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Valuing the benefits from preserving threatened native fauna and flora from invasive animal pests

Contributed paper

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Summary

Invasive animal pests inflict many kinds of damage on the environment, and threaten native fauna and flora. We attempt to value the benefits from the extra biodiversity that is protected if these threats were removed. The NSW Rural Lands Protection Board is a major agency that undertakes pest control, and is organised into 48 districts across the state. A cross-sectional set of data on Board expenditures, pest abundance, and environmental and climatic characteristics, was compiled by district and analysed. The number of threatened native plant and animal species increases with pest abundance and with the total number of native species present in the district. But the number of threatened species decreases as Board expenditures on pest control increase. The value of preserving an extra species is derived from these changes in expenditure, following conventional economic principles. Then the potential gain in economic surplus is estimated if the threats to biodiversity were removed. The results so far suggest that the value of the total benefit of protecting an extra species is at least $44,250 per year, and the potential gain in surplus for New South Wales if the threats were removed is at least $132m per year. This change in surplus is also the total economic loss because invasive pests threaten native flora and fauna. If only half the native species could be protected, the avoidable economic loss is at least $95.7m per year. The assumptions and limitations of these estimates are discussed.

Keywords
Invasive animal pests, unpriced values, biodiversity gains, native flora and fauna

1 Introduction

Invasive animal pests inflict many kinds of damage on the environment, including degradation of the land, reduction in services from water resources, and extinction of native flora and fauna (McLeod, 2004). Feral goats deplete vegetation and expose soil to erosion. Rabbits and kangaroos compete with other native wildlife and livestock for pasture and destroy native plants. Wild horses trample and foul waterholes, collapse wildlife burrows and spread weeds. These impacts are all adverse changes to the environment, and all can be expected to affect agricultural outputs, inputs and profits.

Foxes, feral cats, and other pests, threaten the survival of many Australian mammals and birds, and indeed invasive pests have major effects on biodiversity. The extinction of animals and birds, as a result of this predation, can impose costs in the form of loss of environmental services. The number of species that have become extinct is difficult to determine, but McLeod (2004) documented the more serious threats to native flora and fauna from invasive pests at a national level, and Coutts-Smith et al (2007) detail the threats to native species in New South Wales from pest animals. McLeod (2004) reported that 163 plants, animals, birds and fish were at high known and perceived risk from pest animals. Coutts-Smith et al (2007) record 5346 native species of flora and fauna in NSW that are not threatened at all and a further 388 that are threatened by invasive animal pests.

The broad goal of this research is to value the environmental costs due to pest animals. Since the losses due to land degradation are included in the economic losses in agriculture, and the water impacts appear to be difficult to document, we concentrate on the impacts of pest animals on native flora and fauna. The specific objectives are therefore to value:

- the total benefit of preserving an extra native species from pest animals, and
- the net gain in economic surplus if all these threats to native flora and fauna were removed.

This potential net gain in surplus is also a measure of the current loss in surplus due to the existing threats to native plants and animals.

2 The conceptual framework

2.1 The economic model

The main environmental benefits that accrue from better pest animal management arise from the increase in services from the environment. However environmental services are difficult to describe and measure as commodities, or "goods", so we must use relevant proxies instead. In this study, the number of native plant and animal species in a non-threatened status (as described by Coutts-Smith *et. al.*, 2007) is used as a measure of quantity of environmental services. This proxy is of course the stock of biodiversity that supplies the flow of environmental services. Data on the number of non-threatened species are available (Coutts-Smith *et. al.*, 2007) for New South Wales at the level of the Catchment Management Authority (CMA).

The value of the impact of pest animals on a natural system can be modelled with the concepts of welfare economics. The horizontal axis of Figure 1 represents the number of native plant and animal species in a given area with 'non-threatened' status. The complementary status is, of course, "threatened". The current supply of non-threatened species is represented by the supply function S_0. For example, in the Northern Rivers CMA, there are 3350 native plants and animals of which 346 are threatened and of those 110 are threatened by pest animals (Coutts-Smth, 2007). So OT In Figure 1 corresponds to 3350, Q_0 corresponds to 3004 (3350-346). Point Q_1 is the number of non-threatened species if there were no pest animals so corresponds to 3114 (3004+110).

A range of external factors including weeds, urbanisation, logging, and pest animals, threatens plant and animal species. In Figure 1, the demand function (*D*) represents the willingness to pay, or marginal benefit, for preserving a single species in a non-threatened status instead of allowing it to become threatened. Economists normally assume that:

- when there are many non-threatened species, society is willing to pay a lower value to preserve one more as non-threatened, and
- whereas when there are few non-threatened species, society is willing to pay a high value to protect one more species as non-threatened.

The demand curve is then downward sloping as in Figure 1.

The model of Figure 1 can be applied to estimate the economic benefit of protecting more native species from pest animals or the economic cost of the loss from losing them. There are at least two ways to apply the model to measure these losses.

2.2 Measures of species value

Change in economic surplus Using this model, the usual economic surplus concepts can be applied to measure the impact of a change in the supply function such as a move to S_1, when there are no pest animals in the region under consideration. This move results in an increase in the quantity of non-threatened species (from Q_0 to Q_1), which results in a gain in economic surplus represented by the area *abcd*. This is the economic value of the gain from protecting the non-threatened status of ($Q_1 - Q_0$) species. It is also the value of the loss when ($Q_1 - Q_0$) become threatened by pest animals.

Change in total benefit Because of data limitations, it is sometimes difficult to undertake the standard economic surplus analysis to estimate *abcd*. For example, slopes of the demand and supply curves may be unknown. But once the marginal cost MC_0 (=P_0) is estimated, it is possible to measure the gain in benefit associated with a shift to S_1 as the area Q_0Q_1ed (Figure 2). This is also the loss in benefit when ($Q_1 - Q_0$) native species become threatened by pest animals.

However, this measure will result in a small overestimate of the true change in economic surplus by the area *dec*. But due to the potentially highly-elastic nature of the demand for environmental services, we expect the value of any overestimate (*dec*) to be small.

To apply the economic model and calculate both these measures of value, we need to estimate MC_0 (=P_0), Q_0, the slopes of S_0 and S_1, and the shift (K) of S_o to S_1. To determine MC_0 and the slopes of the supply curves, we estimate the following equation.

Number of threatened species	= f (total number of native species, expenditure on pest control, pest abundance, climatic conditions, location)	(1)

The slope of the supply curve is its elasticity, which is the percentage increase in quantity of output caused by a one percent increase in cost.

2.3 Application to the problem

This application, through Equation (1), will first identify the change in expenditure necessary to reduce the number of threatened species by one. This marginal cost can be interpreted as the minimum value of the benefit from protecting one more native species - - otherwise rational managers would not undertake the expenditures. Thus, the item being valued in this step in the analysis is one more unit of the stock of native plants and animals which is no longer threatened by animal pests.

Then this marginal cost, and the associated elasticity of supply, will be used to calculate the change in economic surplus *abcd*, which is the gain in benefit if pests are reduced and the loss due to the presence of invasive pest animals. The "activity" being valued in this step is the benefit of improved management and research that leads to the downward shift of the supply curve from S_0 to S_1.

3 Data Collection

The data are now described. The unit for analysis is the Rural Land Protection Board (RLPB) in New South Wales. There are 48 such districts in the state, but complete data could only be collected for 38 of them. The mean values of the data for these 38 are summarised in Table1.

3.1 The number of non-threatened and threatened native species

Coutts-Smith et. al. (2007) provide data on the:

- total number of native plants and animals,
- total number of non-threatened native plants and animals, and
- the total number of native species threatened by pest animals,

for each of the 13 Catchment Management Authority areas of New South Wales. The data for each of these three variables were adapted to the RLPB areas by assuming that each district in a given CMA area had the same value of each of these variables as the CMA as a whole. This assumes that all species in a given CMA area occur in all its Board district.

The variable for the total number of native species was labelled TNNS, and the variable for the number of native species threatened by pest animals was labelled NOTS.

3.2 Expenditure on pest control and area

Data were obtained from the RLPB Head office on the total expenditure of the boards on pest control in 2006 and the area of each district. The expenditure data were available for 38 of the 48 boards in the state, so the analyses were restricted to those 38 districts. These two variables were labelled EXP and AREA.

3.2 The climatic index

The threats to native species will also depend on climatic conditions, principally temperature and rainfall. A climatic index was therefore calculated as the multiplicative sum of a temperature index (TI) and a rainfall index (RI), both of which were scaled between 0 and 1. The details of the calculations are shown in Appendix 1, but the procedure is now outlined.

Temperature plays a primary role in the growth and development of plants which respond to a low, optimum, and a high threshold temperatures. The temperature index was calculated from the mean temperature relative to norms for these three figures for each Board. The rainfall index was, in essence, derived from the difference between mean rainfall for the Board area relative to an assumed maximum desirable level of 500mm per year. This procedure followed Jones (2003).

The procedure and calculations inevitably involve assumptions, and these are noted in Appendix 1. A key assumption is that of a maximum level of rainfall for vegetation growth R_{max} which we judged to be 500 mm. To allow for other judgements, the climatic index was recalculated with a level of 700 mm for R_{max}. The two versions of the climatic index were therefore labelled CLIM5 and CLIM7.

3.3 Indices of pest abundance

West and Sanders (2002) collected data on the areas of each RLPB district with high, medium, low, and nil levels of each of several animal pests, including dogs, foxes and rabbits. Two measures of pest abundance were derived from these data.

ABUNHA is the total number of hectares occupied by these three pests in each district. It is calculated as the (areas of high, medium and low infestations of dogs), plus the (areas of high, medium and low infestations of foxes), plus the (areas of high, medium and low infestations of rabbits).

ABUNPC is the percentage of each Board area occupied by these three pests, calculated as ABUNHA/AREA.

3.4 Locational variables

The Rural Lands Protection Board has divided the state into eight administrative regions. The regions are also geographical units that represent different topographies and land of different accessibilities, and so variables to distinguish between them should be included. Dummy variables were therefore defined for each region as 1 = that region and 0 otherwise. The dummy variables were LWD for western division, LNSP for northern slopes and plains, LCSP for central slopes and plains, LSSP for the southern slopes and plains, LST for southern tablelands, LNT for northern tablelands, LSC fort south coast and LNC for the north coast.

4 Analysis and results

4.1 Preliminary analysis

The model to apply Equation (1) is therefore:

NOTS = f (TNNS, EXP, ABUNHA or ABUNPC, CLIM5 or CLIM7, LSSP and/or LCSP) (2)

There are two alternative abundance variables so a choice must be made between them. In the preliminary analyses to estimate Equation (2), the area measure of abundance (ABUNHA) proved to be significantly related to the number of threatened species (NOTS), whereas the percentage measure (ABUNDPC) did not. So the area measure was used in the analysis.

There are also two alternative climate variables, CLIM5 and CLIM7, to choose between. In the preliminary analyses, the use of CLIM7 always had slightly lower adjusted R squared values and gave no noticeable increase in the t-statistic over CLIM5. Further, the use of CLIM7 was associated with lower t-statistics on ABUNHA when both were in the same equation. For these reasons, CLIM5 was adopted as the better climate variable. While a standard procedure, this preliminary test proved important in determining that 500 mm is a superior level to 700 mm in determining the number of threatened species in each RLPB district.

There were eight locational variables, and they were screened in the preliminary analysis on the basis of their correlation coefficients with NOTS. Only LSSP, LCSP, LNSP and LNC had coefficients over 0.25 but LNSP and LNC were correlated with another explanatory variable, namely CLIM. So only LSSP and LCSP were used in the models.

4.2 The estimated equations

The explanatory variables of TNNS, EXP, ABUNDHA, CLIM, LSSP, and LCSP were all included first (Equation 3 in Table 2) and then the two locational variables were excluded one by one to give Equations (4) and (5).

All the equations were estimated by ordinary least squares regression. The preferred equation was selected on the basis of two diagnostic tests, namely the adjusted R squared test and the significance of the explanatory variables. The expected signs can be predicted with some confidence so a one-tailed t-test was used to determine the levels of significance. The adjusted R squared values are high, and about the same value, in each of the three equations of table 2 but the t-statistics are each significant only in Equation (5). On this basis, Equation (5) is to be preferred.

Ordinary least squares regression assumes that the variances of the residuals for each level of an explanatory variable are the same. If this assumption is violated, the residuals are said to be heteroscedastic and the estimated t-statistic will be less than the correct t-statistic. A scatterplot of actual data points for each explanatory variable with NOTS was observed as an early warning of heteroscedasticity.

The observations on NOTS for lower values of ABUNHA were more variable than observations for higher values of ABUNHA, hence indicating a potential case of negative heteroscedasticity. The scatterplot for the variable EXP also indicated a potential case of negative heteroscedasticity. Accordingly a Golfdfeld-Quandt test was undertaken on both variables. The GQ F - statistic for (0.05, 17,17) was 1.61 for ABUNHA and 0.686 for EXP against an F critical value of 2.272, so we accept the null hypothesis of no heteroscedastcity in both cases.

Ordinary least squares regression also assumes that the independent variables are not correlated with each other. If they are correlated, the problem of multi-collinearity exists, and the estimated t-statistics are not good indicators of the role of the independent variables in explaining the variation on the dependent variable (NOTS). A test for multi-collinearity is to estimate the correlation coefficients between each pair of explanatory variables. If the coefficient is of the same magnitude a the coefficient of determination then the problem may be present. The highest correlation coefficient in this case (between each pair of TNNS, EXP, ABUNHA, CLIM, LSSP, LCSP) was 0.43 between CLIM and LSSP, and then 0.39 between CLIM and LCSP. These values are not high when compared to the coefficient of determination of 0.912 for equation (5). There appears to be no problem of multi-collinearity.

4.3 Results

The significance of the variables in Equation (5) indicate that the number of threatened native species rises as:

- the total number of native species (TNNS) rises, and
- the abundance of pests (ABUNHA) rises.

The number of threatened species falls as:

- the Board expenditure (EXP) increases, and
- the climatic index (CLIM) increases.

The coefficients on expenditure (EXP) in the table can be interpreted to give $MC_{0,}$ and hence P_0, in Figure 1. For example, in Equation (5) the coefficient is -0.0226 so every unit increase in EXP decreases NOTS by 0.0226. The variable EXP is coded in \$1000 so an increase of \$1000 reduces the number of threatened species by 0.0226 and therefore increases the number of non-threatened species by 0.0226. Equally, an increase of \$44,250 (\$1000/0.0226) increases the number on non-threatened species by one.

The elasticity of NOTS with respect to expenditures on pest control (EXP) is calculated as:

= -0.0226 x (mean EXP/mean NOTS)
= -0.0226 x (199.8/74.3)
= -0.0226 x 2.689
= -0.0608%

So from Equation (5), MC_0 becomes \$44,250 and the elasticity, or the slope of S_0 is 0.0608%. The value of \$44,250 is a measure of the benefit of removing the threats to one more native species of flora and fauna, and so is a measure of this gain in biodiversity.

5 Estimating the economic losses

5.1 Application of the surplus model

The Rural Lands Protection Boards seek to control pest animals and in so doing increase agricultural productivity. These control activities also reduce the threats to native plants and animals from invasive pests, and so provide biodiversity benefits directly to the community as a whole. The conceptual framework of Section 2 has modelled this market in the production of biodiversity and cast the benefits and losses in the context of surplus changes. We now apply this framework to measure the potential economic gain if the threats from pest animals were removed, which is also the current economic loss due to the impacts of the pests.

The change in economic surplus, *abcd* in Figure 1, measures the:

- loss due to the threats to ($Q_1 - Q_0$) native species from pest animals, or
- gain if ($Q_1 - Q_0$) native species are no longer threatened by the pests.

These are the two alternative, but complementary, ways to interpret Figure 1. The loss is relevant if the pest threats continue, and the gain is relevant if the threats are removed.

We now calculate this change in surplus for the state as a whole, from the results that have been estimated so far for the 38 Rural Lands Protection Boards, and from supplementary state-wide information. Alston (1991) provided a formula to calculate this particular surplus value *abcd*. With the notations of Figure 1:

$$\text{Economic surplus } abcd = P_0 * Q_0 * K * (1+0.5Z\eta) \qquad (10)$$

The variable K is the downward shift in the supply curve from S_0 to S_1 as a proportion of the original price (or original marginal cost). This variable is measured as $(d-f)/P_0$ in Figure 1.

The term Z is calculated as:

$$Z = (K*\varepsilon)/(\varepsilon + \eta) \qquad (11)$$

where ε is the elasticity of supply and η is the elasticity of demand.

We therefore require values for all the variables in Equations (10) and (11). The values for P_0, Q_0, Q_1, and the elasticity of supply (ε) are known, but those for the K shift and the elasticity of demand (η) are not. The value of P_0 is equal to MC_0, which is \$44,250. We know that a total of 5346 species over the whole state are not threatened at present, so this is the value of Q_0. There are 388 species that are threatened by pest animals so Q_1 is 5734 (5346 + 388). The value of ε, the elasticity of supply, has been estimated from equation (5) as 0.0608.

But the values of both K and η, together with the known values of P_0, Q_0, Q_1 and ε, must jointly lead to the value of 5734 for Q_1. So we set the level of one of the unknown variables (K) to an arbitrary value within a likely range and calculate the value of the other variable (η) that satisfies the requirement that Q_1 equals 5734 for the known values of P_0, Q_0 and ε. The elasticity of demand is, of course, calculated as follows:

$$\eta = \text{% change on quantity/% change in price} \qquad (12)$$

Or in terms of Figure 1:

$$\eta = ((Q_0\text{-}Q_1)*100)Q_0 \;/\; (dg*100)/MC_0$$
(13)

where all terms except g are already known and g is calculated from given shift in K as shown in Appendix 2.

Two scenarios that meet the requirement that Q_1 is 5734 are shown in Figure 3. The original equilibrium for MC_0 and Q_0 is point *d*. If the supply shift (*K*) is 55%, we have S_{55} which requires the demand elasticity reflected in D_{55} for the intersection at *c* to give Q_1. Similarly, if the supply shift were 60% giving S_{60}, the demand curve must be D_{60} to attain the intersection at *c** that again leads to Q_1.

Thus each K shift is accompanied by a unique elasticity of demand, and smaller shifts are accompanied by higher elasticities of demand. Also there will be some minimum value for the shift in the supply curve from S_0, because the shift must still be high enough to allow a highly-elastic demand curve to pass though point c at Q_1. In the present analysis for the protection of 388 species that are threatened by invasive pests, this shift in K is 55 per cent.

The calculations of surplus values for three scenarios that meet the requirement are shown in Table 3, together with their surplus estimates derived from Equation (10).

5.2 Interpretation of the surplus changes

The surplus values for each scenario may be interpreted as follows.

- If the supply curve shifts downward by 55%, the elasticity of demand must be 5.584 (Scenario 1) and the change in total economic surplus is $132.2m.

- If the supply curve shifts downward by 57%, the elasticity of demand must be 1.2793 (Scenario 2) and the change in economic surplus is $137.1 m.

- If the supply curve shifts downward by 60%, the elasticity of demand must be 0.5924 (Scenario 3), and the change in economic surplus is $144.3m.

Intuitively, community discussion seems to indicate that there would be little reduction in willingness to pay per species as further native species are protected from invasive animal pests. So the demand for the preservation of more species is likely to be highly elastic. Scenario 1 has the highest elasticity of demand (5.5840) and the lowest reduction in willingness to pay between the 5346^{th} unit and the 5734^{th} unit. While there is little difference between a 55% (Scenario 1) or a 60% (Scenario3) value for K, the former involves only a 1.3% reduction in willingness to pay while the latter involves a less-likely 12.3% reduction.

Across these scenarios then, the annual gain in economic surplus due to removal of threats to the native species of flora and fauna can be assessed at between $132.2m and $144.3m. This is a relatively small range in surplus estimates because the main part is the reduction in cost for all the species up to Q_0, rather than the additions for the much smaller number of extra species now protected between Q_1 and Q_0.

Scenario 1, with the highest elasticity of demand, appears to be the most appropriate so the potential gain in surplus would be at least $132.2m per year if the threats were removed. Equally, the current loss of economic surplus due to the presence of the pests is at least $132.2m per year - - given the parameter values and assumptions.

5.3 Total loss and avoidable loss

The estimates of the change in surplus in Section 5.2 represent the total loss due to invasive pests, or the total potential gain if all pests can be controlled and all threatened species can be protected. It is, however, unlikely that all pests can be controlled and all species can be protected. So the avoidable loss is perhaps a more relevant management concept than the total loss.

There appears to be no information, at the state-wide level, on what loss of species is currently avoidable. So we now assume that one half of all threatened species could be protected with more widespread application of known techniques, and use of economically-feasible methods that are currently being tested. The avoidable loss is now the potential gain in surplus from changing the status of one half of the species at risk from threatened to non-threatened.

In New South Wales, there are presently 388 species threatened by invasive pests and 5346 that are not threatened. If one half of the threatened species become non-threatened Q_1 is now 5540 (5346 + 194). Three combinations of supply and demand curves that meet the requirement that Q_1 is now 5540 are summarised in Table 4. The shift in the supply curve must be at least 40% (Scenario 4) for an elastic demand curve to lead to the new Q_1 of 5540. In this case, the loss in surplus is $95.7m per year for New South Wales.

6 Discussion

In this final discussion, we summarise the results and comment on the assumptions, and set out the further work to be undertaken.

The analysis has indicated that the total benefit of protecting one more species may be set at $44,350 per year at least. Rational managers will undertake activities when benefits exceed costs, so we know that this value is a minimum estimate of the benefit. It is a defensible estimate because it is derived from actual expenditures. The analysis has also indicated that the total net loss of economic surplus due to the threats from animal pests to the 388 species of native fauna and flora in New South Wales appears to be at least $132.2m per year. If only half the native species at risk can be protected, the avoidable loss is at least $95.7m per year in New South Wales.

Further work should attempt to:

- extend the estimate of environmental loss to Australia as a whole,
- estimate the agricultural losses due to pest threats with the surplus models,
- collect data on administrative costs attributed to pest animals, and
- collect data on research cost attributed to pest animals.

The latter costs lead to the development of the techniques and efficiencies that underlie the shift in the supply curve. The further work should also include sensitivity analyses on the estimate of the economic loss, to identify the most influential factors in determining its size.

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REFERENCES

Alston, J M, 1991, Research benefits in a multimarket setting: a review", *Review of Marketing and Agricultural Economics*, 59 (1), 23 -52.

Coutts-Smith, A J, Mahon P S, Letnic, M and Downey P O, 2007, *The threat posed by pest animals to biodiversity in New South Wales*. Invasive Animals Co-operative Research Centre, Canberra.

Fitzpatrick, E.A. and Nix, H.A. 1970, 'The climatic factor in Australian grassland ecology', in *Australian Grasslands*, Ed R. Milton Moore, ANU Press, Canberra.

Hutchinson, M.F., Nix, H.A. and McMahon, J.P. 1992, 'Climate considerations on cropping systems', in *Ecosystems of the World: Field Crop Ecosystems*, ed C.J. Pearson, Elsevier, Amsterdam.

Jones, Randall, 2003, An Economic Analysis of Integrated Weed Management in Australian Cropping Systems, PhD Thesis, university of New England.

McLeod, Ross, 2004, *Counting the Cost: Impact of Invasive Animals in Australia* 2004, Co-operative Research Centre for Pest Animal Control, Canberra.

Nix, H.A. 1981, 'Simplified simulation model based on specified minimum data sets: The CROPEVAL concept', in *Application of remote Sensing to Agricultural Production Forecasting*, ed A. Berg, Commission of the European Communities, Rotterdam.

Sinden, John Alfred and Garry Griffith, 2007, "Combining economic and ecological arguments to value the environmental gains from control of 35 weeds in Australia", *Ecological Economics*, 61, 396 – 408.

Sinden, J A, Paul O Downey, Susan M Hester and Oscar Cacho, 2008, Valuing the biodiversity gains from protecting native plant communities from bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T. Norl.) in New South Wales: application of the defensive expenditure method, Paper presented to the

Annual Conference of the Australian Agricultural and Resource Economics Society, Canberra, February.

West, Peter and Glen Saunders, 2003, *Pest Animal Survey 2002: An analysis of pest animal abundance across NSW and the ACT*, NSW Agriculture.

Table 1 A summary of the variables used in the analysis, with means of the 38 Boards in the analysis

Symbol	Variable	Mean
NOTS	Number of threatened native species	74.3
EXP	Total expenditure on pest control in 2006 $000	199.8
TNNS	Total number of native species	2,206.0
CLIM5	Climatic index	0.776
ABUNHA	Pest abundance* 000ha	556.4
ABUNPC	Pest abundance* per cent of board area	39.0
LSSP	Location: southern slopes and plains	0.184
LCSP	Location: central slopes and plains	0.158
AREA	Area of the RLPB, 000ha	1,652.18

* Both pest abundance indices include high, medium and low areas of three pests, namely dogs + foxes + rabbits. ABUNHA is the aggregate area per board, and ABUNPC is the percentage area (ABUNHA/AREA) per board.

Table 2 Models to explain variations in numbers of species threatened by pest animals: applications of equation (2)

Variable	Equation		
	3	4	5
TNNS	0.0246 (10.3)***	0.0247 (11.9)***	0.0271(11.0)***
EXP	-0.0232 (3.5)***	-0.0232 (3.6)***	-0.0226 (3.1)***
ABUNHA	$2.85^{-0.6}$ (1.1)	2.85^{-06} (1.1)	4.15^{-06} (1.5)*
CLIM5	-13.146 (2.4)**	-13.326 (3.3)***	-22.458 (4.7)***
LSSP	-0.217 (0.1)		6.270 (1.6)*
LCSP	-12.305 (2.9)***	-12.187 (3.4)**8	
Intercept	33.386	33.316	29.872
R	0.932	0.932	0.912
R^2	0.868	0.868	0.832
Adjusted R^2	0.842	0.847	0.806
N	38	38	38

*** indicate significance at I per cent or better
** indicates significance at 5 per cent or better
* indicates significance at 10 per cent or better

Table 3 Estimation of change in economic surplus when all 388 threatened species are protected

Variables	Scenarios		
	1	2	3
Variables with known values			
$P_0 = MC_0$ $	44,250	44,250	44,250
Q_0	5346	5346	5346
Q_1	5734	5734	5734
ε %	0.0608	0.0608	0.0608
Variable that is "arbitrarily" set			
K %	55	57	60
Variable that is calculated, given the above values			
η %	5.584	1.2793	0.5924
Change in economic surplus, using the above values			
Change* $m	132.2	137.1	144.3
Surplus gain ($ per species) by source			
Lower cost of protecting existing species**	24,400	25,200	26,600
Net benefit from protecting extra species***	5,500	5,800	6,000
*Reduction in WTP**** for protecting the 5734th relative to the 5346th species*			
Percentage reduction in WTP	1.3	5.7	12.3

* Calculated as *abcd* in Figure 1
** Calculated as *abfd*/5346.
*** Calculated as *dfc*/388.
**** WTP = willingness to pay

Table 4 Estimation of change in economic surplus when half (194) of the threatened species are protected

Variables	Scenarios		
	4	5	6
P_0 initial price (= MC_0) $	44,250	44,250	44,250
Q_0 initial quantity	5346	5346	5346
Q_1 final quantity	5540	5540	5540
ε % elasticity of supply	0.0608	0.0608	0.0608
K % shift in supply	40	50	60
η % elasticity of demand	0.8664	0.1800	0.1004
Change in economic surplus $m	**95.7**	**119.6**	**143.5**

APPENDIX 1 The Climatic Index

The effects of climate upon vegetation growth can be represented through the use of various indicators of temperature and rainfall. The approach is based upon the GROWEST model developed by Fitzpatrick and Nix (1970) and further presented by Nix (1981) and Hutchinson, Nix and McMahon (1992). The data of mean temperature and rainfall were obtained from the Bureau of Meteorology.

The generalised response functions from the GROWEST model transform the responses of plants to temperature and available rainfall into two dimensionless indexes on a linear scale from zero to unity. The two indexes are temperature index (*TI*) and rainfall index (*RI*). Thus each index has values ranging from zero (completely limiting conditions) to unity (non-limiting conditions for growth). The following description of each of the climatic indexes is drawn from Nix (1981) and Hutchinson *et al*. (1992).

1. Temperature index

Temperature plays a primary role in the growth and development of plants. Plant species exhibit characteristic response curves to temperature, with a lower temperature threshold, an optimum and a higher temperature threshold for growth. Analysis of growth and dry matter production for a wide range of species indicates three distinct groups of plants, namely microtherm, mesotherm and megatherm plants, each with a specific set of thermal responses. The mesotherm group includes field crops which have a thermal optima (t_o) of 19 to 22°C, a lower temperature threshold (t_{lo}) at around 5°C, and an upper temperature threshold (t_{hi}) at around 35°C (Nix 1981).

The curves relating dry matter production to mean daily temperature (T_{mean}) are specified mathematically by a combination of power functions based upon the relative temperature deviations from the mean. The maximum absolute deviations are taken as the differences between the optimum temperature and the thresholds at which fractional dry matter production is zero. Thus the temperature index (*TI*) is at unity at the optimum daily temperature. All temperatures are expressed as relative deviates (*X*) from this optimum. The independent variable is the absolute (non-negative) value of *X* and is determined by

$$|X| = \frac{t_o - T_{mean}}{t_o - t_{lo}} \quad \text{for } T_{mean} < t_o \tag{1}$$

$$|X| = \frac{T_{mean} - t_o}{t_{hi} - t_o} \quad \text{for } T_{mean} > t_o \tag{2}$$

For all values of $|X|$ within the range of 0 to 0.5

$$TI = 1.0 - \frac{(2|X|)^b}{2} \tag{3}$$

For all values of $|X|$ within the range of 0.5 to 1.0

$$TI = 0.5[2(1.0 - |X|)]^{b} \tag{4}$$

The parameter b governs the inflection and asymmetry of the curves. For the mesotherm species b is set at 2 (Nix 1981).

2. Rainfall index

Following Nix (1981), the rainfall index (*RI*) is determined from a function that relates *RI* to the relative available rainfall water in the root zone.

$$RI = 1 \text{ for } \mathrm{R}_{\max} \geq 1 \tag{5}$$

$$RI = \frac{R}{R_{\max}} \text{ for } \mathrm{R}_{\max} < 1 \tag{6}$$

where R_{max} is the maximum precipitation which was assumed to be 500mm in this model. R is the mean rainfall.

3. Climatic index

A simple multi-factor index (*CLIM*) can be defined as a multiplicative function of the two indexes.

$$CLIM = TI \times RI \tag{7}$$

Obviously no simple relation can be formulated that will fully describe the complex environmental interactions involving plant response to the environmental factors. However, a multiplicative function has been found to be marginally superior to Liebig's law of the minimum where the value of the most limiting factor becomes the value of the growth factor (Nix 1981). The *CLIM* has values ranging from zero to unity and can never exceed the value of the single most limiting factor.

APPENDIX 2 Calculation of the elasticities of demand

Refer to Figure 1 and Equations (9) and (10).

1 The elasticity of demand is conventionally calculated as:

η = (gc as % of Q_0)/(dg as % of MC_0), or more simply = gc%/dg%

2 Calculate gc% first.

gc% = ((Q_1-Q_0)*100) / Q_0 (A)

3 Calculate dg% next.

dg% = ((MC_0- Q_0f - gf)*100) / MC_0 (B)

Proceed in several steps to calculate each part of equation (B).
(i) We know MC_0

(ii) Calculate Q_0f = MC_0 * (1-K)

(iii) We can't calculate gf directly, but we know that fb = ch. So we calculate fh from the known elasticity of supply:
Es = fh% / ch% (C)
We know fh% = ((Q_1 – Q_0) *100)/Q_0 (D)

So we insert (D) in equation (C) and solve for fh.

Es = fh% / ((ch*100)/Q_0f) (E)

Re-arrange (E) to bring denominator ((ch*100)/Q_0f) over to the left hand side.
Es * ((ch*100)/Q_0f) = fh% (F)

Insert equation (D) on right hand side of equation for fh% .
Es * ((ch*100) / Q_0f) = ((Q_1 – Q_0) *100)/Q_0

Re-arrange the above equation to shift Es and Q_0f to the right hand side.
ch *100 = (Q_0f * ((Q_1 – Q_0) *100)) / (Q_0 * Es)

Divide by 100, to give ch
So ch = (Q_0f * ((Q_1 – Q_0) *100)) / (Q_0 * Es*100)

4 Calculate dg% from equation (B)
dg% = (MC_0-Q_0f-ch)*100)/MC_0 (G)

5 Calculate η as η = gc% / dg% (H).
The numerator in Equation (H) is taken from Equation (A) and the denominator from (B).

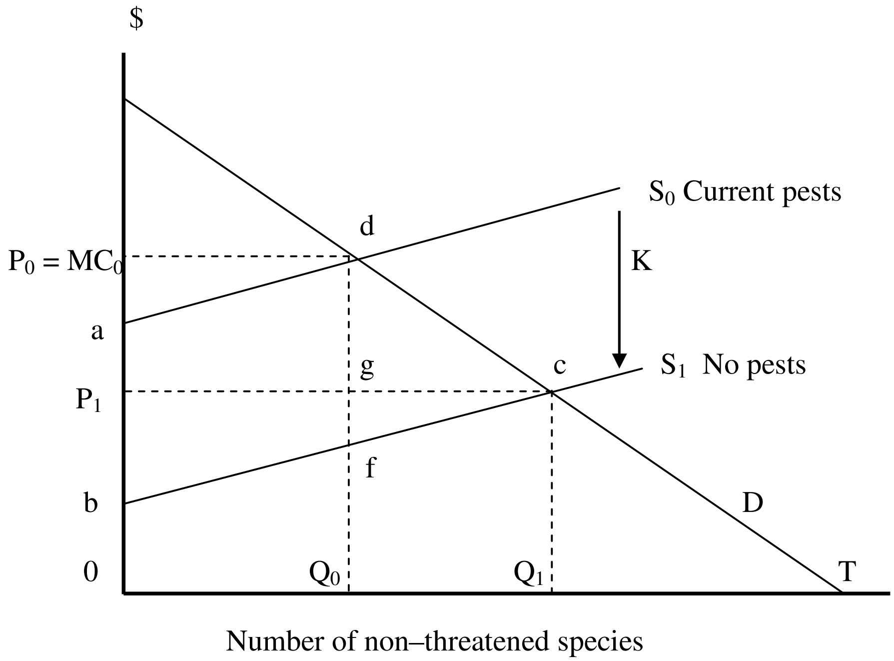

Figure 1 Estimation of the net benefit of protecting native species from pest animals: change in economic surplus (*abcd*)

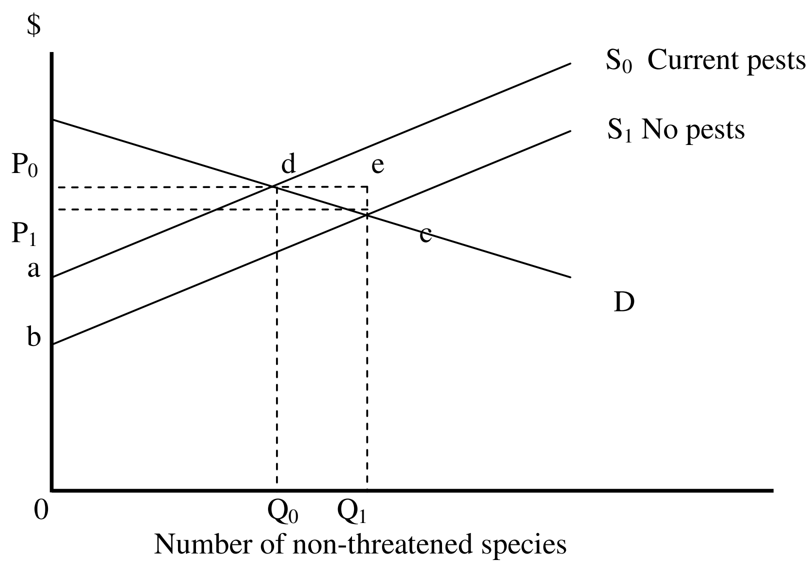

Figure 2 Estimation of the total benefit of protecting native species from pest animals: change in total benefit (*Q_0Q_1ed*)

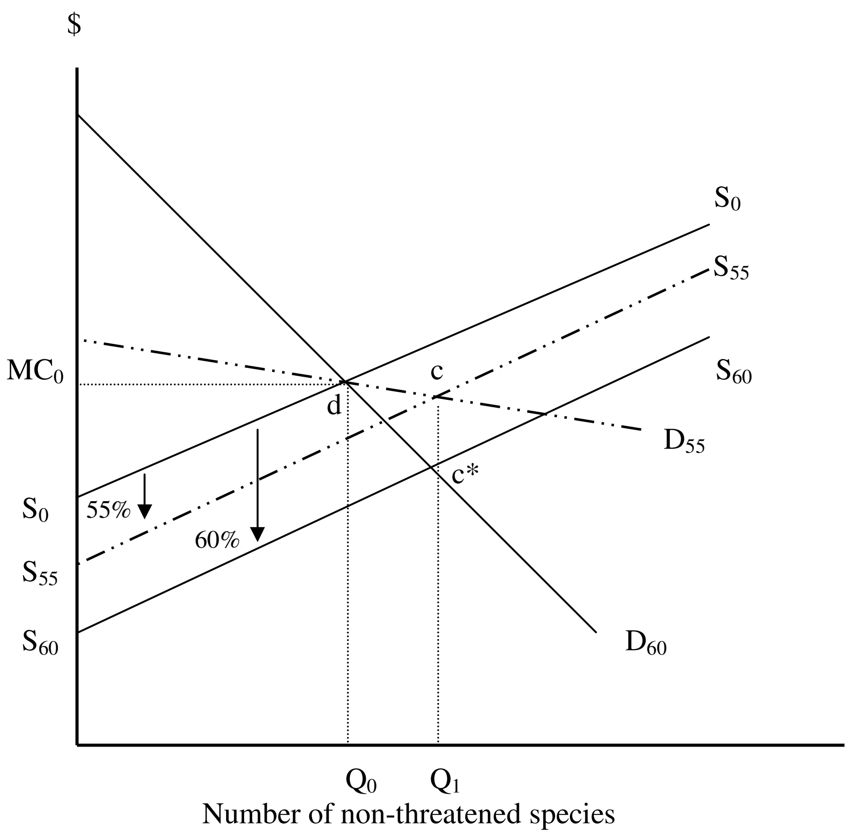

Figure 3 **Estimation of the change in economic surplus, for two alternative combinations of the supply shift (giving S_{55} and S_{60}) and elasticity of demand (giving D_{55} and D_{60})**