastern grey kangaroo and common wallaroo populations in the commercial harvest zones of Queensland between 1992 to 2021. Source: Department of Environment and Science Queensland 2021

In some cases, the owners of properties that were exclusion-fenced around 2013 used damage mitigation permits issued by the Queensland Government to reduce macropod densities. Exclusion fencing has prevented reinvasion of properties by macropods, but it can also result in concentrations of macropods on some properties or parts of properties. Differences in pasture biomass on either side of exclusion fences (Figure 9) were often believed to be due to differences in macropod densities, even though differences in sheep and cattle stocking-rates were unknown.

Figure 9. Differences in pasture biomass across an exclusion fence in the Morven cluster. Source: Lee Allen

Exclusion fencing may have also prevented the easterly movement of macropods during dry years, which was reported by many livestock producers in South West Queensland, leading to higher densities on the western side of fences.

Widely distributed photos of increased pasture availability behind exclusion fencing combined with government grants for exclusion-fencing materials then resulted in widespread and rapid adoption. In addition to this, high cattle prices and good financial positions for many properties was a further catalyst for the construction of privately funded exclusion fencing. Then, from 2019/20 to 2021/22, very high prices for sheep meat and goat meat have provided further motivation for exclusion fencing. Dorper sheep, which appear well adapted to the rangelands of southern and western Queensland, are available for stocking properties, and large numbers of local feral goats have been valuable for seeding domestic-goat enterprises. Mesh fences are required to keep both of these small ruminants in paddocks, further driving the expansion of exclusion fencing. In short, government grants, high macropod population densities, high levels of wild dog activity, and high red meat prices combined with improved fencing materials and methods have driven the widespread construction of exclusion fencing.

METHODS

Livestock productivity of exclusion-fenced properties was compared with that of traditionally fenced properties near Morven, Augathella and Tambo, using two sets of data. First, they were compared based on records of stocking, weaning and mortality rates provided by participating livestock producers. Second, on-ground monitoring of properties was used to record the relative grazing pressure of cattle and macropods, and the relative abundance of wild dogs and foxes. In addition to these indices of macropod grazing pressure (e.g. dung, tracks), aerial surveys during April 2021 and May 2022 provided densities of macropods on several properties.

LIVESTOCK PRODUCTION RATES

Livestock productivity data used was the numbers and classes of livestock carried on properties annually, as reported by livestock producers. It included numbers present at 1 July, births, estimated weights, deaths, purchases and sales during the year, and the final numbers at 30 June.

At the commencement of the project, livestock numbers were provided to the project by several merino sheep producers inside the Morven and Tambo exclusion-fence clusters. These were the 'opening' and 'closing' numbers of sheep and lambs each year. However, at this time, there were no sheep properties without exclusion fencing near Morven or Tambo that could be compared with the exclusion-fenced sheep properties. Furthermore, one of the two sheep properties in the Morven cluster withdrew from the project in 2019. As cattle properties with and without exclusion fencing are common in the Morven region, cattle properties were recruited into the project. A large number of cattle producers in the Morven and Augathella districts were asked to participate in this project, but less than half of those contacted agreed to be involved in the project. Participating properties were selected on the basis of fence type and proximity to other participating properties. Also, attempts were made to recruit properties that differed markedly in densities of macropods and wild dogs.

In total, 11 properties provided livestock records; three predominantly sheep properties and eight cattle-only properties (*Table 1*). The area of each property and its modelled long-term carrying capacity in adult equivalents (AE = 450-kg steer) were sourced from the FORAGE Long-Term Carrying Capacity reports downloaded from The Long Paddock website (The Long Paddock 2022).

Table 1. The area, livestock run, carrying capacity and fence type for the 11 participating properties

Property	Area (ha)	Livestock	Carrying capacity (AE)	Fence type
Sheep 1	8,764	Sheep and cattle	936	Exclusion. Morven cluster
Sheep 2	11,964	Sheep and cattle	1,189	Exclusion. Morven cluster
Sheep 3	27,441	Sheep and cattle	3,757	Exclusion. Tambo cluster
Cattle 1	12,613	Cattle	1,199	Exclusion. Morven cluster
Cattle 2	9,445	Cattle	1,951	Traditional
Cattle 3	5,774	Cattle	986	Traditional
Cattle 4	7,278	Cattle	542	Traditional
Cattle 5	27,431	Cattle	1,166	Exclusion. Individual property
Cattle 6	7,510	Cattle	1,783	Traditional
Cattle 7	6,138	Cattle	1,101	Traditional
Cattle 8	11,007	Cattle	786	Exclusion. Morven cluster

Participating properties provided all or most of the following records needed to calculate the annual AE or DSE for the period 1 July to 30 June:

- numbers of each class of animal (e.g. one-year-old steers, one-year-old wethers) present at 1 July, and the actual or estimated average weights of animals in each class ('opening' numbers)

- the number, weights and dates that livestock were transferred onto the property
- the number, weights and dates that any livestock were transferred off the property
- weaning dates and weights, and the number of weeks weaners remained on the property
- numbers of each class of animal present at 30 June, and the actual or estimated average weights of animals in each class (‘closing’ numbers).

With regard to calf-weaning rates, records were needed of the number of heifers and cows that were exposed to bulls for the purpose of producing a calf, and the number of calves weaned. For sheep, the records used were the number of lambs at marking time relative to the number of ewes exposed to rams. For mortality rates, records required were the number of each class of animal that were known to have died or could not be found during the year.

While all participating businesses had opening and closing numbers of each class of animal for the last four to 20 years, they generally did not have recording systems capable of accumulating all of the records described above. In particular, they mostly did not have records of the numbers, classes, weights and dates of animals transferred onto or off the property between 1 July and 30 June. However, a number of landholders had recently started using AgriWebb, which is a livestock record keeping and analysis program. In this system, livestock producers record the monthly number, class and estimated weights of animals present in each paddock. Likewise, another property had commercial herd-recording software, and a couple of properties had their own Excel-based recording systems. Even so, monthly and annual closing figures were often the net of all transfers on and off the property, and of mortality as well.

Comparison of the stocking rates of properties with and without exclusion fencing required that livestock types and classes be converted to standard livestock units. In relation to daily dry matter intake, one AE is equivalent to eight DSE (Pahl 2020a). The AE and DSE ratings used to standardise the total AE carried on each property are shown in Figures 10 and 11.

CROSSBRED CATTLE AE TABLES

Animal Equivalent (AE) Ratings represent energy demand relative to the standard AE animal (450kg Bos taurus steer with zero liveweight gain)

Growing Animals (any period)
Steers and Dry Empty Females

Average Liveweight	Average Daily Gain (kg/hd/day) 0	0.2	0.4	0.6	0.8	1.0
150	0.43	0.53	0.64	0.75	0.86	0.98
200	0.49	0.61	0.74	0.86	1.00	1.13
250	0.59	0.73	0.87	1.02	1.17	1.32
300	0.68	0.84	1.00	1.17	1.34	1.51
350	0.76	0.95	1.13	1.31	1.50	1.69
400	0.85	1.05	1.24	1.44	1.64	1.84
450	0.94	1.14	1.35	1.56	1.76	1.97
500	1.01	1.23	1.44	1.66	1.87	2.09
550	1.09	1.31	1.53	1.75	1.96	2.18
600	1.17	1.39	1.61	1.83	2.05	2.27
650	1.24	1.46	1.68	1.90	2.13	2.35
for bulls add	11%	7%	5%	3%	1%	0%

Breeding Females (annualised mob average)
Includes calf to weaning, assumes 12mth calving interval and zero LWG

Average Liveweight	Weaning % 60%	65%	70%	75%	80%	85%	90%
350	1.11	1.14	1.17	1.20	1.23	1.26	1.29
375	1.16	1.19	1.22	1.25	1.28	1.31	1.34
400	1.20	1.23	1.26	1.29	1.32	1.35	1.38
425	1.25	1.28	1.31	1.34	1.37	1.40	1.43
450	1.29	1.32	1.35	1.38	1.41	1.44	1.47
475	1.34	1.37	1.40	1.43	1.46	1.49	1.52
500	1.38	1.41	1.44	1.47	1.50	1.54	1.57
525	1.43	1.46	1.49	1.52	1.55	1.58	1.61
550	1.47	1.51	1.54	1.57	1.60	1.63	1.66
575	1.52	1.55	1.58	1.61	1.64	1.67	1.70
600	1.57	1.60	1.63	1.66	1.69	1.72	1.75

Breeding Females (monthly individual average)
Includes calf to weaning, assumes 12mth calving interval and zero LWG

Average Liveweight	Months from birth -5	-4	-3	-2	-1	+1	+2	+3	+4	+5	+6	+7	Annual Average
350	0.77	0.80	0.86	0.97	1.17	1.78	1.85	1.86	1.84	1.79	1.72	0.75	**1.34**
375	0.82	0.85	0.91	1.02	1.22	1.82	1.89	1.91	1.89	1.84	1.76	0.79	**1.38**
400	0.86	0.89	0.95	1.06	1.26	1.87	1.94	1.95	1.93	1.88	1.81	0.84	**1.43**
425	0.91	0.94	1.00	1.11	1.31	1.91	1.98	2.00	1.98	1.93	1.85	0.89	**1.47**
450	0.95	0.99	1.05	1.16	1.35	1.96	2.03	2.04	2.02	1.97	1.90	0.93	**1.52**
475	1.00	1.03	1.09	1.20	1.40	2.00	2.08	2.09	2.07	2.02	1.94	0.98	**1.57**
500	1.04	1.08	1.14	1.25	1.44	2.05	2.12	2.13	2.11	2.06	1.99	1.02	**1.61**
525	1.09	1.12	1.18	1.29	1.49	2.09	2.17	2.18	2.16	2.11	2.03	1.07	**1.66**
550	1.13	1.17	1.23	1.34	1.54	2.14	2.21	2.22	2.20	2.15	2.08	1.11	**1.70**
575	1.18	1.21	1.27	1.38	1.58	2.19	2.26	2.27	2.25	2.20	2.13	1.16	**1.75**
600	1.23	1.26	1.32	1.43	1.63	2.23	2.31	2.32	2.30	2.25	2.17	1.21	**1.80**
	2nd trimester		3rd trimester						1st trimester			2nd trim	
						Lactating							

Figure 10. The annualised mob-based AE ratings for breeding cows and the AE ratings for growing steers or dry and empty heifers used to standardise the annual AE for each property (Bush Agribusiness 2020)

SHEEP DSE TABLES

DSE Ratings represent energy requirements relative to the DSE standard, which is a 45kg wether with zero liveweight gain

Growing Sheep

Liveweight (kg)	Liveweight gain (kg/hd/day) 0.00	0.05	0.10	0.15	0.20	0.25	0.30
20	0.6	0.8	1.1	1.4	1.7	2.0	2.3
25	0.6	0.9	1.2	1.6	1.9	2.2	2.6
30	0.7	1.1	1.4	1.8	2.1	2.5	2.9
35	0.8	1.2	1.6	2.0	2.4	2.8	3.2
40	0.9	1.3	1.7	2.2	2.6	3.0	3.4
45	1.0	1.4	1.9	2.3	2.7	3.2	3.6
50	1.1	1.5	2.0	2.4	2.9	3.3	3.8
55	1.2	1.6	2.1	2.5	3.0	3.5	3.9
60	1.3	1.7	2.2	2.6	3.1	3.6	4.0
65	1.3	1.8	2.3	2.7	3.2	3.7	4.1
70	1.4	1.9	2.4	2.8	3.3	3.7	4.2
75	1.5	2.0	2.4	2.9	3.4	3.8	4.3

Annualised breeding ewe

Liveweight (kg)	Weaning rate 50%	60%	70.0%	80%	90%	100%	110%
35	1.0	1.1	1.1	1.2	1.3	1.3	1.4
40	1.1	1.2	1.2	1.3	1.3	1.4	1.5
45	1.2	1.3	1.3	1.4	1.4	1.5	1.5
50	1.3	1.3	1.4	1.4	1.5	1.6	1.6
55	1.4	1.4	1.5	1.5	1.6	1.6	1.7
60	1.4	1.5	1.5	1.6	1.7	1.7	1.8
65	1.5	1.6	1.6	1.7	1.7	1.8	1.8
70	1.6	1.6	1.7	1.8	1.8	1.9	1.9
75	1.7	1.7	1.8	1.8	1.9	1.9	2.0
80	1.7	1.8	1.8	1.9	2.0	2.0	2.1

Rams

	Liveweight 50	60	70	80	90	100
DSE Rating	1.2	1.4	1.6	1.8	2.0	2.2

Wool production (additional DSE rating)

GFW (kg)	4.0	4.5	5.0	5.5	6.0	6.5	7.0
AE rating	0.06	0.08	0.10	0.11	0.13	0.15	0.17

Pregnancy

Liveweight (kg)	Days pregnant 0	30	60	90	120	150
35	0.8	0.8	0.8	0.9	1.0	1.2
40	0.9	0.9	0.9	1.0	1.1	1.3
45	0.9	1.0	1.0	1.0	1.2	1.4
50	1.0	1.0	1.1	1.1	1.2	1.4
55	1.1	1.1	1.1	1.2	1.3	1.5
60	1.2	1.2	1.2	1.3	1.4	1.6
65	1.2	1.3	1.3	1.4	1.5	1.7
70	1.3	1.3	1.4	1.4	1.5	1.8
75	1.4	1.4	1.4	1.5	1.6	1.8
80	1.5	1.5	1.5	1.6	1.7	1.9
plus twin	0.0	0.0	0.1	0.1	0.2	0.4

Lactation

Liveweight (kg)	Days in milk 1	30	60	90	120
35	2.1	2.4	2.3	2.1	1.8
40	2.2	2.4	2.4	2.2	1.9
45	2.3	2.5	2.5	2.3	2.0
50	2.4	2.6	2.5	2.4	2.0
55	2.4	2.7	2.6	2.4	2.1
60	2.5	2.8	2.7	2.5	2.2
65	2.6	2.8	2.8	2.6	2.3
70	2.7	2.9	2.9	2.7	2.3
75	2.7	3.0	2.9	2.7	2.4
80	2.8	3.1	3.0	2.8	2.5
plus twin lactation provision	1.2	1.5	1.4	1.2	1.0
plus forage for 1 lamb	0.0	0.0	0.3	0.5	0.8
plus forage for 2 lambs	0.0	0.1	0.5	1.0	1.7

Figure 11. The annualised mob-based DSE ratings for breeding ewes and the DSE ratings for growing sheep used to standardise the annual AE for each property (Bush Agribusiness 2020)

A comparison of the total AE carried annually by properties with and without exclusion fencing required that they were standardised in relation to differences in property size, land types, shrub and tree cover, land condition and rainfall. This was achieved by dividing the total annual AEs carried on a property by the modelled safe annual stocking-rate for that property. The safe annual stocking-rates for each property were provided by the FORAGE Long-Term Carrying Capacity reports (The Long Paddock 2022). An example of output used from these reports is shown in Figure 12.

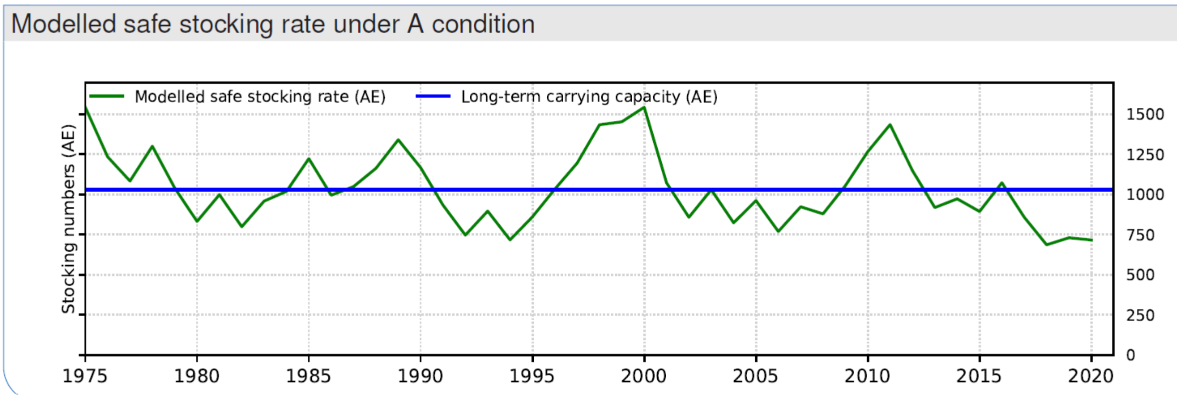


Figure 12. An example of modelled safe stocking-rates and long-term carrying capacity taken from a FORAGE Long-Term Carrying Capacity report (The Long Paddock 2022)

As evident in Figure 12, the modelled safe stocking-rates assumed that properties were in the highest land-condition rating of 'A'. While land-condition ratings are not available for the large majority of properties, some would not be in 'A' condition. However, satellite-determined ground cover – which is available for all properties in Queensland – is an indicator of land condition, providing similar land types under similar conditions are compared. Ground Cover and Ground Cover – Regional Comparison reports (The Long Paddock 2022) were used to compare properties in relation to ground cover. These reports showed how the ground cover of individual land types on a property compared with the ground cover of the same land types on surrounding properties. An example of this is shown in Figure 13. The graph in Figure 13 shows that the ground cover of this property has been relatively low over many years, as it is largely in the 20th to 50th percentiles of the ground cover of surrounding properties.

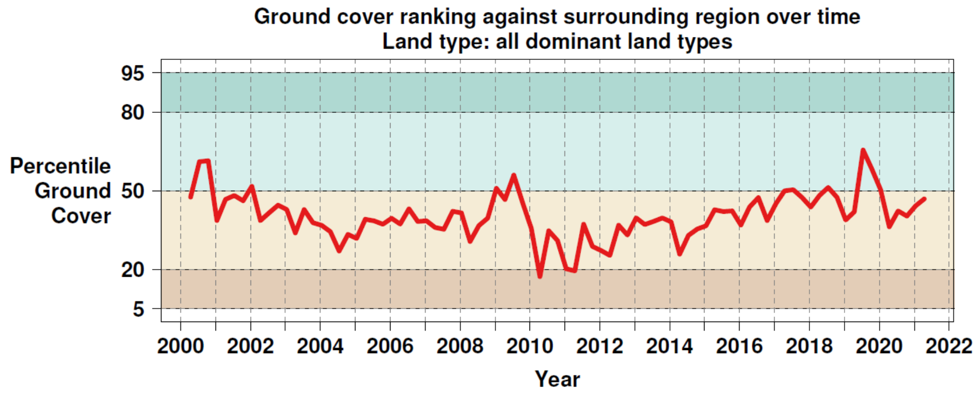


Figure 13. The ground cover for the dominant land types on a property compared with the ground cover of the same land types on surrounding properties (The Long Paddock 2022)

The properties with ground-cover rankings less than the 50th percentile for ground cover in the region over the last 20 years, and that had large areas of ground cover which were more than 30% lower than the highest ground cover of surrounding properties, were considered to be in 'B' condition. As per the FORAGE Long-Term Carrying Capacity reports, the carrying capacity of properties in 'B' condition is only 75% of that of the same property in 'A' condition. Consequently, for properties judged to be in 'B' condition, the modelled annual safe stocking-rates were discounted by 25%.

TOTAL GRAZING PRESSURE

To complement the livestock producer–provided records, on-ground monitoring of pasture biomass was undertaken in 2021. Monitoring during 2022 also included indices of cattle and macropod grazing pressure, and wild dog and fox abundance.

PASTURE BIOMASS AND CATTLE IN 2021

Pasture biomass or total standing dry matter (TSDM) was recorded on participating cattle properties 1–6 (see *Table 1*) during April to June 2021, using the pasture biomass collector app of Cibo Labs, PastureKey (Cibo Labs 2022). TSDM was estimated for 37–60 transects on each property. Transects were located so that they covered the combinations of land types and categories of tree/shrub cover present on each property, as well as the majority of paddocks. At each transect, which was located 50 m from internal vehicle tracks or fence lines, TSDM was visually estimated using photo standards in seven to ten quadrats of 1 m^2.

PASTURE BIOMASS, CATTLE AND MACROPODS IN 2022

Grass dry matter, forb dry matter, dung density and animal tracks were recorded at monitoring sites located on cattle properties 1 to 8 (*Table 1*) during April and May 2022. A modified version of the pasture biomass collector app of Cibo Labs, PastureKey, was used to record pasture characteristics and animal signs (Cibo Labs 2022).

Each monitoring site consisted of a wooden peg placed on the edge of vehicle tracks running through each property. Each monitoring site was located to the side of the track closest to the centre of the property, unless they were difficult to access or unrepresentative of the property. Each sampling point was located 3 km apart along a circular route that passed through as many paddocks of the property as possible. No sites were placed within 200 m of waters or supplementary feeding sites. As monitoring sites were placed 3 km apart, the number of monitoring sites allocated to each property varied with property size. Between 11 and 23 monitoring sites were placed on each of the eight properties.

Parked at each monitoring site, the number of cattle and macropod fresh tracks on the road 20 m in front of the car were recorded. These were the number of individual animals that made the tracks (not the total individual tracks). Monitoring of pastures and dung commenced at a distance of 50 m from and perpendicular to the wooden peg on the edge of vehicle tracks. Ten 0.25-m^2 quadrats, 10 steps apart, were used to monitor forb standing dry matter, grass standing dry matter, per cent utilisation rate and ground cover. Photo standards were used to visually estimate forb and grass TSDM. At the same location as the 0.25-m^2 quadrats, a 1-m^2 quadrat was used for recording the amount of cattle and macropod dung present. The amount of cattle dung present in each quadrat was estimated from photo standards of cattle dung (g/ha), and the amount of macropod dung present was the number of pellets. The number of macropod pellets present was then multiplied by the average pellet weight (0.5 g) to give a density of dung (g/ha). Additionally, the number of cattle pats 1 m either side of a transect line between the car parked on the road and the tenth pasture quadrat (approximately 120 m) were recorded. The number of classes of cattle and species of macropods observed during monitoring on each property was also recorded.

WILD DOGS AND FOXES

As was the case for cattle and macropod tracks, at each monitoring site the number of individual wild dogs and foxes leaving fresh paw marks on the road 20 m in front of the car were recorded.

MACROPOD DENSITIES

The Macropod Management Program of Queensland Parks and Wildlife Service & Partnerships, Department of Environment and Science, Queensland, conducted aerial surveys of macropods on several properties inside and outside of the Morven cluster during April 2021 and May 2022. This was undertaken during their annual statewide monitoring of macropod populations (Department of Environment and Science Queensland 2021). The methods used to conduct these aerial surveys are those described in Department of Environment and Science, Queensland (2021).

Helicopter surveys are conducted with two observers, which results in twice the sampling intensity as one observer. To account for differences between observers, the data was post sampling stratified by applying goodness-of-fit models to the data from each observer using the computer program ‘Distance’ (Buckland et al. 1993). ‘Distance’ was then used to obtain an overall macropod density estimate for the survey block.

Macropod densities were recorded on the same 12 properties during each annual Macropod Management Program survey, seven of which had exclusion fencing, two with traditional fencing located inside the wild dog barrier fence, and two with traditional fencing located outside of the dog barrier fence (*Table 2*).

The May 2022 aerial survey was interrupted by wet weather that prevented access to some parts of the study area. Consequently, fewer of the transect lines were flown on property D, cattle property 1 and the adjacent Chesterton Range National Park and Orkadilla State Forest.

Table 2. Properties monitored for macropod densities in April 2021 and May 2022 by the Macropod Management Program of Queensland Parks and Wildlife Service and Partnerships, Department of Environment and Science.

Properties	**Fence type**
Property A	Exclusion
Cattle 8	Exclusion
Cattle 5	Exclusion
Property B	Exclusion
Cattle 1	Exclusion
Property C	Exclusion
Tregole National Park	Exclusion
Cattle 4	Traditional
Property D	Traditional
Cattle 3	Traditional
Chesterton Range National Park	Traditional
Orkadilla State Forest	Traditional

STATISTICAL ANALYSES

Comparisons of lambing rate, ewe-mortality rate, calf-weaning rate, AE/ha and AE/Forage AE ratio before and after the installation of exclusion fencing of properties were conducted by linear mixed models using residual (or restricted) maximum likelihood (REML) in data-analysis software Genstat 22 (VSN International 2022). The fixed effects were Property*Exclusion fence installed and the random effect was Property_Year. Correlation in measurements from one time to the next on each property was accounted for using a power model, because available measurements were at different times for each property. Data for each variable was included from years when there were at least two properties with data.

REML was also used to compare fence type (exclusion-fenced or traditionally fenced) over the period 2015/16 to 2021/22 for each of the average annual stocking-rates and the average stocking-rate ratios. The fixed effect was fence type, the random structure was property/year, and a power covariance structure was used.

Pasture biomass; cattle stocking-rates; and indices of cattle, macropod, wild dog and fox abundance for the fence treatments (exclusion-fenced versus traditionally fenced) for 2021 and for 2022 were compared using analysis of variance. A log or square root transformation, including square root (value + 0.5), was applied when necessary, and results cross checked with a *t*-test using separate variances. Note: the small sample sizes limited the power of these comparisons, so true significant differences between treatments may not be detected.

Macropod densities for the fence treatments during 2021 and 2022 were compared using analysis of variance with treatment (exclusion fence or not) as the fixed term. For the combined years' data, they were analysed (also using analysis of variance) as a split plot in time with property as the random structure and Treatment*Year and the fixed term. For all analyses, Year needed to be transformed according to log *e* (density + 1) to satisfy normality assumptions.

RESULTS

LIVESTOCK PRODUCTION RATES

Producer-provided records of lamb-marking, ewe-mortality, calf-weaning and stocking rates are presented for individual properties. Lamb-marking rates for the three sheep properties that have exclusion fencing are shown in Figure 14. For sheep property 3, lamb-marking rates before exclusion fencing were mostly between 60% and 75%, with occasional years between 20% and 40%. During the years 2012–2014, dog predation was regarded as the main cause of low marking rates. The marking rate increased immediately after exclusion fencing was completed in 2014/15, but then dropped to very low levels in 2018/19 due to poor nutrition during drought, combined with a burst of cold, wet weather. For the same reasons, lamb-marking rates on sheep property 2 followed a similar trend, rising from just 15% in 2013/14 immediately before exclusion fencing to 95% in the following year.

In contrast to this were consistently higher marking rates before and after exclusion fencing on sheep property 1. Sheep property 1 was privately exclusion-fenced by January 2012 when wild dogs were less common (personal communication, April 2022), due in part to being a member of a small landholder baiting and trapping group. Even so, just before and soon after exclusion fencing, wild dogs did have an impact on some mobs of ewes and lambs. For example, a single dog in one paddock was associated with a (low) 30% lamb-marking rate, while marking rates in other paddocks were close to 100% (personal communication, April 2022). While owners of sheep properties 2 and 3 reported that predation of lambs by dogs was the major cause of low marking rates in the years immediately before exclusion fencing, similar low marking rates occurred in other years due to unfavourable climatic conditions. Consequently, differences in lamb-marking rates before and after exclusion fencing were not significantly different ($p = 0.690$).

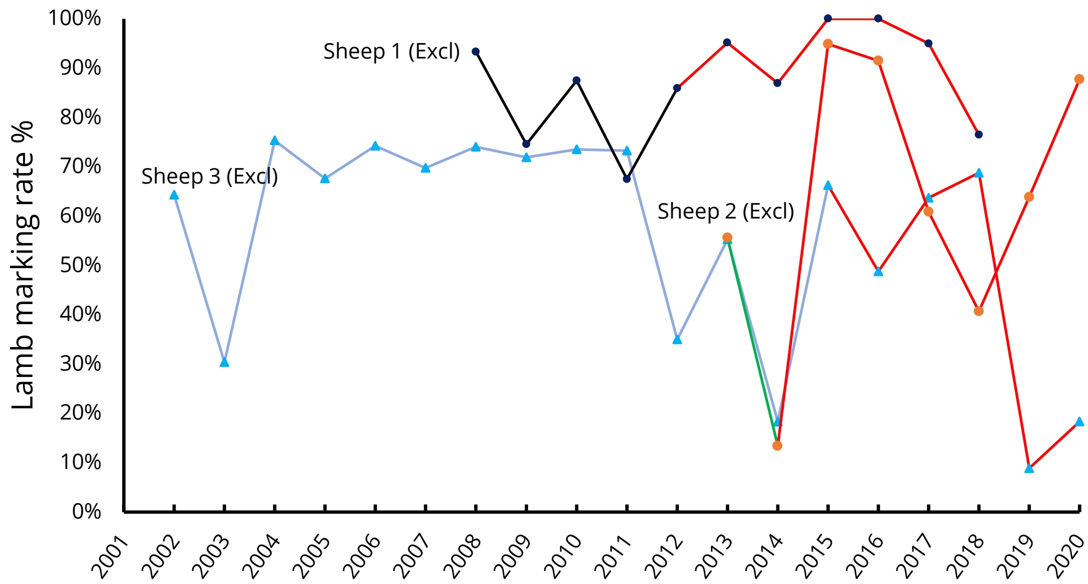


Figure 14. Lamb-marking rates for three sheep properties. Marking rates before exclusion fencing are black, blue and green lines; after exclusion fencing they are red lines.

Ewe-mortality rates, pre-exclusion and post-exclusion fencing for the same three sheep properties are shown in Figure 15. On sheep property 3, mortality rates before and during the first few years of exclusion fencing were less than 10%. The large increase during 2018/19 was due to a burst of cold, wet weather affecting sheep that were weak following drought. Sheep property 2 experienced ewe-mortality rates of 67% in 2013/14, the year preceding exclusion fencing. The owner of this property reported that this was predominantly due to predation by wild dogs. Mortality rates on sheep property

1 after exclusion fencing were similar to those before fencing. As with lamb-marking rates, ewe-mortality rates before and after exclusion fencing were not significantly different (p = 0.084).

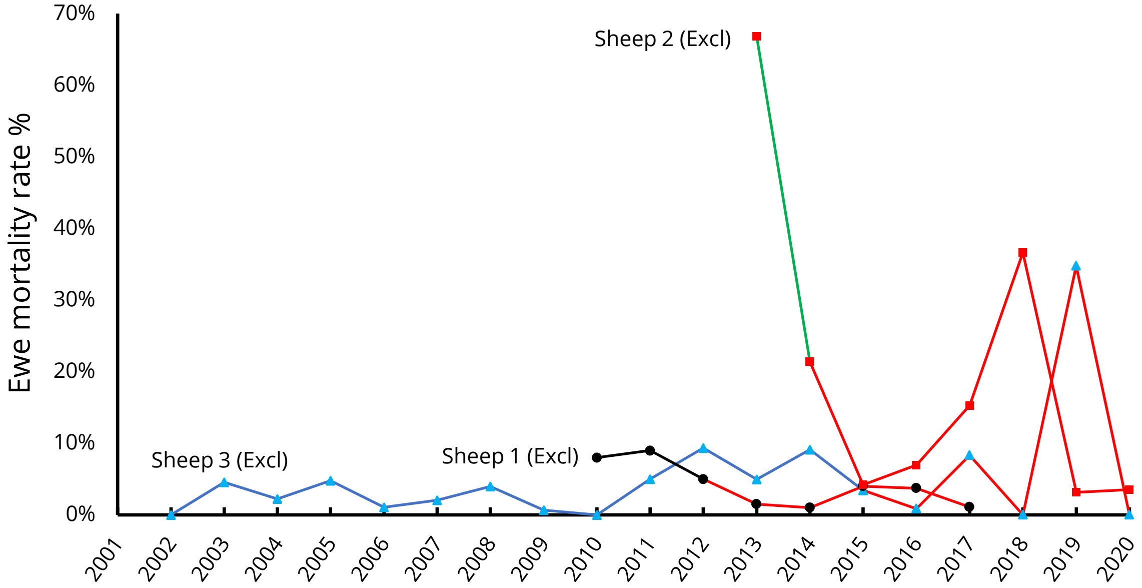


Figure 15. Ewe-mortality rates for three sheep properties. Rates before exclusion fencing are black, blue and green lines; after exclusion fencing they are red lines.

Calf-weaning rates for three cattle properties and for the cattle enterprises on two sheep properties are shown in Figure 16.

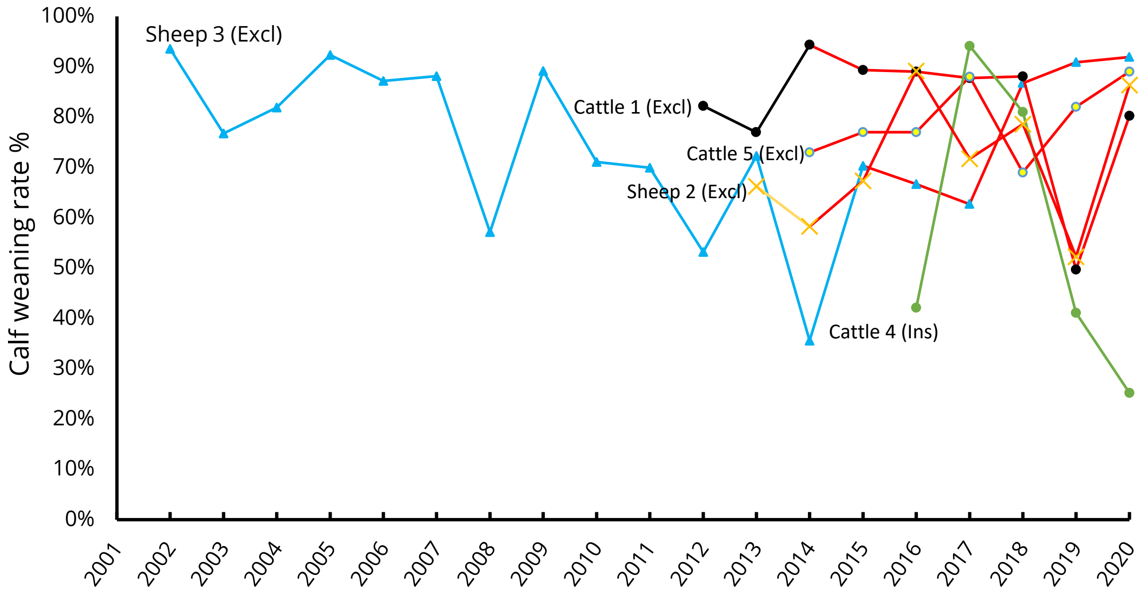


Figure 16. Calf-weaning rates on three cattle properties and two sheep properties. Rates before and without exclusion fencing are black, blue, yellow and green lines; after exclusion fencing they are red lines.

Calf-weaning rates on all properties varied considerably between years, whereas variation between properties was much less. Low calf-weaning rates were mostly due to dry years, although the lowest rates on cattle 4 was due to vibrio infection of cows (by bacteria *Vibrio vulnificus*). No owners reported that wild dogs had killed calves, but two properties reported seeing bite marks on three or four calves in most years. Calf-weaning rates before and after exclusion fencing were also not significantly different (p = 0.111).

Cattle or sheep stocking-rates are also an indicator of livestock productivity. The annual stocking-rates (AE/ha) for the eight cattle properties and two sheep properties are shown in Figure 17. There is considerable variation between properties and between years. For example, stocking rates for cattle property 4 declined sharply from 2016 to 2020 due to a combination of dry weather and vibrio disease in cows. In contrast to this, over a similar period of time, stocking rates increased for cattle properties 2, 3 and 6. These three properties were mainly used to grow out weaners which were either bred on other family properties or were purchased. Stocking rates for properties before and after exclusion fencing (cattle 1; sheep 2 and 3) were not significantly different ($p = 0.648$).

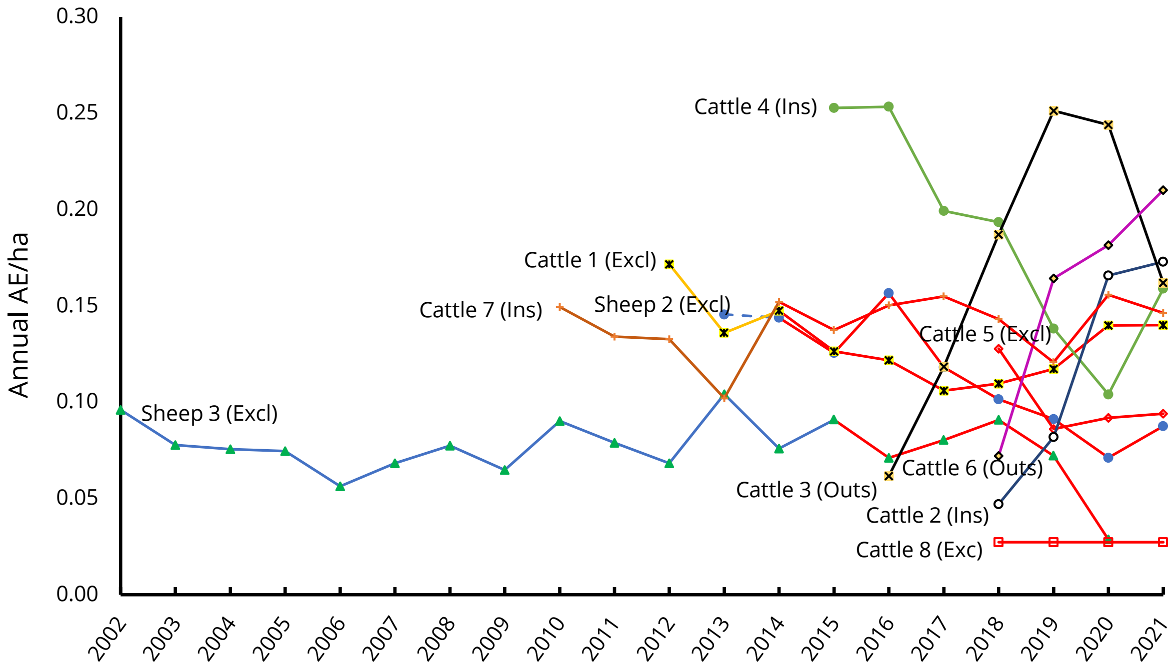


Figure 17. Annual stocking-rates (AE/ha) for eight cattle properties and two sheep properties. Red lines are the years when properties were exclusion-fenced.

To account for differences in the productivity of land types and differences in tree cover between properties, both of which have a large influence on pasture production and livestock productivity, the actual annual AE carried relative to the modelled safe annual AE was compared for eight cattle properties and two sheep properties (Figure 18).

Most noticeable in Figure 18 is the wide variation in the ratio of actual annual AE carried to modelled safe annual AEs between properties, ranging from around 0.4 to 3.6. While variation between years for the same properties was less, it was still considerable. For example, this ratio varied from 1.4 to 3.6 for cattle property 4, and from 1.6 to 3.2 for sheep property 2. Ratios before and after exclusion fencing were available for three properties: sheep 2, sheep 3 and cattle 1. For these properties, annual AE ratios before exclusion fencing were significantly higher than those after exclusion fencing ($p = 0.039$).

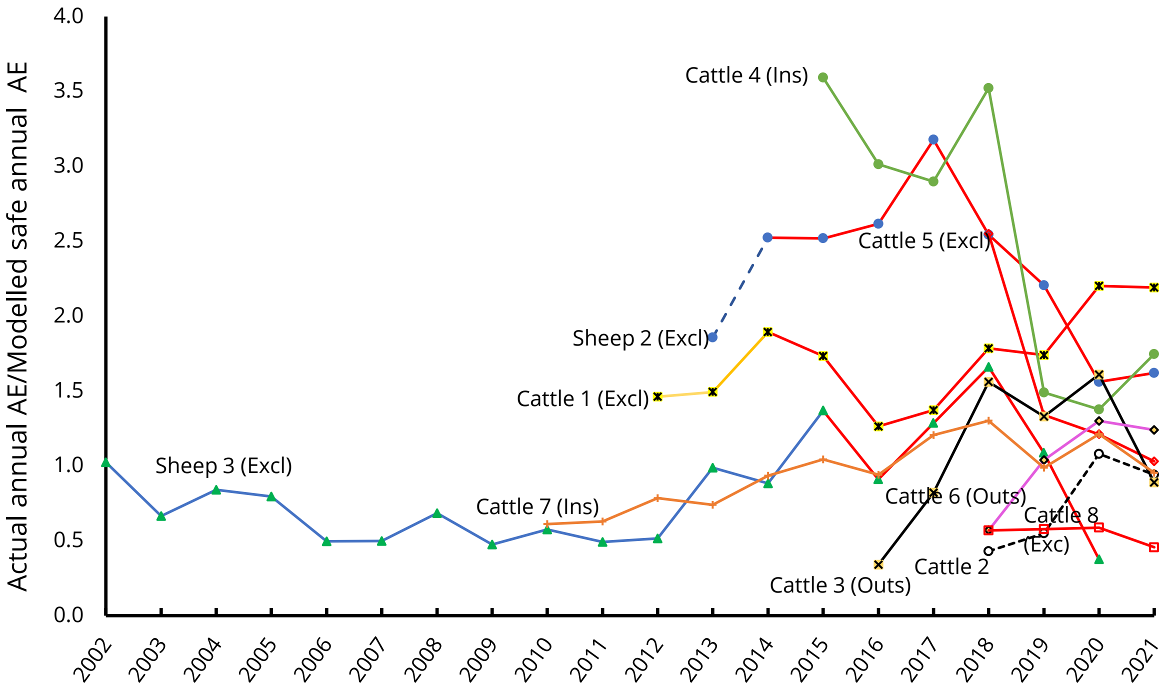


Figure 18. Ratio of actual annual AE carried on properties relative to modelled safe annual AEs provided in FORAGE reports

The average annual stocking-rates for exclusion-fenced and traditionally fenced properties were compared for the period 2015/16 to 2021/22 (Figure 19). The year 2015/16 was the first year when the exclusion fences of all properties had been completed. Stocking rates for properties with exclusion fencing were on average considerably lower than those without exclusion fencing, but they were not significantly different (p = 0.06).

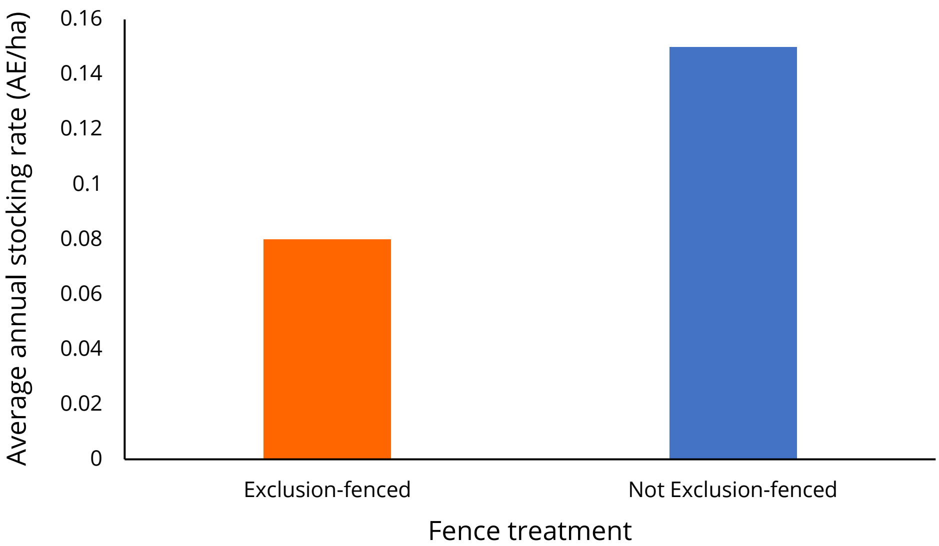


Figure 19. Average annual stocking-rates (AE/ha) for the period 2015/16 to 2021/22 for properties with and without exclusion fencing

The average stocking-rate ratios (actual annual stocking-rated divided by the modelled safe annual stocking-rate) over the period 2015/16 to 2021/22 for exclusion-fenced and traditionally fenced properties were also compared (Figure 20). The average ratio of 1.3 for traditionally fenced properties was similar to that of 1.5 for exclusion-fenced properties (p = 0.99).

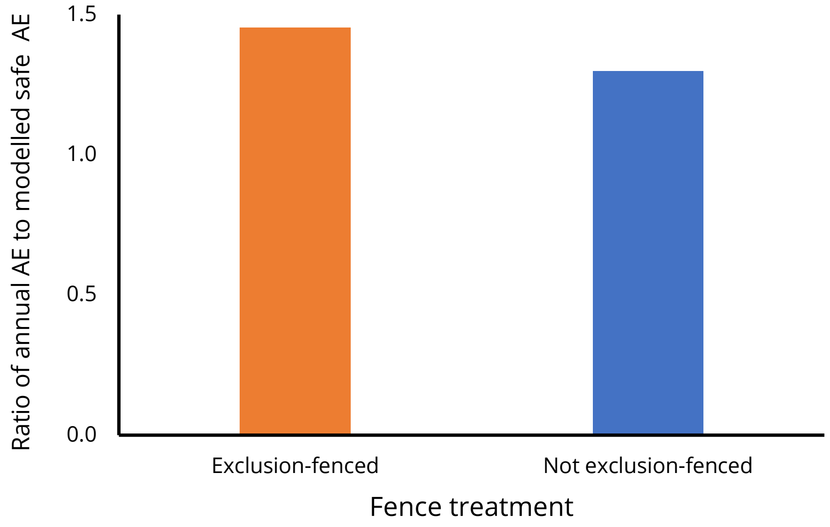


Figure 20. Average stocking-rate ratios for the period 2015/16 to 2021/22 for properties with exclusion fencing and properties without exclusion fencing

TOTAL GRAZING PRESSURE

The results of monitoring pasture biomass and cattle during April–June 2021; and pasture biomass, cattle, macropods, wild dogs and foxes during April–May 2022 are presented below.

PASTURE BIOMASS AND CATTLE IN 2021

Average pasture biomass (kg/ha) for the exclusion-fenced properties was similar to that for traditionally fenced properties (Figure 21), and thus differences were not statistically significant (p = 0.461).

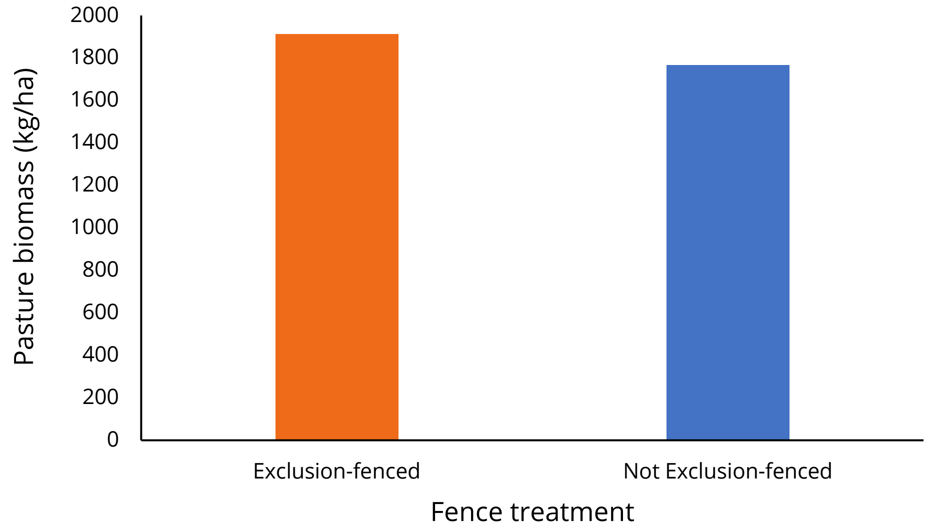


Figure 21. Average pasture biomass for exclusion-fenced and traditionally fenced properties (2021)

Average annual stocking-rates (AE/ha) were lower for exclusion-fenced properties (Figure 22), but again the difference was not statistically significant (p = 0.382).

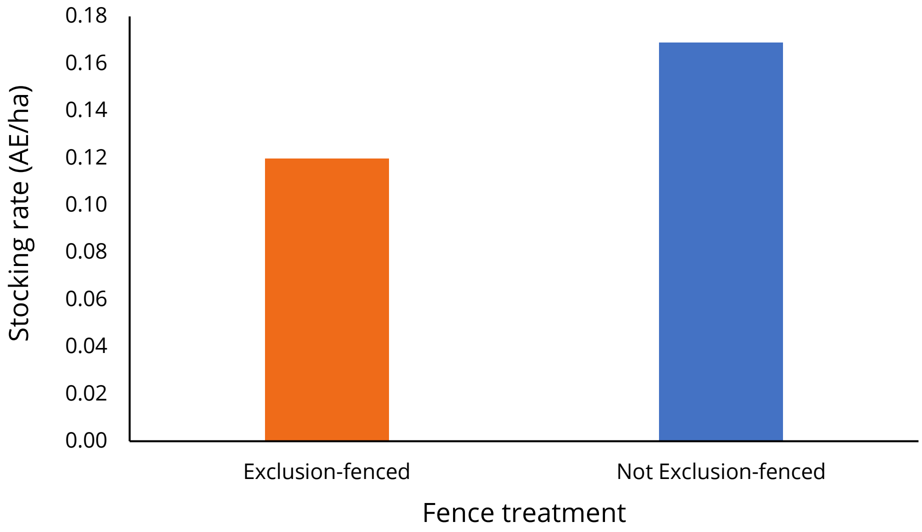


Figure 22. Average stocking-rate (AE/ha) for exclusion-fenced and traditionally fenced properties (2021)

The average kilograms of pasture biomass per AE for exclusion-fenced properties was considerably higher than that for traditionally fenced properties (Figure 23), but the difference was not statistically significant (p = 0.222).

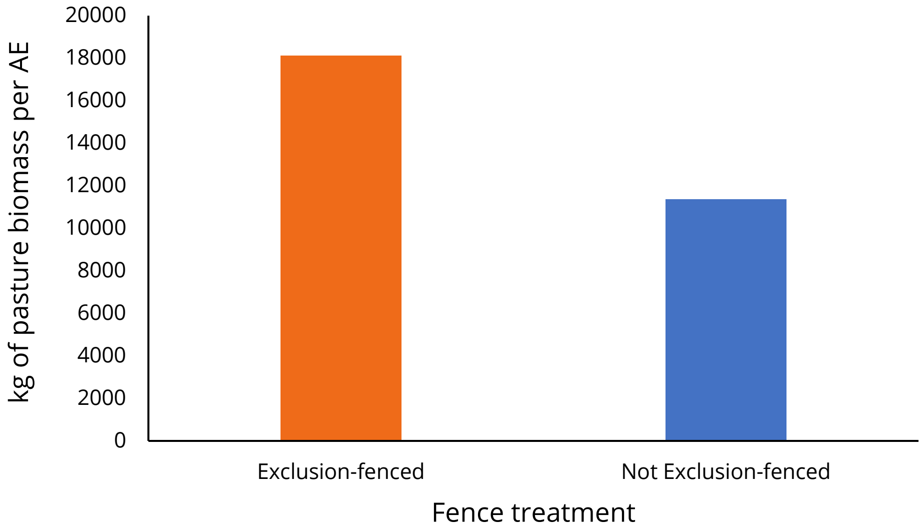


Figure 23. Average kilograms of pasture biomass per AE for exclusion-fenced and traditionally fenced properties (2021)

PASTURE BIOMASS, CATTLE AND MACROPODS IN 2022

Average total pasture biomass (kg/ha) for exclusion-fenced properties was lower than that for traditionally fenced properties (Figure 24), but the difference was not significantly different (p = 0.231). The same trend occurred for grass biomass (kg/ha), while that for forb biomass (kg/ha) was the opposite (data not shown). Given that total pasture biomass (grass and forbs) were lower on exclusion-fenced properties, and that forb biomass was higher, then grass biomass was likely to have been much lower on exclusion-fenced properties.

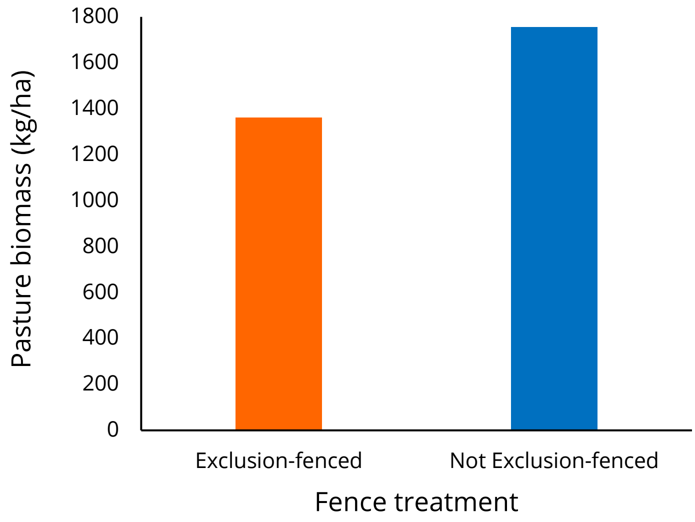


Figure 24. Average total TSDM (kg/ha) for three properties that were exclusion-fenced and five properties that were not exclusion-fenced (2022)

Cattle stocking-rates (AE/ha) for exclusion-fenced properties appeared less than those for traditionally fenced properties (Figure 25), but the difference was not statistically significant (p = 0.09).

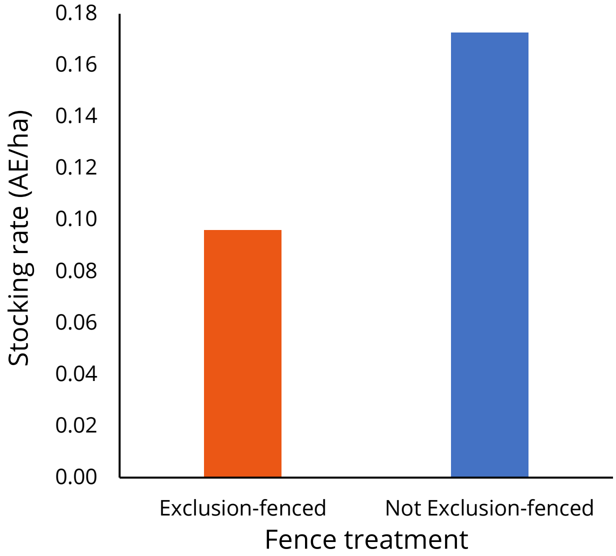


Figure 25. Average cattle stocking-rate (AE/ha) for three properties that were exclusion-fenced and five properties that were not exclusion-fenced (2022)

The kilograms of total pasture biomass available per AE on exclusion-fenced properties seemed higher than that for traditionally fenced properties (Figure 26), but the difference was not statistically significant (p = 0.095).

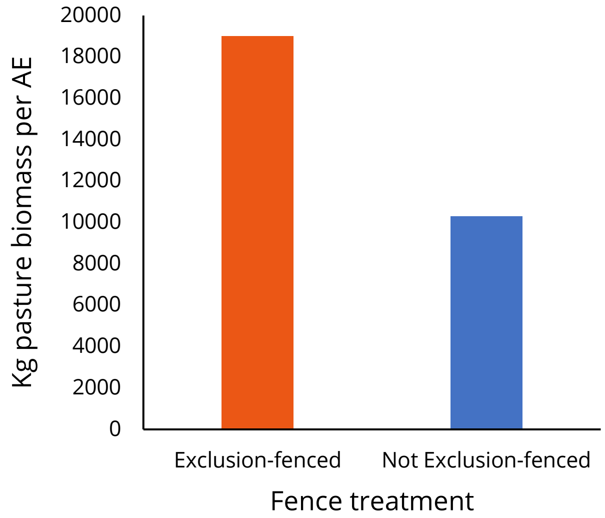


Figure 26. Average total pasture biomass per AE for three properties that were exclusion-fenced and five properties that were not exclusion-fenced (2022)

INDICES OF CATTLE AND MACROPOD ABUNDANCE

In addition to monitoring pasture biomass during autumn 2022, indices of abundance of cattle and macropods were also recorded. For cattle, the number of head (except calves) observed travelling around properties while monitoring transects was the index most strongly correlated (r^2 = 0.94) with the AE of cattle carried during 2021/22 (Figure 27).

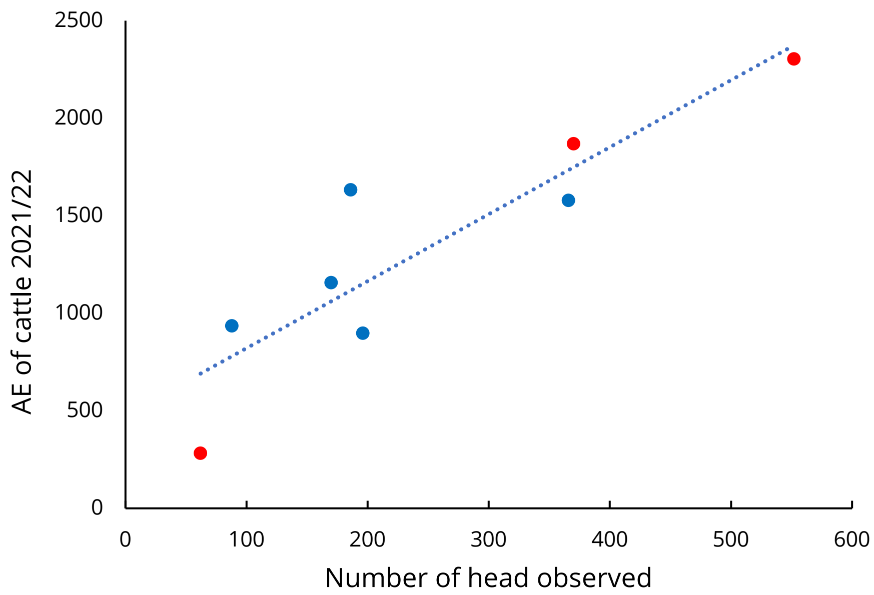


Figure 27. Correlation between AE of cattle carried and number of head observed for three exclusion-fenced properties (red) and five traditionally fenced properties (blue)

The total amount of cattle dung per property (area of the property × kg/ha of dung) was also well correlated (r^2 = 0.93) with the AE of cattle carried during 2021/22 (Figure 28). The number of cattle tracks per property (area of property × tracks/ha) (r^2 = 0.56) and the number of cattle pats per property (area of property × pat/ha) (r^2 = 0.64) were both poorly correlated with the AE of cattle carried during 2021/22. Similarly, the number of cattle pats per ha, amount of dung per ha, and cattle tracks per ha were all poorly correlated (r^2 = 0.51) with AE/ha during 2021/22. Also, the indices of cattle abundance (dung, tracks and number observed per property) were poorly correlated with each other – the highest r^2 of 0.73 was for the correlation between total dung per property and total tracks per property.

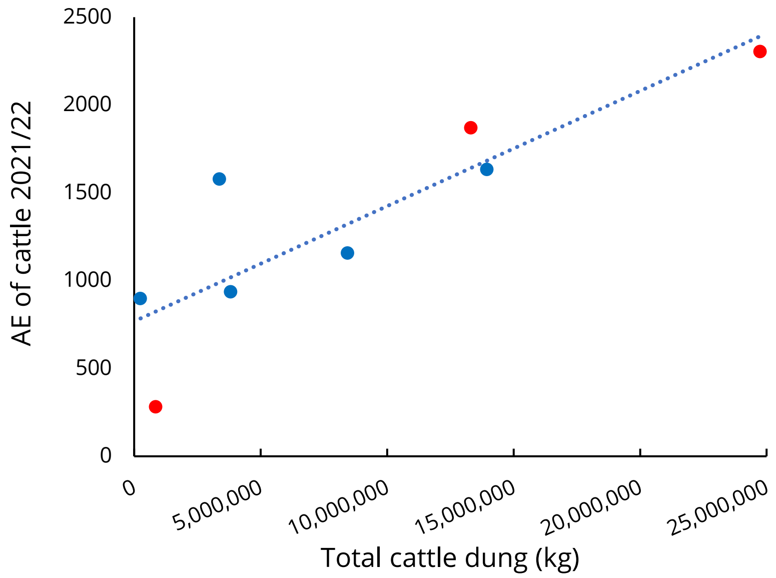


Figure 28. Correlation between AE of cattle carried and total cattle dung for three exclusion-fenced properties (red) and five traditionally fenced properties (blue)

The number of tracks of macropods recorded on properties (area of property × tracks/ha) was closely correlated (r^2 = 0.99) with the total amount of macropod dung present on properties (Figure 29). The amount of macropod dung present on properties (area of property × kg dung/ha) was also closely correlated (r^2 = 0.99) with the number of macropods seen while monitoring transects (data not shown).

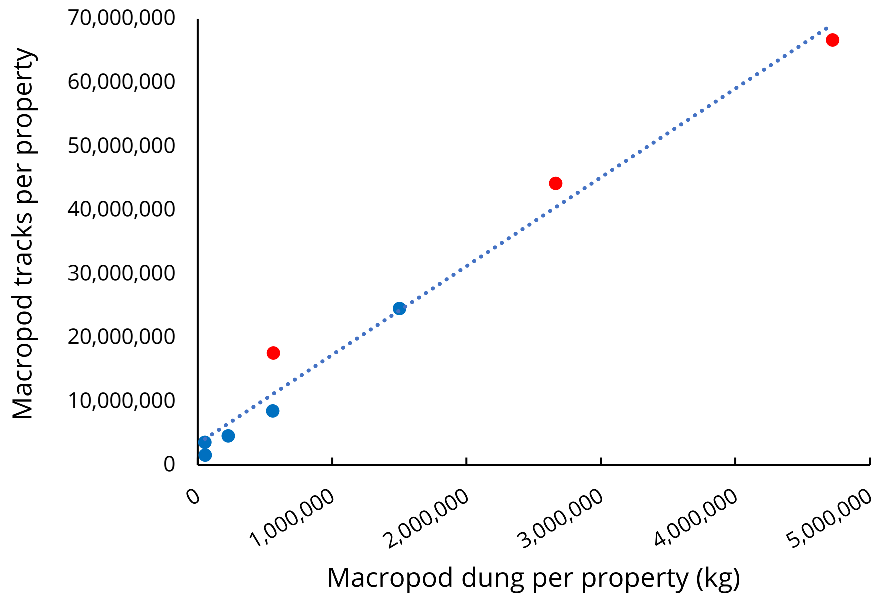


Figure 29. Correlation between tracks of macropods and amount of dung of macropods for three exclusion-fenced properties (red) and five traditionally fenced (blue)

Exclusion-fenced properties appeared to have more macropod dung than traditionally fenced properties (Figure 30) but the difference was not statistically significant (p = 0.206). The same trend occurred for macropod tracks and numbers of macropods observed while monitoring transects on properties (data not shown).

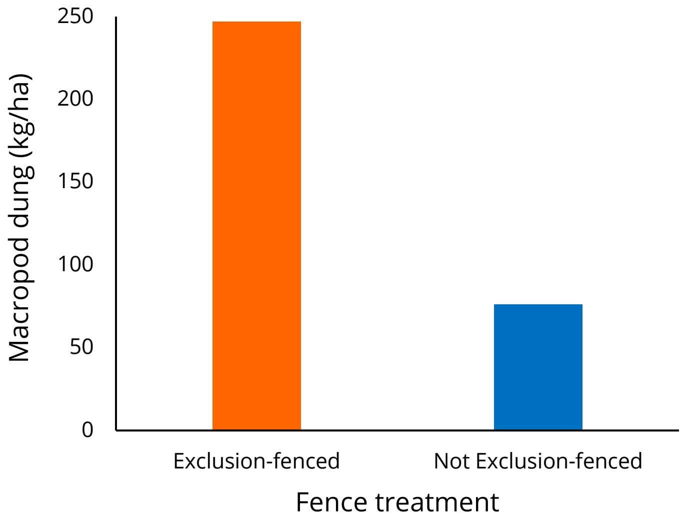


Figure 30. Average amount of macropod dung (kg/ha) for exclusion-fenced and traditionally fenced properties

AERIAL SURVEYS OF MACROPODS

The densities of macropods for each property during April 2021 and May 2022 are presented in Figure 31. Densities varied from zero on cattle property 4 in Aril 2021 to 108 head/km^2 on cattle property 1 during May 2022. Properties with exclusion fencing, such as cattle 1, property C and cattle 8, generally had the highest densities but there were exceptions. For example, cattle property 5, which is also exclusion-fenced, had a relatively low density of macropods and cattle property 3, which is outside the wild dog barrier fence, had densities similar to exclusion-fenced properties in April 2021. The high density recorded on cattle property 1 during May 2022 is partly due to only a small proportion of this property being surveyed at that time: the part of this property surveyed was immediately adjacent to cattle property C, and the high density of this area was applied to the whole property. Also, the lower densities recorded on cattle 3, property D, Chesterton Range National Park and Orkadilla State Forest in May 2022 compared with April 2021 may have also been due to reduced survey effort in May 2022.

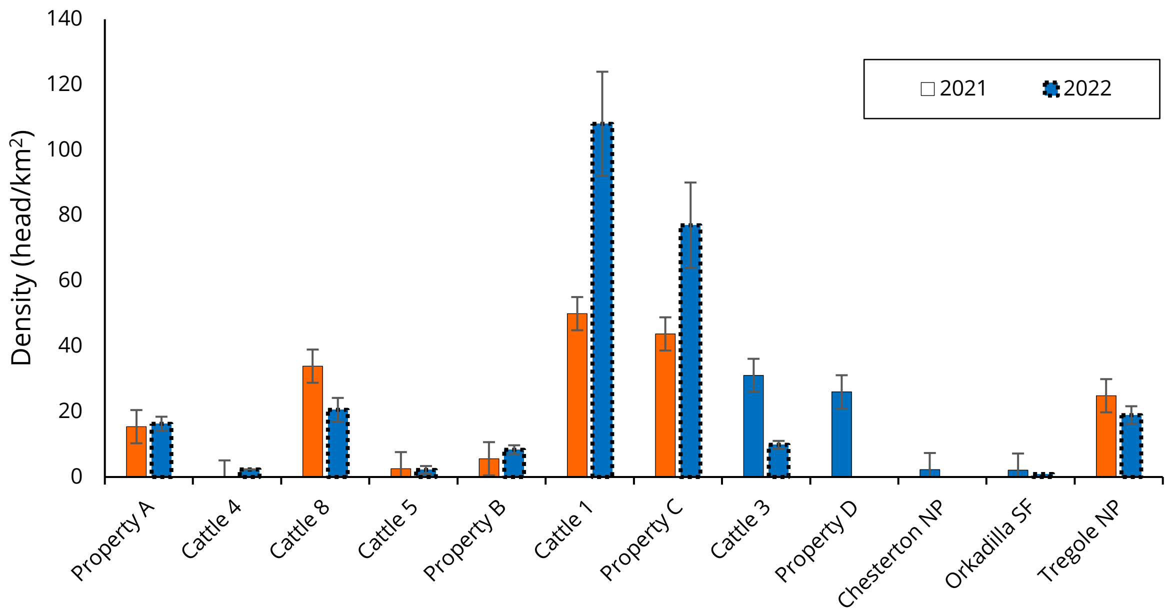


Figure 31. Densities of macropods (head/km^2) on properties inside and outside the Morven cluster in April 2021 and May 2022 (exclusion-fenced = orange; traditionally fenced = blue).

The average density of macropods during 2021 on exclusion-fenced properties was twofold that of traditionally fenced properties, and during 2022, exclusion-fenced properties had threefold higher densities (Figure 32).

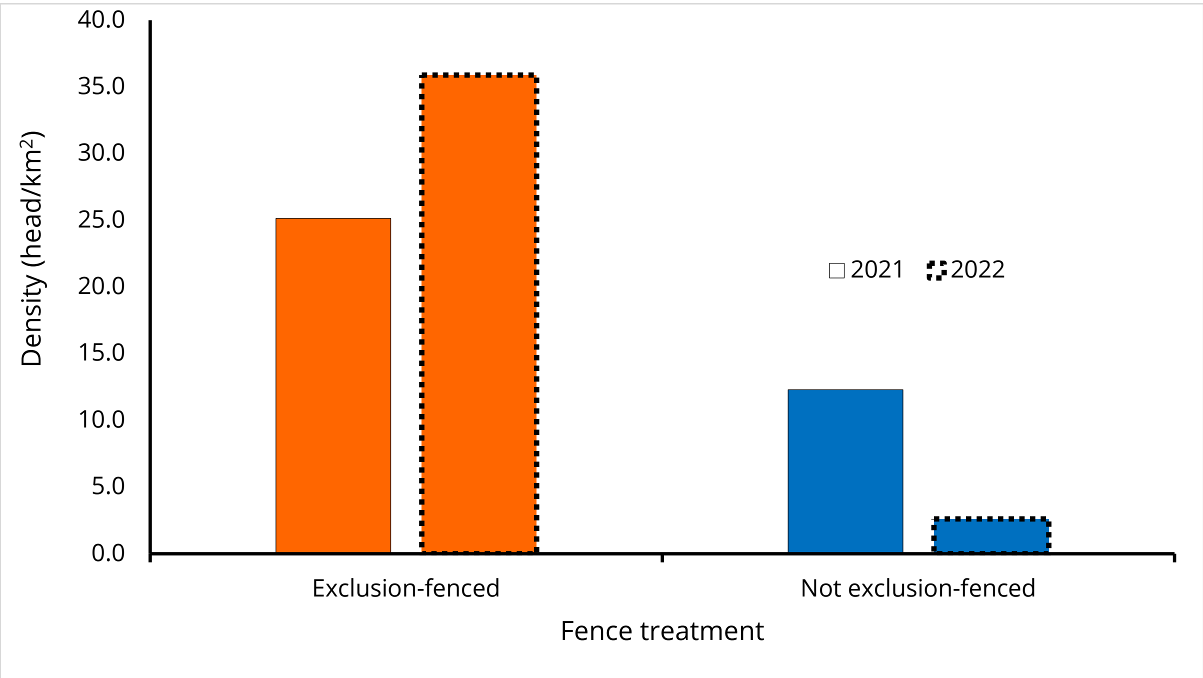


Figure 32. Average densities (head/km2) for macropods during April 2021 and May 2022 inside exclusion-fenced (orange) and traditionally fenced (blue) properties.

However, in 2021, the average macropod density for exclusion-fenced properties was not significantly different to that of traditionally fenced properties ($p = 0.156$). For 2022, the average density of macropods on exclusion-fenced properties was significantly higher than that for traditionally fenced properties ($p = 0.007$). When the macropod densities for both years were combined, the density for exclusion-fenced properties was again significantly higher than that for traditionally fenced properties (*p* = 0.023).

The correlation between macropod densities (head/km^2) and the amounts of macropod dung (kg/ha) recorded on cattle properties 1, 3, 4, 5 and 8 during May 2022 was very poor (r^2 = 0.03), as was the correlation (r^2 = 0.06) between densities and number of macropods observed during pasture monitoring. The correlation was improved (r^2 = 0.46), although still poor, when densities recorded during April 2021 were compared with amounts of macropod dung recorded in May 2022.

WILD DOGS AND FOXES

The average number of wild dogs leaving paw marks on exclusion-fenced properties was significantly fewer than numbers on traditionally fenced properties (*p* = 0.045) (Figure 33). Fox tracks were only observed on two exclusion-fenced properties where tracks and observations were common.

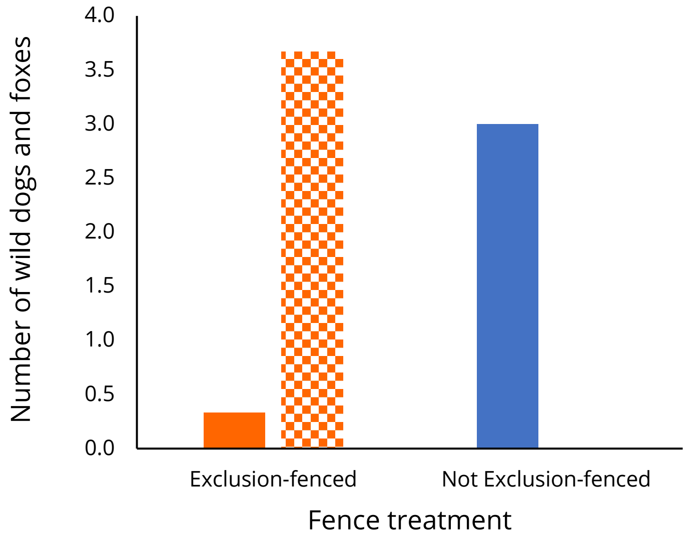


Figure 33. Average numbers of wild dogs (solid fill) and foxes (patterned) leaving paw marks on exclusion-fenced properties (orange) and on traditionally fenced properties (blue)

Numbers of wild dogs leaving paw marks on properties was poorly correlated with numbers of foxes (r^2 = 0.48), numbers of macropods observed while monitoring pastures and dung (r^2 = 0.37), and the total AE of cattle present (r^2 = 0.43).

DISCUSSION

Exclusion fencing in southern and western Queensland is being used as a tool by livestock producers to help them limit losses in livestock productivity due to wild dogs and macropods. The results of this study are consistent with those of previous studies that concluded that production of small ruminants such as sheep and goats is not viable in the presence of uncontrolled wild dog populations (Thomson 1984; Allen and West 2013). However, the impact of wild dogs on beef-cattle enterprises is less clear, as losses due to predation of calves can be offset by gains in carrying capacity arising from wild dog suppression of macropod population density.

INDICES OF MACROPOD AND CATTLE ABUNDANCE

An understanding of the impact of macropod grazing on the productivity of beef cattle requires knowledge of the densities and size of macropods and how much pasture they consume:

- macropod densities and the age and size class structures of populations on cattle properties are rarely known
- densities vary within and across paddocks due to differences in tree cover
- densities on properties can vary over a period of a few months with changes in local pasture conditions.

Cattle densities and age and size classes are generally available from property owners, but their grazing pressure is also unevenly spread across paddocks.

This study was interested in the grazing pressure of macropods, calculated as the ratio of the amount of pasture consumed to the amount of pasture available; hence indices of abundance should also be indices of grazing pressure. Preferred indices will be those that measure grazing pressure over a period of a year, which aligns with the time period for metrics of cattle productivity such as weaning rates, mortality rates and stocking rates.

High correlations between macropod dung, tracks and numbers observed on the eight cattle properties during April and May 2022 suggests these were robust indices of macropod abundance. However, on five of these eight cattle properties for which densities from aerial surveys were also available, these indices of abundance were not correlated with the densities of macropods. While the amount of macropod dung during April and May 2022 and densities during May 2022 of macropods were recorded at much the same time, most of the dung observed was several months to possibly one year old. Therefore, the density of macropods over the period of dung accumulation could have been different to that during May 2022. Correlations between the density of dung and density of macropods might be improved if the amount of fresh dung (kg/ha) was compared with density.

Even so, the density of all the dung present correlated highly with fresh tracks and numbers of macropods observed when undertaking the pasture monitoring. Fresh tracks are only days to weeks old, and the numbers observed were for a single day; hence the time period for these was very similar to that of the aerial surveys. However, fresh tracks and numbers of macropods observed did not correlate with the densities of macropods recorded during aerial surveys. The aerial-survey effort during 2022 was limited by wet weather, and only parts of some properties were surveyed. It is therefore likely that density calculations were more accurate for parts of properties rather than whole properties. In comparison, dung and track monitoring occurred across entire properties.

Several indices of macropod abundance were used in this study. The amount of macropod dung present at the same sites where pasture biomass and cattle grazing were monitored is likely to provide the most accurate estimate of the contribution of macropods to total grazing pressure on cattle properties. The amount of dung excreted by macropods is correlated with the time they spend grazing (Connelly and Pahl 1999), and as dung persists for several months to perhaps a year, the amount of dung present is likely to be related to annual changes in pasture biomass and cattle productivity. In comparison, numbers of tracks and individuals observed were not recorded where pasture biomass was assessed, and they represent macropod abundance for much shorter periods of time than does dung accumulation.

Indices of cattle abundance, such as number of pats, kg dung/ha, tracks and numbers counted were poorly correlated with each other, suggesting they were less robust than the same indices recorded for macropods. However, two indices of cattle abundance were well correlated with the AE of cattle carried on properties during 2021/22. The number of head (except calves) observed travelling around properties while monitoring pasture was the index most strongly correlated (r^2 = 0.80) with the AE of cattle carried during 2021/22.

However, this index of cattle abundance is probably unreliable given that its ability to predict the total AE carried each year will depend on the timing of the count. Several properties monitored during this study were used for growing out weaners, either bred on other family properties and/or purchased from elsewhere. The number of head present on these properties can fluctuate markedly from month to month, particularly for businesses that regularly buy and sell young cattle each year. Therefore, the number of head counted at any one time may be very different to the total AE carried for the year. Similarly, including weaners in counts of head observed on breeding properties is likely to decrease the reliability of this index of abundance, as they are only present on breeding properties for a short period of time, especially on properties that practise controlled mating. In comparison, on breeding properties the number of cows present is much more stable over time and is therefore likely to be a better index of the AE carried annually.

The amount of cattle dung recorded in 1-m^2 quadrats was also well correlated with the AE of cattle carried annually. The total kg of dung per property (area of the property × kg/ha of dung) was correlated (r^2 = 0.74) with the AE of cattle carried during 2021/22. The ability of this index to predict the number of cattle is likely to be improved by increasing the sampling effort (number of 1-m^2 quadrats used) at each pasture-monitoring site.

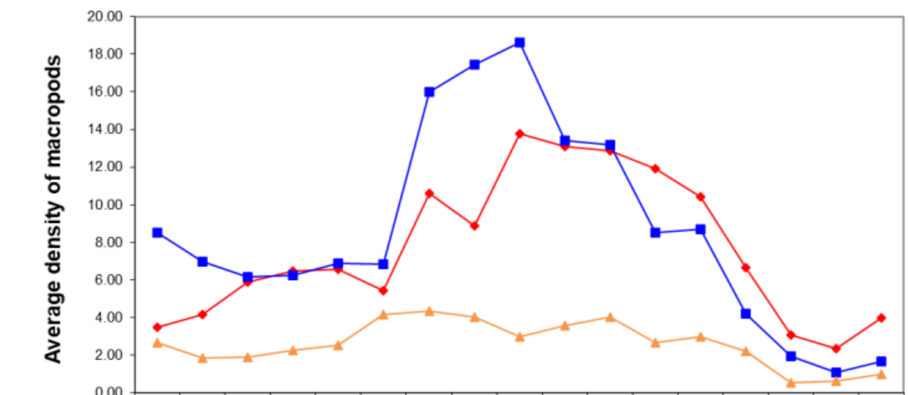
The number of cattle pats recorded at pasture-monitoring sites did not correlate with the AE carried annually. Fresh cattle pats vary greatly in size and weight, and their size and weight decrease over time as they degrade. This is particularly the case during summer wet seasons when dung beetles are active. The ability of this index to predict AE of cattle carried each year could be improved by using photo standards to estimate the weight of each cattle pat encountered at pasture-monitoring sites, in much the same way as the amount of dung in quadrats was recorded. This could be an alternative to recording the weight of cattle dung present in each 1-m^2 quadrat.

Fresh cattle tracks did not correlate with the AE of cattle carried annually. It was often difficult to count the number of cattle that had left fresh tracks on roads at monitoring sites, as these roads were commonly used by mobs of cattle. It was not unusual for dozens of overlapping individual cattle hoof prints to be seen at a monitoring site, making it impossible to count the number of cattle which had made these hoof prints. Additionally, the reliability of fresh cattle tracks as an index of cattle AE carried annually is likely to suffer for the same reasons as counts of head observed while monitoring pastures.

MACROPODS AND CATTLE PRODUCTIVITY

Losses in livestock productivity can potentially occur when macropod densities are high (Wilson 1991). Some sheep and cattle producers in the Morven and Augathella districts contacted during this study believed their properties were carrying up to one macropod per acre (247 macropods/km^2) in 2012. While these densities are very high, they have been reported elsewhere. For example, Lauder (2019) reported that 13,000 kangaroos were removed over a period of three years from a 15,000-acre (approximately 6,070 ha) exclusion-fenced property near Cunnamulla. Similarly, Arthur (2015) spoke with livestock producers near Barcaldine and Yaraka who believed that some properties had one macropod per acre. This coincided with a peak in macropod population densities in South West Queensland during the years 2012 and 2013, with regional average densities reaching 30 and 35/km^2 respectively (Figure 34). Since then, densities have steadily declined, reaching a low of just 4/km^2 in 2020. This corresponds with an eightfold reduction in macropod population size over a period of seven years.

Macropod densities in and adjoining the Morven and Tambo clusters during the period of time covered by this study were historically low, averaging only 7/km^2 in 2021 (Figure 34). Even so, an aerial survey of properties within the Morven cluster at the same time by the same Department of Environment and Science, Queensland staff recorded densities of up to 50/km^2. Generally, macropod densities on exclusion-fenced properties were two to three times those of traditionally fenced properties. This higher density of macropods on exclusion-fenced properties observed in this study is consistent with Castle et al. (2022) who found that properties inside the Morven and Tambo exclusion-fenced clusters had more macropods than adjacent properties outside these clusters.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Red	3.48	4.14	5.88	6.47	6.58	5.44	10.61	8.87	13.77	13.10	12.89	11.91	10.41	6.64	3.09	2.36	3.97
E. grey	8.50	6.96	6.18	6.23	6.88	6.83	15.98	17.45	18.62	13.40	13.18	8.51	8.71	4.22	1.93	1.06	1.66
C. Wallaroos	2.68	1.83	1.88	2.27	2.54	4.17	4.35	4.02	2.99	3.55	4.01	2.68	2.98	2.22	0.53	0.63	0.99

Figure 34. Average annual densities (head/km^2) of commercially harvested macropods in the central southern region of Queensland. Source: Department of Environment and Science Queensland 2021

Based on average amounts of macropod dung present (kg/ha), exclusion-fenced properties had 2.7-fold more macropod grazing pressure than traditionally fenced properties. Similarly, based on macropod densities calculated from aerial surveys, exclusion-fenced properties had two to three times more macropods than traditionally fenced properties. Given that many of the years since properties in this study were exclusion-fenced have been dry or droughts, it is likely that their higher macropod densities are due to better quality habitat (more productive land types and pastures combined with patches of trees) rather than less wild dog predation. It is likely that macropod populations on these properties will continue to flourish now that recent years have received well-above-average rainfall and that very few wild dogs are present.

The same exclusion-fenced properties tended to have lower pasture biomass (kg/ha) and lower cattle stocking-rates (AE/ha) than traditionally fenced properties, although differences were not statistically significant. While exclusion-fenced properties in this study generally had higher macropod grazing pressure, less pasture and lower cattle stocking-rates compared with traditionally fenced properties, the former may not have caused the latter. This is because the average pasture biomass per AE on exclusion-fenced properties during 2021 and 2022 was substantially higher than that on traditionally fenced properties. However, historically high pasture biomass was recorded on all properties during these years, and pasture biomass appeared well in excess of forage demand by both livestock and macropods – even on properties with the highest density of macropods.

Hence, it is possible that livestock producers who have high densities of macropods allocate more pasture per AE when pasture biomass is at a peak during favourable seasons to accommodate the consumption of pasture by macropods in subsequent dry seasons. Or, exclusion-fenced properties are conservatively stocking to maintain or improve land condition with subsequent environmental and productivity benefits. A better understanding of the outcomes of interactions between pastures, cattle and macropods would require longer term monitoring as pasture biomass declines during dry years.

WILD DOGS, FOXES AND LIVESTOCK PRODUCTIVITY

Large numbers of properties in South West Queensland converted from merino sheep to beef cattle during the late 1990s through to around 2010 due to a global decline in demand for and prices of raw wool. Beef producers are less concerned with wild dogs, thus efforts to control wild dogs decreased, and numbers and impacts of wild dogs increased. For example, during the years 2014 and 2015, a total of 324 wild dog adults and 78 wild dog pups were culled by a professional wild-dog control contractor operating in the Morven cluster. At the same time, an unknown number of wild dogs were culled by owners of individual properties within this cluster. Just before exclusion fencing of the Morven cluster, one sheep producer reported that wild dog attacks were primarily responsible for ewe-mortality rates of up to 67% and lamb-marking rates as low as 13%. The productivity, financial and emotional impacts of these lamb and sheep losses in 2014/15 were enormous. Losses such as these were making the few remaining merino sheep enterprises in the Morven area unviable.

While there has been little expansion in numbers of merino sheep enterprises following exclusion fencing and major reductions in numbers of wild dogs, dorper sheep and goat enterprises are now common in southern and western Queensland. This was made possible by exclusion fencing and associated intensive wild dog control, but it was primarily driven by very high prices for lamb and goat meat. Given that beef cattle is by far the most common enterprise type in these regions and that cattle producers have allowed wild dog populations to expand, the continuation of sheep and goat production appears reliant on the establishment and maintenance of exclusion fencing combined with intensive wild dog control. This is consistent with lower wild dog activity recorded inside exclusion-fenced properties during this study, as well as the findings of Castle et al. (2022), who also reported lower levels of wild dog activity on properties within the Morven and Tambo clusters compared with adjacent properties outside of these clusters.

During the current study, foxes were only recorded on two exclusion-fenced properties within the Morven cluster, where they appeared to be common on those two properties. This contrasts with Castle et al. (2022) who did not observe differences in fox numbers between exclusion-fenced and traditionally fenced properties. However, as was the case for macropods, densities of wild dogs and foxes appear to vary substantially between properties within the Morven cluster, and consequently the properties surveyed will have a bearing on levels of activity observed. The high levels of fox activity observed on the two exclusion-fenced properties in the Morven cluster is of concern for nearby sheep and goat enterprises, as foxes can take up to 30% of lambs on particular properties at particular times (Saunders et al. 2010).

The range in annual calf-weaning rates before exclusion fencing was not different to the range after exclusion fencing. In contrast to the sheep enterprises, years with low calf-weaning rates were all due to low rainfall, sales of pregnant cows and reproductive disease. While cattle producers reported occasional bite marks on calves at branding or weaning, they believed very few calves had been lost because of wild dog attacks. This is consistent with Edwards et al. (2021) who reported that cattle producers estimated annual calf losses due to wild dog predation to be between one per cent and seven per cent (Eldridge and Bryan 1995; Hewitt 2009; McGowan et al. 2014; Binks et al. 2015). However, annual calf losses due to wild dog attacks of 15–33% (Allen and Fleming 2004; Fleming et al. 2012; Fleming et al. 2014) can occur during drought when the availability of alternative prey is scarce (Allen 2010).

It appears that calf losses of this magnitude also occur on some cattle properties in some years in the Morven district. The owners of two cattle properties adjoining Chesterton Range National Park both reported large losses of calves during droughts when cows were weak and less able to defend their calves. In these years, they observed over 100 calves with bite marks on them and corresponding weaning rates of around 50%. However, a large contributor to this low weaning rate would have been poor-condition cows that were also unable to produce sufficient milk for their calves.

TRADE-OFF OF WILD DOG AND MACROPOD IMPACTS ON CATTLE PRODUCTIVITY

Wicks and Allen (2012) and Allen (2015) concluded that occasional predation of calves by wild dogs was generally less costly for beef producers than ongoing macropod competition with cattle. These authors claimed this occurred when increased competition from macropods, freed from top-predator suppression, eroded the accrued economic benefits from a reduction in livestock predation. This is more likely to occur as both macropod densities and cattle prices rise.

Here, we use cattle property 8 as a case study to compare potential calf losses due to predation by wild dogs with calf losses associated with a decline in property carrying capacity due to macropod grazing. The size of this property is 11,007 ha or 110 km^2. The long-term annual safe carrying capacity of this property is 786 AE (The Long Paddock 2022). The owner of this breeding property estimated that the average annual calf-weaning rate was 75%. As such, each cow is equivalent to 1.47 AE (Bush Agribusiness 2020). With an annual safe carrying capacity of 786 AE, the herd would consist of 535 cows producing 401 calves.

A 50-kg macropod that is not reproductively active is rated as 1 DSE (Pahl 2020a). Assuming that the average size of a macropod on cattle property 8 is 25 kg, then macropods per head are rated as 0.5 DSE or 0.0625 AE. Given that a high proportion of the macropod population consists of growing and reproductively active animals, the AE rating of 0.0625 has been multiplied by 1.2 to give an AE rating of 0.075 per macropod present.

In this case study of cattle property 8 and its breeding herd described above, the potential numbers of calves lost annually due to several different wild dog predation rates and a range of macropod population densities are shown in Table 3. The number of cows that can be carried by this property decreases with increased macropod grazing pressure, at the rate of 0.075 AE per macropod present on the property. However, the number of calves lost each year is less than the number of cows reduced, as only 75% of cows wean a calf. At macropod densities of around 2.5 head/km^2, which is the current density of macropods outside the wild dog barrier fence where wild dogs were common, 14 cows and 11 weaners (three per cent) would be lost due to reduced carrying capacity. With the current price for weaners of $1,100, the lost annual income when the density of macropods is 2.5 head/km^2 is approximately $12,100.

If macropod densities were 50 head/km^2, which is the case for some exclusion-fenced properties in the Morven cluster, the annual loss in production would be 281 cows and 210 weaners (52% of calves). In this scenario, the lost annual income would be approximately $231,000. The decline in herd size by 281 cows carried when the macropod population density was 50 head/km^2 is consistent with the current size of the herd present on cattle property 8. This property has carried 250 cows with calves over the past several years, which is 285 cows less than the number expected if this property had a cow herd consistent with its simulated long-term safe carrying capacity.

While the reduction in numbers of cows and calves carried on the property is likely to be linearly related to macropod population density, annual losses of calves due to attack by wild dogs does not appear to be linearly related to baiting effort or the density of wild dogs (Smith and Appleby 2018; Campbell et al. 2019; Edwards et al. 2021). This occurs because the number of calves lost is also influenced by the amount of alternative prey available to wild dogs and the social structure of wild-dog packs. However, in an extreme case, where 35% of calves on cattle property 8 were lost due to wild dog predation, 140 fewer weaners would be sold each year (Table 3). At $1,100 per weaner, the total lost annual income would be approximately $154,000.

Table 3. The number of calves lost annually due to wild dog predation rates of between zero and 35%, and the number of calves lost annually from reduced carrying capacity due to macropod populations of densities between zero and 50 head/km²

Wild dog impact		Macropod impact				
Calf predation rate (%)	Calves lost (head)	Macropod density (head/km²)	Macropod number (head)	Cows reduced (head)	Calves reduced (head)	Calves reduced (%)
0	0	0.0	0	0	0	0
3	12	2.5	275	14	11	3
7	28	7.0	770	39	29	7
15	60	10.0	1,100	56	42	10
20	80	20.0	2,200	112	84	21
30	120	30.0	3,300	168	126	31
35	140	50.0	5,500	281	210	52

In this case study based on cattle property 8, a 35% rate of calf loss from wild dogs is still considerably less than the 52% reduction in calves due to grazing by a macropod population with a density of 50 head/km². As well, the lost annual income of $154,000 due to wild dogs is $77,000 less (67%) than the $231,000 lost through macropod grazing. The 35% predation rate of calves appears to be a worst-case scenario that is unlikely to occur every year. If annual calf loss due to wild dog predation averaged seven per cent, which is at the high end of beef-producer estimates reported by Edwards et al. (2021), then 28 weaners would be lost, at a cost of $30,800 annually. The number of weaners and amount of income lost due to a seven per cent calf predation rate is almost the same as that lost with a macropod density of seven head/km² (Table 3). A density of seven macropods/km² is low, as many properties currently have much higher densities than this, and these densities are increasing now that seasonal conditions have improved.

While the results of this simplistic case study favour tolerance of wild dogs that in turn suppress macropod populations, it is possible that the impacts of wild dogs have been underestimated. First, this comparison does not take into account the potentially significant losses in livestock productivity due to diseases introduced by wild dogs (Hewitt 2009). Furthermore, there are circumstances in which uncontrolled wild dogs may kill large numbers of calves, such as during a combination of drought, high cattle grazing pressure and low native-prey abundance (Choquenot and Forsyth 2013; Prowse et al. 2015). This may have been the case for two beef-cattle breeding properties outside the wild dog barrier fence and adjacent to Chesterton Range National Park. The owners believed that abundant wild dogs have been the main cause of frequent, high calf losses. These could be extreme cases that are not representative of beef-cattle breeding properties in the region, or they may be examples of what can occur when wild dogs are common during droughts when cows are weak and alternative prey is scarce. These and other similarly located properties would need to be monitored over time to gauge the results of the trade-off between wild dogs and macropods.

CONCLUSIONS

Lamb-marking, ewe-mortality, calf-weaning and stocking rates on properties before exclusion fencing did not differ to those rates after these properties were exclusion-fenced. While there were individual years when ewe-mortality rate was very high and lamb-marking rate was very low, both due to wild dog attacks, these impacts were masked by high annual variability in rates due to high climate variability and extreme weather events.

While there was little evidence of severe wild-dog impact on livestock productivity during this study, it appears that sheep and goat production is not compatible with even a few wild dogs. Given that wild dogs are now common inside the wild dog barrier fence and that this is unlikely to change in the future, the viability of these small-ruminant enterprises requires that properties are exclusion-fenced and subject to ongoing wild-dog and fox culling programs.

No beef producers reported losses of calves due to wild dogs during this study, and there were very few calves observed with bite marks. Overall, there was no evidence of wild dogs or macropods causing a decline in cattle productivity, either for exclusion-fenced or traditionally fenced properties. This is likely due to this study being conducted over a period of time of plentiful rainfall, historically high pasture biomass, historically low densities of macropods, and possibly the readily available supply of native small-animal prey for wild dogs.

However, compared with traditionally fenced properties, exclusion-fenced properties tended to have lower cattle stocking-rates, higher macropod densities and fewer wild dogs. Given these conditions, it is likely that differences in the impacts of wild dogs and macropods on livestock productivity will emerge in the future as drier seasons invariably return.

It seems likely that high-density macropod populations can substantially reduce the carrying capacity of properties for livestock. Exclusion fences will prevent immigration of macropods during dry years, but in the absence of wild dogs, densities of macropods inside exclusion fencing will increase quickly during favourable seasons. To avoid this and associated high grazing pressure, macropods would need to be subjected to an ongoing control program that keeps them at low densities. It is not clear how this could be implemented given that the Queensland Department of Environment and Science requires demonstration that they are causing or may cause damage to pastures before issuing damage mitigation permits (Department of Environment and Science Queensland 2022) for culling macropods.

Additionally, the culling of commercially harvested macropods (eastern grey kangaroos, red kangaroos and wallaroos) under a damage mitigation permit is limited by a statutory annual quota of two per cent of the estimated population size established under the commercial harvest scheme, and in any given year this two per cent quota is proportionately distributed among landholders across the regions and throughout the calendar year (Department of Environment and Science Queensland 2022). Macropods are unlikely to cause visible pasture impacts when they are at low densities, and damage mitigation permits may not be issued when regional densities are low and commercial harvest quotas are either low or zero.

The production of beef cattle, including breeding enterprises, is generally viable in the presence of wild dogs, and may even benefit from wild-dog suppression of competitive macropod populations. As such, the financial justification for exclusion fencing of beef-cattle enterprises is much weaker than that for small ruminants. However, it is not clear if the density of wild dogs required to keep macropod population densities low is compatible with beef-cattle breeding. For example, only a few years in a decade with 35% calf-predation rates would make cattle-breeding enterprises unviable. The temporal and spatial occurrence of such high calf-loss events are not known, and it is not clear if incidences of this are unrelated to, decreased by or increased by wild-dog culling programs. A better understanding of the incidence, magnitude and circumstances of calf loss due to wild dogs and how these are influenced by wild-dog culling programs is needed before conclusions can be drawn about the value of exclusion fencing for beef-cattle enterprises.

ACKNOWLEDGMENTS

First and foremost, thank you very much to the families who own the sheep and cattle properties investigated during this study. Their generosity in providing access to their properties, willingness to supply livestock records and their interest in this research made this a successful and enjoyable study.

It was also rewarding working with the diverse project team led by Malcolm Kennedy. They brought a large amount of knowledge and skills to the project. This study was made possible by funding from the Centre for Invasive Species Solutions and the Department of Agriculture and Fisheries, Queensland.

Angela Anderson, senior scientist (biometry) with the Department of Agriculture and Fisheries, undertook the large and difficult task of statistical analyses.

Greatly appreciated was the accommodation on Chesterton Range National Park provided by the Department of Environment and Science, Queensland. Also greatly appreciated was the collaboration with Glenn Wallace and Neal Finch of the Macropod Management Program of Queensland Parks and Wildlife Service & Partnerships, Department of Environment and Science. They undertook aerial surveys of macropods on several properties during 2021 and 2022.

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