EXPLOITATION OF BRUSHTAIL POSSUM POPULATIONS IN THEORY AND PRACTICE

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SUMMARY: Recent trends in the New Zealand fur industry, based on introduced brushtail possums *(Trichosurus vulpecula)* include an increasing proportion of small skins and some evidence of declining catch per unit effort, suggesting that populations are being exploited hard. There is a case for considering sustained yield harvesting in non-sensitive habitats. A logistic model is used to estimate the maximum sustainable yield of possums from New Zealand exotic forests. Practical difficulties in controlled harvesting and potential refinements to the simple model are discussed.

INTRODUCTION

Australian brushtail possums *(Trichosurus vulpecula* Kerr) were first introduced to New Zealand around 1840, to establish a fur industry. Their subsequent spread throughout the main islands was aided by a series of liberations (Pracy, 1974), so that by 1946 they were absent from only a few districts (Wodzicki, 1950). During their initial period of spread possums were generally regarded as an asset and, from 1921 to 1946, the trade in possum pelts was supervised by the New Zealand Government, with a royalty charged on each skin. However, increasing concern over possum damage to crops, plantations and native forests led to the eventual declaration, in 1947, of the possum as a 'noxious animal' and the removal of all protection. A bounty on possums was introduced in 1951 to encourage control, but this proved ineffective and was discontinued in 1961. Since then, widespread possum control has been attempted mainly by poisoning, including the use of aerial-sown baits treated with compound 1080 (sodium monofluoroacetate).

A small, fluctuating, export trade in the skins of possums trapped or poisoned by private operators was maintained throughout all of these changes in the status of possums. However, a steady rise in the value of skins from about 1975 led to renewed interest in possums as a source of revenue, and official attitudes changed yet again with the Wild Animal Control Act, 1977, which removed the term 'noxious animal' and permitted the captive rearing of possums under licence. Attempts at possum farming have met with very limited success to date because of stress-related problems in captive rearing and high husbandry costs. Temporary 'ranching' of wild-caught possums to improve pelt quality may prove economic, but for the immediately foreseeable future feral possum populations will continue to be the main source of skins.

The possum fur industry, based on wild possums, has become an increasingly important provider of both local employment and overseas funds. In 1979/80 exports of possum skins were worth over $23 million in overseas earnings. This dropped to just under $20 million in 1980/81, although average skin prices remained at about $7.30.

This paper examines recent trends in the possum fur industry, considers the feasibility of sustained yield harvesting of possums in less sensitive habitats, and uses a simple mathematical model for estimating maximum sustainable yield of possums in exotic forestry plantations.

Recent trends in the possum fur industry.

Over 95% of the possum skins sold in New Zealand are exported, so the figures kept by the New Zealand Department of Trade and Industry on possum skin exports accurately reflect the number of possums killed each year for sale of their skins. Possum skin exports over recent years have increased from about 1.7 million skins in 1976/77 to over 3.1 million in the peak year of 1979/80, falling back to about 2.7 million in 1980/81 (Table I).

Changes in the value of skins (Table 1) have probably been the main factor influencing the number of skins sold, with rising skin prices resulting in increased overall effort by possum hunters.

Possums are caught by both professional and casual operators using gin traps and cyanide paste. Because no licence is required to use gin traps, and because so much trapping is done on a casual basis, it is very difficult to obtain an overall index of effort to relate to annual skin export figures. However some indication of how catch per effort has varied on a local scale can be obtained from records kept

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TABLE 1. *The number of possum skins exported from New Zealand (1), their average value (2), the number of possums taken per permit in Kaingaroa Forest (3), and the percentage of "small" possum skins in fur sales (source-Dalgety NZ Ltd, Dunedin) (4), over the period 1976-1981.*

Year	1976/77	1977/78	1978/79	1979/80	1980/81
1. Skins Exported (millions)	1.66	2.72	2.60	3.17	2.69
(millions)					
2. Skin Value ($NZ)	400	4.61	5.18	7.37	7.26
3. Possums/Permit	305.05	316.40	245.79	216.09	150.49
4. % Small Skins[a]	13.56	13.36	19.42	20.25	22.81

[a] - refers to sales in the calendar year mentioned second in the heading to each column.

by the New Zealand Forest Service of possums killed by the holders of permits to take possums in State forests. In Kaingaroa Forest, which is the largest exotic forest in New Zealand (137,000 ha), the catch of possums per permit (A. P. Farmer, pers. comm.) has shown a steady decline since 1977/78 (Table 1), indicating that possums have been more difficult to obtain there recently.

Anecdotal evidence from possum hunters suggests that similar recent drops in catch per effort have occurred in many other accessible areas. This is often attributed to increasing 'cyanide shyness', but a widespread reduction of possum populations is evident in results of the 1979 national possum survey (Pracy, 1981). This survey reported possum population declines in 240 areas in the North Island and 150 areas in the South Island, which was twice the number of areas with declining populations recorded in the previous survey in 1970.

The other important trend in the possum fur industry in recent years has been the way in which the composition of the catch has varied. The main trader in possum skins is Dalgety (N.Z.) Ltd. On arrival at their Dunedin store all possum skins are graded according to colour, size and quality. The same person has graded the skins for over ten years, using the same criteria. When the percentage of skins graded as 'small' is examined (Table 1) a clear trend is apparent. The proportion of small skins among those sold has increased since 1978, to about one quarter of those handled.

Possums vary in size between habitats, but there is no evidence that the overall possum catch is now being drawn from markedly different habitats than it was five years ago. It is possible that some trappers are now retaining small skins which they would previously have discarded, but the most plausible explanation for the increasing proportion of small skins in sales is simply that the overall catch now includes more young animals. More specifically, since growth in length ceases by two years of age (Kean, 1975) most of the small skins are likely to be from possums aged about one year, and the increasing proportion of small skins probably reflects a corresponding increase in the proportion of possums of this age in harvested populations. A decrease in the mean age of a catch indicates that the effects of exploitation are being felt by the population concerned (Watt, 1968), but by itself does not suggest biological over-exploitation. However, since small skins are of lesser value, an increasing proportion of such skins in the possum catch is not a welcome trend from the fur industry's point of view.

The case for sustained yield harvesting

The above trends suggest that some possum populations have been exploited hard enough to change their composition, and in many areas possum numbers have declined significantly. The general attitude in the recent past has been that any depletion of possum populations is good, wherever or however it occurs. In many habitats, particularly farmland and sensitive areas of native forest, there is no doubt of the value of reducing possum populations to the minimum practicable level. However, in view of the employment and overseas earnings stemming from the possum fur industry, there is a case for at least considering the feasibility of sustained-yield harvesting of possums in less sensitive habitats.

The logistic model

To calculate sustainable yields it is necessary to apply a mathematical model which makes some assumptions about how the population will perform at different densities. The logistic model, ignoring age structure and with constant-effort harvesting, is perhaps the simplest model incorporating density dependence. The logistic model assumes that a population grows at some yearly rate, which reduces as density increases. In particular, the per capita growth rate (dN / dt / N*)* declines linearly with density. More complex single species models (Clark, 1976) and interactive two-species models (Caughley, 1976) are available, but the logistic is a robust model with a good pedigree, and is a useful starting point for assessing optimal harvesting strategies. A thorough discussion of estimating harvests by the logistic model is given by Caughley (1977), but the basic principles are as follows:

The equation for logistic population growth with constant-effort harvesting is:

where r_m = intrinsic rate of increase
N = population density
K = equilibrium population density (carrying capacity)
H = index of harvesting effort

$$\frac{dN}{dt} = r_m N\,(1 - N/K) - HN$$

At equilibrium, dN/dt = 0, so $HN = r_m N - \frac{r_m}{K} N^2$,

which describes an upwardly convex parabola. The quantity HN is the sustainable yield for any level of N and is maximised when N = K/2. The size of this maximum sustainable yield is then $r_m K/4$ per annum.

To estimate maximum sustainable yield from the logistic model the parameters which must be known are the intrinsic rate of natural increase (r_m) and the equilibrium population density (K).

Maximum sustainable yield of possums from exotic forest

New Zealand's exotic forests are a good example of a non-sensitive habitat from which possums might be harvested for their fur on a sustained yield basis. These forests have a relatively low conservation value and the damage caused by possums to young pine trees is probably economically insignificant (Clout, 1977a; Warburton, 1977). Exotic forests are managed as production systems in which possum pelts could be regarded as a secondary product. Access (via forest roads) is good, so possum harvesting can be closely controlled and evenly spread. Moreover, exotic forests in New Zealand form an extensive, well-defined habitat, mainly *Pinus radiata* plantations, for which some possum population statistics are available.

The maximum recorded density of possums in a purely exotic forest habitat is the 'removal' estimate of 2.96/ha obtained by Clout (1977a) for a 15-year-old stand of *P. radiata* in Kinleith Forest, near Tokoroa. The population concerned had shown no change in density or composition over 18 months of live-trapping. On this basis, the value of K for exotic forest is set at 3/ha.

An estimate of the intrinsic rate of increase (r_m) for possums in exotic forests is more difficult to obtain. Bamford (1972) used density changes with time to calculate a value of $r_m = 0.34$ for possums invading new habitat in the rata *(Metrosideros umbellata)*/*kamahi (Weinmannia racemosa)* forests of the Taramakau Valley in Westland. Spurr (1981) used Bamford's estimate of r m in a theoretical comparison of possum control strategies, but noted that there was some doubt about the precise pattern of colonisation of the Taramakau Valley by possums.

A rate of increase comprises both mortality and fecundity rates. Unfortunately there are few data on mortality (as opposed to disappearance) rates of possums in exotic forests, but on the basis of calculated mortality rates in native forests (Bamford, 1972; Boersma, 1974; Brockie *et al.,* 1981) an annual mortality rate of 0.1 is a likely minimum figure (i.e. an overall maximum survival rate of 0.9 per annum). Fecundity (i.e. females born per female per annum) is generally easier to measure than mortality. The available data for possums in exotic forests (Clout, 1977a; Warburton, 1977; How, 1981) indicate that average fecundity in this haitat is about 0.5 and that, despite the occurrence of double breeding in some areas, this rate does not change with density over the range from 3/ha down to 0.44/ha. Combining these educated guesses of maximum survival = 0.9 and maximum fecundity = 0.5, yields an intrinsic rate of increase of:

$$r_m \approx \ln\,[(1 + 0.5)\,0.9] = 0.3$$

In calculating sustainable yields in exotic forest; both Bamford's r_m of 0.34 and the above figure of 0.3 have been used.

The population studied by Warburton (1977) in Ashley Forest, Canterbury, was harvested with a yield which had apparently remained steady over four years. Warburton estimated a rate of increase of r = 0.19 (doubling time = 3.6 years) for the possum population of Ashley Forest by applying the mortality rate of 0.176 calculated by Bamford (1972). When plotted against the corresponding density estimate of 1/ha (Fig. 1) this value of r = 0.19 lies close to the curve for $r_m = 0.3$ and K = 3.0.

According to our model, the maximum sustainable yield (MSY) of possums from exotic forest is obtained from a population held at a density of 1.5 / ha. The two values of r_m = 0.3 and 0.34 give respective MSY estimates of 0.23 and 0.26 possums/ha/annum (Fig. 1). These figures can be compared with actual yields of c. 0.15/ha/annum recorded by fur trappers

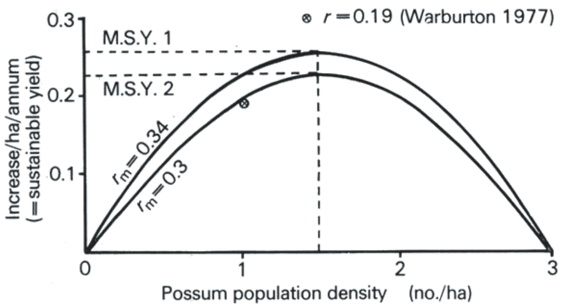

FIGURE 1. *Estimates of MSY for possums in exotic forest.*

from the exotic plantations of Kaingaroa Forest in recent years (A. P. Farmer, pers. comm.).

There are c. 0.85 million hectares of exotic forest in New Zealand, which could provide a total MSY of c. 0.2 million possums per annum according to our model. These figures are put into perspective by comparison with similar estimates for native forest.

Assuming an equilibrium density of l/ha in *Nothofagus* forest (M. N. Clout & P. D. Gaze, unpublished data) and 10/ha in other native forest (Crawley, 1973; Coleman *et al.,* 1980), and applying Bamford's estimate of r m = 0.34, the estimated MSY in *Nothofagus* forest is 0.09 possums/ha/annum and in other native forest it is 0.85/ ha / annum. The area of all types of *Nothofagus* forest in New Zealand is c. 4.5 million ha (J. L. Nicholls, pers. comm.). Excluding Fiordland, which has few possums, (Pracy, 1981), this area reduces to c. 3.3 million ha, corresponding to total potential MSY of 0.3 million possums/annum. The area of other native forest in New Zealand is c. 1.7 million ha (J. L. Nicholls, pers. comm.), corresponding to a total potential MSY of 1.45 million possums/annum. It must be stressed that these estimates are based on crude assumptions about the value of r m and equilibrium density in the habitat concerned, not to mention the somewhat simplistic assumptions of the logistic model itself. Accepting this, a rough estimate of the overall potential MSY of possums from New Zealand forests is about two million possums per annum, with exotic forests contributing about ten percent of this total. In practice, the overall achievable MSY is likely to be less than two million, partly because of problems of access and supervision but mainly because in many (perhaps most) native forest areas, management for MSY of possums would conflict with more important conservation values.

Change in age structure with harvesting

Fur industry statistics indicate that the possum catch includes an increasing proportion of young animals, but the logistic model does not take population composition into account; to do this an age-class model is needed.

A simple model of two age classes (possums aged one year and two or more years) with different survival and fecundity rates illustrates the effect on age structure of varying these survival and fecundity rates (Fig. 2). Simulations were begun with initial proportions of 30 % young possums (i.e. one year old) and 70 % old and run until the age structure stabilised. No density-dependence was included and maximum survival rate and fecundity were set at 0.9 and 0.5 respectively for both age classes. Simulations were repeated for various lower values of overall survival, fecundity and first-year survival, and the results are shown in Figure 2. Changing the overall survival rate (Le. of both age classes) by the same percentage has no effect on age structure, a phenomenon first noted by Leslie (1948) and discussed at length by Caughley (1977). However, increasing the survival rate of young animals alone, or increasing fecundity by the same percentage, have the identical effect of increasing the proportion of one-year-olds in the population. An increase in the proportion of young animals in a population subject to an across-

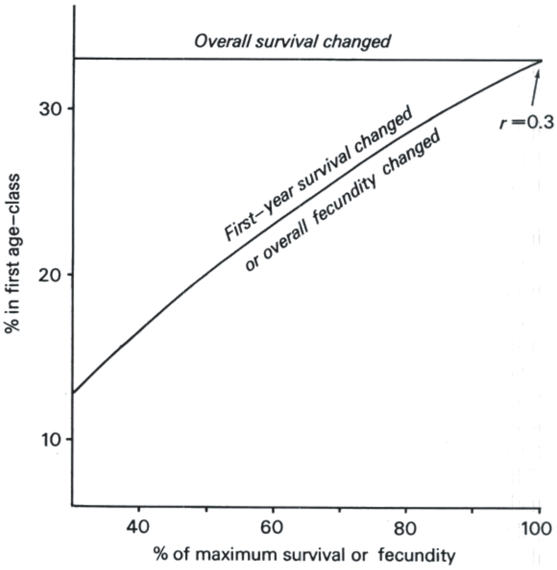

FIGURE 2. *Effect on age structure of changing survival or fecundity.*

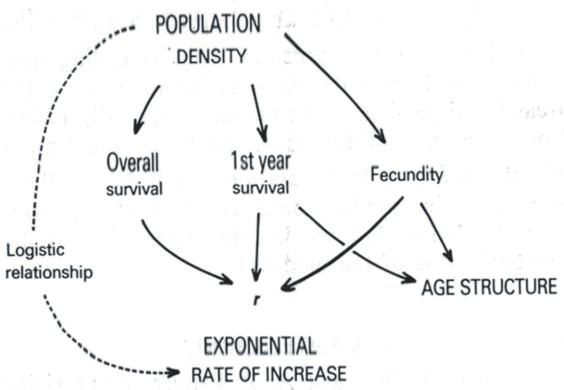

FIGURE 3. *Schematic relationship between parameters.*

the-board mortality from harvesting means that either the survival rate of young animals or fecundity, or both, have increased as a result of reduced population density. In other words, the natural regulatory mechanisms involve these effects rather than changes in overall mortality. Perhaps the extreme case is that of many fisheries which appear to exhibit almost perfect density-dependence in young, pre-recruitment stages, such that the number of recruits stays more or less constant. Under these circumstances an increase in fishing mortality over all other classes will increase the proportion of small fish taken (see Clark, 1976). Returning to the possum, the observed increase in the proportion of young animals caught therefore suggests that the actual mechanism of regulation, not explicitly considered by the logistic model (see Fig. 3), is likely to involve changes in fecundity (overall or age-specific) or in first-year survival with density. Although such a model can explain a change in age structure with population density, it does not permit a prediction of the age structure of a population at any given density, because we do not know how the relative contributions of survival and fecundity to rate of increase change with density. The model is illustrative, not predictive-at least until we have more observations of the relationship between age structure and density for the chosen habitat.

In the unharvested Kinleith Forest population at c. 3/ha sampled by Clout (l977a), the one-year-old age class formed 22% of the population (excluding dependent young) whereas, in the harvested Ashley Forest population studied by Warburton (1977), the equivalent figure was 35 %. Any direct comparison of 'these results must be made cautiously because Clout sampled only in summer and Warburton through the year, but the overall contrast is clear. Clout (l977a) did not attempt to generate a life table from his data because past population trends were unknown, but he did calculate survival over the interval between c. 8 and 20 months. The survival rate of females over this interval was 0.65 compared with an estimate of 0.92 for female survival to over one year old in the harvested population in Ashley Forest (Warburton, 1977). Mortality of pouch young was negligible in both populations (Clout, 1977a; Warburton, 1977).

Since fecundity rates were similar in Kinleith and Ashley Forests (Clout, 1977a; Warburton, 1977) it is likely that any difference in age structure between these two possum populations was largely the result of the difference in first-year survival. However, this does not preclude an increase in fecundity with decreasing density from being an important determinant of changing age structure in other habitats.

DISCUSSION

Although it is possible in theory to estimate maxi mum sustainable yields for possums and to explain recent fur industry trends such as the increasing proportion of small skins, putting this theory into practice is beset by many problems.

From the point of view of the fur industry it would undoubtedly be desirable to manage possum populations in New Zealand for maximum sustainable yield. This would require close control of commercial harvesting, the setting of annual quotas and careful monitoring of effort, catch and composition of catch. Such careful management of a common resource is difficult enough to administer for a commercial fishery, let alone for a land-based resource like possums, where minimal gear is involved and much of the harvesting is done by 'part-timers'. Administrative difficulties apart, a more important problem is the question of conflict with other land uses. Possums damage native vegetation, plantations, crops and pasture and in some areas are carriers of diseases such as bovine tuberculosis and leptospirosis. In many habitats, especially farmland and sensitive areas of native forest, reducing possums to half of their equilibrium density and harvesting them at that level would still result in serious conflict with production or conservation values. In such areas the aim will presumably be to reduce possum populations to the minimum level at which they can practically be held. This is likely to be less than half the equilibrium density, with the result that sustainable yields from such areas will be less than the maximum possible.

According to the logistic model, sub maximal sustainable yields will also be drawn from possum populations maintained at *more* than half their equilibrium density, for example in areas where access is difficult

Because of these practical problems, it is unlikely that possums could be managed to maximise sustainable yield in anything other than a closely controlled system such as an exotic forest, where production and conservation values are not threatened by possums. In such a system, possum pelts could be regarded as another forest product, whose value-exceeds the likely costs of any damage caused to young plantings. Assuming an average pelt value of $7.30, the gross return per ha from the cropping of possums for maximum sustainable yield in an exotic forest could be up to $1.90/ha/annum, with the possum density held at 1.5/ha. The optimum sustainable yield, taking into account economic factors such as possum damage, harvesting costs, and the lesser value of small skins, might of course be different from the maximum sustainable yield.

One of the main values of a modelling exercise such as this is that it highlights areas where information is lacking and further research or model development is needed. We have used a simple model which could be refined in several ways to accommodate other likely responses of possum populations to harvesting. For example, the relationship between population growth rate and density may take a different form to that shown (Fig. l) in which case a third parameter should be included in the logistic. Particularly in native forests, it may be necessary to consider the relationship between possums and the vegetation on which they depend, which would require an interactive model, as described by May (1973) and Caughley (1976).

Other factors which should also be considered include sex ratio effects, behavioural responses to harvesting, and differential movement all of which have implications for harvesting strategy as well as model development.

Adult sex ratios vary considerably between possum populations (Dunnet, 1964; Hope, 1972; Clout, 1977a), but our simple model ignores this. Current possum harvesting methods are probably unselective, but if a strongly male-selective technique could be devised it might be possible to alter the sex ratio of a harvested population and so obtain higher yields. Behavioural responses to harvesting, which are also ignored in our simple model, include the phenomenon known to fur trappers as 'cyanide shyness', which may result from possums experiencing sublethal doses of cyanide and subsequently avoiding poison baits. Differential movement is also potentialty important in the response of possums to harvesting. For example, the observed increase in the proportion of young possums with harvesting may result in part from the colonisation of depopulated areas by dispersing young animals (especially males) from adjacent undisturbed or lightly harvested areas (Clout, 1977a, b). Incorporation of effects like these in a harvesting model would require relatively complex simulation, but would add appreciably to the practical value of the model.

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