CSIRO PUBLISHING

Animal Production Science, 2014, **54**, 214–220
http://dx.doi.org/10.1071/AN12356

Wild dog control impacts on calf wastage in extensive beef cattle enterprises

Lee R. Allen

Robert Wicks Pest Animal Research Centre, Biosecurity Queensland, Department of Agriculture, Fisheries and Forestry, PO Box 102, Toowoomba, Qld 4350, Australia. Email: lee.allen@daff.qld.gov.au

Abstract. Wild dogs (*Canis lupus dingo* and hybrids) are routinely controlled to protect beef cattle from predation yet beef producers are sometimes ambivalent as to whether wild dogs are a significant problem or not. This paper reports the loss of calves between birth and weaning in pregnancy-tested herds located on two beef cattle properties in south-central and far north Queensland for up to 4 consecutive years. Comparisons of lactation failures (identified when dams that previously tested pregnant were found non-lactating at weaning) were made between adjoining test herds grazed in places with or without annual (or twice annual) wild dog poison baiting programs. No correlation between wild dog relative abundance and lactation failures was apparent. Calf loss was frequently higher (three in 7 site-years, 11–32%) in baited areas than in non-baited areas (9% in 1 of 7 site-years). Predation loss of calves (in either area) only occurred in seasons of below-average rainfall, but was not related to herd nutrition. These data suggest that controlling wild dogs to protect calves on extensive beef cattle enterprises is unnecessary in most years because wild dogs do not routinely prey on calves. In those seasons when wild dog predation might occur, baiting can be counter-productive. Baiting appears to produce perturbations that change the way surviving or re-colonising wild dog populations select and handle prey and/or how they interact with livestock.

Additional keywords: 1080 baiting, *Canis lupus dingo*, livestock predation, predator management, prey selection, reproductive performance.

Received 10 October 2012, accepted 18 March 2013, published online 7 May 2013

Introduction

In 2008–09, wild dogs (presently defined to include pure dingoes *Canis lupus dingo*, free-roaming domestic dogs *Canis familiaris* and their hybrid offspring) were reported to cost the Queensland beef industry over $40 million through predation loss of calves ($22.8 million), product loss from dingo-bitten livestock ($2.0 million), parasite (*Neospora caninum* and *Echinococcus granulosis*) transmission ($5.2 million) and management costs ($11.2 million) (Hewitt 2009). Wild dogs are the only terrestrial predator of cattle in Australia and (dingoes) were already distributed across the mainland when Europeans arrived in 1788 (Rolls 1969). Though little information is available from this period, wild dog densities undoubtedly increased from the early 1800s with the development of Australia's pastoral industry and its associated supply of permanent artesian water and prey (Finlayson 1935; Bauer 1962; Corbett 2001).

Throughout Australia, wild dogs are declared as pests in agricultural areas and are managed accordingly (Allen and Fleming 2004; Allen *et al*. 2011*a*). However, in contrast to sheep producers (to whom wild dogs are an anathema), the attitudes of beef cattle producers towards wild dog predation are diverse (Allen and Sparkes 2001). Part of the reason for the ambivalence of the latter is because predation on calves is less visible, where beef cattle properties and paddocks are usually larger, with fewer opportunities for producers to witness livestock predation (Fleming *et al*. in press). Moreover, the observed anti-predator behaviour of cattle in response to the presence of wild dogs (adult cattle cooperatively defend calves and/or act aggressively towards wild dogs) suggests cattle have adequate defensive behaviours to deter most attacks (Thomson 1992*b*; Corbett 2001).

Few reviews of reproductive performance in beef cattle identify or suggest wild dog predation as a significant factor affecting calf loss (Hasker 2000; Schatz and Hearnden 2008; Burns *et al*. 2010). Notably however, one of the features of these reviews is the high level of variation in calf losses between pregnancy diagnosis and weaning between years and properties (Table 1).

Holroyd (1987*a*, 1987*b*) reported for a control-mated *Bos indicus* herd at Swan's Lagoon in north Queensland that mean peri-natal (within 48 h following birth) and post-natal losses (from 48 h post-birth to weaning at 5–7 months) were 4.4 and 5.6%, respectively. Most of the losses of calves were found to occur within 14 days of birth and the largest proportion of loss was from unknown causes, where the calf carcass could not be found (Holroyd 1987*a*). In reviewing calf losses across northern Australia, Holroyd (1977) found that post-natal loss ranged from 2.3 to 31.4% and mostly occurred within 1 month of

Table 1. Reported fetal and calf wastage losses between pregnancy diagnosis and weaning in beef herds of northern Australia

Study	Location	Fetal and calf loss (%)
Rankine and Donaldson (1968)	North Qld	8.5–29
Lamond (1969)	North Qld	6–40
Kirby (1974)	Northern Territory	23
Holroyd *et al*. (1979)	North-west Qld	6–28
Post (1980)	Central Qld	9–27
Ramlibakry (1981)	North Qld	13
Entwistle and Goddard (1984)	North Qld	4–10
Holroyd (1987*b*)	North Qld	9–19
Burns *et al*. (1992)	Central Qld	8–18
Schlink *et al*. (1994)	Northern Territory	22
O'Rourke *et al*. (1995*a*)	North Qld	2–28
O'Rourke *et al*. (1995*b*)	Northern Territory	21
Sullivan *et al*. (1997)	Northern Territory	Up to 25.6
MacDonald *et al*. (1997)	Northern Territory	3.4–10.6
Dixon (1998)	North Qld	4.7–15.8
Brown *et al*. (2003)	Northern Territory	14

birth (see also Hetzel *et al*. 1989; where 75% of calf losses were found to occur between the last trimester of pregnancy and 2 months of age), where the extensive nature of northern Australia's beef cattle industry and the lack of any intensive investigations were believed the cause why most calf losses were classed as 'unknown'. In reviewing calf losses between confirmed pregnancy and weaning over the last 25 years, Burns *et al*. (2010) concluded that the large range of causes of peri-natal mortality rates remains poorly understood, with little progress made in determining causes of peri- and post-natal calf mortalities. Research into beef cattle performance conducted in northern Australia and published between 1988 and 2000 (summarised in Hasker 2000) does not identify predation as a significant factor affecting calf mortality, yet wild dog predation is one of the most common explanations of calf loss given by beef producers (Gibson 1987; Hewitt 2009).

Controlling wild dogs with poisoned bait is intended to reduce predation risks, but Rankine and Donaldson (1968; p. 141) found that 'wild dogs remained a problem even though poisoned baits were continually laid around cattle watering points and camps'. They showed a 14.4% loss between pregnancy diagnoses and weaning, which is comparable to other reports (Table 1), but witnessed that 64% of these losses (or 9% of the calves produced overall) occurred soon after birth and were mostly caused by wild dog attacks (Rankine and Donaldson 1968). Allen and Fleming (2004) reported a similar situation on Ironhurst Station in north Queensland, where wild dogs remained a chronic problem in spite of annual strychnine baiting from 1968 to 1987. Subsequently, from 1988 to 1996, this property was baited by aircraft (in conjunction with adjoining neighbours) across a combined area of ~50 000 km^2. Over the following 8 years, branding rates were 18% higher, on average, than for the previous decade and, on average, an additional 407 calves per year were branded (Allen and Fleming 2004).

These and other studies (Fleming *et al.* 2012) indicate that wild dogs can kill substantial numbers of calves at times. However, the effectiveness of wild dog control at reducing calf losses is less clear. In this study, wild dog predation of *B. indicus* and *B. indicus* × *B. taurus* calves was assessed in paired treatment areas where wild dogs were and were not exposed to poison baiting (with 1080 meat baits).

Methods

All procedures were undertaken in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes and were approved by the University of Queensland and Department of Natural Resources, Animal Ethics Committees (#930 401).

Study design

This study compared lactation failures of pregnant cows between paired baited and non-baited treatment areas on the same property over 3–4 consecutive years on two independent properties (see Allen 2005; for details).

Study site selection

Selection of potential field sites was limited to single properties where: (1) the property was large enough to be divided into two large treatment blocks, (2) property management was amenable to both laying 1080 meat bait and refraining from baiting in different parts of the property; (3) there were subdividing fences and a buffer of >10 km to maintain independence between treatment areas, (4) the two test cattle herds were the same breed, age (or mix of ages) and were managed the same way, (5) the vegetation, soil and pasture conditions did not vary substantially between treatment areas, (6) stock handling practices and yard facilities allowed test cattle to be separated and pregnancy tested at least annually, and (7) management and property ownership was stable, allowing access to pregnancy test cattle for several years. These requirements significantly constrained the selection of test properties. Mt Owen (south central Queensland, 25.45°S, 147.59°E) and Strathmore (north Queensland, 17.52°S, 142.33°E) were selected because they satisfied the above criteria. Seasonal conditions were derived from annual rainfall figures averaged over the preceding 2 years; the quantile ranking based on 80–100 years median rainfall figures from Forrestvale and Georgetown for Mt Owen and Strathmore, respectively (Rainman 3.0).

Cattle allocation and management

Mt Owen

Equivalent groups of ~200 pregnant cows within large herds of mixed age and breed cattle were tagged and allocated to each of the baited (northern) and unbaited (southern) areas. Non-trial cows (~1000) were grazed with the northern (baited) group during summer and then, after the first round muster, transferred to the southern (unbaited) area during winter. Calving and early lactation occurred over summer. During winter, cows allocated to the baited area were kept in a 15-km^2 holding paddock until the second round muster.

Treatments

In the randomly assigned baited areas, up to 400 kg of 1080 meat bait (~eight single dose baits/kg of meat) was dropped from aircraft around natural and artificial water sources and from vehicles along vehicle tracks at least once annually (100–250 kg on Mt Owen, 250–400 kg on Strathmore; for details see table 3.1 in Allen 2005).

Strathmore

Initially, equivalent groups of 200 and 227 continuously-mated, 4-year-old, pregnant (>4 months) Brahman cows were tagged and allocated to baited and non-baited breeding groups, which numbered 600–1400 cows each year, depending on pasture available. Allocated cow numbers were raised to 200 each year in each paddock to replace missing cows (lost ear tags, cows that had died, were culled, were not mustered or had escaped from their test paddocks) by random selection from similar-aged pregnant cows. Cattle were helicopter and ground mustered from paddocks once annually during the dry season for reproductive assessments and other husbandry. The treatment herd, contained in paddocks of 160–300 km^2 within a ~2000 km^2 treatment area, were similarly located in undulating low paperback woodland areas fenced off the rivers.

Cattle measurements

Experienced veterinarians aged pregnancies each year at each site by rectal palpation. Other data recorded included breed, age, body condition score (Holroyd 1978), and lactation status (visual assessment of the udder or by stripping/milking the teats where status was less obvious).

Blood and vaginal mucus samples were taken each muster from a random sample of cattle that had experienced lactation failure, and from lactating cows. Samples were tested for leptospirosis, vibriosis and/or pestivirus by commercial veterinary laboratories.

Predicted calving dates were calculated from estimated fetal age. A lactation failure was recorded when a known-pregnant cow was subsequently found to be not lactating and not pregnant with the same fetus beyond its predicted calving date. A pre-natal loss was recorded when a subsequent conception was calculated to occur before predicted calving date.

Self-weaning and theft were also investigated as potential explanations for any large discrepancies in lactation failures between treatment areas. If dams of older calves stopped lactating due to dry seasonal conditions, previously pregnant cows would be recorded as lactation failures when weaned calves had been produced and were not lost to predation. Alternatively, if unbranded calves had been removed without the knowledge of management (i.e. theft) it would account for the presence of 'dry' previously pregnant cattle when a weaned calf had been successfully produced. These alternatives were evaluated by comparing the proportion of weaned calves to adult female cattle from the whole paddock relative to lactating cows as a proportion of the test herd (self-weaning scenario) or, assuming that theft would produce a disproportionate bias for older calves to be missing, the proportion of 8–12-month-old calves missing as lactation failures compared with proportion of 8–12-month-old calves, predicted to be in the test herd (theft scenario).

Wild dog relative abundance

The relative abundance of wild dogs was measured by counting individual tracks on 50, 1-m-wide tracking stations, located along unformed roads, spaced 1 km apart, for 4–10 days in each treatment area (Allen *et al*. 1996), as recommended for wild dogs (Mitchell and Balogh 2007) and many other species (Smith 1999; Engeman and Allen 2000; Engeman *et al*. 2000; Evangelista *et al*. 2009). Wild dogs characteristically demonstrate a peak in activity [with maximum passive tracking index (PTI) values <2.0 tracks/tracking station/day] during their autumn mating season corresponding to increased urination and territory marking (Thomson 1992*a*) and a decline in activity during pup rearing in late spring when adults keep juvenile wild dogs 'out of sight'. The PTI has been validated against other wild canid monitoring methods and found to be very sensitive (i.e. high probability of detection, high precision of estimates and low variability between surveys, Allen *et al*. 1996). When used and interpreted appropriately (Allen *et al*. 2011*b*) the method tracks changes in the relative abundance of wild dogs. The PTI for wild dogs for the months between each pregnancy examination was calculated from 19 (Mt Owen) and 9 (Strathmore) activity surveys conducted between 1993 and 1999 (details in Allen 2005).

Analyses of data

Linear grouped regression and multiple regression using backward elimination of non-significant effects was used to determine if a combination of wild dog abundance, seasonal rainfall, site or wild dog management affected lactation failures. Two-way ANOVA was used to test the effects of cow body condition score on lactation failure across treatments. The effect of prevalence of antibody titres to infectious reproductive diseases across treatments was tested in a similar manner.

Results

The relative abundance of wild dogs, timing of baiting and rainfall between 1994 and 1998 are shown in Fig. 1. Baiting was almost always followed by reductions in wild dog PTI values, but results were variable, with PTI values returning to pre-control levels within 8 months in most cases. Wild dog PTI values were reduced by up to 71 and 100% immediately after baiting (Mt Owen and Strathmore, respectively), but by 54% overall (mean of all baiting programs). Efficacy of these baiting programs is evaluated in Allen (2005). At Mt Owen, more regular surveys showed annual cycles of activity, with the mean annual PTI values positively linked to rainfall (See also fig. 1 in Allen *et al*. 2011*b*). ANOVA showed a significant difference in wild dog PTI values between treatments (i.e. baiting significantly reduced wild dog activity, $P < 0.001$) and sites ($P = 0.003$). Wild dog PTI values were significantly lower at Strathmore compared with Mt Owen (see Fig. 1).

Lactation failure

Total losses between confirmed pregnancy and weaning in the test herds at Mt Owen and Strathmore over 4 years (1994–98) and 3 years (1995–98), respectively, was highly variable

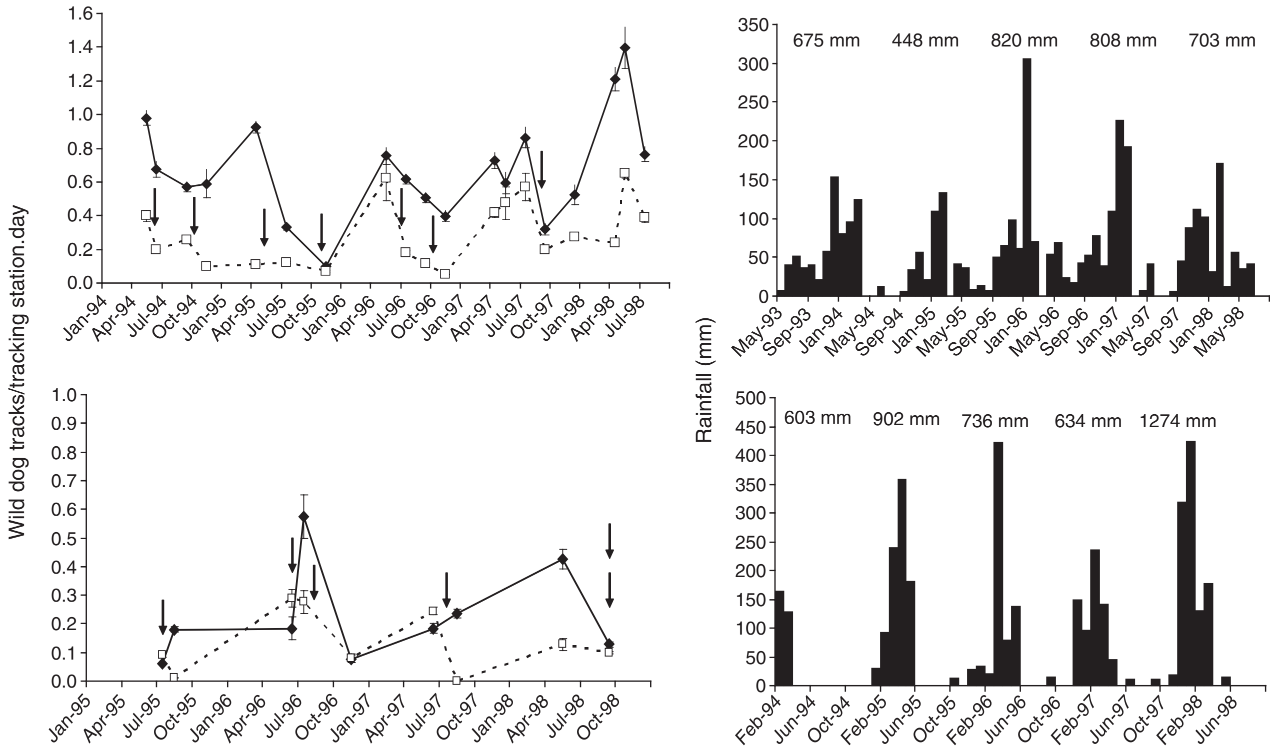

Fig. 1. Monthly and annual rainfall and passive tracking index trends (including 95% confidence limits) of wild dogs in baited (broken lines) and non-baited (solid lines) areas on Mt Owen (above) and Strathmore. Arrows indicate the approximate timing of baiting programs. Both treatment areas at Strathmore were baited at the conclusion of the project.

Table 2. Comparison of peri- and post-natal calf loss (lactation failures) between baited and non-baited areas by site, muster and year

Location	Muster	Baited area Lactation failure/sample size[A]	%	Non-baited area Lactation failure/sample size[A]	%	Chi-square	*P*-value
Mt Owen	Spring to autumn	4/136	2.9	28/162	17.3	14.41	<0.001
	Autumn to spring	7/34	20.6	0/32	0.0	5.36	0.02
	Annual 1995	11/135	7.2	28/175	16.0	5.24	0.022
	Spring to autumn	33/166	19.9	13/166	7.8	9.11	0.003
	Autumn to spring	14/56	25.0	6/58	10.3	3.28	0.070
	Annual 1996	47/188	25.0	19/190	10.0	13.73	<0.001
	Spring to autumn	12/177	6.8	13/178	7.3	0.00	0.988
	Autumn to spring	10/72	13.9	6/67	9.0	0.42	0.519
	Annual 1997	22/233	9.4	19/228	8.3	0.01	0.944
	Spring to autumn 1998	12/113	10.6	12/99	12.1	0.02	0.899
	All years	92/687	13.4	78/692	11.3	0.91	0.339
Strathmore[B]	Annual 1996	33/189	17.5	12/194	6.2	10.67	0.001
	Annual 1997	75/180	41.7	16/166	9.6	46.37	<0.001
	Annual 1998	11/177	6.2	16/174	9.2	0.72	0.397
	All years	119/546	21.8	44/534	8.2	46.37	<0.001
	All properties/all years	219/1233	17.1	122/1226	10.0	30.75	<0.001

[A]Number of known pregnant cows.
[B]Annual musters only.

(Table 2). Average loss from all causes was higher in baited than in non-baited areas (17.1 ± 4.8% vs 10 ± 1.2%; $P < 0.001$). Annual calf loss was significantly greater (11–32%) in the baited area in 3 of the 7 site-years monitored and significantly greater (9%) in the non-baited area once during the same 7 site-years (Table 2).

Multiple linear regression on lactation failure produced a significant interaction between baiting treatment and seasonal rainfall (F = 4.57, P = 0.05). Season was a significant factor in lactation failure where wild dogs had been baited (P = 0.01) but not when they were uncontrolled (P = 0.93). This analysis was unable to discriminate any significant effect of wild dog abundance (PTI values) on lactation failure across baiting regimes.

There was no evidence of self-weaning causing an overestimate in confirmed pregnancy to weaning loss; e.g. in 1997, when confirmed pregnancy to weaning loss exceeded 40% in test herd cows at Strathmore (Table 2), 33.2 calves per 100 cows were weaned from the 1356 cows mustered from the baited area.

At the same time, 32% of 145 weaned calves were estimated to be 8–12 months of age when 23% were predicted to be in this age group from fetal ageing the previous year. Therefore, there was no evidence that older calves had been removed from the herd.

Calf loss did not differ significantly between cow body condition score groups.

There was no significant difference between lactating cows and those that had experienced lactation failure in blood antibody titres against *L. hardjo* or in vaginal mucus antibody titres to *Campylobacter venerialis fetus* (vibriosis) at either site; e.g. 1 of 54 vaginal smears and 2 of 20 blood samples collected at Strathmore in 1997 (when the greatest loss of calves occurred), had positive titres for vibriosis and *L. hardjo*, respectively.

Discussion

There are many first-hand accounts of wild dogs killing calves (e.g. Rankine and Donaldson 1968; Thomson 1992*b*; Corbett 2001) providing compelling evidence that wild dogs indeed have the capacity to outrun, attack and kill calves. However, almost all beef cattle reproductive performance studies that identify the causes of lactation failure ascribe negligible losses to predation (see review of causes of lactation failure in Burns *et al*. 2010), and grazier estimates of predation are typically <7% of calves (Hewitt 2009). The analysis of prey remains identified in >1000 droppings of wild dogs from these two locations (detailed in Allen *et al*. 2012) confirm that wild dogs rarely consumed cattle remains (1% incidence of occurrence) but preyed mostly on small- to medium-sized prey.

The annual lactation failure rates reported in this study (6–42%; Table 2) are comparable with other studies of beef cattle reproductive performance from northern Australia (Table 1), and show median values for annual lactation failures (9.6–10.6%) within maximum acceptable levels (i.e. within 12%). These data support the view that calf predation by wild dogs occurs infrequently. Similar to other studies, there were occasional years when significant lactation failures >12% occurred. Where this study contrasts with all other studies of reproductive performance is in comparing lactation failures in near identical herds in adjacent areas where wild dogs were or were not baited. Unexpectedly, calf losses were more frequently (3 of 7 site-years) greater (up to 32% of calves) in baited areas compared with non-baited areas, and mean annual peri- and post-natal calf losses were substantially greater in these herds (Table 2). Alternative explanations for treatment differences other than predation (e.g. disease, malnutrition or theft) were evaluated and dismissed. For example, dehydration and heat stress, identified as significant contributors to neo-natal calf loss in northern Australia (Daly 1971; Entwistle 1974; Burns *et al*. 2010), are unlikely explanations for occasionally high lactation failures in only one treatment area because adjacent test herds encountered the same environmental conditions.

Six of eight baiting programs during the study resulted in wild dog activity returning to within 10% of pre-control levels in less than 8 months, with recovery mostly occurring over the summer (Allen 2005). Thus, peak calving typically occurred at the same time wild dog activity recovered from baiting. Rankine and Donaldson (1968) and Allen and Fleming (2004) likewise report other examples when wild dogs remained (or became) a problem after baiting programs and where significant predation losses occurred (~9 and 18% of all calves, respectively).

Below-average seasonal conditions appear to be an important factor associated with predation loss, although not through its impact on herd nutrition. Consistent with Eldridge *et al*. (2002) and Fleming *et al.* (2012), when above-average rainfall and good seasonal conditions prevailed (summer of 1996–97 and 1997–98 at Mt Owen, and 1997–98 wet season at Strathmore), predation loss was undetectable irrespective of whether wild dogs were controlled or not (Table 2). The only exception to this was found in 1996 at Mt Owen when drought-breaking rains came late in January in what was mostly a very dry summer at the end of several very dry years (Fig. 1). An additional 15.0% calf loss occurred in the baited area than in the non-baited area that year (Table 2), yet the annual July 1995 to June 1996 rainfall figures suggested a reasonable season with above-average rainfall. Analysis shows that season is a significant factor only where baiting has occurred and is not related to wild dog relative abundance.

The availability of prey was considered to be an important factor influencing the incidence of calf predation (Allen 2005), but is outside the scope of the present study. Rainfall influences the abundance of many wildlife species (Dickman *et al*. 1999*a*, 1999*b*; Letnic and Dickman 2006; Robin *et al*. 2009), which are prey of wild dogs. Reduced availability of alternative prey may explain the trend for calf loss to occur when rainfall had been below average. How baiting-induced perturbations affect a wild dog pack's hunting ability and how they select and handle prey is largely unknown (Allen 2012) yet these data show that baiting increases the risk of calf predation particularly in dry seasonal conditions.

Wild dogs are unlikely to have any difficulty locating calves because cattle and calves bellow noisily and can be easily located around watering points. However, Rankine and Donaldson (1968) observed that cows disassociated from other cattle to give birth a relatively long distance away from water. While the 'paddocks were small by local standards' in Rankine and Donaldson's (1968) study, cows had to leave newborn calves for at least an hour to walk to water, a distance of ~3 km. During this time they observed that newborn calves would lie anywhere and sleep and would wake up to find they had been left behind. Calves responded by wandering along bellowing until their mothers came for them. Even at 6 weeks of age, calves were seldom observed to go to water (Rankine and Donaldson 1968). This behaviour predisposes young calves to wild dog attack – the age that also coincides with the time when most calves disappear and are recorded as 'unknown losses' in reproductive performance studies (e.g. Rankine and Donaldson 1968; Entwistle 1974; Holroyd 1977; Hetzel *et al*. 1989; Burns *et al*. 2010). In contrast, when cows and calves return to their herd, the behaviour of adult cattle to cooperatively protect calves, by mobbing against wild dogs if they threaten calves and forming crèches of up to 20 calves in the custody of two or three adult cattle, helps to deter wild dog attacks. In addition, the bodyweight of newborn calves almost doubles over their first 6 weeks from 33–40 kg at birth to 70–80 kg at 50 days old (Tierney *et al*. 1992), making attacks to maturing calves in the presence of cows increasingly more risky and difficult for wild dogs.

Implications for management

This and previous studies (Table 1) show that wild dogs do not routinely kill calves in detectable quantities in extensive rangeland areas. Consequently, wild dog baiting would not be economically justified most of the time. Predation can occur when seasonal conditions deteriorate and may become economically justified at times, but the quantity of bait distributed, the frequency and timing of baiting programs or the scale they were applied in this study did not appear to prevent substantial losses. In contrast to the fundamental aim of wild dog control, calf losses were greater and occurred more frequently in baited areas. This situation creates a serious management dilemma when different livestock grazing enterprises are intermixed, because sheep and goat enterprises are vulnerable to unacceptable levels of wild dog predation irrespective of seasonal conditions, whereas, neighbouring beef producers are seldom affected by predation. Understanding what triggers predation events and how baiting subsequently changes prey selection and hunting strategies remains a high priority for managing wild dogs in extensive beef cattle production regions.

Acknowledgements

The Bureau of Resource Sciences and Queensland Department of Agriculture, Fisheries and Forestry jointly funded this project. I gratefully acknowledge the advice of Dick Holroyd in the study design and the assistance of Tony Gonzalez who assisted in monitoring the Mt Owen site, Rick Engeman and Allan Lisle for statistical advice, and Alan Newsome and Hamish McCallum for supervision and encouragement. I am particularly indebted to the Bucknell family (Mt Owen) and Peter McNeven (Manager of Strathmore) for their hospitality, patience, assistance, cooperation and for allowing me access to their property and livestock. I also acknowledge Ben Allen, Geoff Fordyce, Tony Pople and two anonymous referees for editorial advice on the manuscript.

References

Allen LR (2005) The impact of wild dog predation and wild dog control on beef cattle production, PhD thesis, The University of Queensland, St Lucia.

Allen BL (2012) Scat happens: spatiotemporal fluctuation in dingo scat collection rates. *Australian Journal of Zoology* **60**, 137–140. doi:10.1071/ZO12038

Allen L, Fleming PJS (2004) Review of canid management in Australia for the protection of livestock and wildlife – potential application to coyote management. *Sheep & Goat Research Journal* **19**, 97–104.

Allen LR, Sparkes EC (2001) The effect of dingo control on sheep and beef cattle in Queensland. *Journal of Applied Ecology* **38**, 76–87. doi:10.1046/j.1365-2664.2001.00569.x

Allen L, Engeman R, Krupa H (1996) Evaluation of three relative abundance indices for assessing dingo populations. *Wildlife Research* **23**, 197–206. doi:10.1071/WR9960197

Allen BL, Engeman RM, Allen LR (2011*a*) Wild dogma II: the role and implications of wild dogma for wild dog management in Australia. *Current Zoology* **57**, 737–740.

Allen BL, Engeman RM, Allen LR (2011*b*) Wild dogma: an examination of recent 'evidence' for dingo regulation of invasive mesopredator release in Australia. *Current Zoology* **57**, 568–583.

Allen L, Goullet M, Palmer R (2012) The diet of the dingo (*Canis lupus dingo* and hybrids) in north-eastern Australia: a supplement to the paper of Brook and Kutt (2011). *The Rangeland Journal* **34**, 211–217. doi:10.1071/RJ11092

Bauer FH (1962) Sheep-raising in northern Australia: a historical review. In 'The simple fleece: studies in the Australian wool industry'. (Ed. A Barnard) pp. 457–471. (Melbourne University Press: Melbourne)

Brown A, Towne S, Jephcott S (2003) Calf loss observation study – 2001. *The Australian Cattle Veterinarian* **26**, 8–16.

Burns BM, Tierney TJ, Rudder TH, Esdale CR, Howitt CJ, O'Rourke PK (1992) Productivity of Hereford, high grade Simmental and grade Belmont Red beef herds in a sub-tropical environment. 1. Pregnancy, calving and weaning rates. *Australian Journal of Experimental Agriculture* **32**, 551–557. doi:10.1071/EA9920551

Burns BM, Fordyce G, Holroyd RG (2010) A review of factors that impact on the capacity of beef cattle females to conceive, maintain a pregnancy and wean a calf – implications for reproductive efficiency in northern Australia. *Animal Reproduction Science* **122**, 1–22. doi:10.1016/j.anireprosci.2010.04.010

Corbett LK (2001) 'The dingo in Australia and Asia.' (J. B. Books, South Australia: Marleston)

Daly JJ (1971) Beef breeder study in the north-west. *Queensland Agriculture Journal* **97**, 93–100.

Dickman CR, Letnic M, Mahon PS (1999*a*) Population dynamics of two species of dragon lizards in arid Australia: the effects of rainfall. *Oecologia* **119**, 357–366. doi:10.1007/s004420050796

Dickman CR, Mahon PS, Masters P, Gibson DF (1999*b*) Long-term dynamics of rodent populations in arid Australia: the influence of rainfall. *Wildlife Research* **26**, 389–403. doi:10.1071/WR97057

Dixon R (1998) Collation of recent information on productivity and use of supplements for breeders in the marginal and harsh regions of northern Australia, 1995. Appendix 3, milestone report 3. In 'Beef cattle performance in northern Australia: a summary of recent research'. (Ed. PJS Hasker) pp. 1–61. (Meat and Livestock Australia, Qld Department of Primary Industries, and Beef Industry Institute: Sydney)

Eldridge SR, Shakeshaft BJ, Nano TJ (2002) 'The impact of wild dog control on cattle, native and introduced herbivores and introduced predators in central Australia, Final Report to the Bureau of Rural Sciences.' (Parks and Wildlife Commission of the Northern Territory: Alice Springs)

Engeman R, Allen L (2000) Overview of a passive tracking index for monitoring wild canids and associated species. *Integrated Pest Management Reviews* **5**, 197–203. doi:10.1023/A:1011380314051

Engeman RM, Pipas MJ, Gruver KS, Allen L (2000) Monitoring coyote population changes with a passive activity index. *Wildlife Research* **27**, 553–557. doi:10.1071/WR98090

Entwistle KW (1974) Reproduction in sheep and cattle in the Australian arid zones. In 'Studies of the Australian arid zone II. Animal production'. (Ed. AD Wilson) pp. 85–97. (CSIRO Publishing: Melbourne)

Entwistle KW, Goddard ME (1984) Productivity of some *Bos indicus* cross genotypes in sub-coastal north Queensland. In 'Evaluation of large ruminants for the Tropics, ACAIR workshop, Rockhampton'. (Ed. JW Copland) pp. 156–160. (CSIRO Publishing: Melbourne)

Evangelista P, Engeman R, Tallents L (2009) Testing a passive tracking index for monitoring the endangered Ethiopian wolf. *Integrative Zoology* **4**, 172–178. doi:10.1111/j.1749-4877.2009.00147.x

Finlayson HH (1935) 'The red centre: man and beast in the heart of Australia.' (Angus and Robertson Ltd: Sydney)

Fleming PJS, Allen BL, Ballard G, Allen LR (2012) 'Wild dog ecology, impacts and management in northern Australian cattle enterprises: a review with recommendations for R, D & E investments.' (Meat & Livestock Australia: North Sydney)

Fleming PJS, Allen BL, Allen LR, Ballard G, Bengsen AJ, Gentle MN, McLeod LJ, Meek PD, Saunders GR (In press) Management of wild canids in Australia: free-ranging dogs and red foxes. In 'Carnivores of Australia: past, present and future'. (Eds AS Glen, CR Dickman) (CSIRO Publishing: Melbourne)

Gibson AL (1987) Northern South Australia cattle industry survey, Technical Report 113. Department of Agriculture, Adelaide.

Hasker PJS (2000) 'Beef cattle performance in northern Australia: a summary of recent research.' (Meat and Livestock Australia, QLD Department of Primary Industries, and Beef Industry Institute: Sydney)

Hetzel DJS, Mackinnon MJ, Dixon R, Entwistle KW (1989) Fertility in a tropical beef herd divergently selected for pregnancy rate. *Animal Production* **49**, 73–81. doi:10.1017/S0003356100004268

Hewitt L (2009) 'Major economic costs associated with wild dogs in the Queensland grazing industry.' (Agforce: Brisbane)

Holroyd RG (1977) Reproductive performance of beef cattle in north Queensland. Masters thesis, James Cook University, Douglas.

Holroyd RG (1978) Methods of investigation of beef cattle fertility. In 'Beef cattle production in the tropics'. (Eds RM Murray, KW Entwistle) pp. 233–246. (James Cook University Press: Cairns)

Holroyd RG (1987*a*) Aspects of reproduction in *Bos indicus* genotypes. PhD thesis, James Cook University, Douglas.

Holroyd RG (1987*b*) Foetal and calf wastage in *Bos indicus* cross beef genotypes. *Australian Veterinary Journal* **64**, 133–137. doi:10.1111/j.1751-0813.1987.tb09661.x

Holroyd RG, Arther BA, Mayer BG (1979) Reproductive performance of beef cattle in north-western Queensland. *Australian Veterinary Journal* **55**, 257–262.

Kirby GWM (1974) Cattle breeding in the Northern Territory. In 'International training course in beef production and ranch management: selected reference papers'. (Australian Development Assistance Agency, Department of Foreign Affairs: Canberra)

Lamond DR (1969) Sources of variation in reproductive performance in selected herds of beef cattle in north-eastern Australia. *Australian Veterinary Journal* **45**, 50–58. doi:10.1111/j.1751-0813.1969.tb13689.x

Letnic M, Dickman CR (2006) Boom means bust: interactions between the El Niño/Southern Oscillation (ENSO), rainfall and the processes threatening mammal species in arid Australia. *Biodiversity and Conservation* **15**, 3847–3880. doi:10.1007/s10531-005-0601-2

MacDonald N, Orton J, Hearnden M (1997) 'Mt Sanford Project, pasture trends and calving patterns.' (Northern Territory Department of Primary Industries and Fisheries: Darwin)

Mitchell B, Balogh S (2007) 'Monitoring techniques for vertebrate pests: wild dogs.' (NSW Department of Primary Industries, Bureau of Rural Sciences: Orange)

O'Rourke PK, Fordyce G, Holroyd RG, Sullivan RM (1995*a*) Mortality, wastage, and lifetime productivity of *Bos indicus* cows under extensive grazing in northern Australia 3. Comparison of culling strategies. *Australian Journal of Experimental Agriculture* **35**, 307–316. doi:10.1071/EA9950307

O'Rourke PK, Sullivan RM, Neale JA (1995*b*) Mortality, wastage, and lifetime productivity of *Bos indicus* cows under extensive grazing in northern Australia II. Continuous mating in the semi-arid tropics. *Australian Journal of Experimental Agriculture* **35**, 297–305. doi:10.1071/EA9950297

Post TB (1980) Post partum anoestrus in different cattle genotypes. In 'Fertility in tropical cattle symposium'. Rockhampton. (Ed. DB Seibert) pp. 29–33. (CSIRO Publishing: Melbourne)

Ramlibakry W (1981) Reproductive performance of *Bos indicus* cattle in coastal north Queensland. MSc thesis, James Cook University, Douglas.

Rankine G, Donaldson LE (1968) Animal behaviour and calf mortalities in a north Queensland breeding herd. *Proceedings of the Australian Society of Animal Production* **7**, 138–143.

Robin L, Heinsohn R, Joseph L (2009) 'Boom and bust: bird stories for a dry country.' (CSIRO Publishing: Melbourne)

Rolls EC (1969) 'They all ran wild: the animals and plants that plague Australia.' (Angus and Robertson Publishers: Sydney)

Schatz TJ, Hearnden MN (2008) Heifer fertility on commercial cattle properties in the Northern Territory. *Australian Journal of Experimental Agriculture* **48**, 940–944. doi:10.1071/EA08057

Schlink AC, Carpenter M, Brown AH (1994) Productivity of a *Bos indicus* cross cattle herd in the western gulf region of the Northern Territory. *Proceedings of Australian Society of Animal Production* **20**, 93–96.

Smith M (Ed.) (1999) 'Natural resource monitoring guide.' (Department of Natural Resources: Brisbane)

Sullivan RM, O'Rourke PKO, Neale JA (1997) A comparison of once- and twice-yearly weaning of an extensive herd in northern Australia II: progeny growth and heifer productivity. *Australian Journal of Experimental Agriculture* **37**, 287–293. doi:10.1071/EA95098

Thomson PC (1992*a*) The behavioural ecology of dingoes in north-western Australia: II. Activity patterns, breeding season and pup rearing. *Wildlife Research* **19**, 519–530. doi:10.1071/WR9920519

Thomson PC (1992*b*) The behavioural ecology of dingoes in north-western Australia: III. Hunting and feeding behaviour, and diet. *Wildlife Research* **19**, 531–541. doi:10.1071/WR9920531

Tierney TJ, Rudder TH, Webber RJ, Burns BM, Knights PT, Howitt CJ (1992) Productivity of Hereford, high grade Simmental and Belmont Red beef herds in central Queensland II: liveweight of the breeding herd and progeny up to weaning. *Australian Journal of Experimental Agriculture* **32**, 559–562. doi:10.1071/EA9920559