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PRODUCTION ANIMALS

REVIEW

Influence of dingoes on sheep distribution in Australia

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Objective To describe the influence of the dingo (*Canis lupus dingo*) on the past, present and future distributions of sheep in Australia.

Design The role of the dingo in the rise and fall of sheep numbers is reviewed, revised data are provided on the present distribution and density of sheep and dingoes, and historical patterns of sheep distribution are used to explore the future of rangeland sheep grazing.

Results Dingoes are a critical causal factor in the distribution of sheep at the national, regional and local levels. Dingo predation contributed substantially to the historical contraction of the sheep industry to its present-day distribution, which is almost exclusively confined to areas within fenced dingo exclusion zones. Dingo populations and/or their influence are now present and increasing in all sheep production zones of Australia, inclusive of areas that were once 'dingo free'.

Conclusions Rangeland production of wool and sheep meat is predicted to disappear within 30–40 years if the present rate of contraction of the industry continues unabated. Understanding the influence of dingoes on sheep production may help refine disease response strategies and help predict the future distribution of sheep and their diseases.

Keywords *Canis lupus dingo*; livestock production; sheep grazing; sheep production; small ruminants; wild dog predation

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East and Foreman recently described the structure, dynamics and movements of the Australian sheep industry, discussing sheep (*Ovis aries*) distribution, density and trade between regions and giving great detail of the types of sheep involved (e.g. lambs, hoggets or rams etc. used for meat or wool production).[1] However, a critical causal factor in the historical and contemporary distributions and density of sheep was not considered. In this supplement to that study, the influence of predation by the dingo (*Canis lupus dingo*) and other free-roaming *Canis* spp. on sheep distribution and the overall Australian sheep industry is described in order to complement data on sheep distribution and highlight the role dingoes did, do and could potentially have on the sheep industry.

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Dingoes and the rise and fall of sheep distribution

Following the introduction of sheep with the First Fleet and the introduction of merino genetics in 1797, the distribution of sheep rapidly expanded across most of the continent to a peak in the late 1800s.[2] Natural water sources and shepherding sustained this expansion, until widespread drought between 1898 and 1903 halved the national flock. National sheep numbers rebounded within 8 years, although a spatial redistribution of flocks necessarily occurred because of the vegetation changes associated with drought and prolonged overgrazing by sheep and wild rabbits (*Oryctolagus cuniculus*).[2,3] Supported by the discovery and proliferation of artesian and subartesian water sources during this period,[4] sheep were being grazed in almost all areas of Australia except the spinifex deserts, Cape York and some of the wetter coastal forests of eastern Australia in the early 1900s[5] (Figure 1).

Dingoes had long been a problem for sheep graziers in south-eastern Australia throughout the 1800s,[4,6] but only after the great drought were dingoes reported to be a problem for the sheep industry in northern and central Australia.[3] Why dingoes were not previously reported to be a problem there is unclear, but it may be that employed shepherds successfully protected flocks or that the rapid expansion of sheep across the country masked the predation of sheep that undoubtedly occurred. Sheep were also left unmanaged across large tracts of land[3] and dingo predation might not have been observed. Alternatively, the associated decline and extinction of preferred native prey species may have been the catalyst for dingoes to exploit sheep populations.[5] The establishment of artificial water points may have also facilitated an increase in the dingo population,[7] which might not have been large until then (perhaps aided by the unrestrained practice of lacing animal carcasses with strychnine[8]). Whatever the reason(s), dingo predation was considered a major threat to the viability of rangeland sheep production by the early 1900s and considerable investment and effort were spent on their control.[4,6,9]

Bauer reports that dingo predation (and grass seeds, which contaminate wool and reduce its value) forced a retraction of the sheep industry from northern and central Australian rangelands that otherwise might have sustained continued sheep production.[3] Localised changes to pasture quality and the effect on sheep reproductive success no doubt also contributed to the decline of sheep production in some areas.[10] Rabbits were a double-blow to the sheep industry where they had major effects on vegetation availability and also provided a valuable additional food source for dingoes.[11] In the early 1900s, the state boundary fences of Queensland, New South Wales and South Australia were erected to exclude dingoes and rabbits, and livestock producers in south-eastern Australia were also fencing off their individual holdings in attempts to curtail the animals' spread,

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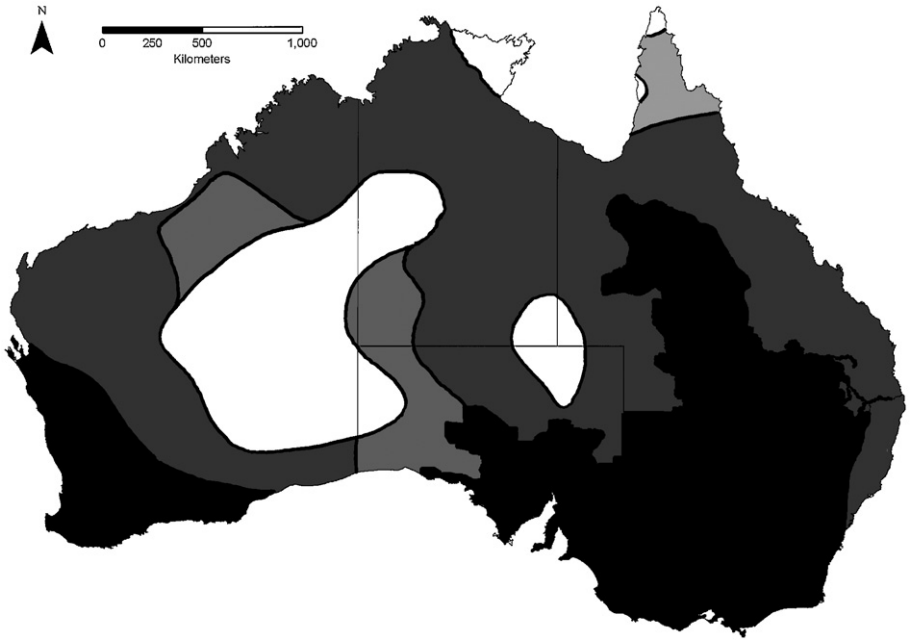

Figure 1. Historical and current distributions of sheep and cattle grazing. White, no/negligible sheep or cattle grazing; pale grey, currently grazed by cattle; medium grey, historically grazed by sheep, then by cattle, currently by neither; dark grey, historically grazed by sheep, currently cattle; black, continual sheep grazing, with recent changes to mixed sheep/cattle grazing and cropping in many areas. Many coastal areas, such as those in south-eastern Australia, historically and currently contain mixed land use, including grazing, that is not explicitly identified here. (Adapted from Allen[5].)

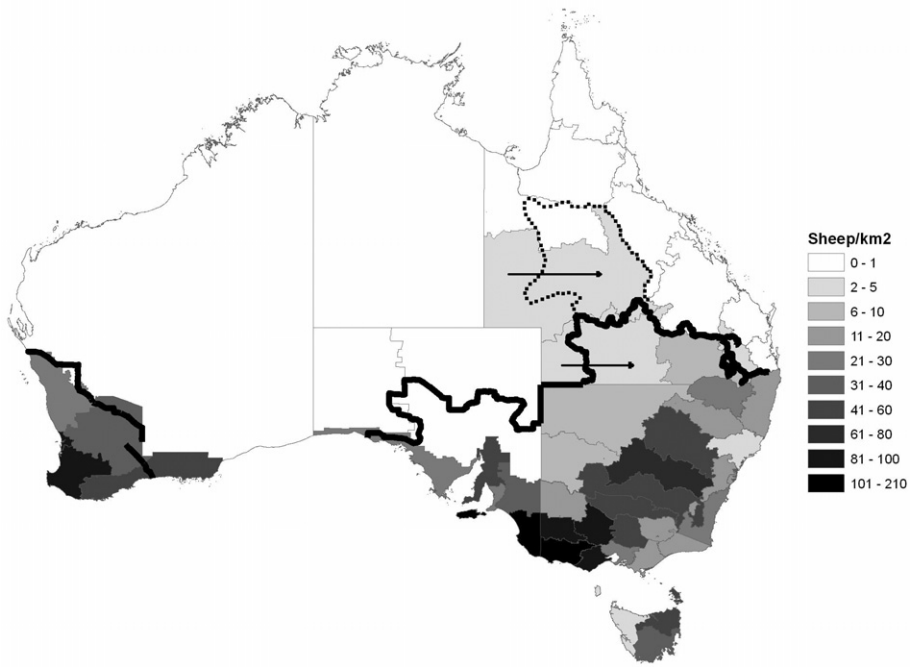

Figure 2. Distribution and density of sheep in 2010. Solid black lines, current alignment of the dingo barrier fence; broken line, former alignment of the dingo barrier fence; arrows indicate that most sheep flocks shown outside the dingo fence should correctly be shown as being inside the fence; administrative boundaries indicate the current Natural Resource Management Regions. (Originally from Australian Bureau of Statistics data, but adapted from: Meat and Livestock Australia. *Australian red meat 2000–2010: a turbulent decade – a vibrant industry*. MLA, Sydney, 2011.)

creating a contiguous mosaic of 'dog-proof cells'.[6,12,13] These cells facilitated the local eradication of dingoes by preventing migration and enabling lethal control methods such as shooting, trapping and poison baiting to overwhelm dingo populations and exterminate them. By the 1940s, the forced retraction of the sheep industry from the north met the expanding mosaic of fences from the south and the dingo barrier fence was established along the periphery separating 'cattle country' from 'sheep country'[13] (Figure 2). Similar fences were established to protect the southwest of Western Australia.[14]

Isolated sheep producers outside these exclusion zones persisted for some time, assisted by the widespread aerial distribution of strychnine baits in some places, but these producers also eventually abandoned sheep production, typically switching to cattle production. For example, sheep were grazed as late as 1978 in far northern South Australia[5] and sheep have also long since gone from the Fortescue River region of Western Australia where the dingo–sheep predation experiments of Thomson were conducted in the early 1980s.[15] Responsible administrative agencies and dingo bounty schemes were

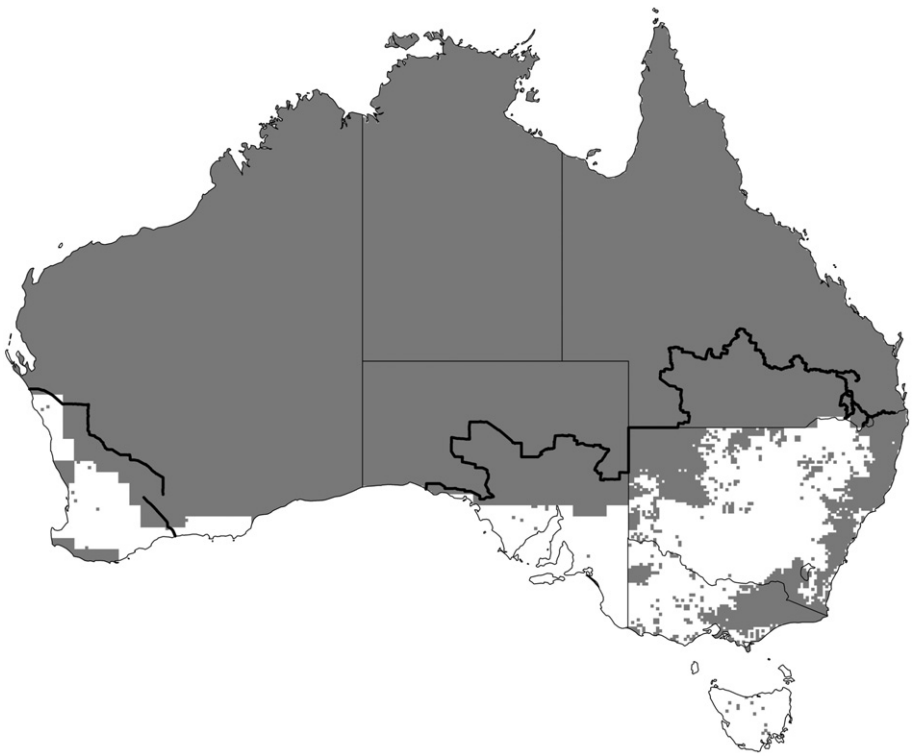

Figure 3. Distribution of dingoes (*Canis lupus dingo*) and other wild dogs (*Canis* spp.) in Australia. Gray, present; white, absent (Source: Invasive Animals Cooperative Research Centre, 2012).

established.[12,16] This exodus of sheep from northern and central Australia, which began in the early 1900s, was significant enough to establish a Royal Commission into rabbit and dingo management.[9] The Commission heard that:

> The main reason for putting a price on a dingo's head was to enable the sheep industry to be extended. Yet all sheep owners in outside districts have to erect dog-proof fences to protect themselves. It is roughly estimated that there are more than 20,000 miles of such dog-netting fencing in Queensland today. If a dog gets inside the netting, so great is the damage he may do that a sheep owner has been known to offer bonuses up to £50 [>A$4,600 in 2012 values] for his destruction. The protection of the Dingo Board is of little avail. Each sheep owner must protect himself.

This pattern of decline and contraction of sheep numbers still continues across what remains of Australia's sheep production regions.[1] For example, following the decision to excise the most northerly portion of the dingo barrier fence in Queensland in 1982, the sheep industry continued to retract from this area as the dingo distribution expanded, with the most noticeable changes occurring in areas at the interface between sheep and cattle grazing.[16] Although the earlier dingo fencing and culling efforts inside many of the exclusion zones were sufficient to decimate dingoes in most places, populations were not completely extirpated from these zones.[12,16,17] Dingoes were effectively absent from much of the 'inside' land in South Australia, New South Wales and Queensland from the early 1900s until the late 1980s and mid 1990s, but they persisted in the forests of south-eastern Australia and a limited number of dingoes breached the barrier fences from time to time.[17,18] Consequently, isolated populations of dingoes have always existed inside the exclusion zones.

Allen warned that the dingo barrier fence would ultimately become redundant and questioned whether the sheep industry could survive in the 'protected area' if these dingo populations were not immediately controlled.[19] Despite all the subsequent efforts to keep the exclusion zone free of dingoes, they are presently distributed across almost all rangeland sheep production areas in eastern Australia (Figure 3). For example, landholder surveys undertaken by state government agencies document the incursion of dingoes into the semi-arid areas of south-eastern Australia inside the dingo barrier fence and a recent dingo genetics study[20] obtained samples from dingoes both outside and inside the barrier fences of Western Australia. The pattern of sheep decline, evident for over 100 years outside the exclusion zone,[5] is presently continuing inside the exclusion zones, where a reduction of over 40% of the national sheep flock has been experienced in all states and over 70% in Queensland.[1]

Dingo predation is by no means the sole cause of the decline in sheep numbers across Australia,[1,21,22] but dingoes are a major cause or, at the very least, 'the straw that breaks the camel's back'. For example, one grazier in the northern Flinders Ranges shot 20 dingoes in the same year that 2800 ewes were mated and only 70 lambs survived (Jeff Mengersen, Depot Springs Station, pers. comm., March 2008) and a nearby grazier lost more than 600 adult sheep to dingoes a short time later, before finally switching to cattle, according to the ABC News, on January 28, 2010. Semi-arid areas of the 'sheep country' in Queensland and New South Wales have experienced a similar transition from sheep to either cattle grazing (Figure 4) or cropping[22] and many areas might now be deemed 'cattle country'. Were it not for dingoes, sheep production might be viably expanded back into many cattle grazing areas formerly grazed by sheep both inside and outside the dingo

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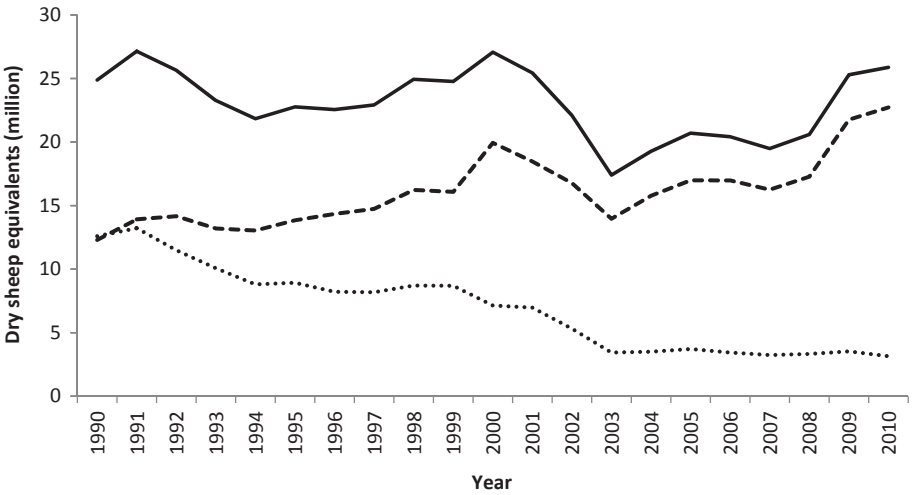

Figure 4. Trends in sheep (dotted line), cattle (dashed line; assuming 8 dry sheep equivalents per cow) and combined (solid line) livestock numbers in south-west and central-west Queensland 1990–2010 (Source: Australian Bureau of Statistics data, cat. no. 7121.0, Agricultural Commodities Australia, available at www.abs.gov.au).

barrier fences. However, it should be noted that tropical climates, land tenure (e.g. conservation reserves) and the presence of sheep diseases (e.g. bluetongue virus, for which there are multiple serotypes in northern Australia that are virulent to sheep) will undoubtedly prevent the sheep industry from ever reaching its former peak distribution.

Given that dingoes are an important causal factor in the present distribution of sheep in Australia, the national map of sheep distribution provided by East and Foreman is misleading because it reports the presence of sheep in places where there are none (such as northern South Australia, or most of Areas 3 and 124 in their figure 1[1]). A comparison with Figures 1 and 2 provided here indicates that outside the existing dingo barrier fences, central Queensland is the only region with noteworthy flocks of sheep, and these are scattered throughout a mosaic of sheep and cattle grazing lands. Although the same root data were used to produce both sheep distribution maps, the substantial differences between the two arise from the use of administrative boundaries to define the distribution of sheep without incorporating important geophysical boundaries such as the dingo exclusion fences or the central Australian deserts.

Dingoes and the future of the sheep industry

Rangeland sheep grazing in Australia is completely dependent on the absence of dingo predation; in other words, dingoes and sheep don't mix[15,23] and unless the two are separated, dingoes will exterminate sheep sooner or later.[9,17] The same is true of goats (*Capra hircus*), which are also highly susceptible to dingo predation,[24] whereas rangeland cattle production can withstand dingo predation events that occur relatively infrequently and usually have a less disastrous economic effect on producers. Substantial improvements in dingo hunting, trapping and poisoning methods over the past 100 years have failed to curtail the retraction of the sheep industry away from rangeland grazing regions where dingo predation occurs,[17,25] for two primary reasons. First, the availability of on-farm labour is now at an all-time low, meaning there are fewer people available to detect dingoes and then remove or deter them. Second, and most importantly, the use of netting fences has diminished dramatically, allowing the widespread migration of dingoes between farms and regions. There were tens of thousands of kilometres of netting fences,[9,13,14] but these have now largely disappeared, fallen into disrepair or been replaced by strand wire fencing in many places. Together, these changes have lead to a reduction in the number of dingoes removed and also allowed dingoes to quickly reinvade areas where control had occurred or to expand into areas from where they had been previously exterminated.

Although most dingoes are relatively sedentary, those in the rangeland sheep grazing areas have been recorded as travelling more than 550 km from their point of origin in 31 days, or more than 1300 km in 4 months.[26] Such movement presents a considerable challenge to producers of small livestock susceptible to dingo predation. Only births, deaths, immigration and emigration influence the density of dingoes (or any species) in a given area; therefore, unless future dingo control efforts can increase the number of dingo deaths and reduce immigration to the point where their sum is greater than the number of births and those lost to emigration, then dingo numbers (and the effect of dingoes) will increase in sheep production areas. If these patterns and causes of the decline in the sheep industry continue to occur at the same rate as has been experienced in the past and no advances are made in the adoption of control technologies and strategies used to protect sheep from dingoes, then we predict that the rangeland production of sheep (and goats) in Australia is likely to disappear within 30–40 years. The realisation of this may be enhanced by growing support from some sectors for the prohibition of lethal dingo control and the active reestablishment of dingoes into the exclusion zones, which is already being promoted across much of the continent in attempts to advance biodiversity conservation agendas[27,28] aimed at reversing the ecological effects of livestock production.[29]

The national implications of increased dingo predation in sheep grazing areas are potentially very substantial, yet often overlooked. Should dingoes persist in any reasonably-sized area within the exclusion zones, they will not be contained to that area without costly exclusion fencing. Given that dingoes are economically significant predators of livestock,[30-32] and that livestock grazing occurs over more than half of the continent,[5,29] uncontrolled populations of dingoes at

the local level may ultimately affect agricultural industries and rural communities across the entire country (as seen historically and discussed earlier). Comparable situations have begun to occur elsewhere that predators have been positively managed and it would be naïve to expect otherwise for dingoes in Australia.[25] For example, the restoration of 66 wolves to the greater Yellowstone ecosystem in North America in 1995 was expected to result in a stable population of approximately 100 wolves.[33] By 2007, the wolf population had exceeded 1500 individuals and was increasing at 25% per annum, despite more than 700 wolves already being killed (9% of the population annually) by producers because of livestock predation problems outside the area designated for wolf recovery.[34] Thus, whether in Europe,[35,36] North America[33,37] or Australia,[26] wolves and dingoes are known to disperse hundreds of kilometres, establish sustainable populations and cause livestock damage.

Broadscale distribution of poisoned bait is the only efficient dingo management tool in rangeland areas[17] and not using it is likely to result in an inability to effectively manage dingoes for any purpose. Because of emigration, even if individual livestock producers use poison baiting, the presence of large tracts of land managed in a way that promotes dingoes will probably affect livestock production sooner or later.[15,17,19] Such a situation, where managers of a Victorian wilderness habitat neglected to appropriately control dingoes adjacent to livestock production, resulted in successful litigation against that state's government in 2001.[38] It is therefore reasonable to assume that future legal action such as this may arise if livestock producers are economically disadvantaged by changes in dingo management policy or practices.

Even if the threat of litigation is prevented by new legal barriers, rangeland wool and sheep meat production may decline or collapse in the presence of an increasing or abundant dingo population,[9,15,19] with downstream economic ramifications in Australia and internationally. For instance, according to the Food and Agriculture Organization (www.fao.org), Australia is one of the largest net exporters of food and fibre in the world, with the Australian sheep industry producing and supplying more wool than any other country and being the world's second-largest sheep meat producer. The country also exports more goat meat than any other, according to Meat & Livestock Australia (www.mla.com.au). If proposed changes to dingo management practice or policy result in a retraction in sheep distribution, the loss of such a geographically diverse industry would have devastating economic effects that will flow through the entire supply chain, inclusive of sheep industry employers and employees, their families and communities, and the related enterprises and institutions they support.[22,32] Enterprise-switching to beef cattle production will not stem this[32] nor will a switch to kangaroo (*Macropus* spp.) production, because populations of kangaroos, which are dingoes' preferred native prey, are also dramatically suppressed by dingo predation.[18,39] Moreover, in a world where human population growth and global food security are increasingly becoming important issues,[40,41] the proposed financial compensation schemes for those livestock producers affected by dingoes (an approach taken in similar situations in other countries[34]) does not result in the production of meat or wool (i.e. food and clothes for humans). The increased productivity of sheep, which has been achieved through improved flock genetics, resilience and reproduction,[41] also becomes redundant, because all types of sheep are susceptible to dingo attack.[15] The decline or collapse of the Australian rangeland sheep industry will also likely increase retail prices of wool and sheep meat products, as well as the food security risk for Australian consumers.

With a global perspective in mind, the loss of Australia's sheep industry will undoubtedly be countered by an increase in sheep production in other countries. Those countries may not be able to produce sheep as economically as Australia does; they may have extant diseases and other pathogens that inhibit broadscale sheep production or export (e.g. rabies or screwworm flies (*Cochliomyia* spp.)), be forced to clear new land for increased livestock production or may have local predators that need controlling in order to viably upscale their sheep production. Changing current land use from wool to an alternative natural fibre, such as cultivated cotton, is also unlikely to yield greater biodiversity benefits (the intended goal of encouraging dingoes) than sustainable rangeland grazing. Hence, while the historical transformation of Australia's natural rangelands may be regrettable, a globally conservative approach would be to continue using Australia's existing sheep production lands for sustainable production of sheep, which will necessarily require the continued destruction and exclusion of dingoes. In this situation, the persistence of dingo populations may be acceptable in the 75% of Australia where sheep production does not occur (Figures 1–3), but their reestablishment in the remaining 25% of Australia may continue to be resisted.

Although previous control efforts do not appear to be excluding dingoes from most areas of sheep production (Figure 3), new dingo (and red fox (*Vulpes vulpes*)) control technologies in development are likely to substantially boost the ability to combat dingo predation. A new toxin, called para-aminopropiophenone (PAPP), is a safer, faster and more humane poison, which also has an effective antidote for domestic dogs that are accidently poisoned;[42,43] the use of M44 ejectors as delivery devices for cyanide, PAPP or sodium monofluoroacetate (commonly known as '1080') offers the ability to widely distribute permanent 'bait stations' and substantially enhances the spatiotemporal coverage of control.[44] Lethal trap devices (a substitute for the use of strychnine rags on traps) also offer a practical solution to reducing the labour required to service traplines;[45,46] and the use of livestock guardian dogs may be suitable in some circumstances.[47] As advantageous as each of these methods may be, they may be still unable to stop the decline of sheep grazing in the absence of new or upgraded netting fences[9,19] or of cooperative and integrated control strategies that actually achieve no gaps in the spatiotemporal coverage of dingo control.

Dingoes and the transmission of sheep diseases

One of the salient features of the effect of dingoes on sheep production is their ability to obliterate it on a local, regional and continental scale[3,5,23] (Figure 5). By changing the distribution and density of sheep flocks, the pattern and potential for physical interaction between flocks are altered. At a national scale, dingo predation effectively separated the two larger sheep production regions of eastern and western Australia (Figures 1, 2). Should a serious disease outbreak occur in one of these regions, their separation may enable the other area to remain free of the disease, providing adequate quarantine measures are

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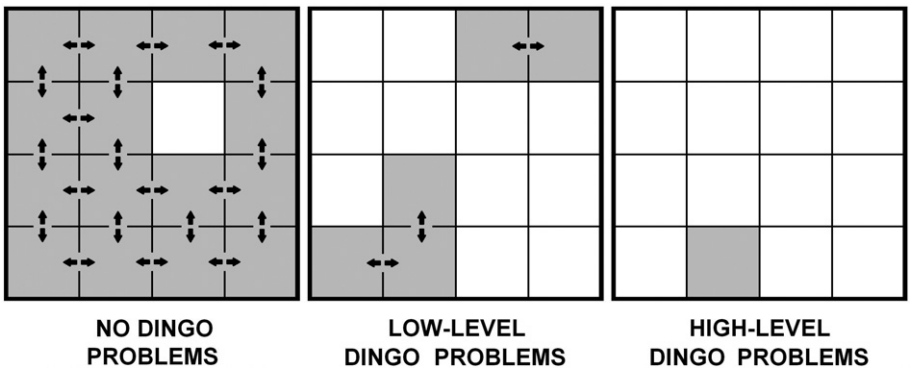

Figure 5. Patterns of sheep (grey cells) and cattle (white cells) distribution when livestock are exposed to various levels of dingo predation, showing potential direct routes of disease transmission (arrows) between sheep flocks (applicable at national, regional and local levels).

effected. Within a given livestock production region, unmitigated problems with dingoes force livestock producers to abandon sheep production and switch to cattle or another enterprise,[22,32] creating a mosaic of sheep and cattle properties when dingo numbers are lower, and converting 'sheep country' to 'cattle country' when dingo numbers are higher (Figures 4, 5).

Such a change in the agricultural landscape can isolate individual sheep properties or clusters of properties. On the one hand, this process reduces the physical interaction between sheep flocks (and the opportunity for disease transmission), but on the other hand, it increases the distances that sheep must be transported between regions or property clusters (increasing both the transport costs and the opportunity for disease to spread between clusters).[1] At the local or property level, the presence of dingoes changes the pattern of paddock usage by sheep from a more ubiquitous distribution to one that is clumped. This imposes fitness costs on sheep forced away from more nutritious pastures by the risk of dingo predation (exacerbating the potential to contract disease) and also increases the physical contact between sheep as they group together to avoid dingo predation (an anti-predator defence strategy that protects the group at the expense of the individual). Knowledge of these ecological and behavioural processes may not only help to develop appropriate exotic disease response strategies, but also contribute to our understanding of the epidemiology of the many endemic parasites and pathogens dingoes can transmit to livestock, domestic animals and humans.[48,49]

Conclusions

Dingoes are one of the important causal factors that have had an influence on the historical, contemporary and future distribution of sheep in Australia. The rangeland production of sheep will likely disappear in the next 30–40 years if the present rate of decline continues unabated. This must not be overlooked, and studies investigating the rangeland production or distribution of sheep should be careful to consider the influence of dingo predation in addition to other important factors.

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