CSIRO PUBLISHING

Wildlife Research, 2012, **39**, 220–229
http://dx.doi.org/10.1071/WR11135

Good dog! Using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems

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Abstract

Context. Wild predators are a serious threat to livestock in Australia. Livestock guardian dogs (LGDs) may be able to reduce or eliminate predation, but their effectiveness in Australian grazing systems has not been systematically evaluated. In particular, little is known about the effectiveness of LGDs in situations where they range freely over large areas in company with large numbers of livestock.

Aims. We aimed to evaluate the effectiveness of LGDs as currently used in Australia and determine the factors influencing effectiveness, in particular in relation to scale of management. We also documented how LGDs are managed in Australia, evaluated their cost effectiveness, and identified factors that influence the number of dogs required in different property situations.

Methods. We conducted a telephone survey of 150 livestock producers with LGDs in Australia, including all livestock types and property situations, in all States. Ten producers were visited, of which one is detailed as a case study.

Key results. Effectiveness was apparently high: 65.7% of respondents reported that predation ceased after obtaining LGDs, and a further 30.2% reported a decrease of predation. When the number of stock per dog exceeds 100, LGDs might not be able to eliminate all predation. Dogs are often kept free-ranging on large properties where wild dogs are the main predator, but are usually restricted in their movements on smaller properties or with smaller predators. The cost of obtaining a LGD is returned within 1–3 years after the dog starts working. The number of dogs required for a property mainly depends on the number of livestock needing protection, and the main type of predator in the area.

Conclusions. Provided a sufficient number of LGDs are used, they can be as effective in protecting livestock from predators in Australia when ranging freely on large properties with large numbers of livestock as they are in small-scale farming systems.

Implications. LGDs can provide a cost-effective alternative to conventional predator control methods in Australia's extensive grazing enterprises, potentially reducing or eliminating the need for other forms of control. LGDs could play a major role in securing the viability of livestock businesses and reconciling people–predator conflict in Australia.

Additional keywords: dingo, human–wildlife conflict, LGD, LPD, predation, predator control, red fox, wild dog, wildlife management.

Received 26 July 2011, accepted 12 January 2012, published online 5 April 2012

Introduction

Livestock guardian dogs (LGDs) have been used for centuries to protect domestic animals from predators and thieves in Europe and Asia. These are generally large breeds of dogs that are trained to live fulltime with livestock, which they treat as their social companions. This is achieved by keeping the dogs with livestock from an early age so that the pups develop a strong bond with them, growing into adult dogs who choose to remain with that type of livestock and display strongly affiliative and protective behaviour towards them for the rest of their lives (Coppinger and Coppinger 2001, 2007; Coppinger *et al*. 1983).

Following the eradication of large predators from parts of Europe, knowledge of LGDs was almost lost, but where predators persisted, so did the tradition of using dogs to guard livestock (Coppinger and Coppinger 2001). Interest in the use of LGDs developed in the USA following the banning of poison to control wild predators in the 1970s (Green and Woodruff 1980; McGrew and Blakesley 1982; Pfeifer and Goos 1982; Shivik 2006). From the USA, LGDs spread to Canada, South America, Africa, and back to Europe as the need for them returned with the restoration of large predators to parts of their former ranges (Gehring *et al*. 2010*a*; Landry 1999*b*; Rigg 2001). Studies on the effectiveness of LGDs are limited, and there are especially few rigorous studies of the factors influencing effectiveness (Gehring *et al*. 2010*a*). However, there is evidence (either experimental or anecdotal) that these dogs can be effective in protecting many types of livestock from many different types of predators, including canids, felids, mustelids and ursids (older studies reviewed in Rigg 2001; see also Gehring *et al*. 2010*b*; Hansen *et al*. 2002; Marker *et al*. 2005*a*; Otstavel *et al*. 2009; Rigg *et al*. 2011). LGDs have the potential to eliminate stock losses from predation, and user satisfaction with the dogs is generally high (Marker *et al*. 2005*a*; Otstavel *et al*. 2009; Rigg 2001). However, on small properties, adequate containment areas for LGDs can be important (Gehring *et al*. 2011). Recent field studies have shown that as well as excluding predators, LGDs can also provide benefits for livestock production by deterring wild herbivores from using pastures grazed by livestock (Gehring *et al*. 2010*b*; Gingold *et al*. 2009; Vercauteren *et al*. 2008).

In Australia, predators cause considerable financial losses in the livestock industries. Wild dogs (including dingoes) have the largest impact, as they affect all livestock species over the entire continent, while smaller predators target smaller stock. The greatest damage is caused to the sheep and cattle industries (Fleming *et al*. 2001; Lightfoot 2011). This has led to a major human–wildlife conflict, and as a result, large-scale control of wild dog populations. Exclusion fencing and lethal control by poisoning are most commonly used for the management of wild dogs and other predators (Allen and Fleming 2004; Allen and Sparkes 2001; Fleming *et al*. 2001). Lethal control is carried out not only in agricultural areas, but also in National Parks in order to protect surrounding livestock producers (Fleming *et al*. 2001; Harden 2001).

The use of LGDs for stock protection is relatively unknown in Australia (Jenkins 2003), but interest in this method is increasing (van Bommel 2010). Traditionally, these dogs are used in groups, working together with a shepherd who keeps the stock together and provides backup for the LGDs when necessary (Coppinger and Coppinger 2001; Gehring *et al*. 2010*a*; Landry 1999*a*; Rigg 2001). However, in Australia LGDs need to work unsupervised with large numbers of stock that may range over large areas. In the sheep rangelands, for example, properties are commonly several thousand hectares in area, and cattle are typically grazed even more extensively. Flocks or herds are for the most part managed with low input and low-intensity monitoring by livestock managers. Some studies from the USA and Europe have suggested that LGDs might be less effective when working over large areas, with large numbers of stock that do not flock very well, and with minimal supervision (Coppinger *et al*. 1988; Hansen and Smith 1999).

Very little information is available on the use of LGDs in Australia. In particular, there has been no systematic evaluation of their performance when ranging over large areas in company with large numbers of livestock. In this study, we surveyed current usage of LGDs in Australia, and evaluated its effectiveness. We had several specific aims. First, we set out to document how LGDs are currently managed in Australia, and, in particular, we wanted to understand how management of the dogs varies with property size and other factors such as type of predator and landscape features. Second, we assessed the effects of LGDs on rates of predation of livestock, and we looked especially at relationships between effectiveness and the size of the area over which the dogs work and the number of stock they are given to protect. Use of LGDs is likely to become widespread only if the costs of acquiring and maintaining the dogs are more than offset by the benefits they bring. Therefore, our third aim was to conduct a simple cost–benefit analysis of the implementation of LGDs in Australia. Finally, we analysed factors that influence the number of dogs needed to achieve protection of livestock across a range of property types and sizes. We did this last analysis because, for a livestock producer contemplating the change from conventional predator control to LGDs, the first crucial choice is how many dogs will be needed for their particular situation. We wanted to produce guidelines on this that, if followed, would maximise the chance of success with LGDs.

Materials and methods

Survey methods

We surveyed 150 users of LGDs. We aimed to include a large variety of livestock types and property situations where LGDs were used. As there is no central register of LGD users in Australia and the proportion of farms using LGDs is still very low for most livestock industries, obtaining a random sample of LGD users was not practicable. Instead, we relied on informal networks of LGD users to build our sample. That is, known users were contacted and included in the sample, and we sought information from them on other users to extend the sample. We were careful to seek contacts for producers who had abandoned use of LGDs as well as continuing users, to avoid a potential bias in favour of successful cases. In addition, we obtained information from one of the major breeders of LGDs in Australia. This breeder keeps records of all dogs sold, and every third person on her records who obtained the dog for livestock guarding was included in the survey.

We included only producers with an agricultural business meeting the minimum size cut-off of the Australian Business Register in 2006/2007. Whether potential participants met this criterion was estimated from the value of livestock owned and produced yearly in the time they stated they were using LGDs. As far as possible, all livestock types, LGD breeds, and property sizes and situations were represented. To ensure a wide and representative geographical coverage, the number of participants in each State was selected in proportion to the number of livestock producers in that State as recorded by the Australian Bureau of Statistics (ABS 2007).

The interviews were semi-structured, with open questions. Questions covered topics including number of years since obtaining the first LGD, property situation (size, number and type of stock etc), number of dogs used, loss to predation before and after obtaining LGDs, costs of dogs, and methods of training and management of dogs. The complete list of survey questions is available on request from the corresponding author. Surveys were conducted by phone at a time that suited the participants, and all surveys were conducted by one researcher (LvB) between June 2008 and December 2009.

Notes were taken during the interviews to record the participant's responses. Not all participants were able to respond to all questions, for example if no records of yearly predation were kept. In that case, a 'no response' answer was registered. Ten properties were visited, and detailed information collected. These properties were selected based on their size and the property owner's willingness and ability to provide detailed information. A range of property sizes from small to large was included in the selection. One of these properties is described as a case study.

Statistical analysis

For the calculation of the relationship between property size and management type of LGDs, the variable property size was log-transformed before analysis.

The percentage decrease of predation after implementation of LGDs was calculated using the formula: ((% predation of flock before obtaining LGDs – % predation of flock after LGDs start working)/% predation before obtaining LGD)) for those participants able to provide estimates of predation before and after obtaining LGDs. Often participants were unable to do this. 100% decrease means all predation ceased, 0% decrease means predation continued on the same level as before.

A generalised linear model was used to investigate the factors influencing the magnitude of the change in predation rate following implementation of LGDs. Only sheep and goats were included in this analysis, as there were too few cases of dogs working with cattle, and it was deemed that the management system for free-range poultry was too different from sheep and goats for them to be combined in analysis. For this analysis, the decrease in predation was entered in the model as a binary variable, with the two states being elimination of predation versus a continuation of predation even if losses due to predation decreased as a result of use of LGDs. A logistic link function was used. The independent variables were: (1) size of the area used by livestock; (2) size of the area used by livestock divided by number of dogs in the same area; (3) total number of stock guarded by LGDs on the property; (4) number of stock per LGD; (5) total number of LGDs on a property; (6) main type of predator in the area (wild dog or fox/other); (7) management type of dogs (whether free range or restricted); (8) vegetation on the property (open or dense); and (9) whether the property was mainly flat or hilly. The first four variables were log-transformed before analysis, and as there was high correlation among these four variables ($r > 0.69$, $P < 0.001$ for all combinations), only the one that had the highest correlation with the dependent variable was included in the final analysis. Principal Components Analysis was not used in this case, as the strong correlation between the variables means that calculating a principal component is unlikely to provide a better description of the data than just using one of the variables in the analysis. In addition, using one of the variables avoids the complication of replacing a concrete variable with an abstract one that would be much harder to understand. Deviance was used as a scaling parameter in the model. All combinations of variables were tried in the model, and the resulting models were ranked according to their Akaike Information Criterion (AIC) weight (Symonds and Moussalli 2011). The importance of individual variables was also analysed by calculating their AIC weight (Symonds and Moussalli 2011).

A generalised linear model was fitted to the sheep and goat data to investigate the factors influencing the number of LGDs needed on a property in order to satisfactorily reduce predation. For this analysis, we included only those properties for which the property owner had reported that he or she was happy with the performance of their dogs and believed that they had sufficient dogs for their property situation. The Poisson distribution was the best fit for the variable [number of dogs on the property], and was therefore the distribution of choice when [number of dogs on the property] was tested in the model as the dependent variable. A loglinear link function was used. The explanatory variables were variables (1), (3), (6), (7), (8) and (9) above. The first two variables were log-transformed, and as there was high correlation between these two variables ($r = 0.82$, $P < 0.001$, $n = 97$), only the one that had the highest correlation with the dependent variable was included in the final analysis. Principal Components Analysis was not used for the same reasons as stated above. Deviance was used as a scaling parameter in the model. All combinations of variables were tested in the model, and the resulting models were ranked according to their AIC weight, as above.

The number of years until LGDs become profitable was calculated for the following livestock categories: sheep, lambs, goats (including goat kids), cattle and poultry. First, we used the information provided by participants in the survey to estimate the cost a producer would incur each year through obtaining and maintaining a LGD, and accumulated this cost over the years of a working LGD's life. Then, for each livestock type, we estimated the average number of livestock saved each year per LGD based on information provided by the respondents, converted this number into a monetary value, and also accumulated this value over the LGD's lifetime. The following dollar values per head of stock were used: AU$810 for calves and cattle, AU$39.70 for sheep, AU$89.90 for lambs, AU$35 for goats and goat kids and AU$3.70 for chickens (ABARE 2009; Agnew *et al*. 2010). These were the average values per head for animals sold for slaughter, and it was assumed this would be the value a farmer could obtain from the animal if it was not taken by predators either as a juvenile or adult. Lambs have a higher individual value than mature sheep, and are therefore included as a separate category, as the loss of a lamb would mean a greater loss than that of a mature sheep. The estimates represent a minimum average value, because many animals would either have a higher individual value (e.g. stud animals) or would provide more value by generating products over their lifetime (breeding animals that produce offspring, animals kept for fleece or eggs, etc.). Finally, on a yearly basis the accumulated cost of implementing a dog was subtracted from the accumulated value of stock protected to produce an estimate of cost or gain from the LGD to that point in time. It was assumed that in the first year the LGD was in training and would not protect any animals so would represent a cost only. We further assumed that in its second year the dog would only be half effective, as LGDs take up to 2 years to mature and before maturity juvenile play behaviour can still interfere with effective guarding (Dawydiak and Sims 1990;

Lorenz and Coppinger 1986; Rigg 2001). The dog was assumed to be fully effective in the third year and later.

All statistical analyses were done in PASW Statistics 18 (IBM, Armonk, NY). Values are represented as mean ± s.e. Sample sizes indicate number of respondents included in a particular analysis; not all respondents could answer all questions. *t*-tests and χ^2-tests were used to test for significant differences between categories of a variable.

Results

Composition of survey sample

Use of LGDs seems to be higher in some industries than in others: in the survey 7% of 150 participants reported using dogs with cattle; 28% ran LGDs with sheep; 21% with free-range poultry; 39% with goats; and 4% with other livestock types (alpacas, rabbits, horses, pigs or emus/ostriches). Participants often had LGDs with multiple livestock species. For comparison, Australia-wide, 58% of livestock producers run cattle, 32% run sheep, 3% run poultry and 2% run goats (ABS 2007). Of the 150 participants in the survey, 35% were located in New South Wales and the Australian Capital Territory, 25% in Victoria, 19% in Queensland, 9% in South Australia, 8% in Western Australia, 3% in Tasmania and 1% in the Northern Territory. Climatic conditions on the properties ranged from alpine to dry tropical.

The time that participants had been using LGDs varied between 2 weeks and 30 years. The distribution of the time since first use shows a relatively equal distribution of users of dogs up to 15 years, after which there is a decrease (Fig. 1). Property sizes of participants ranged from 3 ha to 125 000 ha, and number of stock ranged from 14 to 40 000. The dog breed most often used to guard livestock was the Maremma sheepdog (143 respondents). Also used were Pyrenean mountain dogs (three participants), Central Asian ovcharkas (six participants), Anatolian shepherds (four participants) and crosses between different LGD breeds (six participants). Participants sometimes had more than one LDG breed. The number of LDGs per property ranged from one to 25.

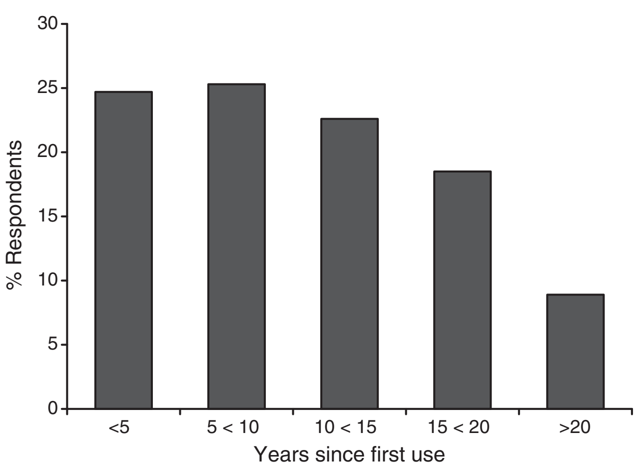

Fig. 1. Percentage of participants in each category of number of years since livestock guardian dogs (LGDs) were first used.

Management of LGDs

The majority of the participants ($n = 111$ out of 150 respondents) indicated that they had tried to bond their LGD to their livestock, usually by putting a pup with young stock and progressively increasing the area and number of stock available to it. Often other training was also provided ($n = 106$ out of 150 respondents), for example boundary training or lead training. Thirty-nine respondents did no training at all, and in 36 of these cases this was because their dog was already trained when they got it, or because an older dog taught the newcomer. Bonding with livestock was least likely to be attempted on smaller mixed farms, where the LGD was not required to spend all of its time with one type of livestock, but rather was expected to roam the farm giving protection to all types of stock. In such cases the farmer sometimes chose to allow the pup to follow them around during the day, and in this way slowly get used to the different types of animals on the farm. Most participants ($n = 111$ out of 150 respondents) reported having had problems with their LGDs at some stage, most often with juvenile play behaviour. The majority of participants solved problem behaviour eventually, but 33 participants indicated they had destroyed one or more problem dogs because of severe behavioural problems.

Two distinct systems for managing LGDs were used: either the dog (or group of dogs) was restricted to one particular paddock by training or fencing ($n = 70$ out of 150 respondents); or the dog (or group) was allowed to wander freely at least within the perimeter of the property ($n = 67$ out of 150 respondents). Which system was used depended mainly on the main predator type and the property size. Predator type and property size were related: properties with wild dogs as the main predator tended to be larger than properties with foxes as the main predator ($n = 138$, $t = 4.05$, d.f. = 135, $P < 0.001$). LGDs were more likely to be free ranging when defending against wild dogs than smaller predators like foxes ($\chi^2 = 4.91$, d.f. = 1, $P = 0.03$). When dogs were free-ranging, properties were on average larger than when dogs were restricted in their movements ($n = 137$, $t = 2.04$, d.f. = 107.82, $P = 0.04$). The number of dogs per group also differed, being smaller when movement was restricted (1.5 ± 0.07) than when the dogs ranged freely (3.0 ± 0.37; $n = 286$, $t = 3.96$, d.f. = 98.5, $P < 0.00$). Since cattle are usually run on large properties, cattle usually had free ranging LGDs with them (this was the case in 80% of participants with cattle). If cattle were excluded there was no significant difference between management types of LGDs for different species of livestock.

Effectiveness of LGDs

Some participants ($n = 21$ out of 150 respondents) indicated that they got LGDs as a preventative measure against predation, having suffered no predation on their stock before obtaining LGDs, or having obtained the LGDs at the same time as their stock. Other participants ($n = 126$ out of 150 respondents) obtained LGDs as a result of a history of predation on their livestock. Of these, 85 (68%) reported that predation ceased after the LGDs started working, and a further 38 (30%) said that predation decreased after their dog(s) started working. Three participants (2%) reported that their LGDs made no difference. This was mainly because of problems with management of the dogs, and the dogs were often only kept for a short period. Fig. 2

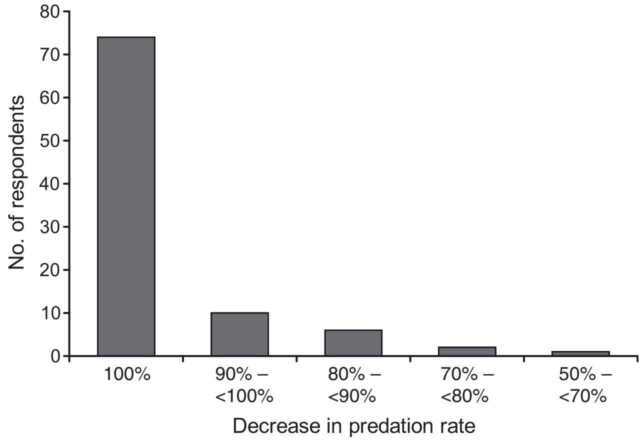

Fig. 2. Percentage decrease in predation after livestock guardian dogs (LGDs) started working, calculated from the participants who were able to give figures of % predation before and after obtaining LGDs ($n = 93$).

shows the breakdown in percentage decrease in predation after obtaining LGDs, calculated for the participants who were able to give predation rates before and after LGDs ($n = 93$ out of 150 respondents). User satisfaction was generally high, with 95% of participants ($n = 143$ out of 150 respondents) stating that they thought their dogs were a cost-effective way of protecting livestock.

Of the four highly correlated variables [size of the area used by livestock], [size of the area used by livestock divided by number of dogs in the same area], [total number of stock on the property that is guarded by LGDs] and [number of stock per LGD] used in the binary logistic regression to identify which factors influence elimination of predation, the variable [number of stock per LGD] had the highest correlation with the dependent variable ($r = 0.30$, $P = 0.004$, $n = 86$, $n = 124$ respondents) and was retained. Of all combinations of variables, the model including only [number of stock per LGD] had the highest Akaike weight, but 29 other variable combinations fall into the 95% confidence interval. These other models always contained the variable [number of stock per LGD], and only that variable was significant in any of the models (Table 1). The Akaike weights of the variables were as follows: [number of stock per LGD] = 0.96; [total number of LGDs on a property] = 0.25; [main type of predator in the area] = 0.43; [management type of dogs] = 0.36; [vegetation on the property] = 0.45; [flat or hilly] = 0.33, indicating that [number of stock per LGD] is likely the most important variable determining the effectiveness of the LGDs. The more livestock a LGD was given to protect, the higher the probability that predation would not cease completely. When the number of stock per dog exceeded 100, 21 (54% of 39) respondents reported predation was eliminated, but 18 (46% of 39) respondents reported predation decreased, but was not fully eliminated (Fig. 3). The effects of other variables on the effect of LGDs were small (as shown by their low Akaike weights) so we did not extend the guidelines to include them.

Table 1. 95% confidence set of best-ranked regression models (the models whose cumulative Akaike weight, acc $w_i \leq 0.95$) for the analysis of the effectiveness of livestock guardian dogs (LGDs)

If a variable had a significant effect in the model, the *P*-value is included in brackets after the variable number. Variable numbering: (4) number of stock per LGD; (5) total number of LGDs on a property; (6) main type of predator in the area (wild dog or fox/other); (7) management type of dogs (whether free range or restricted); (8) vegetation on the property (open or dense); (9) whether the property was mainly flat or hilly. AIC, Akaike Information Criterion; ER, evidence ratio

	Variables included in the model	AICc	Δi	w_i	acc w_i	ER
1	(4, *P* = 0.018)	95.68	0	0.10	0.10	
2	(4, *P* = 0.013), (8)	96.12	0.44	0.08	0.18	1.25
3	(4, *P* = 0.016), (6), (8)	96.94	0.81	0.07	0.24	1.50
4	(4, *P* = 0.025), (6)	96.55	0.87	0.06	0.31	1.54
5	(4, *P* = 0.014), (7)	96.87	1.18	0.05	0.36	1.80
6	(4, *P* = 0.019), (9)	97.09	1.41	0.05	0.41	2.02
7	(4, *P* = 0.015), (6), (7)	97.09	1.41	0.05	0.46	2.02
8	(4, *P* = 0.013), (8), (9)	97.27	1.59	0.04	0.50	2.21
9	(4, *P* = 0.012), (6), (7), (8)	97.79	2.10	0.03	0.54	2.86
10	(4, *P* = 0.022), (5)	97.82	2.14	0.03	0.57	2.91
11	(4, *P* = 0.012), (7), (8)	97.89	2.20	0.03	0.60	3.01
12	(4, *P* = 0.013), (7), (9)	97.97	2.29	0.03	0.63	3.14
13	(4, *P* = 0.017), (6), (8), (9)	98.10	2.41	0.03	0.66	3.34
14	(4, *P* = 0.016), (5), (8)	98.21	2.53	0.03	0.69	3.53
15	(4, *P* = 0.026), (6), (9)	98.31	2.63	0.03	0.72	3.72
16	(4, *P* = 0.025), (5), (6)	98.67	3.00	0.02	0.74	4.49
17	(4, *P* = 0.015), (6), (7), (9)	98.70	3.02	0.02	0.76	4.52
18	(4, *P* = 0.017), (5), (6), (8)	98.76	3.03	0.02	0.78	4.65
19	(4, *P* = 0.012), (7), (8), (9)	98.83	3.14	0.02	0.80	4.81
20	(4, *P* = 0.017), (5), (7)	99.04	3.35	0.02	0.82	5.35
21	(4, *P* = 0.015), (5), (6), (7)	99.28	3.60	0.02	0.84	6.03
22	(4, *P* = 0.013), (6), (7), (8), (9)	99.29	3.61	0.02	0.86	6.07
23	(4, *P* = 0.022), (5), (9)	99.31	3.62	0.02	0.88	6.13
24	(4, *P* = 0.016), (5), (8), (9)	99.50	3.81	0.01	0.89	6.73
25	(4, *P* = 0.014), (5), (7), (8)	100.02	4.33	0.01	0.90	8.73
26	(4, *P* = 0.013), (5), (6), (7), (9)	100.11	4.43	0.01	0.91	9.13
27	(4, *P* = 0.015), (5), (7), (9)	100.25	4.57	0.01	0.92	9.81
28	(4, *P* = 0.016), (5), (6), (8), (9)	100.41	4.73	0.01	0.93	10.63
29	(4, *P* = 0.026), (5), (6), (9)	100.48	4.80	0.01	0.94	11.00
30	(4, *P* = 0.015), (5), (6), (9)	101.11	5.43	0.01	0.95	15.10

Cost–benefit analysis

On average, the cost of buying a LGD was AU\$600 ± 26 ($n = 150$ respondents), with initial additional costs for neutering and vet check/vaccinations of approximately AU\$340 (RSPCA 2011). Yearly running costs added up to AU\$467 ± 37 ($n = 133$, $n = 150$ respondents), for dog food and health care. Sometimes emergency vet treatment was necessary, the cost of which could be high.

The cost of purchasing and maintaining a LGD was usually fully offset by the values of stock saved within 1–3 years of the LGD becoming fully effective (Fig. 4). On average, after a year of training a dog, costs were returned within a year for sheep and lambs, within 2 years for cattle and within 3 years for poultry and goats. These figures will vary depending on the value of the livestock being guarded, numbers saved from predation, and the actual expenses incurred when implementing a LGD.

Number of LGDs

The variables [size of area for livestock] and [total number of livestock to be guarded by dogs] were highly correlated with one

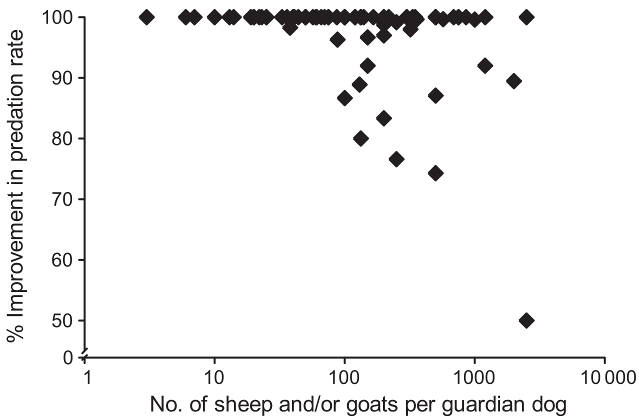

Fig. 3. Percentage decrease in predation rate after obtaining livestock guardian dogs (LGDs) as a function of the average number of sheep and/or goats per LGD ($n = 79$). 100% decrease in predation means that predation is reduced to zero.

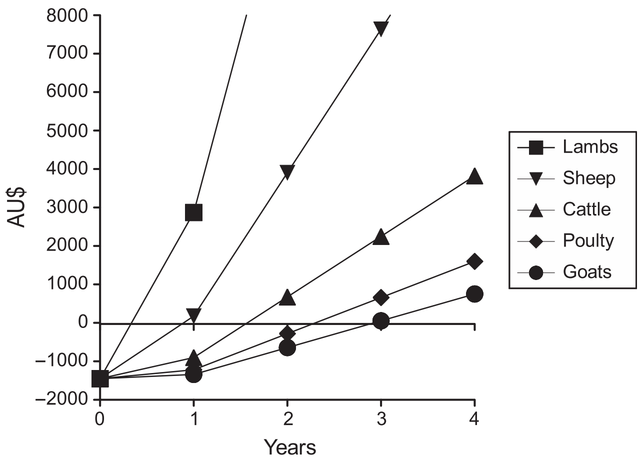

Fig. 4. Cost effectiveness of running a livestock guardian dog (LGD) in the different livestock categories, based on accrued costs and returns in relation to time since implementing LGDs. Costs of obtaining a dog and yearly maintenance were subtracted from yearly profit from additional income of stock saved. It was assumed that in the first year (year 0), a LGD does not save any stock, and in its second year (year 1), saves only half of the stock compared with its full effectiveness when it is 2 years and older.

another, and of those [total number of livestock to be guarded by dogs] had the highest correlation with the dependent variable [number of dogs on the property] ($r = 0.53$, $P < 0.001$, $n = 102$, $n = 120$ respondents), so was retained. Of all combinations of variables, the model including only type of predator and number of livestock to be guarded by dogs had the lowest Akaike weight, but six other variable combinations fell in the 95% confidence interval. These other models always contained the variables [type of predator] and [total number of livestock to be guarded by dogs], and only those variables were significant in any of the models (Table 2). The Akaike weights of the variables were as follows: [total number of stock on the property that is guarded by LGDs] = 1.0; [main type of predator in the area] = 1.0; [management type of dogs] = 0.44; [vegetation on the property] = 0.33; [flat or hilly] = 0.35, indicating that [total number of stock on the property that is guarded by LGDs] and [main type of predator in the area] are the most important variables.

Table 2. 95% confidence set of best-ranked regression models (the models whose cumulative Akaike weight, acc $w_i \leq 0.95$) for the analysis of the number of livestock guardian dogs (LGDs) on a property

If a variable had a significant effect in the model, the *P*-value is included in brackets after the variable number. Variable numbering: (3) total number of stock on the property that is guarded by LGDs; (6) main type of predator in the area (wild dog or fox/other); (7) management type of dogs (whether free range or restricted); (8) vegetation on the property (open or dense); (9) whether the property was mainly flat or hilly. AIC, Akaike Information Criterion; ER, evidence ratio

	Variables included in the model	AICc	Δi	w_i	acc w_i	ER
1	(3, $P < 0.00$), (6, $P < 0.00$)	377.03	0	0.25	0.25	
2	(3, $P < 0.00$), (6, $P < 0.00$), (7)	377.66	0.63	0.18	0.43	1.37
3	(3, $P < 0.00$), (6, $P = 0.01$), (9)	378.29	1.26	0.13	0.56	1.87
4	(3, $P < 0.00$), (6, $P = 0.01$), (8)	378.56	1.53	0.12	0.68	2.15
5	(3, $P < 0.00$), (6, $P < 0.00$), (7), (8)	378.78	1.75	0.10	0.78	2.40
6	(3, $P < 0.00$), (6, $P < 0.00$), (7), (9)	378.82	1.80	0.10	0.88	2.45
7	(3, $P < 0.00$), (6, $P = 0.01$), (8), (9)	379.93	2.90	0.06	0.94	4.27

The number of dogs needed for effective protection was higher if there were more livestock to be guarded. On average, the respondents used 1 dog for 10 livestock, 2 dogs for 100 stock, 4 dogs for 1000 stock, 9 dogs for 10 000 stock and 20 dogs for 100 000 livestock (Fig. 5). If wild dogs are the main predator, approximately one additional LGD is needed in addition to the estimate given based on the number of livestock that need protection. The effects of other variables on numbers of dogs needed were small (as shown by their low weights) so we did not extend the guidelines to include them.

Case study: Dunluce

Dunluce is a 47 000 ha property in the Mitchell grasslands near Hughenden, Queensland. It has a dry tropical climate, with an average rainfall of 492.4 mm, mainly falling in the summer. It carries ~12 000 merino/dohne sheep and 4000 droughtmaster cattle. Dunluce is probably the most northerly sheep enterprise in eastern Australia, as many producers have switched from sheep to cattle production due to predation pressure. The main predators in the area are wild dogs and dingoes.

In 2002, before using LGDs, Dunluce was running ~22 000 sheep and 4000 cattle. The main form of predator control was poison baiting, which was done as part of a coordinated program of the local shire. In addition, Dunluce was baited privately and wild dogs were shot opportunistically. However, around 15% of the sheep flock was lost annually, with predation accounting for most mortality. The total loss of wild-dog-incurred damage on sheep was estimated to be AU$30 000. This included killed and maimed sheep, lost lambs and reduced wool production due to stress. An unknown number of calves were lost to predation as well. These losses made sheep production at Dunluce unviable.

In 2002, 24 Maremma sheepdogs were obtained and integrated with the sheep on the property. After 3 years, sheep losses were reduced to ~4% p.a., with most mortality not predator

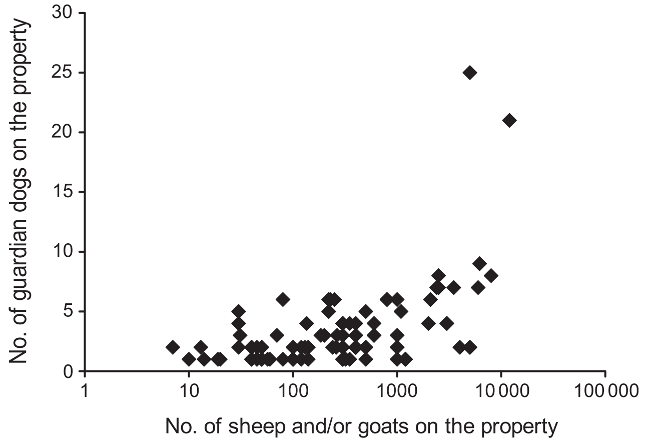

Fig. 5. Relationship between number of sheep and/or goats on properties in the survey, and the number of dogs used for successful predator control.

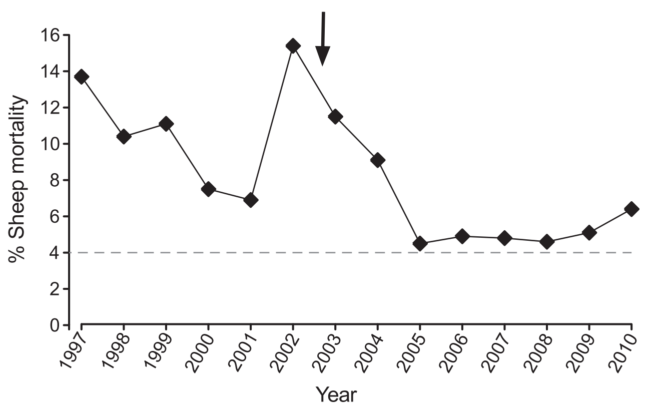

Fig. 6. Percentage of flock of sheep lost yearly at Dunluce. This percentage includes all causes of death, not only predation. 4% loss of a flock (indicated by the dotted line) is the industry accepted standard, this loss is usually due to weather, illness and accidents. Implementation of livestock guardian dogs (LGDs) is indicated by the arrow.

related (see Fig. 6). Sheep grazing is now profitable on Dunluce and poison baiting has been significantly reduced, although wild dogs are still shot opportunistically. The initial cost of obtaining the 24 dogs was approximately AU$20 000, including transport, neutering and vet checks. This money was recouped within the first 12 months in the form of additional income from sheep saved from predation. Yearly running costs are, on average, AU$6000 for maintenance and replacement of dogs. The Maremmas work unsupervised in groups of 1–4 in paddocks with sheep, but are not restricted in their movements, as they easily navigate stock fences. They are therefore free to decide for themselves which stock to guard at what time. They have access to self-feeders with ad lib dry dog food, which are set up in the paddocks containing sheep. Additional LGDs are now raised to guard the breeding cattle as well.

Discussion

Our results show that LGDs can be effective in protecting livestock in Australia from wild dogs and smaller predators. Provided a sufficient number of dogs is used, LGDs may be as effective when ranging freely on large properties where they protect large numbers of livestock as they are in small-scale farming systems. The effectiveness of LGDs in reducing stock losses has also been documented in producer surveys in other parts of the world (Andelt 1984, 1992; Andelt and Hopper 2000; Coppinger *et al*. 1983, 1988; Green 1989; Green and Woodruff 1983*a*, 1983*b*, 1985, 1990; Marker *et al*. 2005*a*; Otstavel *et al*. 2009). In most cases, as in this present study, user satisfaction with LGDs was high.

Most previous studies do not give detailed information on percentage of respondents reporting cessation or decrease in predation after obtaining LGDs, but rather give an overview of the rating of satisfaction of the owners. One exception is Coppinger *et al*. (1988), who found that on US farms, 53% of respondents reported that predation ceased after obtaining LGDs, and 77% of respondents indicated that predation had decreased (including predation ceasing altogether). The high proportion of respondents reporting that predation ceased is similar to the finding in the present study, but we had a much larger number of respondents indicating predation decreased. This difference could be due to differing research methodology. Coppinger *et al*. (1988) placed dogs on selected farms under a lease agreement and then followed their performance through time, surveying the participants each year. Our study sampled participants who had independently chosen to adopt LGDs, so they may have been more motivated to invest the time and effort needed for success. It is also possible that success rates of LGDs have increased since the 1980s, when Coppinger *et al*. (1988) did their work, because more information is now available on management of LGDs. The difference could also be explained if Australian predators are more easily deterred by LGDs. The estimates of effect of LGDs on predation rates were provided by the producers using the dogs, and the accuracy of this estimate probably varies per producer. Nonetheless, the figures still give an indication of the effect of the LGDs, and a good measure of the satisfaction of the producers with their dogs.

The effectiveness of LGDs on a property appears not to diminish over time, as long as replacement dogs are added when appropriate (Green *et al*. 1994). The time that participants in this survey had used LGDs is also an indication of this; if effectiveness decreased over time (for example if predators learned to work around the LGDs), there would have been a higher proportion of participants that had used LGDs for a couple of years only, because if after that time the dogs had lost their effectiveness their use might have been discontinued. The lower number of participants that had used their dogs for 15 years or more is probably due to the fact that 15 or more years ago these dogs were relatively unknown, and their use was not widespread. For example, the first Maremma was imported into the country in 1982, and in 1986 only 10 Maremmas were registered by the Australian National Kennel Council (ANKC 2011). It was not till the mid 1990s that their numbers rose, and > 200 dogs were registered by the ANKC each year (ANKC 2011).

The main factor influencing how well LGDs work in Australia is the number of stock they are required to protect. If the number of animals per dog exceeds 100, predation is not always fully eliminated. This could be due to large groups of livestock spreading out, or forming smaller sub-groups instead of operating as a single group, making it harder for the LGD to keep track of all the individuals. It could also depend on individual dogs' capabilities; 21 respondents with more than 100 livestock per LGD did report an elimination of predation, with one respondent having 2500 stock per LGD. If LGDs do not fully eliminate predation, this could be because there are too few of them for the property situation, and adding more dogs can reduce predation rates further. Other factors that could not be measured in this survey, for example livestock behaviour towards dogs and predator pressure and behaviour, might also influence the number of dogs needed on a property. However, even if LGDs do not fully eliminate predation, reduction of predation can still bring large benefits to producers. For many sheep producers contacted in this survey, LGDs were the crucial factor allowing them to run viable sheep-raising businesses in areas where losses to wild predators would otherwise be too great, even in those cases where LGDs did not fully eliminate predation. The majority of poultry producers also indicated that they would be unable to run free-range poultry without their LGDs. A number had lost all their birds, sometimes more than once, before using LGDs.

The expense of obtaining and maintaining a LGD was quickly recouped in most cases, especially considering that the livestock valuations used in this study were conservative. However, in addition to financial investment, LGDs require a large time commitment, especially when they are in training. Some producers reported spending as much as 50% of their time on the LGDs initially, not only looking after them, but also learning about them (van Bommel 2010). The time investment in pups was usually committed to bonding them to livestock, which most people indicated they had tried to do.

LGDs were more often free ranging on larger properties, and when wild dogs were the main predators, than on smaller properties and when foxes were the main predators. This is probably the result of several factors. On large properties it is hard to maintain dog-proof fences capable of restraining LGDs. Fence-training a LGD to non-electrified fences takes considerable time and effort (van Bommel 2010), and with large numbers of dogs it is probably not feasible. Even if a fence is electrified, it takes consistent handling to teach a LDG not to cross it (Gehring *et al*. 2011). In addition, larger properties are also often situated in more remote areas, where wild dogs still occur in higher numbers than in more densely settled areas. The presence of wild dogs was the reason most often given by participants when asked why they had their LGDs free ranging. If LGDs range freely, they can provide each other with backup in case of attack by a pack of wild dogs, which one LGD alone would be unable to handle.

There are several reasons for preferring LGDs to lethal predator control (although some lethal control of wild predators can be continued alongside use of LGDs). First, lethal control may be expensive and is often not very effective in the long run, as predator numbers quickly recover through immigration (Allen and Gonzalez 1998; Corbett 2001*b*; Fleming *et al*. 2001; Saunders *et al*. 1995). LGDs offer a long-term solution, and producers also report that their livestock become more calm, and are therefore easier to handle and more productive, in the presence of LGDs. For example, fleece quality may improve because the sheep experience less stress as a result of protection by LGDs (van Bommel 2010). Second, there are ethical concerns associated with lethal control, as it can cause suffering in targeted (and non-target) animals (Fleming *et al*. 2001; Saunders *et al*. 1995), and third, suppressing populations of the dingo, Australia's top-order predator, through lethal control also has some major disadvantages from an ecological and conservation perspective (Corbett 2001*a*, 2001*b*; O'Neill 2002; Johnson 2006; Glen *et al*. 2007; Johnson *et al*. 2007; Johnson and VanDerWal 2009; Letnic *et al*. 2009*a*, 2009*b*; Ritchie and Johnson 2009; Wallach *et al*. 2009*a*, 2009*b*, 2010; Letnic and Koch 2010).

LGDs are already used in other parts of the world to reconcile conflict between humans and wild predators, and this supports predator conservation. For example, in Namibia LGDs have been placed on farms to protect livestock from cheetah (*Acinonyx jubatus*) predation (Marker *et al*. 2005*a*, 2005*b*) and in Switzerland and France, where wolves (*Canis lupus*), bears (*Ursus arctos*) and lynx (*Lynx lynx*) are legally protected and are returning to their former ranges, the use of LGDs is encouraged to help farmers minimise predation (Landry 1999*b*). In the USA, LGDs are also used to help mitigate livestock predation in areas were wolves occur (Urbigkit and Urbigkit 2010). Perhaps LGDs can perform a similar function in Australia, facilitating the coexistence of people and wild predators.

Acknowledgements

We thank the Hermon Slade Foundation for financial support for his research. We also thank David Jenkins for his help in planning the survey, Rosemary McCarroll for her help in contacting participants for the survey, and all the participants of the survey for their time and often enthusiastic participation. Many thanks also go to Ninian and Ann Stewart-Moore for allowing us to use their property as a case study, and to Bob Forrester for advice and help with analysing the data. The research was carried out under ethics approval from the Human Research Ethics Committee, James Cook University, Ethics approval nr: H3121.

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