Simulation of Management Strategies for Feral Pig Control in the Wet Tropics

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ABSTRACT

This paper reports the development and application of the Feral Pig Management Model (FPMM). The model is used to examine the affect that alternative management strategies have on a feral pig population and thus the likely economic effect, over a 20-year planning horizon. The model is used to undertake a cost-benefit analysis based on the cost of control versus the benefit associated with the reduction of feral pig damage to agricultural crops. A number of alternative strategies are compared assuming the same types and levels of control measures (shooting, poisoning and trapping) applied. The research identified that irrespective of 'strategy configuration', more frequent control appears to have a higher ranking (lower total costs). Isolated knockdowns appear to have little impact on the feral pig population in the medium to long-term. Regular continuing control at high levels is identified as the optimal control strategy.

INTRODUCTION

Feral pigs (*Sus scrofa*), which reportedly originated in Australia through the escape of pigs arriving in Australia on the First Fleet in 1788, have demonstrated great adaptability to Australian conditions. Inherent characteristics – including their ability to adapt to varying climate, ability to multiply and adaptability to food sources (as an omnivorous species) – have resulted in their spread and population increase. These characteristics have resulted in the feral pig numbers nationally growing to an estimated 23.7 M and inhabiting approximately 40% of the continent Rainforest CRC (2003).

The extent of agricultural damage in Australia caused by feral pigs is still highly uncertain and hence requires extensive research. Australian figures for feral animal control by the public sector are not readily available, being hidden in various federal and state government budgets. Gong *et al.* (2009) estimated the total expenditure in Australia in 2007-08 on feral pest management, administration and research by the Commonwealth at $12.6 M, the state and territory governments $75.5 M, and landholders $34.6 M.

In a triple-bottom-line annual impact assessment of feral pest species in Australia, McLeod (2004) reported the 'economic cost' of 11 pest species but was only able to attach environmental costs for two species (foxes and feral cats), and failed to estimate social costs for any of the 11 species. Rabbits and feral pigs were found to make up 58% of the total economic costs of these 11 main pest species. McLeod's estimated economic cost of feral pigs of $106.5 M may be regarded as conservative when compared with the Tisdell (1982) estimate of $73.3 M agricultural damage due to the increasing feral pig distribution and thus likely population as well as the time value of money.

The uncertainty of feral pig damage levels is borne out by the continuing citation of

Tisdell's 1982 book '*Wild Pigs: Environmental Pest or Economic Resource'* as an authoritative reference on the economic impact of feral pigs. Estimates of the Australian agricultural damage, control costs and research costs for the major vertebrate pests in Australia were reported by Bomford and Hart (2002). Whilst feral pig agricultural damage accounts for $100 M (23.9%) of the total feral pest agricultural losses of $417 M, control costs only account for $5 M (8.7%) of the total control costs of $57.5 M and research costs at $1.5 M accounts for only 8% of the total research costs of $18.5 M. Based on the Bomford and Hart estimates, agricultural damage is approximately 20 times that of control expenditure and 67 times that of research expenditure. These figures reflect that although feral pigs create the second highest level of agricultural crop damage in Australia (after rabbits), the level of control as indicated by control expenditure is a quarter of that for rabbits, half that of mice and feral dogs and dingoes and about 71% that for foxes.

The lack of economic studies directed at feral pigs is confirmed by Fitzgerald and Wilkinson (2009, p. 3), who stated that 'the McLeod (2004) study drew largely on previous studies, supplemented by discussions with experts in the field. Limited resources were available for the study and it was not intended to be exhaustive'. The McLeod (2004) report quotes figures for 'Control', 'Loss' and 'Total' cost with respect to agricultural production, management cost and research that are sourced from the Bomford and Hart (2002) study. A review of the Bomford and Hart material suggests that it is primarily, if not totally, based on previous studies including the Tisdell (1982) work.

The research problem addressed in this research can be summarised as: *What is the optimal control strategy, including instruments and intensity, for feral pigs in the horticultural cropping area of tropical north Queensland?* In examining this research problem a number of specific research questions have been identified, namely:

i. What is the cost of the sugar cane and banana crop damage caused by feral pigs in north Queensland?
ii. What are the current feral pig management techniques utilised by north Queensland banana and cane farmers and what are the success rates and costs associated with the management techniques utilised?
iii. What is the damage cost to the environment caused by feral pigs?
iv. Is regional eradication in north Queensland technically feasible and is it economically preferable to the maintenance expenditure incurred in living with the continued presence of feral pigs?
v. What is the optimal control strategy for feral pigs by stakeholders in the horticultural crop areas in the Wet Tropics of north Queensland?

This paper provides an overview of the model and some of the interrelationships that exist between the sub-models. A brief statement of the research method and modelling assumptions adopted is also provided. This is followed by a brief overview of the decision variables and how the model was used. Concluding comments follow.

RESEARCH METHOD

A 'control expenditure' versus 'economic damage' conceptual model was developed in order to develop a strategy hierarchy based on the present value of the sum of the control and damage costs. Of interest was the cost to farmers imposed by feral pigs in the Wet Tropics. This mainly concerned horticulture and thus the two most important horticultural crops of the Wet Tropics namely sugar cane and banana were selected.

To provide direction for the financial analysis, a model was developed which sets out a framework under which data were collected and processed. In order to identify the cost categories for feral pigs at a regional level, consultations were carried out with key stakeholders including Queensland Department of Natural Resources and Water (DNR&W) staff, sugar industry bodies and landholders. Some guidelines to pig damage categories are provided by the writings of Tisdell (1982) and Choquenot *et al.* (1996) amongst others.

Considerable research effort has been involved in model development. A major step has been the development of the biological relationships between pig removals, pig population and pig movements into cropping areas. Research carried out by Dr Jim Mitchell of the Department of Natural Resources and Mines (now DERM) has yielded information about feral pig biology and reproduction. Further information has been obtained from two workshops conducted in north Queensland with involvement of the Rainforest Cooperative Research Centre.

The control measures were indentified through literature research and consultation with field operators involved in feral pig management in the Queensland wet tropics area. This allowed for the development of control strategies which were then assessed using the FPMM.

The bioeconomic model developed provided a mechanism whereby management strategy simulation experiments could be carried out to ascertain the optimal management strategy.[1]

OVERVIEW OF FERAL PIG MANAGEMENT STRATEGY MODEL

Bioeconomic models are useful for the discussion of issues of economic optimisation based on the concepts of marginal costs and marginal benefits. For instance, many feral pests are well established in Australia and thus the policy focus must be on post-arrival exclusion and control costs. The relationships between the marginal benefits from reduction in the rate of population growth and marginal cost of control would be extremely difficult to assess in practice and in many instances the population size is unknown and the benefits from a reduction in population growth are also unknown.

This Feral Pig Management Model (FPMM) is a bio-economic simulation model developed for assessment in the Wet Tropics in north Queensland. Natural rainforest, National Parks, horticultural plantations, coastal wetlands and agricultural land are the prevailing habitat in which the feral pigs are found. Figure 1 provides a graphical overview of the sub-models and components of the FPMM. The overall model is made up of the Feral Pig Population Density Sub-model, the Human Intervention Sub-model and the Feral Pig Damage Cost Sub-model which includes damage levels of crops (sugar cane and banana) and environmental damage costs.
Weather conditions and geographic location affect not only the availability of resources required by pigs for their survival, but also the type of crops most commonly grown. The level of crop damage is modelled in relation to the feral pig population density in the

[1] Each computer run is a simulation experiment, or more precisely, the simulation of a particular treatment in a wider experiment. The experimental factors in this experimentation are the decision variables in the management strategies.

identified area of potential crop damage. The extent of the damage is also related to crop type, current weather conditions and level of human intervention imposed on the feral pig population. The weather conditions for modelling purposes are simulated on the basis of historical Southern Oscillation Index (SOI) data.

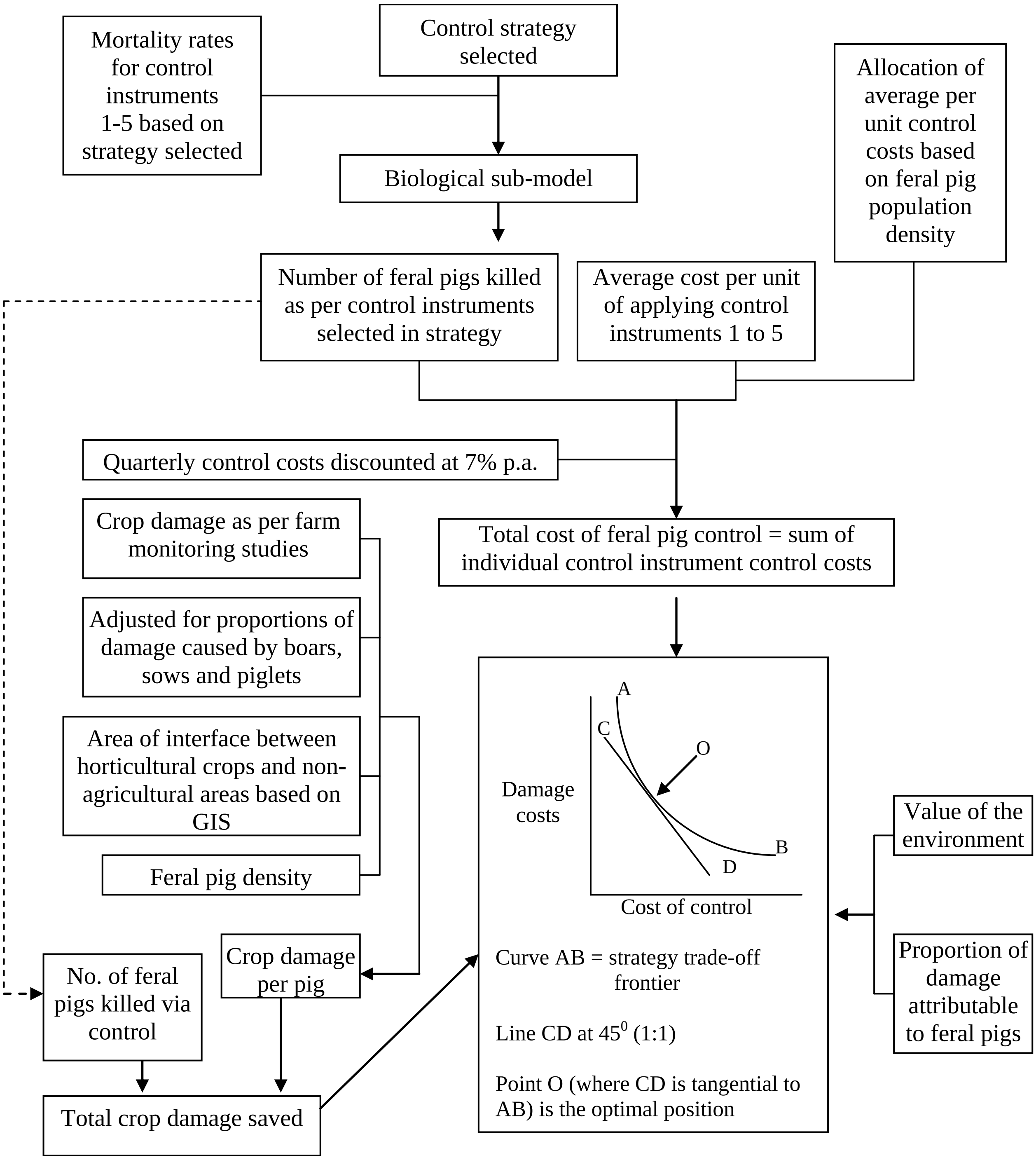

Figure 1. Attributing monetary values to the control and damage costs in the FPMM.

The various components of the model are brought together by identifying various alternate feral pig management strategies, in the form of compatible combinations of control instruments. The control costs and reduction in damage costs associated with alternate strategies are then used to develop *iso-cost curves* which enable the identification of the most appropriate control strategy. The FPMM has a time step of three months, over a planning horizon of 20 years, i.e. control strategies are simulated over 80 three-month periods. The model is implemented in MicroSoft Excel, 2003 version, with Visual Basic macro coding developed to operate the model which incorporates numerous default or user specified parameter values.

DECISION VARIABLES USED IN THE MODEL

An important component of the model is the calculation of the population of the feral pigs for each of the 80 time periods. In each period the initial population is adjusted for immigration, emigration, ageing, natural increase, natural mortality, and human induced mortality (control) in order to compute the feral pig population at the end of the period.

There are a number of variables that had to be quantified in the FPMM. The scope of this research precluded the measurement of these variables in field studies and thus reviewers of the literature were undertaken to provide values for the variables. The literature reviewers were predominantly Australian based although a number of international studies were also consulted with emphasis given to those studies undertaken in the north Queensland region. The model validation undertaken with the aid of a panel of experts included their views on the variables' 'most likely' values that had been attributed. The variables fell into three broad categories namely biological, control and damage.

Extensive research has been conducted into the various biological aspects of feral pigs. The biological variables included initial density, litter size, home range, natural mortality rates (for boars, sows and piglets), farrowing frequency, lifespan and carrying capacity of the area under research.

The reported research undertaken by numerous researchers covering these biological topics included work undertaken by Mitchell (2002) who estimated population density to be approximately 3.1 feral pigs/km^2 in coastal lowland areas bordering agricultural land.

A number of both national and international studies into home range size highlight that boars have a home larger (almost double) that of sows. A paper by Mitchell *et al.* (2009) on feral pigs in the Queensland Wet Tropics indicates little difference in home range area between boars (8.7 km^2) and sows (7.1 km^2). Mitchell (2002) found that the mean distance that the pigs travel from the centre of their home range in any one outing was 1.03 km. The home range is relevant in assessing the size of the feral pig population likely to affect a farm at the cropping interface with Wet Tropics non-farming areas.

The gender and age composition of the initial population is represented in the proportion of the population that are boars, sows and piglets. The rate of population growth is a function of the proportion of sows. In seven of 11 studies covering population structure, boars represent the majority of the population. For those studies where data on piglets is provided, piglets appear to make up approximately 55%. Mitchell's (2002) research indicates that the majority of pigs trapped (56% of 336) were less than 12 months of age and only 5% were older than five years.

The Southern Oscillation Index (SOI) has been used by a number of researchers including McMahon *et al.* (2009), Lee *et al.* (2007), Anders and Post (2006) and Marshal *et al.* (2002) in terms of their population. Holland (1999) reported that based on studies undertaken by various researchers – including Giles (1980), Hone (1987), Saunders

(1988), Caley (1993) and Choquenot (1994) – rainfall determines green feed and thus affects protein intake driving the rate of increase in the feral pig population. Similarly, the impact of weather conditions is important because weather is a 'natural' impact factor which has no cost from a feral pig control perspective, because it is not subject to human control and yet can play an important role in feral pig density. The 6-month moving average has been calculated for the past century and used as an indicator of weather conditions and rainfall for each of the 80 periods.

The age at which feral pigs (sows) can breed can vary but would appear to be weight rather than age based. Research in this area includes that of Mitchell (2002), Kerr (2001), Giles (1999), Choquenot *et al.* (1996), Caley (1993) and Saunders (1993) which indicates 20 to 30 kg weight based breeding which would occur between six and twlve months of age. They also report litter size varying from 0.84 to 2 litters per annum with 1.64 in the Queensland wet tropics.

Another element affecting number of births is population density in the area and this essentially comes back to competition and thus availability of food and water resources. The maximum carrying capacity of the area is an important element as it essentially determines an upper population density level at which those endogenous variables including natural mortality will change resulting in a reduction in the feral pig population.

A numbers of researchers including by Mitchell (2002), Giles (1999) and Saunders (1993) comment on natural mortality rates and in particular the mortality rates of young pigs in their first year when they are more susceptible to disease and predation, tends to be higher than mature animals. These researchers also comment on the feral pigs lifespan where lifespan was identified as four years by Saunders and five years by Mitchell.

In order to achieve greater realism, the model provides for the feral pigs to be aged with the oldest boars and sows (the 16th quarter age group) dying at the end of each year.

The model provides for immigration based on the difference between the pig population at the start of each time period and the maximum carrying capacity. If the period's starting (current) density is below the maximum carrying capacity, then the sub-model provides for an immigration rate (%) to be applied to the difference between the period's starting (current) density and maximum density to calculate the number of feral pigs that will immigrate. As with the initial population, the number immigrating and the gender mix and age are estimated. The population mix and age group parameters used in the initial population estimation are adopted for the feral pig immigrating into the potential damage area.

The model provides for emigration (outward bound) based on the difference between the pig population at the start of each time period and the maximum carrying capacity. If the current population is above the maximum carrying capacity, then the sub-model provides for an emigration rate (%) to be applied to the period's excess of current density over maximum carry population to calculate the number of feral pigs that will emigrate. The emigration rate of 2% was applied in the sub-model. However, there is an overriding test or default setting that if the current period's density does not exceed the maximum carrying capacity, no emigration will take place.

As with the initial population, the emigrating population size, mix and age are estimated. The population mix and age group parameters used in the initial population estimation have been adopted for the feral pig population emigrating from the research area. Another element affecting the number of piglets born is population density in the area and this essentially comes back to competition and thus availability of food and water resources. The maximum carrying capacity of the area is an important element as it essentially determines an upper population density level at which endogenous variables including natural mortality will change.

MODELLING ASSUMPTIONS

The following assumptions are made in the Feral Pig Management Model:

- The mix between boars (24.6%), sows (19.4%) and piglets (56.0%) applies to the initial population and to immigration of feral pigs into the cropping and non-cropping interface area.
- Piglets mature into sows (44.0%) and boars (56.0%) based on the original population structure. (Prior to this conversion from piglets to adult boars and sows, piglets are not classified according to their gender.)
- The feral pigs, at the start of the first period and those migrating into the area each period, are uniformly distributed between the various age groups for maturity (piglets to boars and sows) calculations.
- The Southern Oscillation Index (SOI) – as computed by the Australian Bureau of Meteorology – provides a reliable indicator of the availability of sustaining resources (food and water) for feral pigs.
- The rate of immigration (moving into the area) is based on a comparison of current period population density to the carrying capacity in any period with a greater difference resulting in a higher number of feral pigs immigrating.
- The rate of emigration (leaving the area) is based on a comparison of the current period population density to the carrying capacity in any period with an emigration rate applied to the extent to which current population exceeds carrying capacity.
- The annual farrowing frequency takes place uniformly over the year (four periods) due to the low weather seasonality in north Queensland.

THE IMPLICATIONS OF FERAL PIG CONTROL ON THE PIG POPULATION

The affect that feral pig control has on the population has been determined by using the same 'most likely' parameter values and then adjusting the frequency of the control instrument application as reflected in Figures 2 and 3. Figure 2 reflects a situation where there is no human control involved. The feral pig population reaches the carrying capacity determined upper level around which it fluctuates. In this instance a feral pig carrying capacity of 10 pigs/ha was assumed.

Figure 3 reflects a situation that may be characteristic of the type of control that does occur – in some instances due to a lack of resources where the irregular knockdown is forced upon operational staff due to political reaction at key political periods such as elections. Importantly, the reaction of the feral pig population can be seen where depending on the conditions the population rapidly increases back to its former pre-knockdown levels which fluctuate around the carrying capacity level, resulting in little gain for the efforts and resources expended.

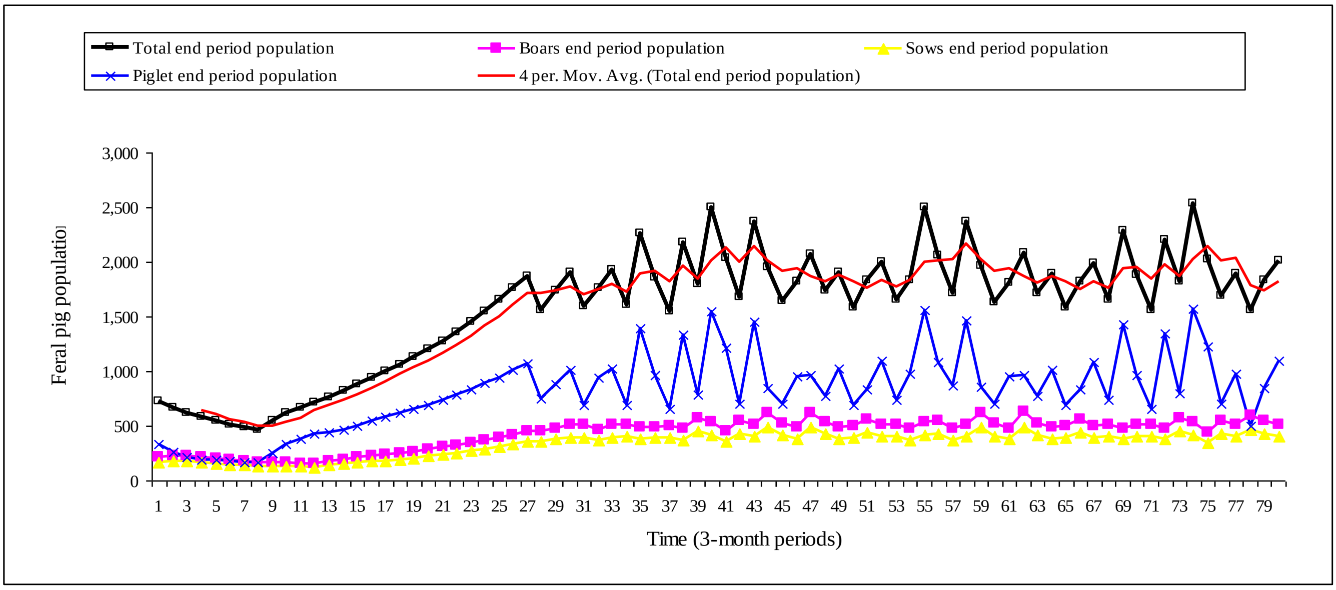

Figure 2. End-of-period feral pig population based on no control.

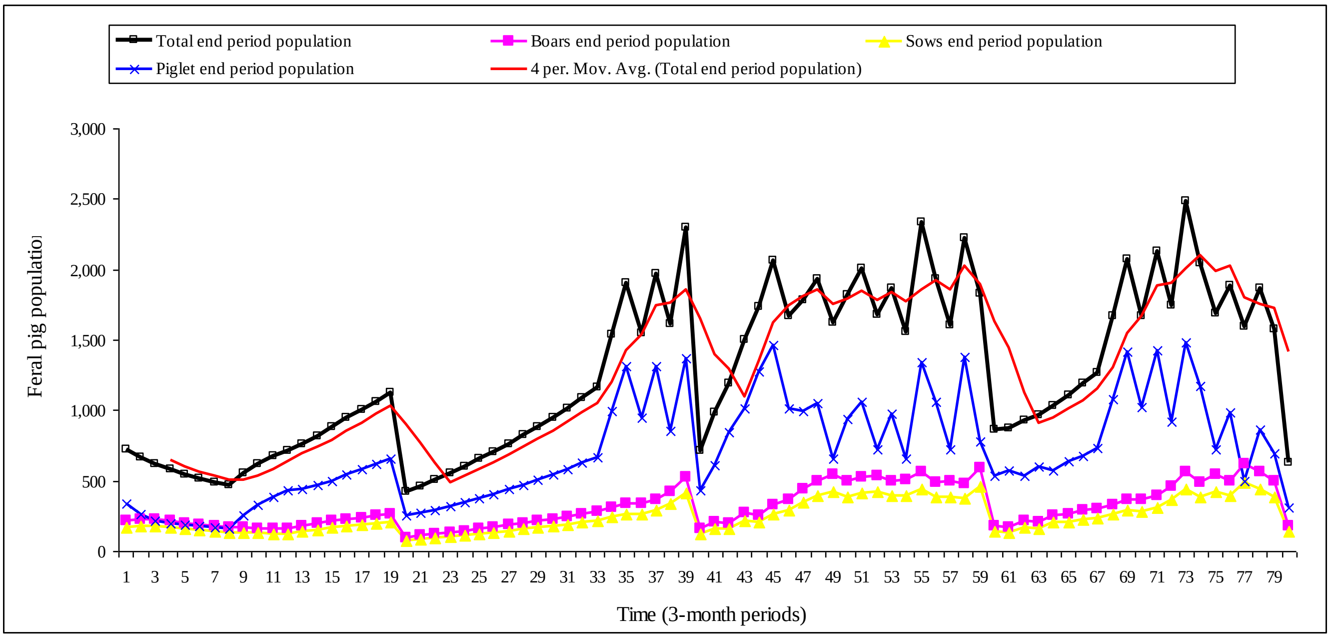

Figure 3. End-of-period feral pig population based on 5 year knockdown.

In total 17 different management strategies have been examined, and have been placed in a hierarchy of economic performance, as summarized in Table 1. The present values of the total damage and control costs combined allowed the optimal control strategy to be ascertained which is 'Annual knockdown'. Notably, it is possible to have a situation where irregular control can prove to be more expensive than no control at all.

The development of the bio-economic simulation model enabled the assessment and ranking of 17 alternative feral pig control strategies. The research identified that irrespective of 'strategy configuration', more frequent or regular control appears to have a higher ranking (lower total of damage and control costs). Isolated knockdowns appear to have little impact on the feral pig population in the medium to long-term. Annual knockdowns presented as the best option or most highly ranked control strategy, which minimised the present value of the total combined control and damage costs. Feral pigs are highly fecund pest animals and thus any control, even a knockdown, would only result in a short-term population reduction, unless there is subsequent continued control. A further finding is that the earlier the control strategy is applied the higher the ranking in the strategy hierarchy.

CONCLUSION

Bio-economic simulation modelling enables a modeller to design a representative model, identify the most likely parameter values for the model, and use the model to determine the economic affect of alternative management strategies. The model was directed at providing a strategy hierarchy for the Wet Tropics horticultural region rather than any individual farmer. The research clearly indicates that farmers can suffer varying levels of damage and thus the optimum control strategies could vary between farmers. In the Wet Tropics horticultural crop scenario, it would appear that regular control at high levels would be appropriate. It is not necessarily the pigs' presence that drives the control program, but rather the level of damage. However, if a farm is damage free in one period this does not mean that it will necessarily remain in that situation into the future. If control measures are applied feral pigs will move, or if resources (food and water) are unavailable, they will migrate even though their general home range may be quite small in the Wet Tropics. The modelling process also highlighted the importance of the carrying capacity of the areas examined. Assuming an eradication strategy is not adopted, the carrying capacity becomes the ceiling below which the feral pig population will fluctuate.

Table 1. Hierarchy of management strategies in descending order using 'most likely' parameter values.

Group[a]	Rank	Management strategy	Total control cost ($ 000)	Total damage after reduction due to control ($ 000)	PV of total control cost ($ 000)	PV of total damage after reduction due to control ($ 000)	PV of total damage and control costs combined ($ 000)
5.1	1	Annual knockdown	534	2484	290	1705	1995
3.1	2	40% annual control	826	8453	406	4143	4548
5.2	3	Biennial knockdown	745	8650	355	4621	4976
1.1	4	Knockdown in period 12 and subsequent continuing control of 40 % p.a. [b]	794	9600	368	5115	5482
3.2	5	Two 5-consecutive-years knockdowns starting periods 12 and 50	565	10,027	286	5383	5669
2.1	6	Continuing control of 40% p.a. starting period 12	871	11,514	402	6210	6612
3.3	7	Knockdown for 5-consecutive-years starting period 20	273	16,233	177	7173	7350
1.2	8	Knockdown in period 12 and subsequent continuing control of 30 % p.a.	897	16,146	398	7517	7916
1.3	9	Knockdown in period 12 and subsequent continuing control of 25 % p.a.	794	19,926	360	9001	9361
1.4	10	Knockdown in period 12 and subsequent continuing control of 22.5 % p.a.	745	20,218	342	9192	9535
2.2	11	Continuing control of 30% p.a. starting period 12	970	19,490	422	9327	9750
3.4	12	Knockdown for 5-consecutive-years starting period 12	198	23,742	147	9880	10,027
2.3	13	Continuing control of 25% p.a. starting period 12	797	22,740	350	10,759	11,108
2.4	14	Continuing control of 22.5% p.a. starting period 12	728	23,609	323	11,217	11,541
5.3	15	5-year knockdown	517	26,381	231	12,454	12,685
4.1	16	No control	0	36,671	0	17,381	17,381
5.4	17	10-year knockdown	263	38,840	100	18,503	18,603

[a] 'Group' refers to a selection of strategies which have some features in common and are also colour coded.
[b] 'Continuing control of a specified % p.a., e.g. 40% p.a., refers to the 40% p.a. control intensity being applied evenly throughout the year.

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