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Cost benefit analysis of feral pig control in North West NSW

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Executive Summary

At a farm level, managers are experiencing feral pig damage and understand that damage translates into enterprise losses. This analysis clearly outlines the cost benefit results of feral pig control across key farming enterprises in the North West New South Wales Natural Resource Management Region (NW NSW NRMR).

Previous research has investigated the extent of physical damage attributable to feral pigs for various agricultural enterprises and identified a wide range of results. Fluctuations in feral pig damage is a product of feral pig populations breeding in response to the environment around them.

A survey was extended to land managers in the NW NSW NRMR to gain insight into their experiences with feral pig damage and control in key cropping and livestock enterprises. There was a positive response with 123 surveys completed, covering 823,000 ha in the region. Alongside the published literature, the survey results informed the range of inputs for the cost benefit modelling.

This study is novel in its application of cost benefit analysis at a farm enterprise level. A farm level economic framework was constructed to quantify the economic viability of five feral pig control methods across multiple cropping and livestock enterprises. Those modelled included barley, wheat, chickpeas, faba beans, sorghum, maize, cotton and hay. The control methods analysed included baiting, exclusion fencing, trapping, and ground and aerial shooting.

The modelling approach incorporated @RISK analysis, which captured the high level of potential variation in underlying variables. Variables modelled included expected yields, anticipated pig damage (as a percentage of yield), commodity prices, and the effectiveness and cost of each control method. The model randomly selected a value from each variable's distribution to perform the calculations. This process was repeated twenty thousand times to create a probability distribution for each result that reflects the range of possible values and the probability of them occurring.

Results indicated in most instances there were net benefits to undertaking feral pig control. Table 1 presents the range of results for each enterprise. Chickpeas, a high value crop that can experience extensive damage from feral pigs had the highest potential net benefits, up to $100 /ha. The highest results were achieved when modelling above average enterprise yields, high avoided losses caused by feral pigs, high commodity prices, or a combination of these factors. While each control measure was modelled independently, it is possible that a combination of approaches would deliver synergies in feral pig control and increase the overall effectiveness per hectare. In addition, the use of a coordinated, area wide management could generate higher than average net benefits and benefits over a longer period.

Table 1: Results summary by enterprise

Enterprise	Net Benefit range $/ha		Benefits highest when… Anticipated damage by feral pigs exceeds	Anticipated enterprise yields exceed
Barley for grain	*-$15.40*	*$23.00*	*2.5%*	*2.5 t/ha*
Cotton lint (irrigated)	*-$5.70*	*$70.00*	*0.9%*	*11.30 bales/ha*
Chickpeas	*-$4.40*	*$100.50*	*6.0%*	*2.3 t/ha*
Faba beans	*-$8.50*	*$61.90*	*5.5%*	*2.7 t/ha*
Hay	*-$12.10*	*$53.50*	*4.0%*	*3 t/ha*
Maize for grain	*-$15.10*	*$24.30*	*1.25%*	*4.8 t/ha*
Sorghum for grain	*-$12.00*	*$32.80*	*3.0%*	*3.5 t/ha*
Wheat for grain	*-$15.70*	*$22.60*	*2.5%*	*2.1 t/ha*
Sheep and lambs	*-$6.40*	*$22.20*	*9.0%*	*Weaning % < 85%*

Across all cropping enterprises baiting and aerial shooting returned the highest results, followed by trapping. Ground shooting (as the least effective method) returned the lowest results. Exclusion fencing was analysed separately in consideration of the long-term investment. Even when the cost was annualised, exclusion fencing was the highest cost control method per hectare; however, it was also modelled as the most effective option. These two factors meant that the economic outcome from exclusion fencing was highly variable. Exclusion fencing was best suited to high value enterprises that experience year on year damage from feral pigs for example, lambing paddocks. One consideration of exclusion fencing is that the feral pig population is shifted rather than reduced, this option does not contribute to a holistic area wide management plan.

The results of this study can be extended to land managers in the NW NSW NRMR to encourage feral pig control programs.

Contents

Introduction

This report aims to investigate and establish baseline figures for production losses caused by feral pig impacts within the North West New South Wales Natural Resource Management Region (NW NSW NRMR). This analysis aligns with the North West Regional Strategic Pest Animal Management Plan 2018-2023 (NWRSPAMP).

The biology and ecology of feral pigs are two of the primary reasons why they are such a significant and successful vertebrate pest in Australia. Their large, robust bodies, snouts specially developed for rooting up the ground, omnivorous diet and adaptive activity patterns allow them to live in a wide range of habitats.

Feral pigs are habitat generalists and have colonised subalpine grasslands and forests, dry woodlands, tropical rainforests, semi-arid and monsoonal floodplains, swamps and other wetlands in many parts of Australia. Their prime requirements are a reliable and adequate supply of water, food and cover. Temporal changes can occur in their use of habitats to satisfy these requirements, mainly to obtain shade and water and exploit seasonally abundant food sources.

The reproductive potential of feral pigs is more similar to that of rabbits than to that of other large mammals in Australia. Fecundity increases with age and body weight but can be strongly affected by seasonal conditions. Under favourable conditions, breeding can occur throughout the year and sows can produce two weaned litters every 12-15 months, with an average of six piglets per litter. Fecundity gives feral pigs the capacity to recover quickly from the effects of management programs or other setbacks such as droughts.

Feral pigs are sedentary animals, confining their movements to a defined home range. The most critical factors affecting their distribution are their poor heat tolerance and accompanying need for access to daily water and dense shelter.

SECTION 1: Review of Literature

This section reviews published literature for the impact of feral pigs on agricultural enterprises, types of control and their effectiveness. A body of literature was found, noting very few studies have taken place in the last five years. Assumptions for this analysis were derived from Australian research findings together with more recent detailed analysis from the United States. A perceived weakness of this research identified by multiple authors is having a clear understanding of the distribution of feral pig populations.

Table 2 provides a summary of studies published since 1983 relating to feral pig control method and cost, as well as estimated losses to broadacre industries.

The literature has estimated that feral pigs inhabit around 38% of Australia's land mass. Populations vary from 3.5 to 23.5 million (McLeod and Norris, 2004b). Rainfall is the primary determinant of pasture, crop growth, and therefore relates directly to feral pig breeding cycles and related agricultural damage. During dry periods the feral pig population is likely to be concentrated around water sources near areas of cover. Agricultural enterprises within close proximity are likely to have the highest occurrence of damage (Saunders, 1993a).

Table 2: Summary of literature in Australia and the United States on feral pig control methods, costs and production losses

Authors	Study title	Origin	Focus area	Crop(s)	Findings
Hone (1980)	Managing Vertebrate Pests: Feral Pigs	Australia	Reduction in native and introduced pasture attributable to rooting by feral pigs	Pasture	On native pasture, rooted areas had green feed reduced by 98%, standing dry matter reduced by 74%, and the abundance of weeds also declined. On the introduced pasture, green feed was reduced by 74% in rooted areas, standing dry matter by 37%, and the abundance of non-grass matter increased ten-fold.
Tisdell (1982)	Wild Pigs: Environmental Pest or Economic Resource?	Australia	Losses caused by feral pigs on Australian cereal crops	Wheat, sorghum, barley, maize	Estimated losses: 3 % losses in wheat 5% sorghum 1% barley 3% maize
Hone and Atkinson (1983)	Evaluation of Fencing to control feral pig movement	Australia	Fencing pigs out	Pasture	Hinge joint was pig proof, but most expensive. Electrification was pig resistant at much lower cost.
Saunders (1993b)	Observations on the effectiveness of shooting feral pigs from helicopters	Australia	Helicopter control of feral pigs	Grasslands	Shooting large pigs results in a 'rapid replacement' of the population. Although instantaneous reduction occurs, more than one program needed. Higher cost per pig as pigs thin out.
Bomford and O'Brien (1995)	Eradication or control for vertebrate pests?	Australia	Eradication vs control: goats, pigs and horses	Rangeland	Eradication is almost impossible due to more resources for remaining animals and high expense.
Choquenot et al. (1996)	Managing Vertebrate Pests: feral Pigs	Australia	Pig damage	Crops and rangelands	National guidelines for managing feral pigs: historical evidence, public perceptions, impacts and control efficacy.
Choquenot et al. (1997)	Assessing lamb predation by feral pigs in Australia's semi-arid rangelands	Australia	Lamb mortality	Rangeland	Lamb predation increased with feral pig density. Twin lambs were 5-6x more likely preyed upon.
Gee (2003)	Proceedings of the Feral Pig Action Agenda	Australia	Potential for disease	Ag sector generally	Estimates that foot and mouth disease could cost Australia $1.5-10 billion.
Lapidge (2003a)	Proceedings of the feral pig action agenda	Australia	Control	Rangeland, cane and banana crops	Eradication too expensive. Enhanced barrier protection recommended. Aerial baiting considered. Trapping most cost-effective method in wet tropics.
McLeod and Norris (2004b)	Counting the cost: impact of invasive animals in Australia	Australia	Economic loss	Ag sector generally	Estimated losses: 3% losses in wheat 1.5% of losses incurred in management costs 35% mortality in lambs.
Cowled et al. (2006)	Measuring the demographic and genetic effects of pest control in a highly persecuted	Australia	Genetic make-up and control methods	QLD and WA	Unchanged genetic makeup of pig populations, and the geographic boundaries of the population were not reached. Seasonal conditions play a large role.

	feral pig population				
Cowled et al. (2012)	Controlling disease outbreaks modelling classical swine fever incursions in wild pigs in Australia	Australia	Exotic disease modelling of swine fever	Northern Australia	Culling of animals can be used to stop exotic disease spread. Only a small proportion of pigs move much greater distances.
Gentle and Pople (2013)	Effectiveness of commercial harvesting in controlling feral-pig populations	Australia	Selling pig meat for incentive to control pigs	QLD Murray Darling Basin	Commercial harvesting is capable of reductions but is best as a supplement with other control techniques.
Gentle et al. (2015)	Consumption of crops by feral pigs in fragmented agricultural landscape	Australia	The diet of feral pigs	Southern QLD	Selectively consume crops: wheat/barley/oats 50% of diet. Sorghum, chickpea and cotton then preferred.
Tanger et al. (2015)	Monetary estimates of feral hog damage to agricultural producers in Louisiana	United States	Economic costs	Louisiana State	Estimated losses: 3% wheat losses 6-11% oats and hay 0.5% cotton 1-3% sorghum.
eSYS Development (2016)	Cost of Pest Animals in NSW and Australia 2013-14	Australia	Cost of feral pigs: wool, sheep meat and crops	NSW and QLD	Detailed loss assumptions for 3x enterprises. Annual loss $13.49m in 2013-14.
Anderson et al. (2016)	Economic estimates of feral swine damage and control in 11 states	United States	Economic costs and control methods	11 US states	Estimated losses: 1-5% yield loss to corn 1-3% to beans/sorghum 0.5-4.5% to wheat 1-9% to peanuts.
Engeman et al. (2018)	Prevalence and amount of feral swine damage to three row crops at planting	United States	Row crops	Corn Cotton Peanuts	Estimated losses: 1% losses for corn 0.17% losses for cotton 6% for peanuts Some crops more palatable.

Description of study areas

The NW NSW NRMR covers 8.2 million hectares, with 85% of land under agricultural production. It is a major broad acre cropping region, producing cotton, cereals, pulses and oilseeds. Beef, lamb, wool, poultry and eggs are also substantial contributors to the region's economy. The value of agricultural production in the region totalled $2.13 billion in 2017-18 (Local Lands Services, 2020).

The NW NSW NRMR comprises three sub-regions: the western division (west), the slopes (central), and the tablelands (east). Based on the Köeppen climate classification system the NW NSW NRMR is best defined as Grassland (western division), Subtropical (slopes) and Temperate (tablelands) (Australian Bureau of Meteorology, 2015). A map of the NW NSW NRMR within the state of NSW is shown in Figure 3.

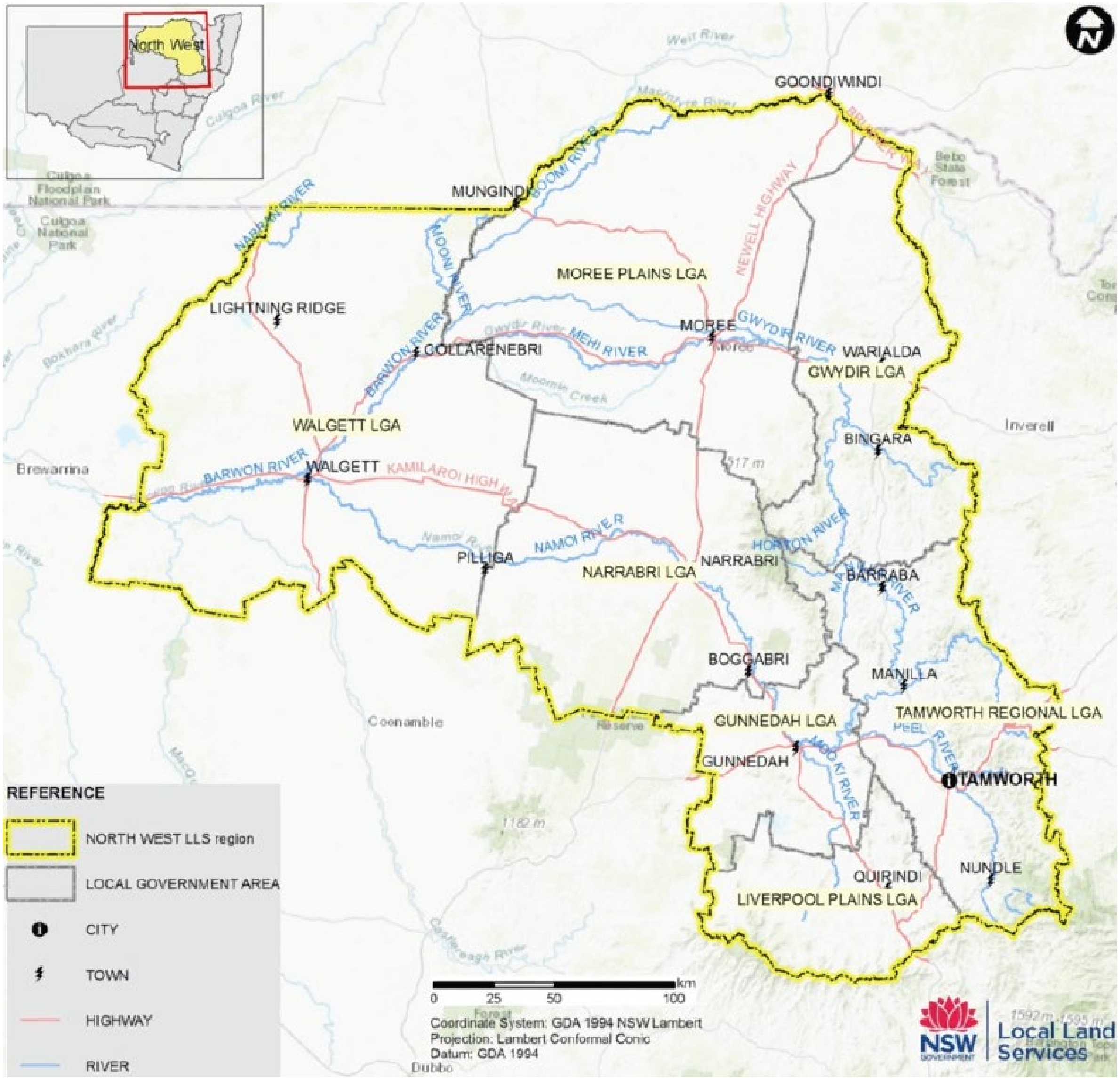

Figure 1: Map of the NW NSW NRMR area within NSW (inset): SOURCE (Government, 2018)

Agricultural damage

> *"Feral pigs are significant environmental and agricultural pests and they are widespread and abundant throughout the North West. They cause damage to crops, pasture and the environment through wallowing, rooting for food and nesting, [thereby] creating significant soil disturbance, altering drainage, increasing turbidity and sedimentation and greatly assisting the spread of weeds. They also prey on a wide range of native animals including frogs, reptiles, birds and small mammals, as well as livestock such as lambs. Feral pigs can carry disease and parasites that affect stock and pose a disease risk to humans (Brucellosis (B. suis), Leptospirosis (L. pomona) and Q Fever). They can be a major potential host and vector of a number of exotic diseases, such as foot-and-mouth disease which is not found in Australia however poses a major threat. The social and economic costs of foot and mouth disease in Australia would be extreme as meat, dairy and wool export markets would be closed until the outbreak was eradicated. Individual farmers would be severely impacted as herds and flocks would be destroyed and domestic markets for animals and animal products would be heavily restricted."*
>
> **North West Pest Plan (2018)**

Authors have concluded that comparison of regional areas under crop production with the diet composition of feral pigs broadly suggests that pigs are selectively consuming crop over non-crop foods (Gentle et al., 2015, Engeman et al., 2018).

The economic cost of feral pig damage to agriculture in NSW was estimated at $13.49 million in 2013-14 (eSYS Development, 2016). Approximately half of the estimated losses were attributed to crop losses and the remaining losses attributed to increased mortality in wool and sheep-meat enterprises.

Damage caused to livestock by feral pigs in the NW NSW NRMR comes predominantly in the form of lamb losses. Pavlov et al measured an average of 18.7% predation of merino lambs for four lambing seasons over two years (Pavlov et al., 1981), with twin lambs on average 5-6 times more likely to be at risk (Choquenot et al., 1997). Feral pigs also pose a threat to Australian livestock biosecurity, with Gee (2003) estimating that an outbreak of foot and mouth disease that moves from the feral pig population to domesticated livestock could cost Australia $1.5-10 billion.

The North West Pest Plan (2018) identifies the goal to reduce production losses from feral pigs by 10% in active control areas.

Control methods

Research into the population growth of feral pigs suggests that between 55% and 75% of the area's population requires eradication each year to prevent rapid re-invasion (Gentle and Pople, 2013). Because of the feral pig's ability to quickly reproduce, the most effective way to utilise control methods is to implement them over a large geographical area. The smaller the area covered, the more often control methods will need to be repeated in order to prevent rapid repopulation (Bengsen et al., 2014).

The most common methods of control used in the North West region of NSW are lethal methods, with the most effective of those being 1080 poisoning, trapping and aerial shooting. Recreational shooting is also a commonly used control method. However, there is little evidence to prove that it is effective in significantly reducing population sizes (Gentle and Pople, 2013) without combining it with another control program.

1080 grain poisoning is the most cost-effective method of population reduction, with evidence that at least 89% of the population can be eradicated if the baiting is continued for a period of 7-10 days (Twigg et al., 2005). Most effective is the free feeding approach, where pigs are fed for approximately three days with poison-free grain before the poisoned grain is made available.

Aerial shooting can also be a highly effective form of population reduction. It is especially useful on a population that has not been controlled in recent years and is in abundance, or for short-term protection of assets such as lambing ewes or crops (Saunders, 1993a). However, the cost-effectiveness of aerial shooting decreases as the population reduces due to the increased flying time (and cost) to find and remove smaller numbers of pigs (Saunders, 1993a).

Fencing is a non-lethal control method sometimes used in North West NSW. This is not effective at excluding a feral pig population unless the whole property is fitted with an electrified mesh design, a costly venture that many landowners aren't prepared to undertake (Hone and Atkinson, 1983). On a smaller scale, fencing can be an effective solution to protect valuable assets such as lambing ewes. However the cost of labour and resources often makes other control methods more appealing.

Studies recommended that a combination of control methods be utilised regularly, at least on an annual basis, in order to effectively control a feral pig population and decrease the damage caused to crops and livestock caused by this adaptable pest.

SECTION 2: Method

The method of cost benefit analysis was chosen to understand the net benefits of controlling feral pigs in the study area.

The study focused on the economic benefit of feral pig control in terms of avoided yield loss within agricultural enterprises. Enterprises analysed had the highest value in North West NSW as per ABS 7121 Table 2 (ABS., 2020) and were known to experience losses due to feral pigs. The enterprises analysed are listed in Table 3.

Table 3: Agricultural enterprises analysed

Enterprise	Category
Barley for grain	*Broadacre crop, cereal*
Cotton lint (irrigated)	*Broadacre crop, non cereal*
Chickpeas	*Broadacre crop, non cereal*
Faba beans	*Broadacre crop, non cereal*
Hay	*Crops and pastures cut for hay*
Maize for grain	*Broadacre crop, cereal*

Sorghum for grain	*Broadacre crop, cereal*
Wheat for grain	*Broadacre crop, cereal*
Cattle and calves	*Livestock slaughtered*
Sheep and lambs	*Livestock slaughtered*

Net benefit for cropping enterprises

Feral pigs can cause yield loss in both winter and summer crops by consuming the crop itself or by using the crop as a habitat, where they often root, trample and wallow, destroying the plants. Taller crops such maize, cotton and sorghum are commonly used by feral pigs for shelter, while crops such as faba beans, barley, chickpeas, wheat and hay are more often impacted by feral pig consumption. In some cases, the crop is impacted by a combination of both, such as cotton, which is destroyed by feral pigs feeding on the bolls as well as rooting and trampling the plant itself. Crop damage equates to yield loss and lower income for the enterprise.

Given the above, the net cropping benefit was calculated as an increase in yield due to feral pig control, less the cost of the control.

Where the following formulas were applied:

Yield benefit = (Yield loss caused by feral pigs x control method effectiveness) x wheat yield

Economic benefit = (Yield benefit x commodity price) – cost of control method

Net benefit for livestock enterprises

For sheep and cattle livestock enterprises, the economic losses from feral pigs are predominantly in the form of increased mortality rates. As such, the benefits of feral pig control were accounted for as decreased mortality rates.

The livestock benefit was calculated as the increase in the weaning rate as a result of feral pig control, less the cost of the control. Control of feral pigs increases the weaning percentage thereby increasing flock numbers. Where we assume the goal is to maintain steady flock numbers in a self-replacing flock, an increase in weaning percentage effectively increases livestock sales. The change in livestock sale income metrics were based on per hectare terms.

Additional assumptions were required for livestock. Stocking rates for sheep enterprises vary in NW NSW depending on available feed. A stocking rate range of 1.3-3.5 DSE was applied across 3500 ha (the average size of the stocked area within the survey). Exclusion fencing analysis assumes 150 km of fencing to create secure lambing paddocks.

Where the following formulas were applied:

Weaning benefit = (Loss caused by feral pigs x control method effectiveness)

Economic benefit = Control method income – counterfactual income – control method cost

Understanding variability

The extent economic damage by feral pigs varies depending on three main factors: feral pig population and behaviour, farm enterprise yield, and commodity values. Feral pig population and behaviour relates to the farm proximity to feral pig habitats, feral pig populations, the rate at which feral pigs are repopulating and the abundance of food and water sources. The typical yields of each enterprise in the region vary depending on a range of agronomic factors. The value of the commodities vary due to the influence of both local and global supply and demand. These three areas of uncertainty compound to create a broad range in the potential value of agricultural damage caused by feral pigs. Additionally, the cost and effectiveness of each control method vary due to a range of factors.

To effectively consider the variability in both benefits and costs and analyse the full range of economic outcomes, a risk analysis package called @RISK was used (Palisade, 2020). Where there is variability in value, this program replaces a static value with a distribution that reflects the range of possible values and the probability of them occurring. To establish an appropriate distribution, @RISK uses a set of historical data (i.e. price series) and identifies the distribution with the best fit. Where there is insufficient data, the distribution can be created manually. Within this analysis distributions were created using available price series, in the absence of a price series, findings from published literature and the survey results were drawn upon. Distributions and the data sources used to develop them can be found in Appendix 1 - @RISK model distributions.

Within the analysis, variables represented by distributions include:

- Damage caused by feral pigs for each enterprise
- Livestock weaning rates
- Commodity yields and prices
- The cost and effectiveness of each control method.

All other factors were considered deterministic (fixed) for the analysis. Within the model, control costs were estimated per control event per hectare. In the case of exclusion fencing, the total cost of the fence was divided by 25 (expected fence life) to indicate an annualised cost.

@RISK uses Monte Carlo stochastic simulation which samples random numbers from the distributions, while considering correlations, to generate results for various outcomes (in this study, the benefit of controlling feral pigs). The program repeats this process approximately twenty thousand times to create probability distributions for each outcome. Within this study all distributions were assumed independent (without correlation).

The analysis results are displayed in box and whisker plots which highlight the probability of a result occurring. The box and whisker plot (Figure 2) displays the results that fall between the 5th and 95th percentile. These plots exclude the upper and lower "tails" which are more likely to contain outliers. (i.e. there is a 90% probability that the result will occur within this range). The box and whisker plots also show the 75th, 50th (average), and 25th percentiles and the mean which is the average result.

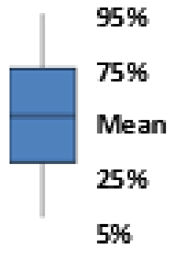

Figure 2: Box whisker plot

By considering the full range of potential values for each input variable, @RISK can clearly identify the extent to which the results are sensitive to each model variable. Input variables are ranked by sensitivity and the results displayed in a tornado graph. Inputs with the largest impact on the results have the longest bars.

SECTION 3: Survey

A primary survey was conducted to understand the experience farmers within the region have with feral pigs. Combined with published literature, the survey results informed the input data for the economic analysis.

The survey had 123 responses. The location of responses within the study region can be seen in Figure 3. One respondent hadn't experienced feral pig damage so their responses were removed from the sample data. 75% had experienced recent damage on their farm from feral pigs. The land use reported by respondents was 306,000 ha cropped, 445,000 ha grazed, and 72,000 ha unused timbered areas (including scrub and riparian).

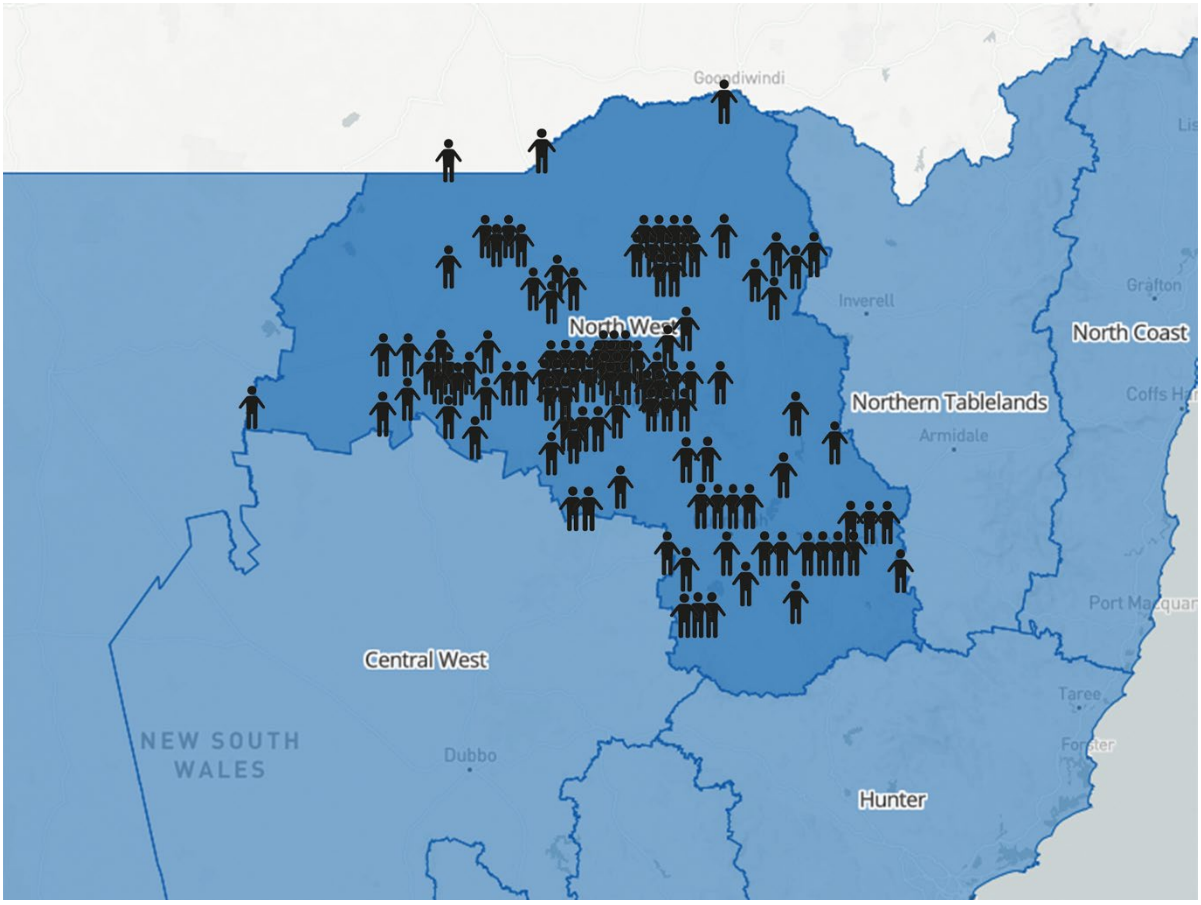

Figure 3: Map indicating the location of survey respondents

The enterprises found on the respondents' farms are shown in Figure 4. Cereals (including corn and sorghum) were grown by 70% of respondents, half grew pulses or chickpeas and 32% grew cotton. 68% of respondents grazed cattle and 48% sheep or goats. Other enterprises noted were cattle feedlots, horses and environmental services.

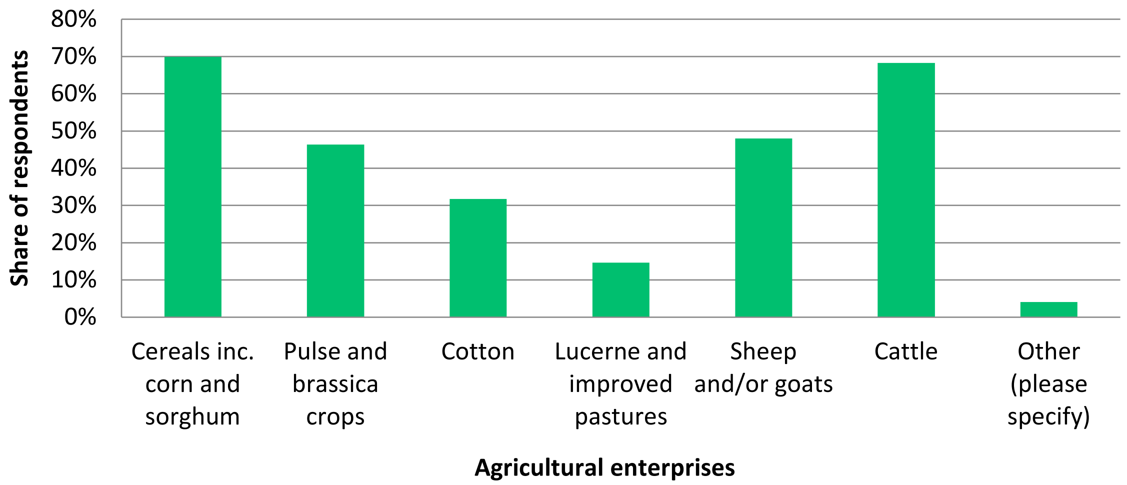

Figure 4: Enterprises generally found on respondent's farms

Respondents were asked for their best estimate of feral pig damage to their different enterprises (Figure 5). For summer crops, respondents reported sorghum to suffer the most feral pig damage, with 38% of respondents reporting yield losses of 5–10%. Cotton and corn were reported to experience under 5% in yield losses. Among winter crops, chickpeas were found to have the highest damage with 20% of respondents estimating over 10% yield loss. Faba beans were ranked as the next highest damage, with wheat and barley likely to experience less than 1% yield loss. Some survey respondents commented on high cropping losses from feral pigs and the patterns of damage to different crops – some of their comments are below.

"Pigs are a major issue, we have had up to 30% loss in canola paddocks. Often 10% loss in our cotton."

"Can lose up to 60-70% of a barley paddock."

"We do not grow faba beans because of our pig problems."

"Chickpeas and fabas losses prior to emergence, in crop damage to Fabas and cotton as they live in it."

"Chickpea damage along timber lines pre plant emergence."

"Damage occurring when the grain is set makes eradication hard and damage extensive."

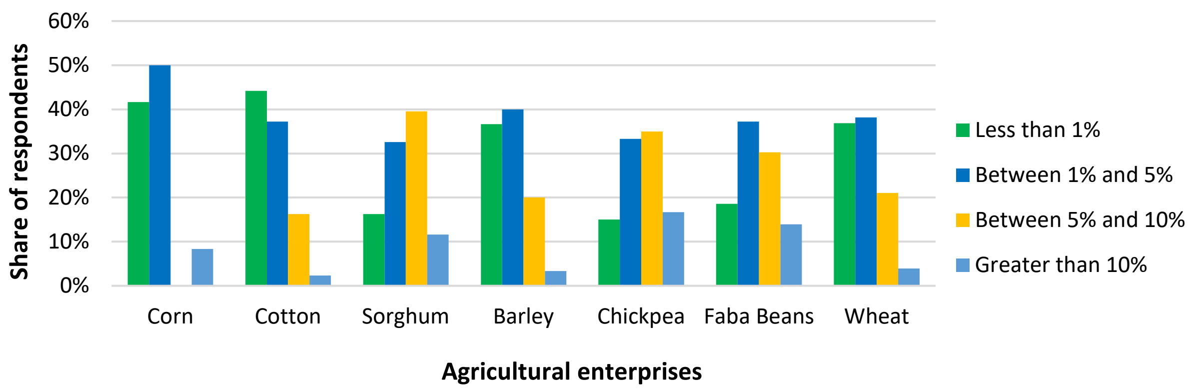

Figure 5: Estimated yield loss caused by feral pigs in cropping enterprises

Yield loss related to feral pigs for livestock enterprises is illustrated in Figure 6. Results suggest that feral pigs eating grain out of livestock feeders was one of the largest issues. This result is likely to be influenced by the prolonged drought and increased incidence of paddock feeding livestock in the three years preceding the survey. Consistent with the literature, the broadest range of yield losses were in sheep enterprises. The two comments below, made within the survey, highlight the range in loss.

"Heavy baiting campaigns have reduced our lamb losses from an estimated high of 60%."

"We haven't experienced lamb losses to feral pigs."

40% of respondents reported experiencing an estimated loss of between 1%-5% and 34% reported less than 1%. 14% of respondents estimated their lamb mortality from feral pigs greater than 10%. Several respondents also noted damage to fences as an issue.

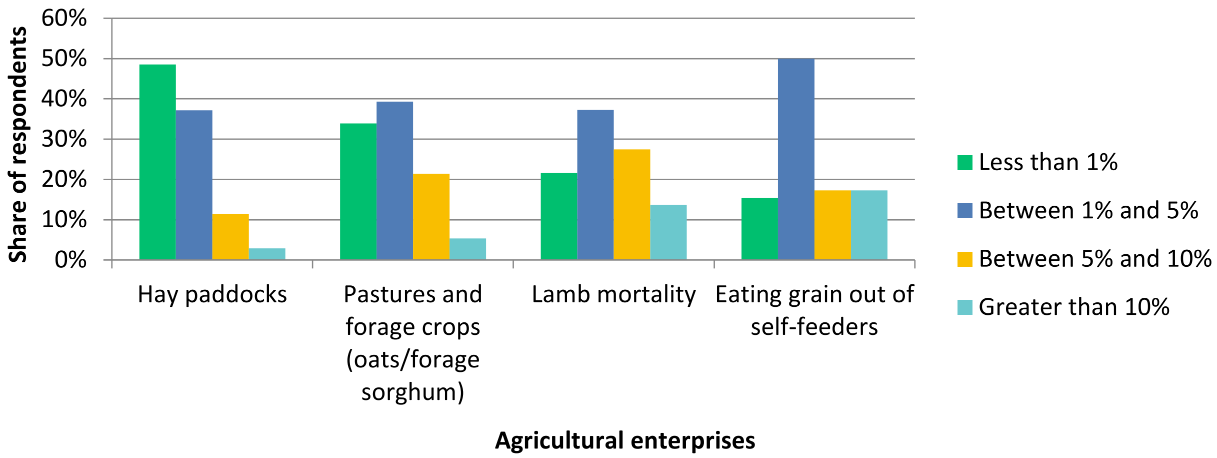

Figure 6: Estimated yield loss caused by feral pigs in livestock enterprises

Respondents were surveyed on control methods they used and how effective the method was (see Figure 7). Ground shooting was the most commonly used control method, utilised by 96% of respondents; however, it was also regarded as the least effective method. Exclusion fencing was reported as the most effective control method, however it was the least used. Only 33% of respondents reporting experience with exclusion fencing. Trapping, 1080 ground baiting and aerial shooting were also broadly used by 92%, 83% and 81% of respondents. Aerial shooting was reported as the second most effective method, followed by 1080 baiting and trapping.

Responses varied for preferred control methods in rough terrain. One respondent noted that aerial shooting is not very effective in scrubby areas and that 1080 baiting is highly effective at night controlling every feeding pig. One respondent noted that in heavily timbered areas where visibility was low, they had had success ground hunting with the use of dogs to flush the pigs out; however, for the same situation another respondent identified that the use of dogs resulted in minimal reduction, and instead scattered the pigs.

Environmental management of Pilliga National Park and Pilliga State Conservation area includes a 5800 ha fenced 'Feral Free' zone. It was noted by management in their survey response that over the past 2 years exclusion fencing has been very successful in keeping out feral pigs.

"All techniques are useful. We have used a combination – as they get used to one, swap to another. This is the first year we have had minimum damage in the chickpeas after sowing. It has required continually implementing these techniques for at least 4 years."

"All methods must be tried to help control the pest."

"From many years experience there is no silver bullet, a holistic approach is needed. Exclusion fencing does not address the wider problem."

Respondents also noted the benefits of area wide management.

"Baiting is very effective, especially when the neighbours are involved."

"There are benefits when landowners work together to implement control methods in order to cover the largest area possible."

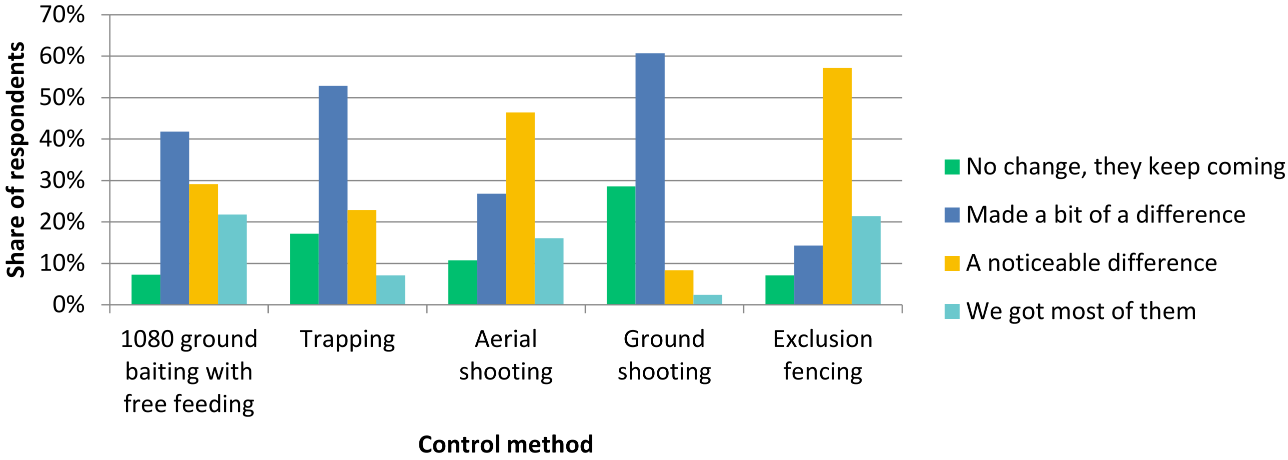

Figure 7: Effectiveness of each control method

To further elucidate findings from literature regarding the alignment of feral pig populations with seasonal conditions, respondents were presented with the statement '*Wet years affect feral pig populations and they become a real problem'*. 85% of respondents agreed with this statement. Several respondents noted that feral pig numbers were noticeably higher in 2020 compared to last year with an expectation that it is a result of higher and regular rainfall.

Survey comments provided further insight into feral pig populations and observations relating to seasonal conditions;

- ***"Feral pigs are more prominent in dry years as the natural feed is scarcer, and they rely on crops or the grain being fed to stock."***
- ***"In the dry years pigs move out of the hills and invade crops."***
- ***"The damage is often less noticeable in crops on a wet year because the crop can better compensate for any losses. Damage is more noticeable on dry years, and compounding this, the prices per ton and therefore lost revenue are generally higher in the dry."***
- ***"In good seasons feral pigs have plentiful food and higher reproduction rates. "***
- ***"Feral pigs are harder to control in wet seasons as they move around less with plentiful food and have good grass cover."***

- ***"The year after a wet year is a bigger problem once the pigs have had a good breeding season, and as the seasons become poorer the pigs become more visible."***

The majority of respondents reported vaccinating their livestock to protect them from Leptospirosis, a bacteria carried by feral pigs.

Several respondents noted that due to their individual and area-wide feral pig control programs they experience reduced damage to enterprises "***…because we manage our pig population, we suffer little loss."***

Other losses reported from feral pig control included damage to native pastures, fencing and soil erosion.

The survey provided a strong insight into the effect of feral pig's and the effectiveness of control options utilised by land managers in North West New South Wales.

SECTION 4: Results and sensitivity

Results are discussed by enterprise and presented as a box and whisker plot, reflecting the range of potential net benefits or returns on feral pig control. Exclusion fencing, being a long-term investment, is discussed separately.

Cropping Enterprises

Figure 8 presents the net benefits for feral pig control for barley enterprises. The varied results for each control method reflect their cost and effectiveness in controlling feral pigs. The most cost-effective control methods for feral pigs in barley was aerial shooting, baiting and trapping. The placements of the box and most of the whiskers above the $0 /ha net benefit line indicate that most of the time (92%) these three control methods resulted in a net benefit. These control methods have a maximum net loss per ha of $2.70. A negative result can occur when the cost of control exceeds the avoided yield loss. For example, if the damage incurred to the crop was near to zero, or the incurred cost for the control was unusually high.

Ground shooting had a tight range of results with 90% probability of results between $3.98 /ha net benefit to $7.00 /ha loss. There was also an 84% probability of the costs outweighing the benefits resulting in a loss for this method.

The per hectare net benefit for all control methods was most sensitive to the yield loss caused by feral pigs, the expected yield and commodity price. The effectiveness and cost of the control method had the least effect on the results.

Results and sensitivity modelling indicated that net benefits of up to $23 /ha could be achieved when controlling feral pigs in barley crops. Net benefits were highest when the key variables were above average. In barley for example, if yield damage by feral pigs was estimated over 2.5%, yields were expected over 2.5 t/ha, the commodity was valued over $200 /t, or a combination of these factors. When using baiting and aerial shooting, nine times out of ten there was a net benefit for feral pig control.

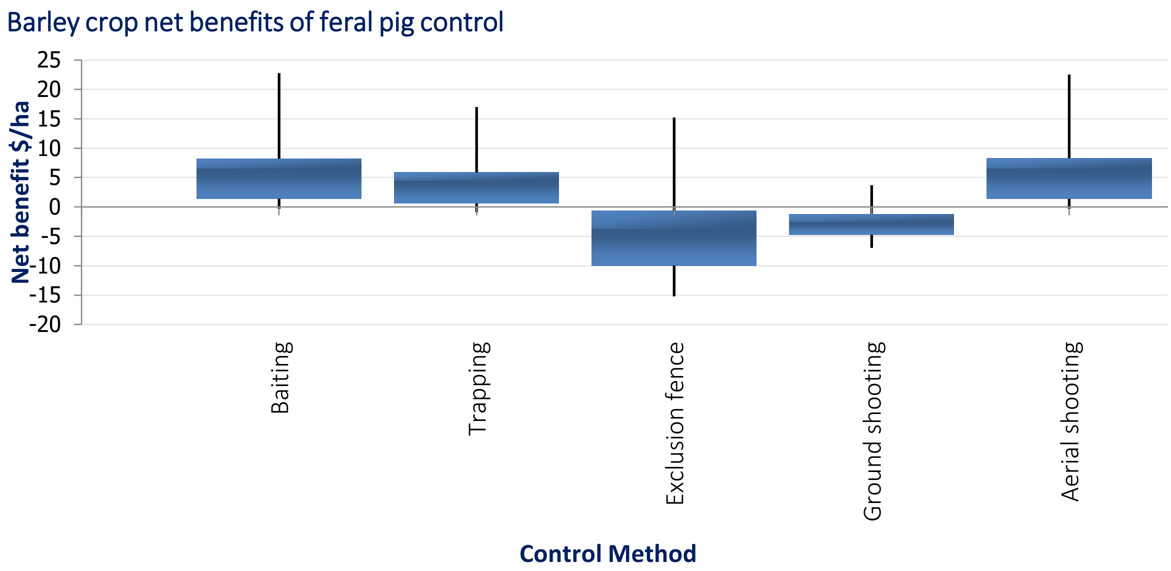

Figure 8: Net benefit of feral pig control in barley crops

A comparison of the net benefits of feral pig control in wheat crops is presented in Figure 9. Net benefits were similar to those in barley with the baiting and aerial shooting methods displaying the potential to achieve the highest results.

Like barley, results and sensitivity modelling found net benefits of up to $22.60 /ha could be achieved when controlling feral pigs in wheat crops. These net benefits were highest when losses were estimated over 2.5%, wheat yields were expected over 2.1 t/ha, the commodity was valued over $225 /t, or a combination of these factors.

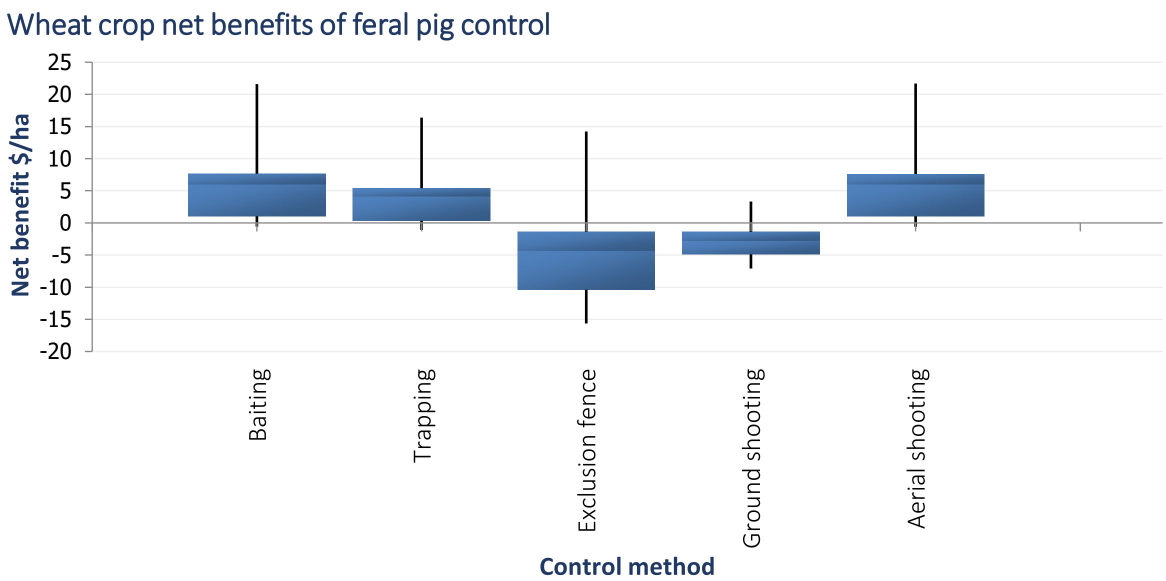

Figure 9: Net benefit of feral pig control in wheat crops

As a high value crop that can experience high yield losses to feral pigs, the net benefits of feral pig control in chickpeas was the highest in the cropping analysis — up to $100 /ha for the control methods of baiting, and aerial shooting (Figure 10). Results indicated that control of feral pigs using baiting, trapping or aerial shooting would result in increased per hectare profit margins 100 percent of the time in chickpea crops. Ground shooting which has been modelled with a lower effectiveness, increased per hectare returns 75% of the time.

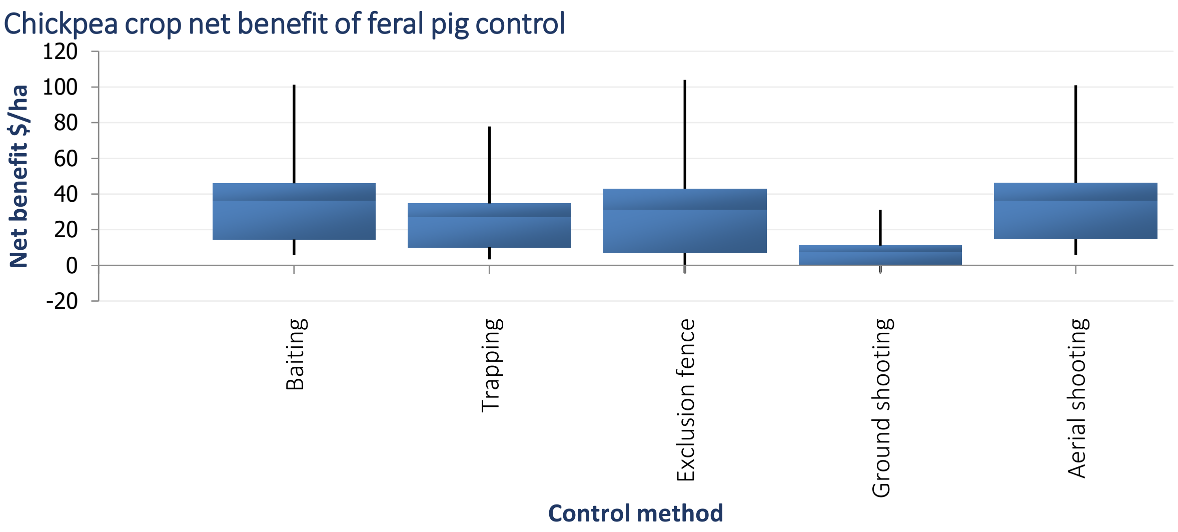

Figure 10: Net benefit of feral pig control in chickpea crops

The sensitivity analysis results for each control method in chickpeas are presented in Figure 11. The longer the bar on the sensitivity graph, the larger the potential change in per hectare benefit when that variable is changed. Like barley and wheat, chickpeas were also most sensitive to the anticipated yield of the chickpeas and the yield losses experienced by feral pigs.

Combining the results with sensitivity testing, it was evident that feral pig control is economically beneficial in chickpea crops. Above average per hectare returns were most likely to occur when the damage from feral pigs was anticipated to exceed 6% of a crop with an expected yield of 2.3 t/ha or more. However, when using baiting, aerial shooting or trapping control methods, there was always likely to be a positive return.

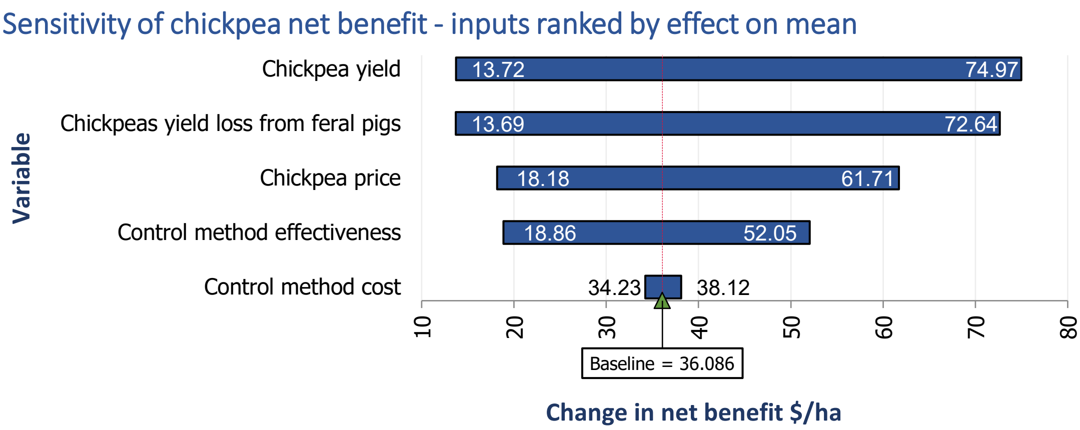

Figure 11: Sensitivity of chickpea crop net benefits

Analysis shows there were net benefits of feral pig control in faba bean crops of up to $62 /ha. Baiting and aerial shooting had the highest returns, followed by trapping which was slightly less effective. Ground shooting was the least effective of the four control methods and 40% of the time returned a loss.

Results were most sensitive to the yield loss from feral pigs, the anticipated crop yield, and the effectiveness of the control method.

The net benefits from feral pig control were above average when the crop was anticipated to yield 2.7 t/ha or above and the anticipated yield loss from feral pigs was 5.5% or above.

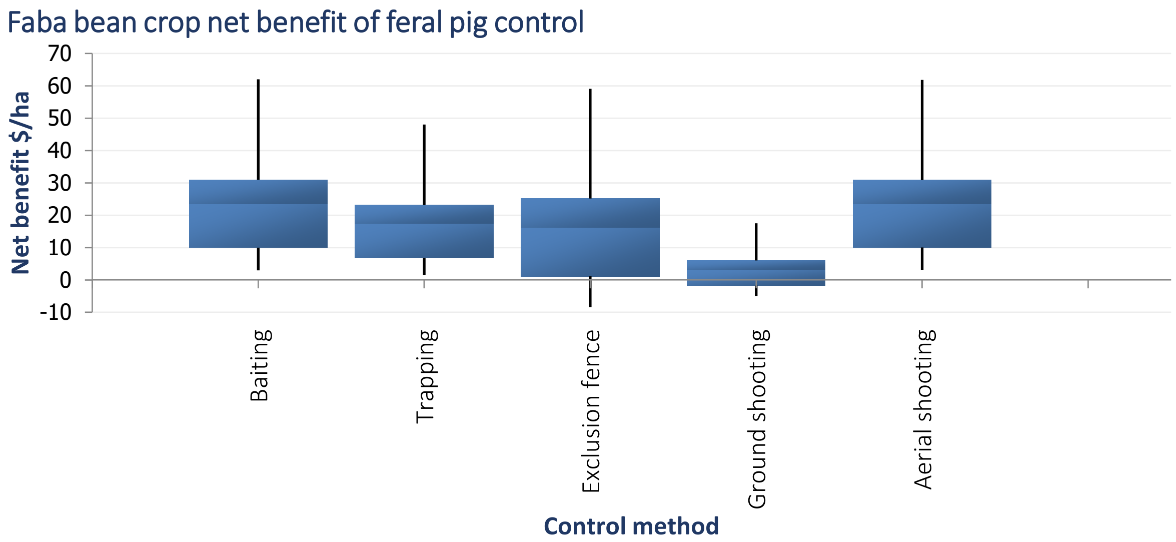

Figure 12: Net benefit of feral pig control in faba bean crops

The net benefits of controlling feral pigs in cotton are presented in Figure 13. The results indicated a likely positive outcome for the control methods of trapping, baiting and aerial shooting. The net benefit was as high as $70 /ha. The analysis indicated a 33% probability of a loss for ground shooting due to the lower effectiveness of this method.

Analysis (Figure 14) found that the results were most sensitive to the yield loss due to feral pigs, and to a lesser extent the effectiveness of the control method, commodity price and cotton yield.

Above average results were most likely to occur when the anticipated yield loss from feral pigs was over 0.90%, crop yield was 11.3 bales/ha or above, the cotton price was $460 /bale or above, or a combination of these factors

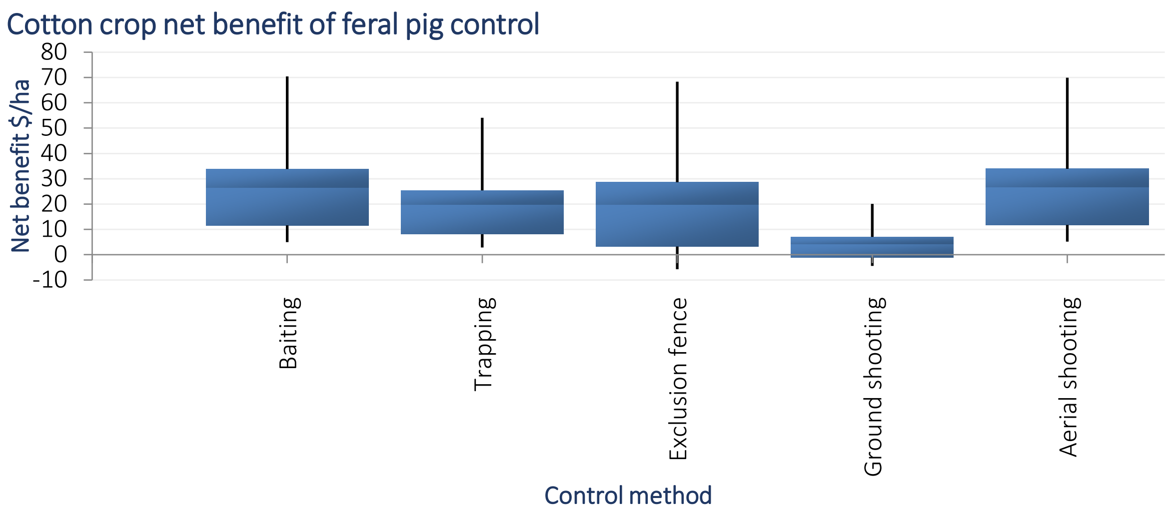

Figure 13: Net benefit of feral pig control in cotton crops

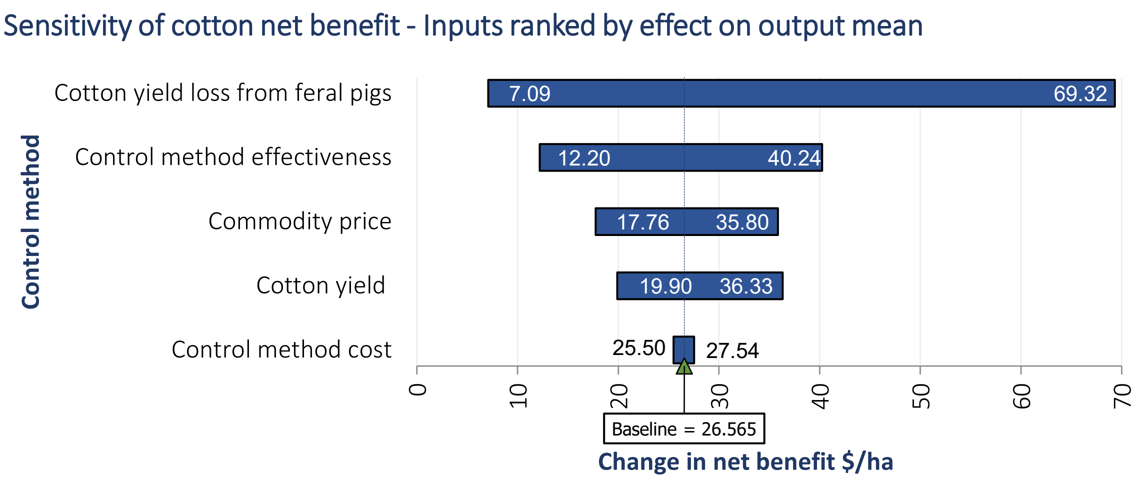

Figure 14: Sensitivity of cotton crop net benefits

Results indicated positive returns for control of feral pigs in hay crops or stored hay. Hay cropping benefits were up to $53 /ha (Figure 15). Aerial shooting and baiting showed the highest returns followed by trapping. Ground shooting had a 60% probability of returning a loss. Results were most sensitive to the yield loss caused by feral pigs and the estimated yield of the crop.

Above average results were most likely when the crop was estimated to yield over 3 t/ha, the price of hay was over $249 /t and the yield damage caused by feral pigs would have been over 4%.

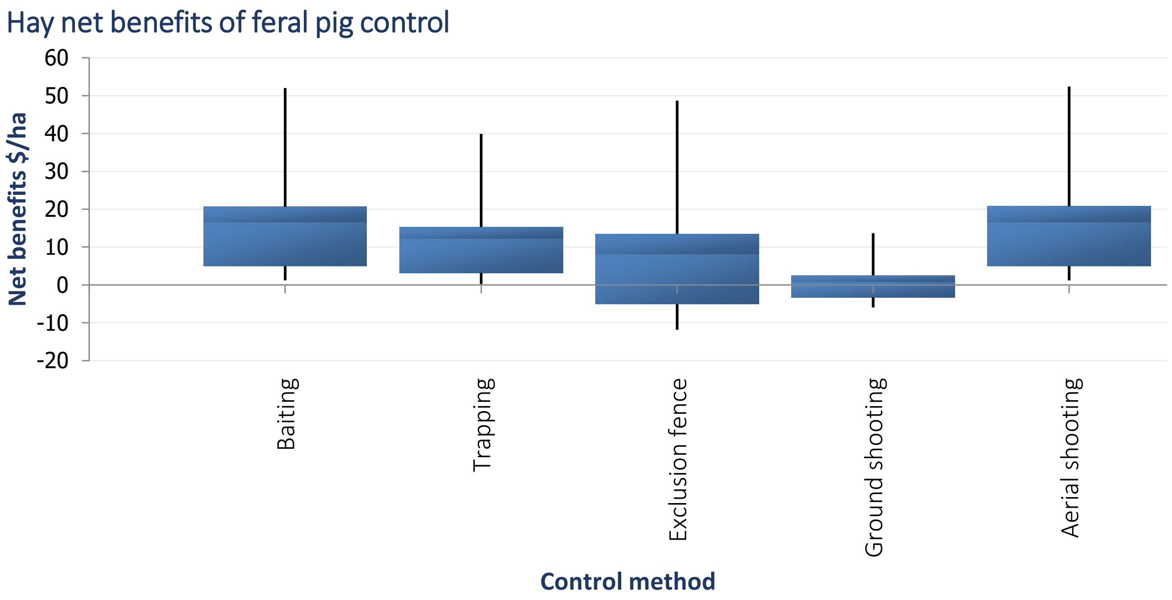

Figure 15: Net benefit of feral pig control in hay

The analysis showed that there were up to $24 /ha net benefit when controlling feral pigs in maize (corn) crops. Aerial shooting and baiting results were highest followed by trapping. The least effective method was ground shooting with an 85% probability of a loss. Results were most sensitive to the yield loss caused by feral pigs and the estimated yield of the crop, followed by the effectiveness of the control method. The highest net benefits occurred when the maize crop was anticipated to have 1.25% or higher damage, had an estimated to yield over 4.8 t/ha, was valued at $228 /t or above, or a combination of these factors

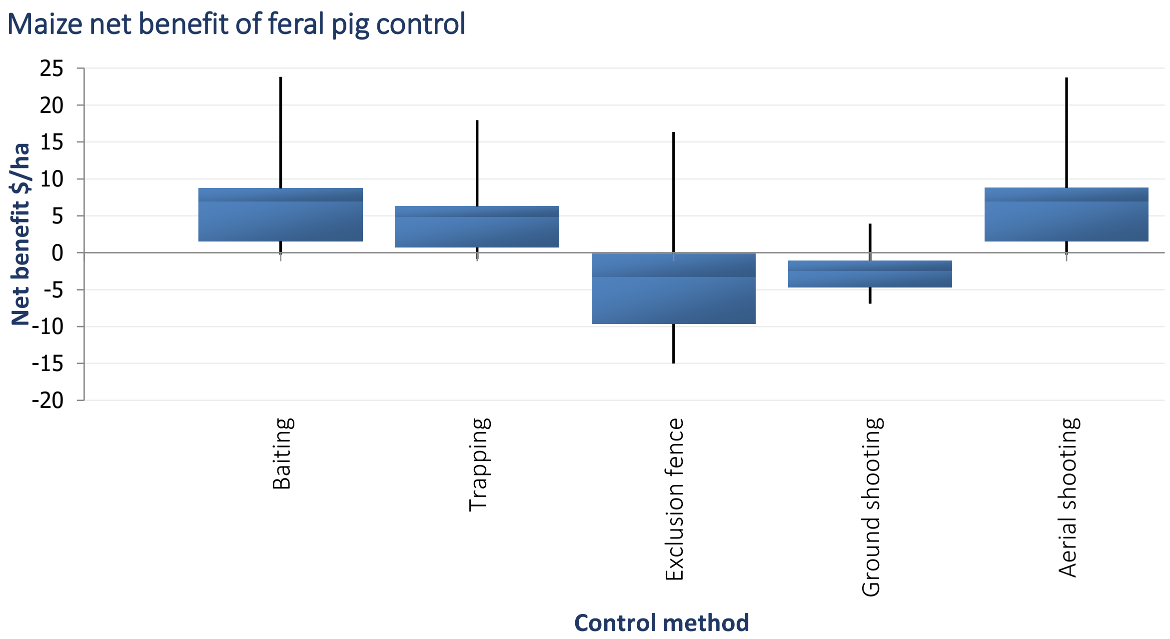

Figure 16: Net benefit of feral pig control in maize crops

Control of feral pigs in sorghum can return up to $33 /ha (Figure 17). The most effective control methods, baiting and aerial shooting returned the highest results, followed by trapping, and lastly ground shooting. Trapping was 4% likely and ground shooting 68% likely to result in a net loss per hectare. The results were most sensitive to the anticipated sorghum yield and the potential yield loss caused by feral pigs. Result were highest when the anticipated yield was above 3.5 t/ha, the yield loss was 3% or above, sorghum was worth $206 /ha or above, or a combination of these factors.

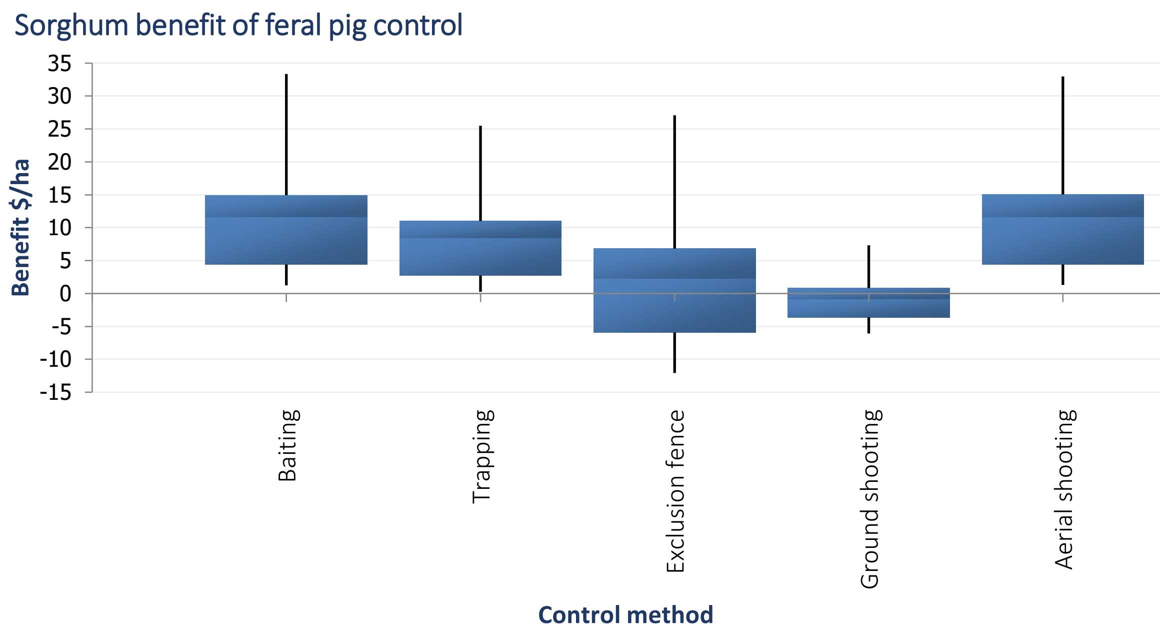

Figure 17: Net benefit of feral pig control in sorghum crops

Exclusion fencing: cropping enterprises

Exclusion fencing can return high annual benefits for individual crops (Figure 18). However, in contrast to baiting, trapping, and shooting which need to be continuously applied to maintain benefits, exclusion fencing involves a high upfront cost with a long period of benefits of up to 25 years. In a cropping scenario, land is likely to be rotated between crops and left fallow for periods during the useful life of the exclusion fencing, with the final benefit reflecting the crop rotation.

As an example, averaging the benefits over a five-year cropping cycle that includes wheat, chickpeas, barley, faba beans and a fallow resulted in a 30% probability of a loss. The variance in results between the different cropping enterprises (Figure 18) suggests that when considering exclusion fencing for a cropping scenario, serious consideration would need to be given to the cropping rotation and likely period the land may be left fallow. An additional consideration of exclusion fencing is that the feral pig population is shifted rather than reduced, this control method does not contribute to a holistic area wide management plan.

The relatively higher cost of this control measure resulted in higher potentially losses per hectare; however, the relatively high effectiveness of the control meant potentially high benefits. This combination of factors creates a wide range of results.

In the NW NSW NRMR, farm sizes and cropping rotations will often remove exclusion fencing as an economical option. Sustained broadscale control using baiting and aerial shooting are likely to have higher returns and longer term, area wide benefits.

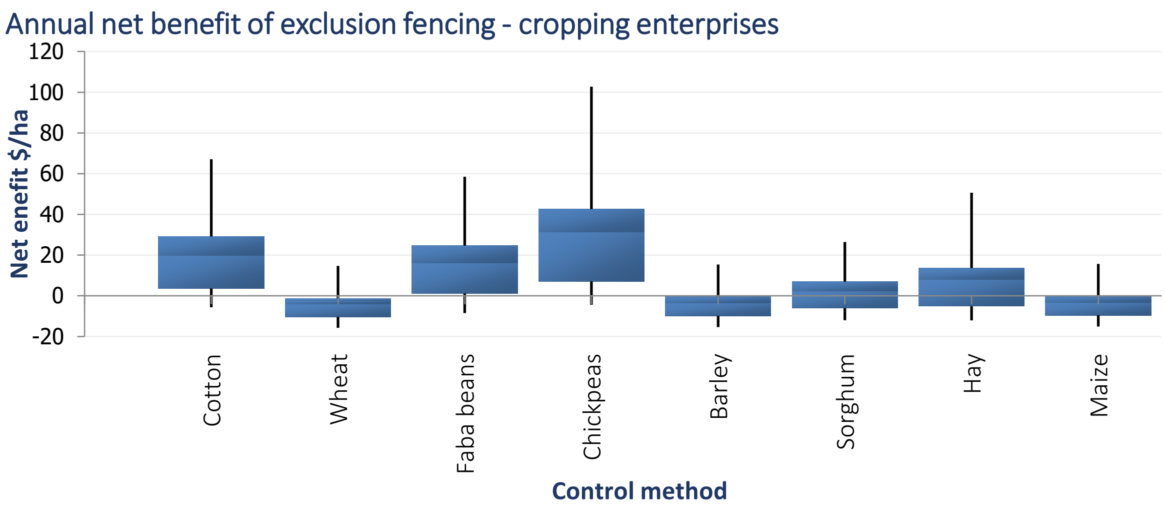

Figure 18: Exclusion fencing benefits for feral pig control

Livestock Enterprises

The net benefits of controlling feral pigs in a sheep enterprise is presented in Figure 19. The results indicated a likely positive outcome for all control methods except ground shooting. The net benefit can be as high as $22 /ha for exclusion fencing and up to $18 /ha for the more commonly used methods of baiting and aerial shooting. The analysis indicated an 8% probability of a negative result for baiting, trapping and aerial shooting and 79% likelihood of a negative result for ground shooting due to the lower effectiveness of this method.

Analysis found that the results were most sensitive to the anticipated lamb mortality caused by feral pigs and the lamb price. As the benefits are expressed per hectare, the stocking rate also influences the net benefit.

Of note, while the average area of land used for sheep enterprises from survey responses was 3500 ha, exclusion fencing was applied only to the lambing paddocks with 150 km of exclusion fence. Exclusion fencing was uneconomical when applied to the entire farm area. An additional benefit of exclusion fencing that was not considered within the analysis was the ability to keep other pests out (i.e foxes).

Above average results were most likely to occur when lamb losses of 9% or over may be attributable to feral pigs and the lamb price was over 339 c/kg. Additionally, the literature and survey concluded that substantial yield losses can be experienced from grain self-feeders, improved pastures and forage crops. Consideration of these additional benefits would shift the box higher, increasing the probability of higher net benefits from feral pig control in sheep enterprises.

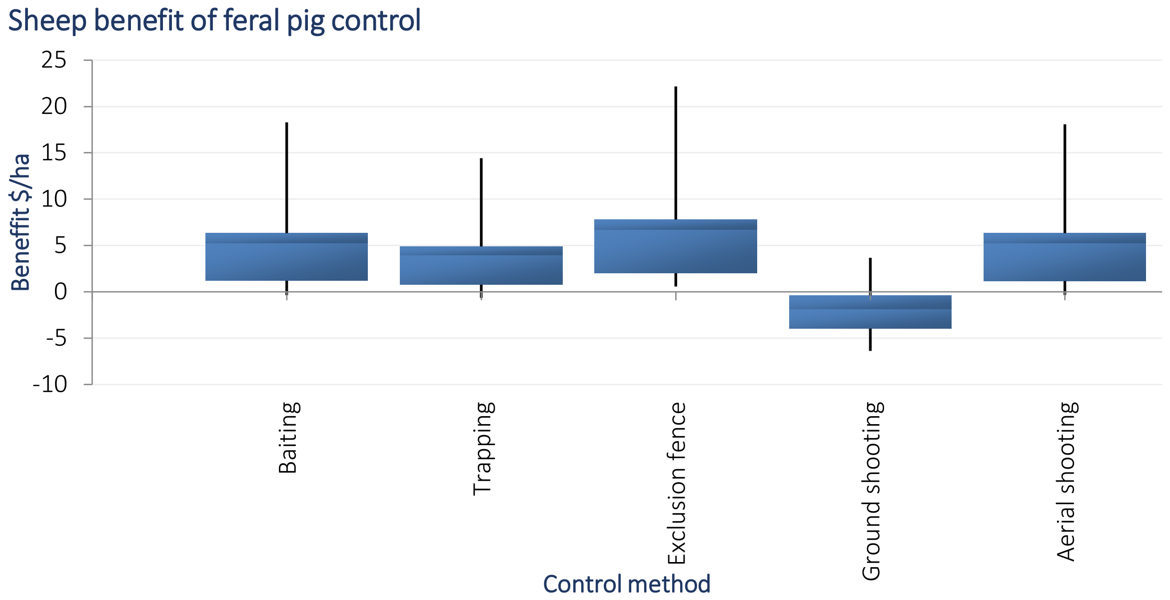

Figure 19: Net benefit of feral pig control for sheep

The estimated current cattle losses attributable to disease spread by feral pigs was modelled at low levels due to widespread vaccination programs. The benefit of reducing already low mortality did not outweigh the control costs. Other benefits of controlling feral pigs in cattle enterprises come from reducing yield loss to grain self-feeders and forage crops.

The potential for disease spread in cattle enterprises is of concern for land managers. In 2018-2019 the industry of slaughtered cattle and calves was valued at $347 million for the NW NSW NRMR (ABS., 2020). Biosecurity is essential for the long-term sustainability of the farmers that contribute to the industry and for the communities they support. Additional studies are required to investigate the value of this biosecurity.

Farm infrastructure

Published literature and the survey both identified that feral pigs cause damage to farm infrastructure such as fencing and bogging up dams. This enterprise level analysis did not quantify these benefits of feral pig control.

SECTION 5: Discussion and conclusion

The aim of this research was to quantify the agricultural costs and determine the value of various control methods for feral pigs in NW NSW NRMR. Results found that across all crops analysed there are economically viable options to control feral pigs. Potential benefits of control ranged from a net benefit of $100 /ha to a $20 /ha net loss.

Feral pig control generated the largest per hectare returns where high yield damage was minimised in high value crops, such as cotton and chickpeas. Faba beans also returned high results with a range of $70 /ha net benefit to a loss of $9 /ha. Avoiding feral pig damage in any crop with anticipated higher than average yields or a higher than average commodity price can achieve a positive economic benefit from feral pig control. Sorghum and hay net benefits were as high as $33 / ha and $53 /ha respectively.

Modest results were achieved in the cereal crops of barley, maize and wheat. Net benefits ranged from $23 /ha to a loss of $15 /ha. A per hectare loss occurred when the cost of the control method was larger than the yield damage that would have otherwise occurred from feral pigs. For these crops, ground shooting and exclusion fencing were most likely to result in a per hectare loss. Results indicated that for barley, maize and wheat when using the control methods of baiting and aerial shooting, nine times out of ten a positive net benefit was achieved.

Results for each control method varied according to their range of effectiveness and the cost of control. Baiting and aerial shooting achieved the best results across each cropping enterprise due to their high effectiveness and modest control costs. In contrast, while exclusion fencing was the most effective control measure, it was also the highest cost. As a long-term investment, exclusion fencing results indicated positive returns for productive areas such as lambing paddocks or potentially for cropping areas, such as adjacent to waterways, that see sustained high cropping damage from feral pigs. Exclusion fencing has the additional benefit of keeping out other pests such as foxes, however it does not contribute to the reduction of a feral pig population and shifts the problem elsewhere, therefore not contributing to area wide management.

Results for all crops were sensitive to the estimated crop yield and the estimated percentage yield loss caused by feral pigs. Together these variables represent the opportunity cost of feral pigs in terms of tonnes of grains per hectare.

Modelling for sheep enterprises indicated net benefits of up to $22 /ha. Ground shooting was the method most likely to return a negative result, up to a loss of $6 /ha. Exclusion fencing, modelled for lambing paddocks, returned the highest net benefits of all control methods, followed by baiting and aerial shooting.

The results for this analysis were presented annually; however, the benefits of thorough control can flow on to other enterprises and subsequent seasons.

Previous studies are consistent in the message that there are benefits in regular control and area wide management. Applying this theory to this study, covering the largest area possible may also create economies of scale, reducing control costs and further improving net benefits. It could be inferred that farm managers participating in area wide management and a planned control process may experience higher than average net benefits from feral pig control.

Additional studies are required to investigate the value of sustained biosecurity for the cattle industry and the value of feral pig damage environmentally and socially in NW NSW NRMR.

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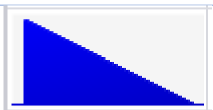
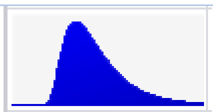
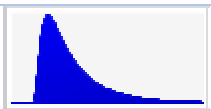
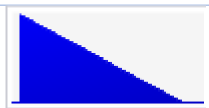
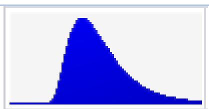
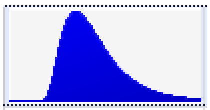
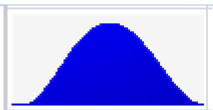
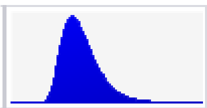
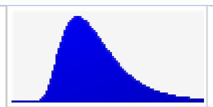
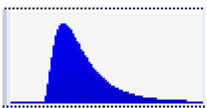
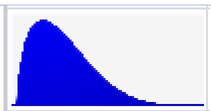
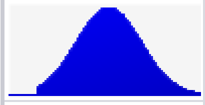
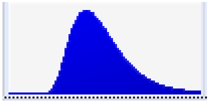
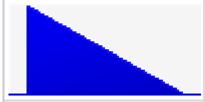
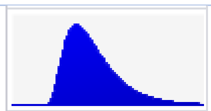
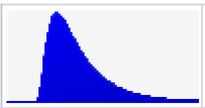
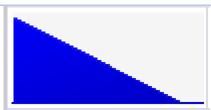
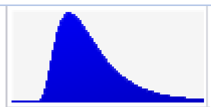
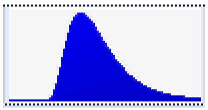
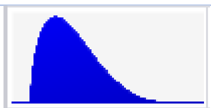
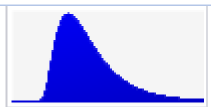
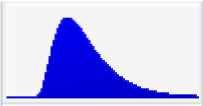
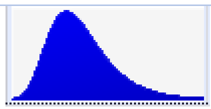
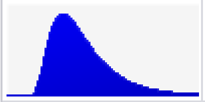
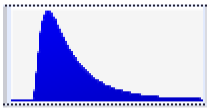
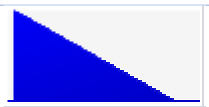
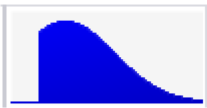
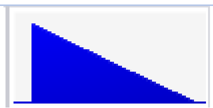
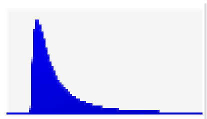
Appendix 1 - @RISK model distributions

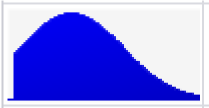
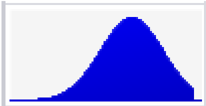
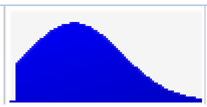
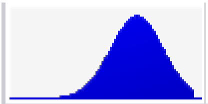
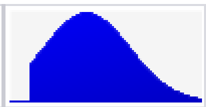
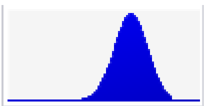
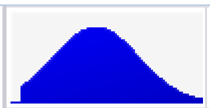
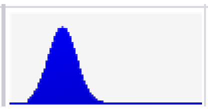
Cropping Enterprises					
Input	**Data distribution graph**	**Mean**	**10%**	**90%**	**Data sources**
Barley price		$209 / t	$134 / t	$303 / t	(ABARES, 2020)
Barley yield		2.5 t/ha	1.2 t/ha	4.2 t/ha	(ABS., 2020, ABS., 2017, ABS., 2018)
Barley yield loss from pigs		2.5%	.79%	4.9%	(Tisdell, 1982)
Chickpea price		$458 /t	$265 /t	$698 /t	(ABARES, 2020)
Chickpea yield		2.3 t/ha	1.1 t/ha	3.7 t/ha	(ABS., 2020)
Chickpea yield loss from pigs		6%	3%	9.8%	(Personal Communications, GVIA[1])
Cotton price		$460 /bale	$343 /bale	$578 /bale	(ABARES, 2020)
Cotton (irrigated) yield		11.3 bales/ha	9.1 bales/ha	13.8 bales/ha	(ABS., 2020)
Cotton (dryland) yield		2.5 bales/ha	1.2 bales/ha	3.7 bales/ha	(ABS., 2020)
Cotton yield loss from pigs		0.90%	0.3%	1.7%	(Tanger et al., 2015, Anderson et al., 2016, Engeman et al., 2018, eSYS Development, 2016)

[1] Gwidir Valley Irrigator's Association, emails and phone communication, May 2020

Faba bean price		$280 /t	$194 /t	$385 /t	(ABARES, 2020)
Faba bean yield		2.7 t/ha	1.2 t/ha	4.2 t/ha	(ABS., 2020)
Faba bean yield loss from pigs		5.5%	2.8%	8.9%	(Anderson et al., 2016) (Personal Communications, GVIA[2])
Maize price		$228 /t	$146 /t	$329 /t	(ABARES, 2020)
Maize yield		4.8 t/ha	2.4 t/ha	7.9 t/ha	(ABS., 2020)
Maize yield loss from pigs		1.25%	0.5%	2.3%	(Anderson et al., 2016, Engeman et al., 2018)
Sorghum price		$206 /t	$120 /t	$313 /t	(ABARES, 2020)
Sorghum yield		3.5 t/ha	1.6 t/ha	5.9 t/ha	(ABS., 2020)
Sorghum yield loss from pigs		3%	1.7%	4.5%	(Tisdell, 1982, eSYS Development, 2016, Tanger et al., 2015, Anderson et al., 2016)(Personal Communications, GVIA[2])
Hay price		$249 /t	$123 /t	$400 /t	(Australia, 2020)
Hay yield		3.0 t/ha	1.4 t/ha	5.1 t/ha	(ABS., 2020)

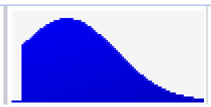
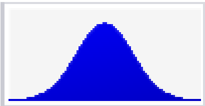
[2] Gwidir Valley Irrigator's Association, emails and phone communication, May 2020

Hay yield loss from feral pigs		4%	1.7%	7%	(Gentle et al., 2015, Tanger et al., 2015, Anderson et al., 2016)
Wheat price		$227 /t	$160 /t	$306 /t	(ABARES, 2020)
Wheat yield		2.1 t/ha	0.8 t/ha	3.7 t/ha	(ABS., 2020)
Wheat yield loss from feral pigs		2.5%	0.8%	4.9%	(Tisdell, 1982, eSYS Development, 2016, Tanger et al., 2015, Anderson et al., 2016, McLeod and Norris, 2004b)
Livestock enterprises					
Input	**Data distribution graph**	**Mean**	**10%**	**90%**	**Data sources**
Beef price		$287	$146	$464	(ABARES, 2020)
Cattle enterprise loss due to feral pigs*		1.7%	0.3%	3.6%	(Mason et al., 1998, Ridoutt et al., 2014)
Lamb price		$3.39 /kg	$1.21 /kg	$6.09 /kg	(ABARES, 2020)
Lamb / wool enterprise loss due to feral pigs*		9%	1.6%	20.5%	(eSYS Development, 2016, McLeod and Norris, 2004b, Choquenot et al., 1997)
***includes mortality increase, pasture loss, feed loss from feeders**					
Control methods					
Input	**Data distribution graph**	**Mean**	**10%**	**90%**	**Data sources**

Aerial shoot cost		$1.19 /ha	$0.37 /ha	$2.09 /ha	(Lockrey and Marshall, 2019, Saunders, 1993a, Cowled et al., 2006) (Personal Communication, GVIA[3])
Aerial shoot effectiveness		59%	37%	81%	(Lockrey and Marshall, 2019, Cowled et al., 2006, Saunders, 1993a) (Personal Communication[4])
Baiting cost		$1.17 /ha	$0.38 /ha	$2.09 /ha	(Lockrey and Marshall, 2019)
Baiting effectiveness		59%	37%	82%	(Lapidge, 2003b, Saunders et al., 1993, Twigg et al., 2005, Hone and Pedersen, 1980) (Personal Communication[4])
Exclusion fence cost		$12.81 /ha	$7.92 /ha	$18.01 /ha	(Hone and Atkinson, 1983, Lockrey and Marshall, 2019)
Exclusion fence effectiveness		70%	55%	85%	(Hone and Atkinson, 1983, Lockrey and Marshall, 2019) (Personal Communication[4])
Ground shoot cost		$5.18 /ha	$2.80 /ha	$7.61 /ha	(Lockrey and Marshall, 2019)
Ground shoot effectiveness		20%	10%	30%	(McLeod and Norris, 2004a, Gentle and Pople, 2013, Lockrey and Marshall, 2019)

[3] Gwidir Valley Irrigator's Association, emails and phone communication, May 2020

[4] Dave Lindsay, Local Land Services, emails and phone communication, June 2020

					(Personal Communication[5])
Trapping cost		\$1.30 /ha	\$0.44 /ha	\$2.57 /ha	(Lockrey and Marshall, 2019)
Trapping effectiveness		45%	25%	65%	(Lockrey and Marshall, 2019, Saunders, 1993a, Lapidge, 2003b) (Personal Communication[5])

[5] Dave Lindsay, Local Land Services, emails and phone communication, June 2020