REVIEW OF THE STATUS OF
THE POSSUM (Trichosurus vulpecula)

IN NEW ZEALAND

C.L. Batcheler
Forestry Research Centre
Forest Research Institute
PO Box 31-011
Christchurch

and

P.E. Cowan
Ecology Division
Department of Scientific and Industrial Research
Private Bag
Lower Hutt

Contract report commissioned by:
Technical Advisory Committee (Animal Pests)

for the:
Agricultural Pests Destruction Council
Department of Conservation
MAFQual, Ministry of Agriculture and Fisheries

ECOLOGY DIVISION
Dept. of Scientific & Industrial Research
PRIVATE BAG, LOWER HUTT
NEW ZEALAND
CONTENTS

SUMMARY AND RECOMMENDATIONS i

GENERAL INTRODUCTION
Previous reviews & terms of reference 1
Names & units 3

A. ESTABLISHMENT AND SPREAD
Introduction 6
Numbers of possums 6
History of control 7

B. POPULATION DYNAMICS
Introduction 11
Life history and habits 11
Densities 12
Fecundity 12
Mortality 14
Sex ratio 15
Response to control 15
Rate of recovery 16
Mechanism of recovery 16
i. Dispersal 16
ii. Breeding 17
Reduced mortality 17
Population dynamics 18
Eruptive fluctuation 18
Mathematical models 20

C. EFFECTS ON PRODUCTION AND PROTECTION VALUES

C.1 INDIGENOUS VEGETATION
Overview 22
North Is. 22
Westland 23
Debate on dieback 23
Other forest types 25
Current status 25
North Is. forests 27
Northern kauri-podocarp-hardwood 27
Coastal pohutukawa 28
Central tawa 28
Central-southern podocarp-hardwood 29
Beech/beech hardwood 30
Discussion 32
Westland rata/kamahi canopy 32
Introduction and methods 32
Overall canopy mortality 36
Geographic variation 36
In individual catchments 38
Status and trends 40
Unmodified forests 40
Modified forests 41
Conclusions 41

C.2 NATIVE ANIMALS 42

C.3 BOVINE TB IN POSSUMS
Introduction 44
Discovery in wild possums 44
Source in possums 45
Virulence in possums 48
Agents of spread 50
Rate of spread 53
Control 55
Effectiveness of control 57
Computer modelling 59
Prospects of progress 60

C.4 CROPS AND PASTURE
Introduction 62
Pasture 62
Crops 63
Horticulture 63
Urban areas 65
Control 65

C.5 CATCHMENT PROTECTION
Introduction 66
Poplar improvement programme 66
Nature of damage 67
Cost of damage 68
Control methods 68
North Is. situation 69
South Is. situation 70

C.6 EXOTIC FORESTS
Introduction 73
Damage to Pinus species 74
Control policy and methods 75
Conclusions 76

D. POSSUMS AS A RESOURCE

D.1 HISTORY OF SKIN EXPORTS 78

D.2 POSSUM FUR IN WORLD TRADE
Introduction 80
Industry developments 82

D.3 POSSUM FARMING
Legislation 87
Economics 88
Current possum farming 88
Improving returns 89
Industry review 91

D.4 POSSUM MEAT
Threat of tb 92
Foreign competition 94

E. CONTROL OF POSSUMS AND DAMAGE
Introduction & National priorities 96
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E.1 LETHAL DEVICES AND PROTECTIVE BARRIERS</strong></td>
<td></td>
</tr>
<tr>
<td>Traps and cyanide</td>
<td>97</td>
</tr>
<tr>
<td>Mechanical barriers</td>
<td>99</td>
</tr>
<tr>
<td>Behavioural barriers</td>
<td>99</td>
</tr>
<tr>
<td><strong>E.2 COMMERCIAL HARVESTING</strong></td>
<td></td>
</tr>
<tr>
<td>Effect of harvesting</td>
<td>100</td>
</tr>
<tr>
<td>Supporting harvesting</td>
<td>101</td>
</tr>
<tr>
<td>Price support model</td>
<td>103</td>
</tr>
<tr>
<td><strong>E.3 LARGE-SCALE CONTROL</strong></td>
<td></td>
</tr>
<tr>
<td>1080 poisoning and problems</td>
<td>104</td>
</tr>
<tr>
<td>Acceptance of bait</td>
<td>105</td>
</tr>
<tr>
<td>Acceptance of 1080</td>
<td>105</td>
</tr>
<tr>
<td>Bait size and toxicity</td>
<td>105</td>
</tr>
<tr>
<td>Bait distribution</td>
<td>105</td>
</tr>
<tr>
<td>Alternatives to 1080</td>
<td>106</td>
</tr>
<tr>
<td>Problems with regulations</td>
<td>106</td>
</tr>
<tr>
<td>1080</td>
<td></td>
</tr>
<tr>
<td>Cyanide</td>
<td>107</td>
</tr>
<tr>
<td><strong>E.4 DISEASES, PARASITES, BIOLOGICAL CONTROL</strong></td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td>107</td>
</tr>
<tr>
<td>Possum parasites and diseases</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>108</td>
</tr>
<tr>
<td>New Zealand</td>
<td>108</td>
</tr>
<tr>
<td>Bovine tb in NZ possums</td>
<td>109</td>
</tr>
<tr>
<td>Exotic infections</td>
<td>110</td>
</tr>
<tr>
<td><em>Koala chlamydia</em></td>
<td>110</td>
</tr>
<tr>
<td>Caveat</td>
<td>111</td>
</tr>
</tbody>
</table>
SUMMARY AND RECOMMENDATIONS

This review outlines the biology of possums; the threats they pose to indigenous biological values; agriculture and forestry; their values as skin and meat resources; the efficiency and costs of commercial and non-commercial control methods; and the adequacy of the various control methods and the non-target risks entailed. It also identifies aspects where scientific information is inadequate to serve as a basis for good management. High priority topics, with a clear link to improvement of the management of wild possums, harvesting, and the protection of natural resources, are summarised, regardless of whether they justify support from Government funds or would be more appropriately funded by commercial interests.

Section A. Establishment and spread

Since their introduction from Australia in 1837, possums have spread to occupy more than 92% of New Zealand. The population now numbers 60-70 million, two-thirds of which are in the North Island.

They are currently spreading into or increasing in:

- The northern tips of the North Auckland and the Coromandel peninsulas.
- The south Kaimai-northern Mamaku Ranges and parts of the Raukumara Range.
- The west Taupo-Taranaki and north-west Nelson forest tracts.
- South Westland-Fiordland.
- The upper reaches of some Canterbury Rivers.
- The southern tip of Stewart Island.

Section B. Population dynamics

A review of available information on the dynamics of possum populations concluded:

- Each habitat tends to support possum populations within a characteristic range of densities.
- Productivity varies considerably between possum populations.
- The roles of food supply, disease, and social and other factors in regulating possum populations remain unclear.

Subjects in which further research on population dynamics would benefit management include:

- Rate of population recovery after control.
- Changes in productivity after density is reduced by harvesting or control.
- Development of mathematical models, using information on rates of recovery and changes in productivity (above), to determine the relationships between population growth rates and densities in different habitats, and to determine optimum strategies for control and harvesting.
- Effects of spacing behaviour on reproduction and dispersal of possums and on the strategies of baiting.
- Relationships between genetic variation and demographic differences of possum populations.
Section C.1. Effects of possums on indigenous vegetation

Possums are unquestionably a major cause of the death of trees and shrubs in indigenous forests. The impact depends on the type and stage of succession of the forest, and the length of time it has been occupied by possums.

- Beech forests are least vulnerable, and podocarp/mixed hardwood forests and rata/kamahi forests are most vulnerable.

- There is no evidence that possums have attained an ecological balance with the vegetation in any indigenous forest type.

- Some rata/kamahi forests have been virtually devastated. Generally, broadleaved hardwood forests, particularly those which include kamahi and/or rata and/or pohutukawa, are under threat of major mortality and modification. A few areas are as-yet unmodified by possums. These should be protected.

- High priority areas for protection in the North Island include the Great Barrier and other Hauraki Gulf islands which are as-yet unoccupied (but vulnerable to illegal introductions); Aupouri Peninsula - Hokiaiga tract of North Auckland, Whangeraru Peninsula and Bream Head, Bay of Islands coastal pohutukawa, Rangitoto Island, northern tip of Coromandel Peninsula, east-central Raukumara Range, Pureora Forest and Ratanunui area, Central North Island and Egmont National Park.

- In the South Island, the canopy of more than a quarter of the indigenous forest is vulnerable to possum damage.

- The Westland rata/kamahi forests constitute the most important and vulnerable broadleaved hardwood tract of the South Island. There is an urgent need for a coordinated management strategy to evaluate possum control priorities, especially for the forests of the Westland catchments which reach east to the main divide of the Southern Alps, because these appear to be more vulnerable to possum-triggered dieback than the smaller western front catchments.

- A general assessment of the impact of possums on other forest types in the South Island and on Stewart Island should be commissioned immediately.

- Although beech forests are generally less vulnerable to possums than the mixed broadleaved hardwood types, and their structure will probably remain largely unaltered, the abundance of some plant species (e.g., mistletoes) has drastically declined, and the long-term effects of possums need further evaluation.

Section C.2. The effect on native animals

The overall effect of possums on native animals such as birds and insects is poorly understood. However, there is good evidence that the effects are pervasive through: modifying the habitat; killing trees and shrubs; reducing fruit production and regeneration; competing directly for food, (particularly flowers and fruits); and by acting as predators.

- Further research is needed on the effects of possum control on populations of native animals.

Section C.3. Bovine Tb in possums

Bovine tuberculosis (Tb) was first reported in possums in 1967. There is some evidence to suggest that a novel strain or strains of the disease evolved in north Westland during the late 1950s - mid 1960s and has continued to evolve and spread to other areas from that source. Tb in possums has already spread to more that 20 localities in both North and South Islands, which together comprise at least 13% of the total New Zealand land area (confirmed 1986 Tb boundaries). Since 1986 alone, at least nine new outbreaks have been
identified. The most serious and widespread Tb problems occur in Central North Island, Wairarapa, and Westland.

- Surveillance, testing, and Tb eradication in livestock in the high priority areas currently costs in excess of $12 million/year.

The role of possums as vectors of the disease has been clearly established, but:

- The roles of other wild and feral animals such as deer, goats, and pigs, needs to be clarified, particularly in relation to long-distance disease transmission.

- If the disease continues to spread in future as it has during the past 20 years, it is predicted that Tb will occur in all New Zealand mainland possum populations by about 2030 A.D. Control by the present policy and methods would then cost about $80 million p.a. (1987$).

Wherever possums are known to be implicated in maintaining Tb in livestock, the current MAF strategy to minimise spread of the disease involves the establishment of a buffer zone around the infected area. Possum control therein is accorded high priority.

Combined cattle surveillance/possum control programmes dramatically reduce the incidence of Tb, but:

- Relaxation of possum control is usually followed within 5-10 years by increasing reactor rates in livestock.

Preliminary studies suggest that large-scale poisoning followed by sustained annual cropping of possums may eliminate the disease from possum populations. Progress with these studies is hampered by a lack of information on various parameters relating to both the disease and the dynamics of possum populations.

Some attitudes expressed by sectoral groups involved with Tb in possums and the livestock industry are highly polarised. This is believed to reflect the great technical complexity and potential importance of the Tb epidemic, and the immediate and personal threat it poses to farm incomes.

The review identified an urgent need for more resources for research on problems which beset understanding of the epidemiology of the disease, and for developing a national management strategy which is completely consistent with the biology of the Tb organism and its mammalian hosts. These include:

- Development of a diagnostic method for identifying sub-clinical Tb infection in possums and other animals.

- Identifying all the factors relevant to control of the disease (modelling and field studies).

- Virulence of possum-adapted and cattle-adapted strains of Tb in possums and other animals.

- Modes of transmission and spread, and survival of the Tb organism.

- Improved surveillance and management of livestock in Tb-infected areas.

- Further computer modelling and field studies of possum control in and near infected areas.

Section C.4. Effects of possums on crops and pasture

Possums damage pasture and a wide variety of crops and horticultural products, but the economic values involved are poorly known. The review indicated that:
• More precise measurements of the effects of possums on crops and pasture are needed so that the actual costs and benefits of possum control can be assessed.

• There is a widespread need for more effective traps and baits which incur the minimum possible risks of death or injury to non-target animals.

• Many crops could be more effectively protected if repellents and deterrent techniques were further developed.

• Practical information needs to be made available to farmers and horticulturalists for "self-help" pest control.

Section C.5. Effects on catchment protection plantings

Poplar and willow poles are subject to severe and persistent damage, which is assessed by Catchment Boards to cost $320 000 - $800 000 p.a. Control of possums causing damage is mainly conducted by Pest Boards in consultation with Catchment Boards, but it often provides only temporary relief. Metal and plastic sleeves on the poles provide a high degree of protection, but their more widespread use has been affected by high costs.

Improved protection could be gained by developments such as:

• A cheap, lightweight, durable sleeve protector which is effective against both livestock and possums, and which is easy to install.

• Possum browse-resistant varieties of poplars and willows.

• Durable chemical repellents or deterrents which can be economically applied to newly planted poles and seedlings.

• Implementation of simple "self-help" methods and schemes for use by farmers.

Section C.6. Possums in exotic forests

Serious damage to exotic forests was recorded during the rapid expansion of exotic forestry from the 1960s to mid 1970s. By 1980 however, most of the forests had passed the age at which they were vulnerable to browsing and bark stripping. Intense hunting pressure by private hunters in response to high fur prices also contributed to a general reduction of possum damage.

• No additional research need was identified by the review.

Section D. Possums as a resource

Most possums are harvested for their skins, of which exports have recently ranged between 1.5 million and 3.2 million/year, worth $8 - $23 million. Numbers harvested increase during the year after higher auction prices are reported. Wild-caught possum skins are regarded as a low quality fur of unreliable quality.

Possum fur finishing (i.e., keeping wild-caught possums for several weeks before slaughter to improve the quality of fur) and possum farming are in their infancy. Their futures depend on the premium which could be obtained through market recognition of improved quality of farmed skins, and the development of markets for possum meat. The industry has yet to overcome many problems relating to:

• Susceptibility of the possum to stress in captivity.

• Low breeding rate.

• Varied genetic characteristics (and fur colour).
Relatively slow growth rates.

Continuing broad-based research is required into the biology and economics of possum fur finishing and farming. Priority topics include:

- The causes and management of stress and stress-related diseases in captive possums.
- Nutritional requirements and the relationships between nutrition and growth.
- Enhancing fertility and production rates of captive possums.
- Lactation and rearing of young possums.
- Effects of nutrition on pelt and meat quality.
- Genetics of fur colour, growth, and replacement.
- Efficient and humane slaughtering methods.

Section E. Control of possums

A nation-wide Priority Area Strategy was devised for the review to identify priorities for protection of unmodified but vulnerable indigenous forests, Tb control, and the general protection of scientific and other reserves (mostly National Parks). It calls for intensive possum control over 14% of the South Island, 23% of the North Island, and 18% of New Zealand as a whole. The protection of other aesthetic, scientific, and commercial values would raise the figure to a considerable degree, but an appropriate estimate was not made for this review.

Section E.1 Lethal techniques and protective barriers

Similar numbers of possums are caught by cyanide poisoning and gin-trapping; use of these techniques together account for about 92% of all possums harvested.

The use of cyanide entails less risk to non-target species such as weka and kiwi. However, the poison rapidly loses its potency in high-rainfall districts and, at least with inexpert use, induces bait shyness in many possums.

Therefore, the continued use of gin-traps is vigorously advocated by commercial hunters, despite their reputation for inflicting cruelty upon the victims and catching more non-target animals. The current prospects of finding a more humane yet equally efficient alternative leg-hold trap are very good.

Further research is needed on the following topics:

- The risks to non-target species associated with poisons, traps, and other devices.
- Further development and evaluation of non-lethal damage control methods such as electric fences and chemical repellents.
- Development and evaluation of humane but efficient traps.

Section E.2. Commercial harvesting

Current commercial harvesting of possums has no significant lasting effect on the national possum population although, when fur prices are high, intensified harvesting causes local reductions in accessible areas.

The only rigorous trial so far completed showed that commercial possum hunters were able to reduce densities to the same extent (80%) as that achieved by a large-scale poisoning
operation. To achieve this, a performance-linked subsidy was required to supplement the income from skins. With the subsidy, however, the overall operational costs to the State of both commercial hunting and aerial poisoning are about $20/ha.

A price support model developed for the review suggests that, if subsidised hunting were used to reduce possums by about 40% nation-wide, the required State subsidy input would amount to $190 - 310 million. A State subsidy of this kind would amount to a general bounty scheme, such as that tried during 1951-61 and found to be an inefficient means of reducing possums in areas where control was regarded as of high priority. The review concluded that:

- Although commercial hunting should be favoured wherever possible, commercial hunting should be subsidised only to achieve clearly defined objectives such as conservation of sensitive forests, bovine Tb control, or other purposes.

To prevent abuses or irrelevant expenditure of available finance, subsidised commercial hunting has to be supervised. Appropriate supervision and monitoring costs can be high. A substantial infrastructure of huts and tracks is necessary to attract the hunters to remote problem areas. Taking these overheads into account, the choice on cost criteria alone falls in favour of large-scale poisoning.

The review identified some ways in which the effectiveness of commercial harvesting could be enhanced:

- A registration scheme for commercial hunters of proven ability.
- A rationalised system of allocating hunting areas.
- Implementation of a State-controlled scheme to support and stabilise fur prices.

The review also identified other topics in which further research would benefit the management of commercial harvesting and its use for the control of possums:

- The importance of movements in fur prices on private hunting.
- More precise evaluation of the relative social and economic costs and benefits of commercial hunting and large-scale poisoning, and integration of the options into a coherent national possum control policy.

Section E.3. Large-scale control

Aerial poisoning with 1080-poisoned carrot or cereal bait is currently the only viable direct control method in larger, more remote forest tracts. Large-scale operations, using 1080 poison in diced carrot and cereal pellet baits, has made advances through improvements in the quality of bait materials, attainment of uniform toxic loading of baits, and better distribution of baits. Nevertheless:

- About 20% of a poisoned possum population usually survives aerial poisoning. Numbers increase to near pre-poisoning numbers in about a decade.

Past research suggests that, currently, patchy distribution of baits (up to 50% of a poison block may not be treated) is the greatest impediment to efficient poisoning operations.

- Inadequate aircraft navigation techniques and inefficient sowing equipment are believed to be the main impediments to efficient aerial poisoning.

The reduction obtained by large-scale poisoning is usually sufficient to protect indigenous forests, but:
Further research and improvement of aerial poisoning (or other) methods is necessary to eliminate bovine Tb and to protect particularly vulnerable types of vegetation.

Many alternative poisons to 1080 are available. An anticoagulant poison, brodifacoum, has been evaluated and registered for use in New Zealand against rabbits. Its use against possums is currently being evaluated. Generally however, evaluating the advantages of alternative compounds is very expensive. Until the imperfections and limitations of existing systems are resolved or understood, it is not clear what problem(s) would be specifically addressed or solved by using the alternative compound. The review concluded that:

- Investigations of the use of navigational guidance systems to improve the distribution of bait should be considered a high priority.
- Sowing equipment used on fixed-wing aircraft and helicopters should be improved to obtain more uniform distribution of baits.
- Obsolete carrot bait processors should be replaced with the improved equipment which has been developed.
- The evaluation of brodifacoum for possum control should be continued.
- A watching brief should be maintained on the development of other alternative poisons.
- Research on the behavioural and toxicological response of possums to 1080 and brodifacoum should be continued.
- Research should be continued into the production of cheaper baits.

Some deficiencies in the legislation governing the use of 1080 poison and cyanide for possum control have been identified:

- The Agricultural Chemicals Act 1959 has been replaced by the Pesticides Act 1979 (Second Schedule), but under the transition provisions (Section 54) of the Act, licences for use of poisons granted under the Vertebrate Pest Control Regulations 1977 are deemed to have been issued under the Pesticides Act. The necessary amendments should be made to the Pesticides Regulations 1983 to include the supply and use of 1080 and cyanide.
- Regulation 8 should be amended to include a test of the candidate's knowledge of 1080 mixing procedures (as is required in Australia) as part of the "Approved Operator" examination requirements.

Cyanide poison is the main weapon of commercial possum hunting. Its use is controlled by the Pesticides Act, under which it can only be used by a certified "Approved Operator" after a course of instruction. At present, the licence is issued "for life". Abuses of the regulations are common, and it is recommended that:

- Licences should be revoked every 2-3 years and re-issued only upon the application and payment of a fee. The fee should be sufficient to defray administration costs.

Section E.4. Disease, parasites, and biological control

The most spectacular and successful example of biological control of mammals is the introduction of myxomatosis into Europe and Australia to control rabbits. We know of no other examples.
There is no evidence that possum numbers are limited by diseases (including bovine Tb) or parasites in either New Zealand or Australia.

However, biological control may be the most viable and inexpensive long-term alternative option for the control of possums in New Zealand. A venereally transmitted organism in the Australian Koala, and some diseases which afflict South American marsupials, have been identified as possible biological control agents for New Zealand possums. However, the feasibility of introducing them successfully, their likely efficacy, and any associated risks to other animals, are unknown. The research necessary to assess these aspects would require a large investment both in New Zealand and overseas.

All attempts to control pests by biological methods are inherently irreversible: Once established, there would be no feasible method of eradicating the pathogen. Therefore:

- We do not consider that the current problems caused by possums are so intractable that they justify this irretrievable option.

- A watching brief should be maintained into the sources, taxonomy, virulence and host-specificity of pathogens which could be considered in future for the biological control of New Zealand possum populations.
REVIEW OF THE STATUS OF THE POSSUM IN NEW ZEALAND

C.L. Batcheler
Forestry Research Centre
P.O. Box 31 011
Christchurch

and

P.E. Cowan
Ecology Division
Department of Scientific and Industrial Research
Private Bag
Lower Hutt.

GENERAL INTRODUCTION

Previous reviews and terms of reference

The status of possums in New Zealand was reviewed by Wodzicki (1950), who provided the first account of the liberations, densities, reproduction, food habits, and the contribution of possums to the fur trade. Much of the information collected since then was reviewed at a symposium on Marsupials in New Zealand in 1977 (Bell, 1981a). The Agricultural Pests Destruction Council reviewed the status of the possum, primarily as a pest of agriculture, in 1981. Green (1984) reviewed the scientific information pertinent to management. A sub-committee of the Wildlife Research Liaison Group reviewed the adequacy of research on possums (Brockie et al., 1984), giving a brief summary of existing knowledge, a list and evaluation of current research projects, and a suggested priority list for future work. A fairly comprehensive bibliography of works on possums is given by Morgan and Sinclair (1983).

The present review was coordinated by the Technical Advisory Committee (Animal Pests) (TAC) - established under the Agricultural Pests Destruction Act (1977) - on behalf of the three client organisations, the Agricultural Pests Destruction Council (APDC), the Department of Conservation (DOC), and the Ministry of Agriculture and Fisheries (MAF). It was prompted by increasing concerns about the effects of possums as a vector of bovine tuberculosis (Tb), and their continued effect on indigenous forests. TAC's terms of reference were written in the form of working questions:
Phase 1: What do we need to know? i.e., where is the possum going in New Zealand? How do we fill in the gaps?

in relation to:

1. POPULATION BIOLOGY AND DISTRIBUTION

(a) Possum population dynamics;
(b) Present distribution;
(c) Pest status and distribution.

   (i) Forest damage;
   (ii) Native animals;
   (iii) Tb/disease spread risks;
   (iv) Pasture consumption/competition;
   (v) Horticultural damage;
   (vi) Catchment protection plantings;
   (vii) Exotic forests.

2. PRODUCTION STATUS: ECONOMIC ISSUES

(a) Feral population fur harvesting;
(b) Domestic fur and meat industries.

3. MANAGEMENT OPTIONS FOR CONTROL (Is living with them an option?)

(a) Chemical control;
(b) Diseases (i.e. biological control);
(c) Physical control.

4. OPTIONS FOR CONTROL

(a) Forest environment;
(b) Pastoral environment;
(c) Horticultural environment;
(d) Environmental and non-target animal risks.

Phase 2: Identify agreement and disagreement on the issues and options for possum management.

Phase 3: Report back to TAC for adoption.

C.L. Batcheler and P.E. Cowan were asked to undertake the review, and report back to TAC by 30 June 1988. A 1-month extension was approved when it became clear that the report could not be completed by that time.

We gratefully acknowledge having been able to call upon the knowledge and expertise of many people in completing the assignment. Those who gave us information are acknowledged in appropriate places in the report. Others, who contributed to writing sections, were: L.R. Crozier, G.R. Hickling, D.R. Morgan, I.J. Payton, A.B. Rose,
K. Varcoe, of Forestry Research Centre (FRC) of the Forest Research Institute (FRI) and R.E. Brockie and M.G. Efford of Ecology Division (ED). These contributors also refereed and edited various sections. Further refereeing and editorial advice was received from J.D. Coleman and A.J. Pearce of FRC and J.E.C. Flux and A.D. Pritchard of ED. J. Orwin, FRC, edited the whole report. T. Pearson, FRC, drew the figures. M. Hearfield of Ecology Division provided computer file handling assistance. J.E. Berney of Ecology Division typed the ED contributions; K. Varcoe typed some of the FRC contributions. W. Weller, FRC, formatted and produced the final report on the Laser printer. Special thanks are due to K. Varcoe for also researching files, computation, compiling graphs and references, and other assistance at all stages of the task.

**Name and units used in this Report**

*Trichosurus vulpecula* is a marsupial of the family Phalangeridae (claw-footed) and, through the sharing of vernacular names, is frequently confused by non-specialist people with *Didelphis virginianus*, the American "opossum" or "possum". The confusion persists, despite many attempts to resolve it. *T. vulpecula* has variously been called 'opossum', 'common brushtail possum' (which is recommended by the Australian Mammal Society Vernacular Names Committee), 'Australian phalanger', 'Australian opossum', 'Brush-tailed possum', or 'common possum'. But the legal name is still 'opossum', as defined in the Wild Animal Control Act, 1977. In commercial circles, skins and meat are marketed under the name 'New Zealand Opossum' and 'Kiwi Bear'.

In this Report we use 'possum' because: this is the prevalent use in Australia (Bell, 1981a); its expanded forms (*brushtail ..., Australian brush-tailed ... *) convey the distinctive character of the Australian arboreal animal compared with its distant American cousins (*Didelphis*).

We have converted all relevant price and cost data to the 4th. quarter of 1987 equivalents according to Table 4 of the Monthly Abstract of Statistics for August 1984 CPI (Consumer Price Index annual food and all-groups long-term linked historical series) and more recent updates (N.Z. Department of Statistics).
Fig. 1a. Liberation points of possums in New Zealand (redrawn from Pracy, 1974).
Fig. 2. Number of liberations per 10 years (histograms) and the numbers of sites where possums were judged to be declining during the four national surveys, 1948 to 1980 (from Pracey, 1974 and L.T. Pracey, in APDC, 1981).
A. ESTABLISHMENT AND SPREAD IN NEW ZEALAND (C.L. Batcheler)

Introduction

The possum and the rabbit (*Oryctolagus cuniculus*) were among the earliest mammals introduced by European settlers into New Zealand for the sole purpose of establishing a fur industry. Between 1837 and 1922, 31 batches of possums - mainly of Tasmanian origin - were imported (Pracy, 1974). These possums and their descendants were liberated at about 464 places (Fig. 1a), principally by private individuals (1837 – 1861), Acclimatization Societies (1870 – 1930), and private trappers who have continued to liberate them illegally to the present day.

The distribution of possums up to the late 1940s is not well documented. L.T. Pracy (in Agricultural Pests Destruction Council, 1981) published maps from which we calculate that 54% of New Zealand was occupied by possums in 1948-50; 84% by 1961-63; 90% by 1974; and 91% by 1980 (Fig. 1b). The possum is now one of the most widespread mammals in New Zealand.

In 1948-50, populations were still increasing in density in most places, declining in only six of about 390 sites surveyed (L.T. Pracy in APDC, 1981). However, populations were declining at 111 of those sites by 1961-63, 190 sites by 1974 and over 390 sites by 1980. This natural decline in population densities occurred about 30 - 40 years after the peak of the liberation wave (Fig. 2). At present, possum populations are spreading and increasing only in a few places. These include the northern tips of North Auckland and Coromandel Peninsula, the south Kaimai - northern Mamaku Ranges, the central portion of the Raukumara Range east of Opotiki, a small part of the West Taupo - Taranaki forest tract, part of North-west Nelson centred about the Gouland Downs, South Westland, the upper reaches of some Canterbury rivers, South-east Fiordland, and the southern tip of Stewart Island (L.T. Pracy, pers. comm).

Estimates of present numbers of possums

A nationwide "census" of a free-living nocturnal forest-dweller such as the possum is impossible. Nonetheless, L.T. Pracy (1981b) derived a New Zealand-wide estimate of 46 million in 1946 by trapping possums in a small block of native forest near Wellington and extrapolating the result by his "feel" for relative densities elsewhere.

Three other NZ-wide estimates have been made recently. Keber (1985) multiplied five census results by the areas given in an abbreviated land cover classification, to estimate a population of 72-73 million. Brockie (1986), used five density estimates from grassland, crops, scrub, pine forest, beech, and lowland native forests, and multiplied them by the extent of these habitat types (*Blaschke et al.*, 1981), and derived a "conservative estimate" of 63 million possums.

For this Review, we rechecked Keber's and Brockie's estimates by using 37 density estimates (see Table 2, Section B), the extent of 232 New Zealand vegetation cover classes in Blaschke *et al.*'s resource inventory, our collective knowledge of faecal pellet count densities, accessibility to harvesting, and "quality of the habitat for possums" (M.D. Thomas, C.L. Batcheler, unpubl. data). We arrived at a total of 68.8 million
(Table 1). We concluded that the present possum population is between 60 and 70 million, of which about 40 million are in scrubland habitats.

Of the estimated population, 66% is in the North Island, and 34% is in the South Island. The average density in the North is equivalent to 4 possums/ha, 2.7 times that in the South and is almost exactly the same as the distribution of livestock in the two main islands. This undoubtedly reflects the warmer climates and relatively low altitude in the north. For the possum in particular, the imbalance also undoubtedly reflects a higher proportion of forests other than beech in the North Island, and the more complex mosaics of "prime possum habitats" such as scrub-gullies bordering farmland.

**TABLE 1. Estimate of the numbers, densities and distribution of possums.**

<table>
<thead>
<tr>
<th></th>
<th>Land area (ha)</th>
<th>Possum No.</th>
<th>%</th>
<th>Density</th>
<th>LU's%¹</th>
<th>Skins%²</th>
<th>Skins%³</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Island</td>
<td>11 413 400</td>
<td>45 600 000</td>
<td>66</td>
<td>4.0</td>
<td>65</td>
<td>62</td>
<td>77</td>
</tr>
<tr>
<td>South Island</td>
<td>15 021 900</td>
<td>23 200 000</td>
<td>34</td>
<td>1.5</td>
<td>35</td>
<td>38</td>
<td>23</td>
</tr>
<tr>
<td>N.Z. total</td>
<td>26 435 300</td>
<td>68 800 000</td>
<td>100</td>
<td>2.6</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

(1) Based on expressing dairy cattle, beef cattle, sheep, pigs, deer and goats in sheep units (=1). Livestock units data from Kerr et al., 1979 (Table A 17) and assuming 0.5, 2 and 0.7 for farmed pigs, deer and goats respectively. Numbers from N.Z. Official Year Book 1987-88, for 1985.

(2) % of skins presented for sale from the 2 main islands during 1934-45. From Wodzicki, 1950.

(3) % of skins presented for sale from the 2 main islands during July 1979-June 1983. Data ex Wrightson Dalgety Ltd. tabulated by B. Warburton (pers. comm.).

*History of the control of possums*

Pracy (1974) records that although the scientific journal *Nature* (1872) had forecast damaging consequences of the "silly mania for acclimatization", the prevailing New Zealand voice before 1920 was that "we shall be doing a great service to the country in stocking these large areas (of rough bush hills) with this valuable and harmless animal" (cited by Wodzicki 1950). But even by 1910, farm settlers and fruitgrowers had become concerned about their depredations. The conflict of opinion was quickly reflected in a seesawing succession of gazette Notices among which a 1911 Notice forbade taking possums at all; another removed all protection (1912); a third prohibited introductions in certain areas (1913). The Department of Internal Affairs then sent out a circular questionnaire to all Acclimatisation Societies, the Department of Tourist and Health Resorts, and the Department of Agriculture in 1916. In 1919, the Government, through the New Zealand Institute, sought the opinion of Professor H.B. Kirk.

Kirk replied that the damage to New Zealand forests was negligible, and losses to orchards and gardens were far outweighed by the advantages obtained from the sale of skins. Therefore, in Kirk's opinion, except near orchards and plantations, possums could be liberated in all forest districts. Leonard Cockayne (1926), the most distinguished forest ecologist of the day, endorsed Kirk's assessment.

The pendulum of opinion swung rapidly against the possum as the released populations spread and damage became more evident. By the late 1940s, there was little doubt that
licensed trapping for skins was insufficient to stem the increasing and spreading populations. A bounty scheme was introduced as an interim measure to encourage more intensive killing, and the Department began to organise control campaigns of its own.

Under the bounty system, private hunters were paid $3.13 (2s.6d.) for the ears and attached neck and back skin (which destroyed their commercial value). By 1961, $23.8 million had been paid out on 8.2 million tokens (Pracy, 1981a). The scheme was abandoned when analysis indicated that most tokens were coming from "nuisance" possums in prosperous farming and semi-urban areas, or from possums killed on country roads rather than from areas where possums were critically affecting production, watershed protection, and wildlife values.

At the same time, the Department of Internal Affairs undertook official cyanide poisoning campaigns in winter, notably in Poverty Bay and the Kokatahi Catchment (Hokitika River). These campaigns failed to make any lasting impression.

In 1956, the control of Noxious Animals was transferred to the NZ Forest Service, and the first trials of aerially distributed 1080 cereal pellet baits for poisoning possums were run (L.T. Pracy, 1961). Reductions were estimated to range from 50% to 98% (Batcheler et al., 1967; Batcheler, 1978).

The results of these trials were judged to be good enough to warrant applying them to large-scale control programmes. From 1960 to the early 1970s, the objective of most large-scale aerial poisoning operations was to protect downriver farm lands from the effects of erosion which might occur if the watershed forests were destroyed by introduced animals (Holloway, 1959; McKelvey, 1959; Poole, 1959). The rata-kamahi protection forests of the Southern Ruahines and Westland received particular attention. Other operations were conducted in pine forests such as Kaingaroa and Karioi State Forests to protect their commercial value.

By the late 1970s the need for large-scale operations was being questioned (Anon, 1981). First, private hunters were placing increasing pressure on possum populations in accessible areas as skin prices improved. This seemed to give sufficient protection, and avoided the criticism which often attended the use of 1080 - particularly where native birds were accidentally killed (Batcheler, 1978; Harrison, 1978, Spurr, 1979). Second, it became obvious that poisoning at 10 - 20 year intervals would be required in the mountain protection forests to maintain possums at low levels (Spurr, 1981). The continuing costs would be enormous.

At the same time, a new generation of scientists was beginning to question whether the possum was the primary culprit in the widespread death of the forests. Other factors needed to be examined. Diseases or droughts could be of greater importance than introduced animals (e.g., Mosley, 1978; Jane & Green, 1983; Veblen & Stewart, 1982). Synchronised death of large areas of trees might be due to many basic causes (Veblen & Stewart, 1982). As a result of these and other doubts, the scale of operations on non-rateable, State-owned and administered lands declined.
Fig. 3. Approximate areas in which major aerial possum control operations have been run for protection of indigenous forests and Tb control.
From the early 1950s, the Rabbit Destruction Council sought involvement in possum control on rateable lands, wanting mandatory possum control throughout New Zealand, irrespective of local need. However, local perceptions of the relative importance of rabbits and possums conflicted. In 1961, Rabbit Boards were enabled to impose a separate possum control rate where possums were recognized as "Pests of Local Importance"; otherwise, possums could be killed by Rabbit board staff incidental to their primary job of killing rabbits. By 1967, of the total of 214 Rabbit Boards then constituted, only 75 Boards, mostly in the South Island, declared they had no interest in possums.

Bovine tuberculosis was first reported in possums in 1967 by Livestock Officer L.O.J. Pearson who was concerned about the persistence of Tb in cattle in northern Westland (J.D. Coleman, pers. comm.). By the mid-1970s it was commonly being identified in possums throughout much of northern Westland (Cook, 1975a,b), the Wairarapa, west of Lake Taupo, and elsewhere - about 23 general localities in all (Davidson, 1976). Compelling circumstantial and experimental evidence linked infected possums with persistently high Tb reactor rates in cattle (Julian, 1981).

Both the NZ Forest Service and the Agricultural Pests Boards (through APDC) became involved in extensive poisoning operations as agents of the Animal Health Division of MAF, with the clear-cut objective of eradicating Tb from possums. But by 1980, with eradication of the disease clearly not attainable, the policy changed to one of "cost-effective control". In the meantime, the Forest Service had diverted most of its available financial and physical resources to the protection of livestock. Poisoning for watershed protection, which had been undertaken throughout the 1960s and 1970s almost as a matter of course, had ceased. In the last 8 years, large-scale operations against possums in indigenous forests have only been run in areas such as the mountains of Westland and the coastal pohutukawa forests of Northland where researchers or local managers have identified critical damage.
B. POPULATION DYNAMICS (M.G. Efford)

Introduction

The study of population dynamics is concerned with how population density changes through time, and with the processes which combine to cause those changes (birth, death and migration). Any consideration of the economics of possums, either as pests or a harvestable resource, must consider population dynamics since the intensity of browsing, the yield of skins, and the potential for transmitting disease all depend on density.

Methodological problems still hamper the development of a quantitative picture of the population dynamics of possums, so there is an understandable measure of speculation and possible over-interpretation in the literature. This account draws heavily on Green's (1984) recent review of possum population dynamics in New Zealand. Some results of the Orongorongo Valley live-trapping study (Efford, unpubl.) are presented here to make up for a lack of published information on some topics, especially mortality rates (see also Crawley, 1973; Bell, 1981b).

Possum life history and habits

Possums are largely solitary animals with no strong pair bond or social grouping. They do not defend exclusive territories, but generally share their range with others, although dominant animals may exclude intruders from part of their range (Triggs, 1982; Green, 1984). Green (1984) gives an average range size in New Zealand of 1.9 ha for males and 1.3 ha for females. Much larger ranges have been recorded where possums regularly move long distances (up to 1.5 km) through forest to feed on pasture (Green & Coleman, 1986b), and in open farmland (average 30 ha males, 31 ha females: Brockie et al., 1987a).

Females typically give birth to a single young each year in autumn (April-June). There may be a second peak of births in spring (September-November) during which up to about 80% of females give birth a second time in some areas. A few young are born at other times of year.

Most females 2 years of age and older breed (81% in the Orongorongo Valley). Breeding among 1-year-olds varies between areas, ranging from about 11% (average over 22 years in Orongorongo Valley) to 60% (Green, 1984).

The sex ratio at birth is biased towards males (e.g., 57% of births in the Orongorongo Valley). Males and females do not differ in growth or survival while in the mother's pouch.

The young possum is dependent on its mother for 5-8 months before weaning. In-pouch mortality appears to be low in many populations (e.g., Clout, 1977; Triggs, 1982), but Bell (1981b) reported average losses of 48% before 170 days in the Orongorongo Valley (1966-1975). Young of 1-year-old females suffer higher mortality than those of older females (e.g., Bell, 1981b; Triggs, 1982).

On average, 73% of female offspring in the Orongorongo Valley disappear before their second birthday (this includes mortality in the pouch). The disappearance rate of males in the same period is higher (90%) because many disperse out of the study area. Male
numbers are replenished by immigration so the sex ratio of 1-year-olds is not significantly different from that at birth.

Live-trapping in the Orongorongo Valley showed that annual mortality in the first 4 years of adult life (ages 2-6) was low for both females (10%) and males (16%). Mortality increased rapidly among males older than 6, reaching 50% in the 9th year. Female mortality rose only slightly with age until the 12th year when it also reached 50%. (These figures assume that dispersal was a negligible component of adult disappearance).

Mortality is strongly seasonal in the Orongorongo Valley; 66% of 149 known natural deaths occurred in July, August, or September.

Densities of possums in New Zealand habitats

Each habitat tends to support possum populations within a characteristic range of densities. Population densities recorded in New Zealand broadleaf/podocarp forests (Table 2) are consistently higher than in Australian populations (viz. 0.3 - 2.16/ha; Green, 1984).

The maximum densities in Table 2a for broadleaf/podocarp forest and for farmland (25.4 & 8.4/ha respectively) both refer to areas from which possums routinely moved out to forage on pasture; they are therefore not fully comparable with other density estimates. Both farmland areas included scrub, swamp vegetation, or willows, which served as refuges.

Higher local densities undoubtedly occur in some places, but the available evidence (pellet counts and trapping returns) is difficult to relate to absolute densities. Capture rates in gin traps sometimes exceed 90% for several nights on end (Batcheler et al., 1967) which presumably indicates a high population density. Batcheler et al., suggested a procedure for converting capture rate to absolute density, but the method was calibrated only for a capture rate of about 50% (7 possums/ha). Trap catch estimates of density are shown in Table 2b. Kean and Pracy (1953) recorded that "20 or more possums/acre" (i.e., 50/ha) had been taken from isolated patches of forest or scrub in Poverty Bay, but provided no other details.

Density is generally lower at higher altitudes (Coleman et al., 1980; Clout & Gaze, 1984; Wardle, 1984). However, Pekelharing (1979), working in the Taramakau Valley, recorded higher densities of faecal pellets in rata-totara forest at 700-900m than at lower altitudes in rata-kamahi forest; Pekelharing and Reynolds (1983) found a similar altitudinal pattern in Westland National Park.

Fecundity

Fecundity varies considerably between possum populations in New Zealand.

Many 1-year-old females fail to breed. Only 11% of 1-year-old females bred in the Orongorongo Valley between 1966 and 1987, and in some years none bred at all (Bell, 1981b; Efford, unpubl.). At the other extreme, Green (1984) gives an average of 60% for New Zealand populations "colonizing broadleaf/podocarp forests, or in pasture/scrub or exotic forest habitats".
TABLE 2. Possum population densities in New Zealand habitats.

### a. Mark-recapture and removal estimates.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Density ha⁻¹</th>
<th>Local variation</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadleaf/podocarp forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orongorongo 1946-1947</td>
<td>7.0</td>
<td></td>
<td>Batcheler et al., 1967</td>
</tr>
<tr>
<td>&quot; 1966-1987</td>
<td>7.7</td>
<td></td>
<td>Efford unpubl.</td>
</tr>
<tr>
<td>Mt Bryan O’Lynn</td>
<td>10.7</td>
<td>1.9 - 25.4</td>
<td>Coleman et al., 1980</td>
</tr>
<tr>
<td>Kapiti Island</td>
<td>ca 9.0</td>
<td></td>
<td>Cowan unpubl.</td>
</tr>
<tr>
<td>Beech forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt Misery, Nelson Lakes</td>
<td>0.5</td>
<td></td>
<td>Clout &amp; Glaze 1984</td>
</tr>
<tr>
<td>Pine forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tokoroa</td>
<td>3.0</td>
<td></td>
<td>Clout 1977</td>
</tr>
<tr>
<td>Ashley Forest</td>
<td>1.0</td>
<td></td>
<td>Warburton 1977</td>
</tr>
<tr>
<td>Albany</td>
<td>2.7</td>
<td></td>
<td>Triggs 1982</td>
</tr>
<tr>
<td>Farmland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridge Pa, Hawkes Bay</td>
<td>0.5</td>
<td>0.12 - 8.4</td>
<td>Brockie et al., 1987</td>
</tr>
<tr>
<td>Banks Peninsular</td>
<td>1.2</td>
<td></td>
<td>Jolly 1976</td>
</tr>
</tbody>
</table>

### b. Trap catch estimates
(Converted to densities by method of Batcheler et al., 1967)

<table>
<thead>
<tr>
<th>Area</th>
<th>Habitat</th>
<th>Density ha⁻¹</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aorangi</td>
<td>Podocarp/hardwood/beech</td>
<td>18.0</td>
<td>Batcheler et al., 1967</td>
</tr>
<tr>
<td>Mt Bruce</td>
<td>Mixed hardwood/beech</td>
<td>17.3</td>
<td>&quot;</td>
</tr>
<tr>
<td>Rotoehu</td>
<td>Lowland podocarp/hardwood/pine</td>
<td>9.9</td>
<td>&quot;</td>
</tr>
<tr>
<td>Ruahine</td>
<td>Rata/kamahi</td>
<td>24.2</td>
<td>&quot;</td>
</tr>
<tr>
<td>Orongorongo</td>
<td>Lowland podocarp/hardwood</td>
<td>11.4</td>
<td>&quot;</td>
</tr>
<tr>
<td>Kokaahi</td>
<td>Rata/kamahi</td>
<td>9.4</td>
<td>&quot;</td>
</tr>
<tr>
<td>Aorangi</td>
<td>Upland beech</td>
<td>6.3</td>
<td>Thomas et al., unpubl.</td>
</tr>
<tr>
<td>&quot;</td>
<td>Lowland podocarp/hardwood</td>
<td>8.6</td>
<td>&quot;</td>
</tr>
<tr>
<td>Waipoua</td>
<td>Kauri</td>
<td>0.9</td>
<td>Thomas unpubl.</td>
</tr>
<tr>
<td>&quot;</td>
<td>Lowland podocarp/hardwood</td>
<td>1.7</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>Pine</td>
<td>1.9</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
Each adult female may bear up to two young/year but the average number born is usually in the range 0.87 (Orongorongo Valley) to 1.8 (Banks Peninsula; Jolly quoted by Spurr (1981)). Green (1984) calculated that in the habitats referred to above, spring births averaged 13% of all births.

Keber (1986b, unpubl.) found consistently high rates of double breeding in the low density possum populations of young pine plantations near Taupo (about 60% of all females bred twice). Some small samples consisted entirely of double-breeders.

The intensity of spring breeding and the proportion of 1-year-olds breeding are generally thought to reflect the relative 'condition' of the population, as expressed particularly in fat reserves and body weight (e.g., Boersma, 1974; Fraser, 1979; Bell, 1981b; Green, 1984; Humphreys et al., 1984). The relationship may not however be so simple. In South Island beech forest at Mt Misery, females grew rapidly and matured early, but, despite their high body weights and low density, none gave birth in spring (Clout & Gaze, 1984). The authors suggested that absence of spring breeding might "... reflect a relative lack of nutritious foods (e.g., fruit) in this habitat at the critical season".

**Mortality**

Little information is available on causes of death and the annual rate of mortality in populations not subject to control or harvesting.

Fitzgerald and Karl (1979) noted possum remains in the scats of feral cats in the Orongorongo Valley, especially in winter and spring. Most occurrences probably represented scavenging of carcasses, though some live juveniles were probably taken in spring. Predation is unlikely to be an important cause of death.

Brockie, Clark and White (1977) autopsied 23 possums found dead on the Orongorongo study area during the severe winter of 1977. The animals' fat reserves were depleted, their guts were empty, and they carried heavy, probably pathogenic, infestations of fur mites (*Trichosurolaelaps crassipes*) and a duodenal nematode (*Parastrongylus trichosuri*). An exceptional winter flood apparently drowned about 30% of the farmland study population of Brockie *et al.*, (1987a). Several marked possums died later in the study when they were hit by cars or attacked by farmers' dogs (R. Brockie, pers. comm.). The overall annual disappearance rate was about 50%.

The disappearance of marked possums from live-trapping grids provides an upper estimate of mortality. 'Disappearance' includes an unknown amount of emigration, but the bias is probably small if the sample is restricted to adults.

Clout (1977) recorded annual adult disappearance rates of 18% and 27% on his two study areas. Triggs (1982) gave 'rough estimates' of 5%, 11% and 28%, excluding 'transients'. Annual disappearance of all adult females live-trapped in the Orongorongo Valley averaged 21% (years 1966-1985; range 0-58%, Standard Deviation (SD) 15%) and that of adult males 29% (range 6-54%; SD 14%).
Spurr (1981) derived a minimum annual adult mortality of 20% from 'stable age distributions' presented by Bamford (1972) and Boersma (1974). In the relatively crowded equilibrium population of the Orongorongo Valley, only 10% of females aged 2-6 disappeared each year (see Summary above); in optimal conditions adult mortality may be well below 10%.

Sex ratio

The sex ratio of adults ranges from mildly female-biased (e.g., Clout's (1977) Fox Road study area; Fraser's (1979) 'established' population in the Copland Valley) to strongly male-biased (e.g., Clout's Mamaku study area).

Variation in adult sex ratio appears to be related to higher rates of dispersal among young males and higher mortality of older males compared to females. Long-established, stable populations tend to have even sex ratios or show a female bias, especially in the older age classes. Populations re-establishing by immigration following local control operations or natural mortality are often dominated by young males (Clout & Efford, 1984; Green & Coleman, 1984).

Kill-trapping may itself induce biases, in both the sample and the remaining population, if one sex is more trappable. Because male possums are known to range further than females, trapping may differentially remove males (Brockie et al., 1981; Fraser, 1979; Coleman & Green, 1984). This argument is plausible, but no conclusive evidence has been presented.

Coleman and Green (1984) suggested that "some trapped populations are becoming debilitated through a loss of mature males ... Any real dearth of mature males may therefore impose an upper limit on the reproductive potential of the population and may markedly influence its absolute rate of recovery." Most adult females do give birth in all populations so far studied (Green, 1984), so this effect of a biased sex ratio remains hypothetical.

Response to control

After an isolated episode of harvesting or control, a possum population tends to return to the equilibrium density appropriate to the habitat.

There are few published data on the local intensity of persistent commercial hunting or the population response of the possums (Brockie, 1982; Warburton, 1987). This section therefore concentrates on the pattern of recovery in populations subject to episodic control, which is interesting for several reasons:

- Control operations can only be economic if recovery is relatively slow.
- If the mechanism of recovery is understood it may be possible to design control operations so that recovery is delayed.
- Intermittent control allows insights into how populations are regulated, because performance may be monitored over a range of densities.
Rate of recovery: Batcheler (1968) suggested that the recovery of populations poisoned with compound 1080 might be delayed because the most desirable dens would be contaminated and tracks would become overgrown. Evidence that possums in native forest generally use several dens (Ward, 1978; Green & Coleman, 1986a) led Green and Coleman (1984) to question the hypothesis, and no positive evidence has been produced to support it. Cowan (1980, 1981) found evidence for reduced breeding among the survivors of gins-trapping on Kapiti Island.

Several control operations have been monitored to determine both the percentage kill and the subsequent rate of recovery, but they differ greatly in percentage kill, geographic scale, and methodology.

Poison baits containing compound 1080 were distributed aerially over a 19km x ca. 1.5km forested section of the Taramakau Valley in June 1974 (Pekelharing, 1979). The faecal pellet density index declined by 85% between April 1974 and June 1975. Surveys in 1977, 1981, and 1983 showed a steady recovery; after 11 years the density index had reached 80% of the pre-control level (Green, 1987).

Clout (1977; see also Clout & Efford, 1984) killed all the possums in 24ha of pine plantation near Tokoroa using cyanide and 1080 baits. Carcasses recovered from near cyanide baits indicated an initial density of 3.0/ha. Twelve months later a further cyanide operation showed that the population density had recovered to more than 50% of its previous level.

Another total removal experiment was conducted in podocarp/mixed hardwood forest on Mt Bryan O’Lynn, Westland, by Coleman, Gillman and Green (1980). The average density of possums was 10.7/ha within the core 98 ha study area at the time of trapping in June and July 1978. Point-distance estimates of pellet density dropped from 7070 pellets/ha before possum removal to almost zero immediately afterwards; estimated average pellet density then recovered to 26% of its original value in the 3 years to August 1981 (Green & Coleman, 1984). The percentage occurrence of pellets on survey plots recovered to 50% of the pre-treatment level in the same time.

Mechanism of recovery

In each of the examples above the population was probably initially static. (The Taramakau population may have been declining - see below.) The increase from lowered density therefore implies either increased per capita recruitment (by breeding or immigration), decreased per capita losses (deaths or emigration), or both.

i. Dispersal: Initial recolonisation of depopulated areas is mostly by immigration when there are adequate source areas nearby. This is generally the case when a small part of a large tract of forest has been cleared of possums, as in the examples from Tokoroa and Mt Bryan O’Lynn above. Green and Coleman (1984) estimated that in the second year after depopulation at Mt Bryan O’Lynn, the population increased 75% by immigration and 25% by local births.

Young (0-1 year) males predominate among dispersers (Clout & Efford, 1984), and populations re-established by immigration typically contain a high proportion of males
from the year class preceding the control operation. Females also colonise depopulated areas, but little is known about their recruitment.

ii. Breeding: Females in most populations bear less than the maximum of two young/year (see above); a population reduced to low density might thus respond by increasing its breeding rate. The evidence for this is unclear.

Keber (1986b) reported that "as the study areas in Tauhara Forest (a central North island pine plantation) became more heavily populated the proportion of double breeders fell". However, there is insufficient information given to fully interpret these findings and the effect of population density is, in addition, confounded with successional changes in the vegetation and other annual variation. Hocking (1981) provides an example from Tasmanian eucalypt forests in which fecundity actually increased with density for a short time as the vegetation recovered after fire.

The conclusion of Clout and Barlow (1982) appears to stand: "average fecundity in (pine plantations) ... does not change with density over the range from 3/ha down to 0.44/ha".

Previous attempts have failed to induce spring breeding in habitats where females usually only breed in autumn. Kean (1971) stated that "It was expected that sustained (removal) trapping in the Orongorongo valley would lead to the emergence of double breeders in the better locations, but this did not occur ... Evidently a high incidence of fast breeders required selection for genetical types; it cannot be induced somatically." (The details of this experiment were not published.)

Gin trapping on Kapiti Island in 1980 reduced local density by at least 70%, but there was no detectable change in the incidence of spring breeding the following year (Cowan, 1982, pers. comm.).

Green and Coleman (1984) did not check for spring breeding after the 1978 trap-out at Mt Bryan O'Lynn, but they found a higher autumn breeding rate in a sample taken in 1981, compared to the 1978 census. However, in 1981 females from outside the removal zone were breeding at a rate not significantly different from those inside the zone, so the difference between 1978 and 1981 can be linked only tenuously to reduced density. The 'general condition' of possums from the removal zone was better than in the (presumably) higher density population outside the zone, suggesting that the population had responded positively to the low density.

Breeding rate was not correlated with the initial population density over 20 years in the uncontrolled Orongorongo Valley population (M.Efford, unpubl. data).

Reduced mortality: There are few published data on the effect of artificially lowered density on survival rates.

Density-dependent mortality of juveniles has been suggested as a regulating mechanism for some Australian populations (references in Green, 1984).

In the Orongorongo Valley, the proportion of juvenile females which were marked as pouch young and survived to at least 12 months, varied from year to year (18-87%). However, the correlation with the number of adult females was weak (n=20; r=-0.34;
p>0.1), possibly because sample sizes were small in most years. Annual survival of adult females was also variable (42–100%) and was not significantly correlated with density (n=19; r=-0.33; p>0.1).

Despite the lack of positive evidence, it seems likely that density-dependent reduction in mortality is an important and understudied factor in the recovery of possum populations.

**General models of possum population dynamics**

*The eruptive fluctuation model*: Our understanding of possum population dynamics has been strongly influenced by models which have guided the collection and interpretation of data. The 'eruptive fluctuation' model derived from work on ungulates (e.g., Caughley, 1970) has been particularly favoured as a general explanation of differences between populations in areas recently colonized by possums (Bamford, 1972; Fraser, 1979; Pekelharing, 1979; Pekelharing & Reynolds, 1983).

Pracy (1981a) provided a concise description of colonisation by possums which closely follows the eruptive fluctuation model:

"Following liberation of opossums or colonisation by dispersion into unoccupied territory there is a well marked series of changes in population levels... Initially there is a slow but steady increase in the populations, followed by a relatively short eruptive period to peak population levels... The period of peak population is generally of short duration followed by a sharp and often drastic decline in numbers brought about by malnutrition or exposure through the lack of adequate nest sites ... The initial sharp decline is arrested after a relatively short period and is followed by a slow but steady decrease in the populations with minor fluctuations often occurring."

The application of the eruptive fluctuation model to possums in New Zealand has never been critically reviewed. That cannot be attempted here, but a few comments are offered to encourage a more sober evaluation of its relevance.

It is unremarkable that a colonising population increases from low levels to a maximum ('peak'). Bamford (1973) suggested from indirect evidence that the increase phase took 11 years in the Taramakau Valley (but note reservations about Bamford's interpretation expressed by Spurr, 1981). In most places the increase phase has probably taken longer, if only because modification of forests by deer may have been a prerequisite for successful colonisation by possums (e.g., Kean & Pracy, 1953).

Several questions may be asked about the eruptive fluctuation model:

i. **How widespread is the evidence for natural declines?**

The model implies that possum populations decline substantially after the peak, but there is a dearth of numerical evidence for spontaneous declines in possum populations.

Anecdotal evidence from possum control staff suggests that "post-peak" declines in some regions (e.g., Southern Ruahines and Central Westland) were spectacular with possums "dying like flies" (C.L. Batcheler, pers. comm.). None of these observations were
systematically recorded. For the Aorangi Range however, L.T. Pracy (in: Batcheler et al., 1967) reported catches in 112 traps of 2474 possums in 1945, and 663 in 1951. The application of relative density models and estimation-by-removal models indicated that the population had gone through the peak period about 1945, and "crashed" by about 70% in the following six years.

Pekelharing and Reynolds (1983) analysed data from Westland National Park as a case study of colonisation. They recorded the area near Fox which Pracy scored as having a "heavy to dense" possum population in both 1950 and 1960, as having only "moderate" faecal pellet densities in 1978. Density may have declined, but it is difficult to know by how much or over what time because of the long interval between surveys and the lack of cross-calibration.

Faecal pellets were counted in rata-kamahi forests of the Taramakau Valley in 1970 and before the major 1080 control operation in winter 1974 (see above). Counts declined 45% between 1970 and 1974, which Pekelharing (1979) interpreted as the decline phase of an eruptive fluctuation.

Trapping by Cowlin and Barnett gave evidence for a slight decline in possum numbers in the headwaters of the Kokatahi River between 1959 and 1967 (Boersma, 1974). Interpretation is complicated by aerial poison operations in 1959 and 1961, and there is no supporting information.

Field inspections and questionnaire returns from pest boards led Pracy (1981a) to the conclusion that possum populations were declining naturally in many parts of the country by 1978–79. The method of population assessment was not described, although it was implied in the 1979–80 APDC Annual Report that population trend could be inferred from the condition of the vegetation. The two need not be closely linked (see below).

Natural populations may vary from year to year depending on the severity of winter weather etc., and it is important to distinguish this variation about an equilibrium from systematic trends. The Orongorongo Valley study provides a useful example. Batcheler (1983) stated that peak density was reached in the Orongorongo Valley "about 1940". Mason (1958) reported density estimates from removal trapping in 1946/47 that were little different from those reported later (Table 2). In 22 years of live-trapping (1966–1987) there has been no overall trend in density, but short runs of years show increases or decreases of up to 50%. The 'decline' noted in the Taramakau Valley between 1970 and 1974 may have been of this sort.

Variation about an equilibrium density does not imply an equilibrium with the vegetation. Sustained browsing by a stable possum population has successively eliminated the more palatable plant species in the Orongorongo Valley (Fitzgerald, 1976; Meads, 1978; Campbell, pers. comm.). Coleman, Gillman and Green (1980) reported that possums continued to alter the composition of forests at Mt Bryan O'Lynn although they were "probably ... at lower densities than before and closer to the carrying capacity of the modified habitat". As Green (1987) concluded, "...population stability is compatible with major switches in diet and ongoing changes in forest composition".
ii. How similar are possums and non-territorial ungulates?

Caughley and Lawton (1981) emphasised that the mathematics of the ungulate eruptive fluctuation model depend on a lack of behavioural interference between the herbivores. Adult possums differ from most ungulates in being extremely site-attached. Although possums do not occupy exclusive ranges (Crawley, 1973; Green, 1984), there have been persistent suggestions that some form of spacing behaviour limits density (Triggs, 1982; Green, 1984). If this is so, a 'laissez-faire' model of possum-plant interactions is inappropriate.

iii. Is there a general pattern?

The interaction between possums and forest is likely to differ significantly between forest types (e.g., Coleman, Gillman & Green, 1980), and to take on a different aspect on different time scales. In some forest types (e.g., some rata/kamahi stands) the effect of possum browsing is to abruptly change the structure of the forest—a phenomenon which could only be reversed on a time scale of decades or longer (see Batcheler, 1983 & references therein). On the other hand, trees which have been heavily browsed but not killed may respond very rapidly to the removal of possums, as shown by the regeneration, flowering and fruiting of kohekohe (Dysoxylum spectabile) on Kapiti Island after possum control in the early 1980s (I.A.E. Atkinson, pers. comm.). Tree mortality and the suppression of annual vegetative production are both influenced by the same process (browsing), but different models (or one more complex model) may be needed to cope with the two time scales.

iv. Are there other explanations for differences between colonizing and established populations?

Demographic differences between possum populations have mostly been analysed in terms of the relationship between possums and vegetation (Green, 1984); this is the framework of the eruptive fluctuation model. Kean (1971) suggested that possum populations also differ genetically as a result of selection for different reproductive strategies in colonising and equilibrium populations (see also Krebs, 1978). The possibility has largely been ignored by later authors, partly because it was associated with unfashionable ideas of group selection.

Mathematical models: Spurr (1981), Clout and Barlow (1982), and Barlow and Clout (1983) have used simple deterministic models to explore the behaviour of isolated possum populations subject to control or harvesting. These models treat the population growth rate as a function of the population density relative to the carrying capacity of the habitat.

The basic parameters of these models are the intrinsic rate of increase, $r$, and the equilibrium density, $K$. The intrinsic rate of increase has been estimated for possums from the maximum recorded per capita rates of reproduction and mortality (Table 3).
Table 3. Estimates of annual rate of increase of possums in New Zealand.

<table>
<thead>
<tr>
<th>(females/female)</th>
<th>Survival</th>
<th>Recruitment</th>
<th>rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spurr, 1981</td>
<td>0.90</td>
<td>0.50</td>
<td>34</td>
</tr>
<tr>
<td>Clout &amp; Barlow, 1982</td>
<td>0.90</td>
<td>0.45</td>
<td>30</td>
</tr>
<tr>
<td>Barlow &amp; Clout, 1983</td>
<td>0.90</td>
<td>1.00</td>
<td>59</td>
</tr>
<tr>
<td>Keber, 1985</td>
<td>0.90</td>
<td>0.75</td>
<td>46</td>
</tr>
</tbody>
</table>

Several comments are required on the parameters used by the various authors:

- It is assumed that juvenile survival (from birth to 12 months) is either 100% (Spurr, 1981) or the same as adult mortality. Even in sparse populations, this is unlikely to be true.
- The breeding rate of 1-year-olds has been significantly less than that of older females in all field studies to date.
- The sex ratio at birth is biased towards males, so the recruitment of females has probably been over-estimated (by about 16%, assuming 43% of births are female).
- Keber’s estimate of maximum productivity in pine plantations needs confirmation.
- Survival in optimal conditions probably exceeds 90%. (See above).

Taking these qualifications into account, the rate \( r \) may have been generally overestimated. It must be noted, however, that \( r \) is expected to vary between habitats. Maximum population growth rates in unmodified forest are likely to be much greater than in modified forest. Successional vegetation changes unrelated to possum browsing (e.g., in maturing pine plantations) will also change the parameters of possum population growth. Climate itself may have a decisive role, with greater intensity of breeding in dry, eastern areas (e.g., Hawkes Bay, Banks Peninsula).

The recovery of the Taramakau population between 1974 and 1985 (see above) is consistent with logistic growth with an intrinsic rate of increase of about 0.3 as proposed by Spurr (1981). Spurr’s model allowed for density-dependent variation in both mortality and fecundity.

Barlow and Clout (1983) discussed models with a third parameter, \( \theta \), which allows the shape of the growth curve to vary from backward-peaked (maximum growth rate at less than half equilibrium density) through symmetrical (\( \theta = 1 \)) to forward-peaked (maximum growth rate at more than half equilibrium density). Although there are no field data on which to base an estimate of \( \theta \), Barlow and Clout argue that the biology of possums implies a forward-peaked growth curve (\( \theta \) about 2). In that case, density-dependent checks to population growth take effect only at relatively high densities: for a given \( r \) the maximum sustainable yield is increased, and control must be more intensive to achieve the same reduction in numbers.
C. THE EFFECTS OF POSSUMS ON PRODUCTION AND PROTECTION VALUES

C.1 EFFECT OF POSSUMS ON INDIGENOUS VEGETATION

Overview (C.L. Batcheler)

Although Kirk (1920) and Cockayne (1926) had concluded that possum damage in indigenous forests was so slight as to be negligible, opinions began to change during the 1940s as many populations increased towards peak density. Zotov (1949) reported extensive damage throughout the Tararua Range, and Kean and Pracy (1953) stated that there was conclusive evidence of progressive elimination of up to 70% of trees and shrubs, particularly on high steep faces - although they did not specify the areas, or forest types to which they referred.

Canopy defoliation in the North Island: In the North Island, the rata/kamahi forests of the Southern Ruahine range attracted early attention. Although there was little evidence of damage caused by possums before 1940, 19 tree and shrub species were being defoliated by possums by 1948; canopy defoliation was becoming conspicuous from the plains; and by 1955 widespread death of canopy had attracted general notice and was reported from several quarters almost simultaneously (Elder, 1958). Droughts, disease, insect epidemics, earthquakes, and fires were considered as possible causes, but in Elder's view, the absence of evidence for any major endemic natural cause, and the diagnostic browsing pattern, implicated the possum. By 1965, possums had almost completely defoliated large areas of Weinmannia-dominant forest in the southern Ruahines (Elder, 1965). The former rata/kamahi forest then generally collapsed, leaving only scattered trees of species not preferred by possums (James, 1973). An overall review of the changes caused by man and introduced animals in the Ruahines was given by Cunningham (1979). Batcheler (1983) assessed the overall effect in the Pohangina Valley, Ruahine Range, from aerial photographs. High forest cover declined from 74% in 1946 to 6% in 1978. Tall scrub declined from 20% (principally Fuchsia excorticata/Aristotelia serrata) to 13% (principally Pseudowintera colorata/Melicytus ramiflorus). By 1978, short scrub, grasses, ferns and other herbaceous species covered 69% of the ground surface.

The rata/kamahi forests of the Manawatu hills south-west of the Ruahines suffered a similar fate. Esler (1978) recorded: "The vegetation is no longer northern rata/kamahi forest but a mosaic of shrubland and grassland ... the kamahi took on a greyish appearance as it was defoliated by possums. The defoliation was closely examined and there is not the slightest doubt about its cause."

Surveys of the Urewera forests, north-eastern North Island, led to the general conclusion that the possum had browsed and killed out many species of plants, and that the progressive depletion of Fuchsia, Aristotelia, and other characteristic species, was a readily discernible measure of the stage of possum colonisation (Wallis & James, 1972; G.T. Jane, 1978, 1979). Jane noted that Metrosideros robusta and kamahi were eliminated from the canopy about the time possums reached peak density. Dying forests formed concentric zones around liberation points (Wallis & James, 1972) and all age classes of forest were affected (e.g., see Howard, 1965:59).

The forest in the Orongorongo Valley near Wellington has been under observation since the 1940s, and the evidence for possum damage was reviewed by Fitzgerald (1976).
Possum numbers reached peak density about 1940. By 1976, *Fuchsia excorticata* and *Alectryon excelsus*, formerly common and preferred foods for possums (Mason, 1958), were rare and constantly browsed. Dead or substantially defoliated kamahi were common; the survival of *Beilschmiedia tawa* and *Pseudopanax arboresus* appeared to be threatened; and only a few *Myrsine salicina* survived. In the same area, Meads (1976, 1978) recorded the defoliation by browsing and the subsequent death of 11 of 50 *Metrosideros robusta* over the years 1969–1974, and the recovery to full canopy of five trees protected from possums by metal sheaths.

**Canopy defoliation in Westland:** The information on dieback in Westland forests has been reviewed (Batcheler, 1983; Batcheler, 1986; Payton, 1987; Stewart & Rose, in press). In parallel with the concern for the North Island rata/kamahi, the causes of canopy mortality in the rata forests of Westland were investigated (Chavasse et al., 1955). Chavasse et al. considered drought, insect attack, ageing of the forests in the aftermath of earthquake-synchronised regeneration pulses centuries beforehand, the influence of topography, soil and rock type, and the effects of introduced mammals. Although they discussed apparent "exceptions to the rule", they concluded that possums were primarily responsible for the defoliation of the forest canopy; that ground browsing animals (mainly deer and goats) were responsible for destruction of the shrub- and ground layers, duff layer, and for the complete inhibition of regeneration. They suggested that this damage may have altered forest microclimates, reduced insectivorous bird populations, and initiated fungal and insect attacks. The nett result was extensive mortality of the canopy trees of the forests - what has more recently been described as "dieback".

Since then, collapse of substantial areas of rata/kamahi on the north bank of the Kokatahi River has been the subject of many reports (Holloway, 1959; Travers, 1964; James, Jane & Barr, 1973). The effects of possums in other Westland catchments areas have been described by Best and Crozier, (1970), Bamford (1972), Pekelharing (1979) and Coleman, Gillman, and Green (1980). Pekelharing's (1979) synthesis of the sequence of events on the north bank of the Taramakau River is typical. Possums spread into the area some time after 1950, and a wave of canopy defoliation progressed upriver as the animals attained high densities. The same sequence has occurred in montane forests throughout Westland.

Although much of this evidence has been published only during the past decade, most of its substance was well known by the late 1960s, and the possum had now "assumed the rank of number one problem animal ... as anyone familiar with the situation in Westland or the southern Ruahines range will be well aware" (Holloway, 1973). This consensus was the rationale for extensive possum aerial poisoning campaigns from the early 1960s to the mid 1970s throughout the rata/kamahi forests of the Southern Ruahines and the Taramakau - Hokitika catchments (Boersma, 1974; Cunningham, 1979; Pekelharing, 1979) (Fig. 3).

But this consensus was then challenged.

**Debate on causes of canopy dieback:** After studying erosion and sedimentation in the Manawatu River Catchment, Mosley (1978), suggested that severe weather in the 1930s and 1940s may have triggered the forest collapse. Further north, for the Kaimai Range, Jane and Green (1983) deduced that widespread canopy mortality which had largely been blamed on possums and other browsing mammals (e.g., Dale & James, 1977) was, more probably, attributable to droughts in 1914 and 1946.
Veblen and Stewart (1982) made similar suggestions about Westland rata/kamahi forests. While conceding that possums may have had a pervasive effect on the rata/kamahi forests and had "caused some shifts in the abundance of some tree species", they concluded that the more dramatic changes were related to geological and meteorological events - earthquakes, storms, droughts, and long-term climatic changes. Many rata/kamahi stands had originated in large-scale regeneration pulses after ancient earthquakes and storms. Many of the trees were now old and extensive mortality could be attributed to normal processes of stand-dynamics, regardless of possum browsing.

These doubts stimulated more detailed studies of the possum and mortality and regeneration processes in the rata/kamahi forests. The added information has overwhelmingly reinforced the "conventional" view of the gravity of the possum problem.

Coleman, Green and Polson (1985) showed that on a steep hillside bordering pasture, forest species provided 88% of the total food taken by possums; southern rata and kamahi were selected as favoured foods, providing 69% of the intake. These species showed clear evidence of possum browse and were often represented by many dead stems.

In Westland, Payton (1983, 1985) simulated browsing by clipping various proportions of leaves off rata trees. The timing and extent of defoliation and the age of the trees influenced subsequent growth. Partial (50%) defoliation depressed growth more in old trees than in young trees. Although total defoliation before budbreak did not kill shoots in old or young trees, most of the shoots died after the new foliage was attacked by insects. The results simulated the effects of intensive browsing by possums, which browsed and killed first the old trees, and later the younger, more resilient trees.

A study near Fox Glacier and in a tributary of the Hokitika River concluded that, because of possum browsing, southern rata will be less abundant or virtually absent as a canopy tree, for at least one generation of the replacement canopy (Allen & Rose, 1983). Leutert (1988) studied rata mortality in three areas with different possum histories in the Copland Valley, South Westland; one where possums were still increasing, one where they were near peak density, and one where they were past peak density. He found that as the time of possum occupation increased, the severity of foliage loss and incidence of possum browsing also increased. Loss of foliage on exposed trees and in the proximity of seral vegetation was significantly greater than elsewhere. Browsing was heaviest on large trees. He concluded that the stress imposed by browsing is a principal cause for the observed dieback in southern rata. In the Taramakau Catchment, reduction of possums at peak density resulted in lower mortality rates of palatable canopy trees than when control was deferred until 4 years after the possums reached peak (Pekelharing & Batcheler, unpubl. report). Another study in the Taramakau showed that mortality of southern rata and Hall's totara is closely linked to the density of possums and their length of occupation of the forests (Rose, Pekelharing & Hall, 1988).

The severity of dieback varies from place to place. The forests most affected are on landscapes most prone to natural geologic disturbance that contain a high proportion of seral scrub (Chavasse et al., 1955; Stewart and Rose, in press; Reif & Allen, 1988). On more stable landscapes plant species favoured by possums are progressively replaced by those characteristic of low fertility sites (Reif & Allen, 1988). Generally, forests on indurated stable granite country west of the main Alpine Fault (e.g., Karamea-Heaphy,
Paparoa Range, Mt. Hohonu), on broad valley floors (e.g., Waiho River), and on wetter, easy terrain are typically less affected by possums. Conversely, forests on less stable, fractured schist, near the main Alpine Fault, and on steeper terrain, are more severely affected by possum-induced dieback.

Thus, the evidence for a strong causal link between possum browsing and large-scale dieback of the Westland rata/kamahi forests has been reaffirmed. This more recent research has made it clear that geological and climatic factors predispose individual stands to dieback, but that the possum triggers its onset.

Accordingly, virtual abandonment of possum control operations from the late 1970s (Batcheler, 1986) on the basis that the possum had not been proved responsible for the declining condition of these forests, was both unfortunate and unjustified. As is shown in the following sections, there is now little of the broad-leaved mixed hardwood forest left in good order.

**Susceptibility of other forest types:** Possums had never been considered a major threat to beech forests (James, 1974). However, Wilson (1983) and Ogle & Wilson (1985) showed that the mistletoes (*Peraxilla* and *Alepis*), formerly abundant in beech forests, are being reduced to the point of local extinction. Also, many beech forests contain highly palatable seral vegetation (fuchsia, ribbonwood, wineberry) along the stream channels and on mass movement sites (James, 1974). These sites are highly susceptible to lateral erosion and reactivated mass movements (slipping) after loss of the browse-susceptible species.

Wardle (1984) interpreted the general impact of possums in forests as a gradient of increasing susceptibility from simple beech forests to broad-leaved hardwood forests. "Even though possums feed on leaves and bark of the beeches, (in) the simplest ... stands ... possums will have little, if any discernible effect. As the forests become richer ... and the broad-leaved hardwood and shrub-hardwood components increase, susceptibility to damage also increases ... In mixed forest, where southern rata and kamahi are common ... these species could be removed from the canopy by possums". The key place of kamahi is indicated by its listing as a diagnostic canopy component of 22 out of a total of 34 forest types considered vulnerable to possums (Pracy, 1977).

The priority for re-assessment for this review is clearly indicated by all these results as the broad-leaved mixed hardwood forests.

**Current status of indigenous forests:** Blaschke et al., (1981) classified the North Island and South Island forests as 18% and 9% respectively with an exotic plantation element, 27% and 65% with a beech element, and 55% and 26% without a beech element. Thus in the North Island, the canopy of about two-thirds of the indigenous forests can be considered vulnerable to possum browsing. I.J. Payton therefore assessed contemporary opinions, investigated the effect of possums on forests throughout the North Island, and identified areas of vulnerable forest types which are still largely unmodified. His assessment was based on a review of available literature and visits to DOC offices at Wellington, Wanganui, Rotorua, Hamilton, Auckland, and Whangarei, Department of Scientific and Industrial Research offices at Kaikohe and Taita, the Indigenous Forest Management Section at FRI Rotorua, N. Mitchell (Auckland University), G. Campbell (Auckland Regional Authority), and L.T. Pracy, A.H. Leigh, and I.R. Logan, formerly officers of the Forest Service who had been intimately involved with the management of possums.
Fig. 4. Distribution of broad North Island forest classes.
We had neither the time nor the resources to attempt an equivalent overview in the South Island (although this should be done). Therefore, as the Westland rata/kamahi tract is the most vulnerable, large, and important tract of broadleaved hardwood forest in the South Island, A.B. Rose, C.J. Pekelharing, and K.H. Platt surveyed its current situation. The objectives were: To describe canopy damage in the rata/kamahi forests east of the Alpine Fault, between the Haupiri and Mahitahi Rivers; to infer the degree of past canopy modification in these forests; forecast likely future trends in canopy damage and their impact on forest composition; and to identify and comment on the feasibility of maintaining representative areas of relatively unmodified forest.

*Current possum damage to North Island indigenous forests*  (I.J. Payton, FRC)

**Northern kauri-podocarp-hardwood forests:** This broad class of forests includes forest types in which kauri is present, together with the lowland hardwood associations of the Northland, Auckland, and Coromandel regions (Fig. 4). The presence of beech (*Nothofagus*) is limited to a few localities, most south of Auckland and Coromandel.

Although a wide range of forest species is browsed by possums, the most conspicuous possum-induced damage to these northern forests is the severe defoliation and death of emergent northern rata (*Metrosideros robusta*) and kohekohe (*Dysoxylum spectabile*). In some areas shrub hardwoods such as five-finger (*Pseudopanax arboreus*), fuchsia (*Fuchsia excorticata*) and pate (*Schefflera digitata*), and the mamaku treefern (*Sphaeropteris medullaris*) are also reported to be severely defoliated and killed. Canopy species not palatable to possums include kauri (*Agathis australis*) and taraire (*Beilschmiedia tarairi*). Not all forest canopy damage however is possum-related. For example, storms damaged forest canopies in parts of the Hunua Ranges in the 1930s (G. Campbell, pers. comm.).

On the Coromandel Peninsula, forest damage is greatest in the south, where dead northern rata forms a conspicuous part of the canopy, and least in the Moehau Range at the northern tip, where possums have only recently arrived and are still in low numbers. However even in the relatively intact forest of the Moehau Range, possums have largely defoliated areas of kohekohe at the southern end. Pigs, goats, and in some areas wild cattle, are causing considerable damage to the understorey vegetation. Great Barrier Island, which has substantial areas of kauri-podocarp-hardwood forests, is free of possums although goats and pigs are present.

A characteristic type of possum damage occurs in the Hunua and Waitakere Ranges near Auckland. Esler (1983) notes that kohekohe would almost certainly become a prominent species in cut-over forest areas in the Waitakere Range "but the plants are seriously damaged by opossums before the saplings reach the canopy".

The eastern Northland kauri forests also show a south to north gradient of possum-related damage. Northern rata, five finger, and mamaku have been severely damaged in Russell State Forest. A short distance further north, at Ngaiotonga, where possum colonisation is more recent, damage to northern rata and kohekohe is light, but fuchsia is being heavily browsed. Northern rata has largely been eliminated from the forests south of Kaikōhe. Further north, in Puketi and Omahuta State Forests, there is as yet little canopy damage apart from local defoliation of kohekohe. Shrub hardwood species however are being depleted.
In western Northland possums are present throughout the kauri forests south of the Hokianga Harbour. These include Matarua, Waima, and Waipoua State Forests, which together make up the largest continuous tract of native forest in Northland. Although little or no possum-related canopy damage is evident, kohekohe and a range of shrub hardwood species are being defoliated. North of the Hokianga Harbour colonisation by possums is recent and numbers are low. Little possum damage is evident in Warawara State Forest. Further north forests on the Herekino and Maungataniwha Ranges remain unmodified by possums, although some animals are undoubtedly present (Julian, 1984).

The Aupouri Peninsula in the far north has until recently been free of possums. Scattered populations now occur as far north as Te Kao (Julian, 1984) with recent sightings just south of Cape Reinga.

Coastal pohutukawa forests: Pohutukawa (Metrosideros excelsa) dominated forests are a feature of the Northland and Coromandel coastlines, extending south towards Gisborne and New Plymouth on the east and west coasts respectively.

Although possum damage to these forests has been observed over much of their range it is most conspicuous on the east coast of Northland between Auckland and the Bay of Islands. As for other Metrosideros species, possums frequently browse and eventually kill one or a few trees, while ignoring others nearby. Damage to individual pohutukawa appears to be greatest in areas which are farmed or otherwise developed (e.g., picnic areas, camping grounds) (Pracy, 1978). Where coastal forested areas are less disturbed (e.g., Whangaruru Peninsula) possum damage is most severe on extreme coastal faces within the salt spray zone (N. Clunie, pers. comm.). In addition to pohutukawa, wharangi (Melicope ternata), Pittosporum umbellatum, karamu (Coprosma lucida), and taupata (C. repens) are heavily browsed and killed. The dieback does not appear to be salt spray related as the forest cover on offshore rock stacks has remained healthy. Further inland, possum-related damage to these stands is less severe.

The most extensive area of pohutukawa forest occurs on Rangitoto Island. Possums and wallabies are present. Damage to the forest canopy is patchy, with severe dieback and death of canopy trees confined to what appear to be more fertile sites (e.g., around blackback gull colonies). Other sizeable stands of coastal pohutukawa forest on the east coast of Northland are at Bream Head and the Whangaruru Peninsula. At Bream Head, described by Ogle (1982) as "the most extensive and intact coastal hardwood forest in Northland", some canopy dieback of pohutukawa and kohekohe is evident, but the structure of the forest remains intact. Further north, on the Whangaruru Peninsula, possum damage to pohutukawa and kohekohe is more extensive.

Coastal pohutukawa forests are less extensive on the west coast of Northland. At Maunganui Bluff, north of Dargaville, canopy damage is severe in places, with an estimated 60% loss of canopy cover between 1979 and 1985 (N. Mitchell, pers. comm.). Patches of possum-related dieback have also been noted from coastal forest on the western fringes of the Waitakere Ranges, near Auckland, and at Karioi, on the southern side of Raglan Harbour, where kohekohe and the mamaku treefern have been heavily defoliated.

Central North Island tawa forests: Tawa (Beilschmiedia tawa) is a major or dominant canopy component in a belt of forests extending through the central North Island from the Raukumara, north and central Urewera, and lowland Bay of Plenty forests in the east, to
the western King Country and inland Wanganui forests west of the Volcanic Plateau. On Mt Egmont tawa is present in the lower altitude forests. The tawa forest belt is mainly hill country below 700m altitude.

Tawa forests are regarded as good habitat for possums. Apart from the defoliation and eventual death of scattered emergent northern rata, forest canopies on ridge and hillslope sites are not greatly modified by possum browsing. Most change occurs in the gully hardwood communities where fuchsia, mahoe (Melicytus ramiflorus), pate, kamahi (Weinmannia racemosa), wineberry (Aristotelia serrata) and raukawa (Pseudopanax edgerleyi) are heavily browsed. In some areas these communities have been replaced by Uncinia-dominated clearings, with ungulate (usually goat or deer) browsing preventing forest regeneration.

In the inland Wanganui, north Taranaki, and western King Country forests, black beech (Nothofagus solandri) and/or hard beech (N. truncata) is common on ridge crests. Tawa, northern rata, and kamahi are the main hillslope canopy species with podocarps present in the valleys. Where beech is absent (e.g., Matemateonga Range), kamahi is a more prominent canopy species. Dead standing northern rata are present throughout the forests and in some areas kamahi is reported to be dying. Estimates of rata mortality in the inland Wanganui forests range from 10 to 15%.

At Pureora, in the Rangitoto Range north-west of Lake Taupo, podocarp-tawa forest canopies are little damaged despite high numbers of possums (in Leathwick, 1987). However gully hardwood vegetation has been severely depleted and in places eliminated, and ungulates (mainly deer) are inhibiting regeneration.

With the exception of the demise of northern rata, the structure of lowland hardwood and podocarp-hardwood forests in the Rotorua district has been little affected by possums. The recent death of fuchsia trees around the Rotorua Lakes does not appear to be attributable to possum browsing (J. Herbert, pers. comm.).

Northern rata is also being adversely affected by possums in the Urewera and Raukumara Ranges. While opinions differ over the extent to which northern rata is disappearing from these forests, the trend is definitely downwards. Damage to both northern rata and possum-palatable shrub hardwoods is greatest in the northern and central Urewera forests. Fuchsia and pate, once major components of gully hardwood stands, are now rare or absent on these sites. The least modified forests in the region occur in parts of the Raukumara Ranges where possums and goats are still only present in low numbers. The Raukumara forests are characterised by beech on the ridges and tawa dominance in the valleys. Damage to emergent rata and shrub hardwood species is light east of the Motu River. The most intact forest stands occur between the Haparapara and Kereru Rivers (L.T. Pracy, pers. comm.).

Central-southern North Island podocarp-hardwood forests: South and east of the tawa forest belt, kamahi replaces tawa as a major canopy species in hardwood and podocarp-hardwood forests. These mixed forests, which frequently contain scattered-to-dense emergent northern rata, are heavily modified by possum browsing. Damage appears to be greatest in areas with a high percentage of seral vegetation (i.e., possum-palatable shrub hardwoods).
In the Paeroa Range, south of Rotorua, massive kamahi dieback, over a period of 10 years, reduced podocarp-hardwood forest to scrubland dominated by treeferns, with some emergent miro (Podocarpus ferrugineus) on the ridges. Where the forest canopy was dominated by tawa there was little change in canopy composition. A similar collapse of kamahi-dominated forest canopies occurred 20–30 years ago in podocarp-hardwood forests west of Mt Ruapehu. However, it is not clear whether possum browsing caused the collapse of the canopy in either forest.

Scattered northern rata are reported as dead or dying on the eastern side of the Hauhungaroa Range, west of Lake Taupo. Probably the most extensive area of northern rata forest (ca 100 ha) occurs in the Ratanunui Ecological Area on the western slopes of the Hauhungaroa Range. Possums have extensively damaged this stand, although a substantial northern rata component remains.

On Mt Egmont, kohekohe, kamahi, mahoe, fuchsia, northern rata and Pseudopanax spp. are heavily browsed and killed by possums. Locally there is also considerable forest dieback which does not appear to be possum related (B. Clarkson, pers. comm.).

As mentioned in the overview by Batcheler, massive forest collapse coincided with the buildup of possum, deer and goat populations in the mixed hardwood (rata/kamahi) forests of the southern Ruahine Ranges and the Manawatu hill country, south of Palmerston North. Similar damage has occurred in rata/kamahi forests on the flanks of the northern Ruahines.

Possum-related forest damage is not confined to hardwood species. In the Hihitahi forest sanctuary, south of Waiouru, high altitude kaikawaka (Libocedrus bidwillii)/totara (Podocarpus hallii) forest has been extensively damaged by high populations of possums and deer.

Before possums were eradicated from Kapiti Island, Atkinson (1982b) considered that "possums were changing the development of the Kapiti (hardwood) forests by killing some tree species more than others". Canopy species at risk included northern rata, kohekohe, tawa, kamahi, and toro (Myrsine salicina). As noted earlier, substantial changes in forest composition as a result of possum browsing have also been documented in the podocarp-hardwood forests of the Orongorongo Valley, near Wellington (Meads, 1976; Fitzgerald, 1976). Similar changes in forest composition resulting from possum browsing have been reported from hardwood and podocarp-hardwood forests in the Tararua, Rimutaka, and Aorangi Ranges in the southern North Island.

Beech/beech hardwood forests: Major areas of beech or beech/hardwood forest occur in the Raukumara, southern Urewera, Kaweka, Kaimanawa, and northern Ruahine Ranges. Beech species also form the predominant forest cover west of Mt Ruapehu and over large areas of the southern North Island ranges.

Possums feed on both leaves and bark of beech species, but they are not preferred foods, and damage to individual trees is usually minimal. However, Druce (in Ogle & Wilson, 1985) considers that mistletoes are now extremely rare wherever possums have been present for any substantial time.
Fig. 5. Forested areas for which low (cross-hatched) or nil (stippled) possum populations are recommended in the North Island.
Possum-related damage in beech forests is concentrated on seral and subcanopy vegetation and is therefore frequently difficult to separate from ungulate browsing. In the Kaweka Range damage by possums was generally confined to river and stream banks, gully heads and faces (Pracy, unpubl. NZ Forest Service report). However, highly preferred food species such as fuchsia, wineberry, Pseudopanax spp., and locally kamahi are depleted throughout the area. Fuchsia gully communities in the red (Nothofagus fusca)/silver (N. menziesii) beech forests of the southern Ureweras, however, are still largely intact (W.B. Shaw, pers. comm.). Damage to silver beech forests in the Tararua Ranges is also most evident in seral communities which have a high proportion of both deer and possum-preferred species (P. Brady, pers. comm.).

Discussion: Virtually all of the North Island indigenous forests have been colonised by possums. Their impact, however, has been far from uniform. In general, major changes are occurring (e.g., the collapse of rata/kamahi forests in the southern Ruahine Ranges) where palatable species are important structural components of the forests. Conversely, where the predominant forest species are not browsed or are only lightly browsed (e.g., the beech species) forest structures may remain largely unaltered, although even in these forests the abundance of some species (e.g., mistletoes) has drastically declined.

The response of individual plant species to possum browsing can also be variable. For example, within the central North Island tawa forests, tawa canopies appear to be little affected by possum browsing, but on Kapiti Island mature trees are defoliated and killed by possums (Atkinson, 1982a,b). Fuchsia also shows a variable response to possums. A reddish-leaved form common in many eastern areas is little browsed, but elsewhere the species is highly preferred and rapidly depleted (Batcheler, 1983).

With such a large proportion of North Island indigenous forests already substantially modified by possums and other introduced browsing animals, every effort needs to be made to retain the remaining largely unmodified forests as near possum-free as possible. In addition specific cases for possum control need to be developed to enable the protection of habitat for rare or endangered flora and/or fauna. Often these two approaches will coincide.

Any proposal to control or eliminate possums needs to take into account the presence or creation of buffer zones to prevent or at least impede recolonisation. In the recommendations, emphasis is placed on the control of possums in a few larger tracts of forest rather than over a plethora of smaller areas, each set aside for a specific purpose (Fig. 5). Most of the recommendations relate to areas in the northern half of the North Island. This reflects the more recent colonisation of parts of this area by possums and the highly vulnerable species composition of many of the forests. Indigenous forests in the central and southern North Island are generally already substantially modified by possums or are beech forests which do not have a highly vulnerable species composition.

Canopy mortality in Westland rata/kamahi forests (A.B. Rose, C.J. Pekelharing, K.H. Platt, FRC)

Introduction and methods

The survey of Westland rata/kamahi forest was undertaken by first analysing the amount of visibly conspicuous canopy dieback (proportions of grey or white crowns) on
monochrome aerial photographs taken in 1984 and 1985, and then relating this to the proportions of dead canopy trees found by inspection of representative areas. Broad dieback classes were used because of differences in the timing and scale (1:17000 - 1:25000) of the available photographs.

Minimum units for mapping conspicuous dieback were defined, from the aerial photographs and NZMS1 maps (1 inch:1 mile), as tracts of rata/kamahi forest between 500 m elevation and the timberline (c 900 m), of at least 1.6 km (1 mile) horizontal dimension, and bounded by distinct topographic features such as creeks, ridges, and bluff systems.

We independently assessed each unit under 1.5x magnification. After consensus was reached, the map unit was classified in one of the following four dieback classes:

1. Light: No defoliated crowns visible, or if present, only isolated and apparently involving individual trees.
2. Moderate: Defoliated crowns present at low densities over most of the map unit, mainly involving single trees, or small groups.
3. Heavy: Defoliated crowns present at high densities over most of the map unit. Usually involving large groups of trees. Groups often coalescing.
4. Severe: Most of the forest canopy consisting of defoliated, apparently dead crowns.

For consistency, reference photographs of each dieback class were regularly consulted.

After analysing the photographs, we inspected selected parts of the study area (February 1988) by helicopter and fixed wing aircraft, flying at about 1000 m altitude and 500 m from the hillslope. This inspection verified the dieback classes as mapped and allowed estimation of current canopy mortality, as: (1) Light = <10% mortality; (2) Moderate = 10 - 30% mortality; (3) Heavy = 30 - 50% mortality; (4) Severe = >50% mortality.

<table>
<thead>
<tr>
<th>Area</th>
<th>Approx. time since conspicuous canopy death (yrs)</th>
<th>% death of two major canopy species (approx)</th>
<th>Canopy death category 1984-85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox (part)</td>
<td>35</td>
<td>90-100</td>
<td>50-100</td>
</tr>
<tr>
<td>Kokatahi (part)</td>
<td>35</td>
<td>90-100</td>
<td>NA</td>
</tr>
<tr>
<td>Taramakau Block 1</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Taramakau Block 2</td>
<td>15</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>


The mapped patterns of current canopy mortality (Fig. 6a & 6b) largely reflected patterns of possum invasion and build-up. Superimposed were the influences of forest composition and the timing of dieback (Table 4).
Fig 6a. Death of the canopy of rata/kamahi forest above 500m in northern Westland. Unmodified areas in Western Forest Catchments have not been mapped separately because of difficulties of assessment. The numbers show the places and last 2 digits of the years possums were liberated (from Pracy, 1974). See colour Key, Fig 6b.
6b. Death of the canopy of southern Westland rata/kamahi forest above 500 m.
Overall current canopy mortality

In the 83,000 ha of upper elevation forest surveyed, about 20% of all canopy trees were dead. Less than 30% of these forests showed only light canopy mortality (<10% dead canopy trees). Canopy mortality was moderate (10-30%) in almost 60% of the forests, and heavy (30-50%) or severe (>50%) in the remaining 12% (Fig. 6a, b, Table 5).

<table>
<thead>
<tr>
<th>Canopy death class Approx. % dead crowns¹</th>
<th>Area (ha)</th>
<th>Proportion (%) of area in each canopy death class</th>
<th>% Overall canopy death (D)²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light &lt;10</td>
<td>Moderate 10-30</td>
<td>Heavy 30-50</td>
</tr>
<tr>
<td>Western front catchments</td>
<td>18204</td>
<td>73</td>
<td>27</td>
</tr>
<tr>
<td>Major catchments</td>
<td>64615</td>
<td>17</td>
<td>67</td>
</tr>
<tr>
<td>Total study area</td>
<td>82819</td>
<td>29</td>
<td>59</td>
</tr>
</tbody>
</table>

¹ Estimated from aerial inspection of selected map units.
² Calculated from the percentage of each area in each canopy death class and the approximate mid-points of the canopy death classes:

\[ D = \frac{1}{100} (5L + 20M + 40H + 70S) \% \]

... Where L = % of the area showing light canopy death, M = % of the area showing moderate canopy death, etc.

Geographical variation in current canopy mortality

Three gradients were recognised.

1. Current canopy mortality was less severe in the small western front catchments immediately east of the Alpine Fault than in the 27 larger catchments with their headwaters further east towards the Southern Alps (Fig. 6a, b, Table 5).

Overall canopy mortality in the front catchments was about 10%, with almost 75% of these forests showing only light mortality and no areas of heavy or severe mortality. In contrast, overall canopy mortality in the more eastern catchments was about 20-25%, and more than 80% of these forests showed moderate to severe mortality.

Several lines of evidence, including early ground photographs (e.g., Pracy, 1955), anecdotes (e.g., M. O'Reilly, pers. comm.), the many canopy gaps or old spars visible from the air or road, and early aerial photographs all indicate that dieback in most of the front catchments was greater in the 1950s-1970s than at present. Nearly all recorded liberations of possums in the study area were west of the Alpine Fault, from
where they invaded towards the heads of the main valleys. In general, therefore, the front catchments were subjected to the effects of high possum populations earlier than the main valleys further east. We therefore conclude that most of the front catchment forests are in a ‘post dieback’ phase. The west-east gradient of increasing current canopy mortality therefore largely reflects possum invasion patterns and the increasing conspicuousness of the more recent canopy mortality in the major catchments.

Nevertheless, aerial inspection suggests that the front catchment forests suffered less severe canopy mortality than that now occurring in many of the major catchments. We estimated that earlier dieback removed less than 30% of all canopy rata in the forests currently showing light canopy mortality that we inspected (Haupiri–Styx and Wanganui–Karangarua). This contrasts with much more severe mortality in major catchments such as the Hokitika and Wanganui. In addition to this west-east gradient reflecting possum invasion and timing of dieback, compositional or structural factors resulting from differences in climate and/or site stability and underlying rock types, make the front catchment forests less susceptible to possums (Stewart & Rose, in press).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy death class</td>
<td>Area (ha)</td>
<td>Proportion (%) of area in each canopy death class</td>
</tr>
<tr>
<td>Approx. % dead crowns¹</td>
<td>Light &lt;10</td>
<td>Moderate 10–30</td>
</tr>
<tr>
<td>Northern (Haupiri–Taramakau)</td>
<td>2097</td>
<td>3</td>
</tr>
<tr>
<td>Central (Taramakau–Karangarua)</td>
<td>14379</td>
<td>89</td>
</tr>
<tr>
<td>Southern (Karangarua–Mahitahi)</td>
<td>1728</td>
<td>28</td>
</tr>
</tbody>
</table>

1 Estimated from aerial inspection of selected map units.
2 Calculated from the percentage of each area in each canopy death class (see Table 5).

2. Canopy mortality was more evident in northern and southern than in central front catchments. In the north, between the Haupiri and Taramakau Rivers, more than 95% of the forests showed moderate canopy mortality. In the south, between the Karangarua and Mahitahi Rivers, this figure exceeded 70%. In contrast, light canopy mortality was recorded in almost 90% of the forests of the central front catchments (between the Taramakau and Karangarua Rivers, Fig. 6a,b, Table 6).

We interpreted the greater current canopy mortality in southern than in central front catchments as reflections of more recent invasion by possums. Reasons for the greater current canopy mortality in the northern front catchments are less clear. One
possibility is that these northern forests, close to the unstable biotite schist zone, contain a high seral component, and are thus more favourable possum habitat. On aerial inspection, we noted a higher proportion of seral forest (30-60%) in this northern block than in the adjacent part of the central block between the Taramakau and Styx Rivers (20-30%). A further possibility is that possum populations are again building up after extensive 1080 poisoning operations during the 1960s and 1970s.

<table>
<thead>
<tr>
<th>Canopy death class</th>
<th>Area (ha)</th>
<th>Proportion (%) of area in each canopy death class</th>
<th>% Overall canopy death (D)²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Light &lt;10</td>
<td>Moderate 10-30</td>
</tr>
<tr>
<td>Northern (Haupiri-Wanganui)</td>
<td>38807</td>
<td>14</td>
<td>64</td>
</tr>
<tr>
<td>Central (Poerua-Copland)</td>
<td>22226</td>
<td>12</td>
<td>82</td>
</tr>
<tr>
<td>Southern (Karangarua-Mahitahi)</td>
<td>3577</td>
<td>80</td>
<td>20</td>
</tr>
</tbody>
</table>

1 Estimated from aerial inspection of selected map units.
2 Calculated from the percentage of each area in each canopy death class (see Table 5).

3. Overall current canopy mortality decreased from 24% in northern major catchments (Haupiri-Wanganui) to 19% in central catchments (Poerua-Copland) to 8% in the southern catchments (Karangarua-Mahitahi). In the north, 22% of these forests showed heavy to severe canopy mortality (Table 7, Fig. 6a,b). This declined to 6% in central catchments, and there were no areas of heavy to severe mortality in the south. In the southern catchments, 80% of the forests had only light canopy mortality compared to 12-14% further north.

This pattern clearly reflects the history of possum liberation and invasion from north to south.

Canopy mortality in individual catchments

Overall, current canopy mortality was most severe in the Hokitika, Taramakau, and Wanganui catchments. In the Hokitika, 80% of the forests showed conspicuous, heavy to severe mortality (25% severe). In the Taramakau, 34% showed heavy to severe mortality (15% severe), the remainder largely representing forests that underwent heavy to severe canopy mortality 15-30 years ago and now show moderate mortality. No areas of light canopy mortality were found in either the Hokitika or Taramakau catchments.

The canopy mortality pattern in the Wanganui reflects progressive invasion by possums towards the headwaters. Post-dieback forests in the lower reaches now show light or
moderate canopy mortality. More recent heavy to severe canopy mortality, as well as largely unmodified forests occur in the headwaters (Fig. 6a,b).

In contrast, all forests of the Fox and Makawhio catchments showed only light canopy mortality (Table 8). Heavy to severe dieback occurred in areas of the Fox catchment 30-40 years ago (Allen & Rose, 1983). The Makawhio forests have never been extensively modified by possums. Other catchments showing relatively little canopy mortality at present included the largely unmodified Mahitahi (78% light) and Karangarua as well as the more modified Tartare (76%) and Mikonui (67%) (Fig. 6a,b, Table 8).

There was considerable variation among catchments showing intermediate overall canopy mortality (Fig. 6a,b, Table 8). For example, all forests of the Haupiri, Deception, and Waiho catchments showed moderate mortality. In the Otrira-Kellys catchment 82% showed moderate mortality, and 18% light. In the Kokatahi, 73% showed moderate mortality in predominantly post-dieback stands (Allen & Rose, 1983), and 20% heavy mortality.

<table>
<thead>
<tr>
<th>Canopy death class</th>
<th>Area (ha)</th>
<th>Proportion (%) of area in each canopy death class</th>
<th>% Overall canopy death (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approx. % canopy death</td>
<td>Light &lt;10</td>
<td>Moderate 10-30</td>
<td>Heavy 30-50</td>
</tr>
<tr>
<td>Fox</td>
<td>347</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Makawhio</td>
<td>468</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Mahitahi</td>
<td>1033</td>
<td>78</td>
<td>22</td>
</tr>
<tr>
<td>Karangarua</td>
<td>2076</td>
<td>76</td>
<td>24</td>
</tr>
<tr>
<td>Tartare</td>
<td>343</td>
<td>76</td>
<td>24</td>
</tr>
<tr>
<td>Mikonui</td>
<td>413</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>Arahura</td>
<td>3083</td>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>Styx</td>
<td>1581</td>
<td>23</td>
<td>77</td>
</tr>
<tr>
<td>Otrira-Kellys</td>
<td>2712</td>
<td>18</td>
<td>82</td>
</tr>
<tr>
<td>Waitaha</td>
<td>1335</td>
<td>18</td>
<td>82</td>
</tr>
<tr>
<td>Poerua</td>
<td>886</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>Copland</td>
<td>1807</td>
<td>18</td>
<td>77</td>
</tr>
<tr>
<td>Toaroha</td>
<td>1318</td>
<td>8</td>
<td>92</td>
</tr>
<tr>
<td>Deception</td>
<td>1714</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Haupiri</td>
<td>2231</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Waiho</td>
<td>105</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Whataroa</td>
<td>16809</td>
<td>9</td>
<td>86</td>
</tr>
<tr>
<td>Taipo</td>
<td>4217</td>
<td>6</td>
<td>86</td>
</tr>
<tr>
<td>Kokatahi</td>
<td>1697</td>
<td>7</td>
<td>73</td>
</tr>
<tr>
<td>Callery</td>
<td>1127</td>
<td>-</td>
<td>84</td>
</tr>
<tr>
<td>Crooked</td>
<td>2052</td>
<td>5</td>
<td>66</td>
</tr>
<tr>
<td>Cook</td>
<td>802</td>
<td>-</td>
<td>70</td>
</tr>
<tr>
<td>Whitcombe</td>
<td>4533</td>
<td>3</td>
<td>64</td>
</tr>
<tr>
<td>Wanganui</td>
<td>5825</td>
<td>36</td>
<td>22</td>
</tr>
<tr>
<td>Taramakau</td>
<td>2391</td>
<td>-</td>
<td>67</td>
</tr>
<tr>
<td>Hokitika</td>
<td>3167</td>
<td>-</td>
<td>20</td>
</tr>
</tbody>
</table>
Status and trends of the rata/kamahi resource

Unmodified forests: Approximately 24 000 ha (29%) of the upper elevation rata/kamahi forests in the study area currently show only light canopy mortality (Table 5). However, we estimate that, at most, about 9000 ha (11%) have not experienced peak possum population densities and can thus be regarded as having unmodified canopies (Table 9). Only 9% of the major catchments are considered to be unmodified by possums. At most, 19% of the the front catchment forests are unmodified (Table 9).

| TABLE 9. Location and area of largely unmodified¹ rata/kamahi forest in the study area. |
|---------------------------------|--------------------------------|
| Area (ha)                       |                               |
| (a) in major catchments         |                               |
| Waitaha                         | 245                           |
| Wanganui (Adams)                | 581                           |
| Poerua                          | 108                           |
| Whataroa                        | 1505                          |
| Tartare                         | 261                           |
| Copland                         | 335                           |
| Karangarua                      | 1586                          |
| Makawhio                        | 468                           |
| Mahitahi                        | 805                           |
| Total                           | 5894                          |
| % all major catchments          | 9                             |
| % study area                    | 7                             |
| (b) in western front catchments |                               |
| Doctors - Mikonui               | 704                           |
| Mikonui - Kakapotahi            | 109                           |
| Whataroa - Tartare              | 2082                          |
| Karangarua - Makawhio           | 365                           |
| Makawhio - Mahitahi             | 117                           |
| Total                           | 3377                          |
| % all western front catchments  | 19                            |
| % study area                    | 4                             |

¹ Defined as areas now showing <10% canopy death which do not appear to have experienced peak possum densities.

Of all unmodified forests, only those in the Copland (335 ha) and part of the Karangarua (c 500 ha) have been poisoned (in 1986) by aerial sowing of 1080 impregnated carrot to control possum populations (D.R. Morgan, unpubl. FRC report). Further damage is expected in the remaining 90% of unmodified forest as possum numbers increase (e.g., Pekelharing & Reynolds, 1983). This may be a rapid process. For example, on aerial inspection in 1988, parts of the Adams River forests (Wanganui catchment, Fig. 6b) mapped as unmodified in 1985, have developed severe defoliation in the intervening
3 years, presumably because possums have since invaded from surrounding heavily modified forests.

Modifying forests: The impact of browsing by peak possum populations has not been uniform on Westland rata/kamahi forests (e.g., Stewart & Rose, in press; Payton, ms). The major depletion of canopy species, especially rata, resulted in shifts in forest type over tens to hundreds of hectares in parts of the Kokatahi and Fox catchments (Allen & Rose, 1983). Similar shifts now appear to be happening in parts of such catchments as the Taramakau (A.B. Rose, C.J. Pekelharing, G.M. Hall, 1988; Pekelharing & Batcheler, unpublished data), Hokitika, and Wanganui (Fig. 6b). However these changes have not occurred in the central western front catchments, nor in all catchments that have experienced peak possum population densities. In some catchments, major canopy damage has been averted by past poisoning campaigns against the possum (e.g., Deception). However, other catchments have not been poisoned, yet do not appear to have undergone severe dieback.

Despite the differential impact of possums between and within catchments, overall the rata/kamahi forest resource in Westland has been widely depleted. Based on our survey, imminent major shifts in forest composition can be expected in at least the 12% of the resource currently showing heavy to severe canopy mortality (Fig. 6a,b, Table 5).

The future trend in forests now showing moderate or light mortality is more difficult to predict. Overall, further depletion is likely if perhaps less imminent. In catchments such as the Deception, which now contain near-peak possum populations, depletion may be rapid (A.B. Rose, C.J. Pekelharing, G.M. Hall, 1988). In other areas such as the central western front catchments, further depletion may be minimal or slow because of less susceptible forest types.

Conclusions

1. Current canopy mortality and dieback in Westland rata/kamahi forests largely reflect the past and present impact of browsing by possums.

2. There is an urgent need for a coordinated management strategy to evaluate possum control priorities, especially for the forests of the major catchments, which appear to be more vulnerable to possum-triggered dieback than the smaller western front catchments.

3. The objectives for possum control should be clearly defined to maximise efficient use of resources. Such objectives could include: To minimise further canopy damage in the whole area; to maintain representative areas of relatively unmodified forest; and/or to minimise further damage in forests highly visible to the public.

4. Because only about 9% of the forests of the major catchments remain unmodified, these areas should be among those selected as high priority for possum control.
C.2 EFFECT OF POSSUMS ON NATIVE ANIMALS (P. Cowan)

Concern about the possible effects of possums on native animals has been long-standing. As early as 1924, the Royal Forest and Bird Protection Society opposed possum liberations because of presumed competition with native birds (Pracy, 1974). Oliver (1955) stated "there is evidence to show that the possum does harm to native birds by defoliating native trees and also eating the young of forest birds". The major effects of possums are likely to fall on the nectivorous and frugivorous birds - silvereye, bellbird, tui, saddleback, stitchbird, kokako, kaka, and native pigeon. Bull (in Batcheler, 1962) reported a decline in the numbers of nectivorous birds due to the elimination of food plants by deer, goats, and possums.

More recent research has vindicated these fears.

Long-term reductions in forest diversity are occurring as a result of possum browsing (Atkinson, 1982b; Coleman et al., 1980; Fitzgerald & Wardle, 1979). For example, in the Orongorongo valley, mistletoe, northern rata, tawa, five-finger, tutu, titoki, and fuchsia have become locally extinct (Fitzgerald, 1976; D.J. Campbell, pers. comm.). As a general principle, reducing forest diversity is likely to reduce the numbers and diversity of forest-dwelling native animals (Hackwell & Dawson, 1982).

About 26 species of native plants are important sources of nectar for honeyeaters - bellbird, tui and stitchbird (Craig et al., 1981). The flowers of at least 20 of these regularly feature in the diet of possums (P.E. Cowan, unpubl. data). There is extensive overlap in the diets of possums and that of the native frugivorous birds (P.E. Cowan, unpubl. data). Leathwick et al., (1983) attributed at least part of the decline in the range of the kokako to competition with possums for food. The failure of the kaka to breed in beech forests in north-west Nelson may result from competition for resources with introduced wasps and possums (P.R. Wilson & J.R. Beggs, pers. comm.).

The eradication of possums from Kapiti Island during 1980–86 has been accompanied by a steady increase in the total numbers of forest birds; bellbirds and native pigeons showed the greatest relative increase in numbers (Lovegrove, 1986). Lovegrove attributed the increase in bird numbers to habitat improvement, with greater quantities of nectar, fruit, and foliage now available as food for birds.

Many of the changes caused by possums currently escape notice. The potential impact of possums on invertebrates was reviewed by Cowan and Moeed (1987), and is highlighted by such observations as those of increased stick insect numbers in northern rata trees when possums were excluded (Meads, 1976).

These studies, and much other circumstantial evidence (Cowan, 1985) leads to the conclusion that if the possum competes for resources with native animals and/or modifies their habitat, populations of the native animals are likely to decline.
Fig. 7. Known distribution of Tb in possums in 1976 (Coleman, 1981), and 1986 (Boland and Livingstone, 1986), and suspected outbreaks recorded since 1986 in unpublished MAF reports (numbers).
C.3 EFFECT ON LIVESTOCK - BOVINE TB (C.L. Batcheler)

Introduction

Human (*Mycobacterium tuberculosis*) and bovine Tb (*M. bovis*) - which is similarly pathogenic to humans - have been public health issues in New Zealand for many decades. Pasteurisation of milk began in the 1920s, and the immunisation of children against tuberculosis began during the 1940s (Boland & Livingstone, 1986). Control of *M. bovis* in cattle began in 1945 with the introduction of voluntary testing of town supply dairy herds. Animals which reacted to an injection of tuberculin were slaughtered. The programme was gradually extended and all cattle were considered to be under test surveillance by 1977 (although young beef cattle are still not tested). By 1979-80, the programme had reduced the infection rate of dairy and beef cattle from 8.6% to 0.05% and 0.8% to 0.01% respectively. "Clinical cases" (i.e., those with clinically identifiable symptoms) have largely been eliminated. The programme is now largely concerned with the detection and elimination of pre-clinical infections (Boland & Livingstone, 1986).

Discovery of Tb in New Zealand possums

In Buller and Inangahua (Westland), the progressive introduction of tuberculin testing of cattle from 1956 onwards appeared to reduce the incidence of tuberculosis until about 1967-68. Then, "reactor and tuberculosis rates increased dramatically in many herds under test and in several areas. Moreover, it became apparent in 1969 that ... testing procedures were not producing the rapid and progressive reduction of cattle tuberculosis achieved elsewhere in New Zealand; it was then suspected that local environmental factors such as the wet climate and possible associated long survival of infection on pasture, were responsible for perpetuation of the disease." (Stockdale, 1975).

However, in 1967, a commercial hunter operating at Mokihinui, north of Westport, submitted 25 possums to MAF, who provisionally identified tuberculosis in 20 of the specimens. *M. bovis* was confirmed in the one sample cultured (Ekdahl, Smith & Money, 1970). That 1967 report was regarded as an "isolated incident" (Boland & Livingstone, 1986) until Cook (1975a,b), Davidson (1976), and others had accumulated compelling evidence of the consistent coincidence of Tb in cattle and nearby possums. Within 5 years, Tb was identified in possums in many places in Northern Westland, in the Wairarapa district (1969) and the Western Bays of Lake Taupo, Central North Island (1972). To date, Tb has been confirmed in possums in least 20 areas from north of Auckland to the south-eastern corner of South Island (Fig. 7).

All observers have commented on the localised nature of infection. In Westland, Stockdale (1975) recorded: "Marked Tb problems have arisen in a number of (cattle) herds with several previously clear tests ... and, almost without exception ... investigations revealed the presence of usually only one tuberculous possum ... on the property" or on only part of a farm. Cook (1975a) also noted that around the Hohonu Range, Westland, infection was restricted to discrete "colonies", usually associated with small clearings grazed by cattle, and that the frequency of infection declined towards more remote reaches of the adjacent bush. However, a Tb-infected possum was found 3.4 km into the bush (J.D. Coleman, pers. comm.).
Cook (1975a) described Tb in Hohonu possums as "a subacute to acute fulminating (i.e., explosive) infection occasionally epidemic in character, often generalised, and often associated with sinus formation (i.e., "weeping" internal or skin ruptures). The tendency to sinus formation appeared most significant because Mycobacterium bovis was the only species of Mycobacteria found in discharges, and contrary to what can be expected in ... cattle lesions, smears or histopathological sections from possums showed enormous numbers of organisms" - in one case estimated at 5 000 million/gram of tissue (Smith, 1972).

Among 327 infected wild possums sampled in Westland and Waikato, lesions occurred most commonly in the lungs (62%), axillary lymph nodes (40%), mesenteric lymph nodes (19%), liver (18%), inguinal lymph nodes (15%), mediastinal lymph nodes (12%), and 15 other sites (Julian, 1981, from Cook, 1975a,b, and Lake, 1974). Somatic (i.e., body wall) lymph node lesions are typically a soft abscess up to 4cm across which contain lime-green pus and occasionally discharge their contents through open sinus tracts. Visceral (i.e., chest and gut cavity) organ and lymph node lesions are white to yellow nodules up to 2cm in diameter. These vary from typical tubercles to poorly organized necrotic tissue. "The limited cellular response (of possums to M. bovis), lack of organization of the response, extreme tissue necrosis and high rate of multiplication of bacilli are the histological hallmarks of a susceptible host" (Julian, 1981).

Source of Tb in possums

Tuberculosis in cattle is a cosmopolitan and ancient disease (Coleman, 1987) and was, presumably, a common fellow-traveller with domestic cattle in the course of European colonisation of Australasia. It is widespread in cattle throughout both countries (Andrews, 1983; Boland & Livingstone, 1986). Within Australia the distribution of cattle soon overlapped that of the native possum. This also happened in New Zealand as cattle farms were developed wild cattle spread into the bush and possums spread. Possums had been officially liberated in 90 places by the turn of the century (Pracy, 1974), and half the country was occupied by 1950 (Fig. 1b).

Despite this long-standing overlap, the harvesting of many million possums in both countries, and the scientific autopsy of many thousands, there was no authenticated record of Tb in wild possums until 1967. It has never been identified in wild possums in Australia. Several scientists have suggested that this may be because possum densities in Australia are much lower than in New Zealand (Green, 1984), implying a lower level of interaction between possums and cattle. The drier climate (except in western Tasmania) has also been suggested as a possible cause.

That M. bovis was first transmitted from cattle to possums is affirmed in all the papers consulted for this review; this suggestion is consistent with the ease and frequency with which it can be transmitted back to cattle, and with the absence of plausible alternative sources. But the suggestion that the passage from cattle to possums occurred independently in several widely separated areas in New Zealand (Davidson, 1976; Collins et al., 1986) is a controversial opinion which is difficult to reconcile with the absence of any authenticated suspicion of its occurrence until 1967. Why would it pass simultaneously in several different areas at about the same time, without evidently having done so for several decades?
Fig. 8. Distribution of the 33 types of Tb in possums in the Central North Island, Wairarapa and Westland endemic areas (redrawn from Collins et al., 1986).
The possum has been known to be susceptible to Tb for over 80 years. Julian (1981) cites three cases of probable or certain Tb in captive possums, dating from 1895. Bolliger and Bolliger (1948) showed that a captive possum could be experimentally infected with a cattle strain of *M. bovis* through contact with an artificially infected cage mate. Corner and Presidente (1980) showed that Australian (Victorian) possums were highly susceptible to an injection of 10⁷ viable *M. bovis* cells cultured from a Queensland bovine lymph node.

Recent DNA restriction endonuclease typing studies ("genetic fingerprinting") of *M. bovis* throws interesting light on the origin of the disease in possums (Collins, de Lisle & Gabric, 1986; Collins, Gabric & de Lisle, 1988). Based on subjective grouping of DNA fragment patterns they identified 33 types in Central North Island, Wairarapa and Westland. Types were usually found in adjacent localities and were always limited to one of the three regions. Some types (particularly in Westland) were more widespread than others, and some groups of types were particularly closely related (Fig. 8). They concluded: There was a high degree of genetic relatedness in this species; each type originally came from a single infected possum in that area; the large number of restriction types was probably due to rapid genetic change after possums first became infected.

Collins *et al.*, (1986, Table 1) emphasised the distinctness of regional groups of types. However when I applied a discriminant analysis to their pattern designations derived from three enzyme treatments, I found a gradient of similarity which was consistent with supposing that spread occurred from Westland to Wairarapa, and thence to Central North Island. As shown in Table 10, 9 of the 12 restriction types defined for Westland by Collins *et al.*, were similarly assigned by my discriminant analysis, but 2 and 1 types respectively were more closely allied to the Wairarapa and Central North Island types. Of the 18 types defined for the Wairarapa by Collins *et al*, 11 were similarly assigned by the discriminant analysis, but 3 and 4 types respectively were more closely allied to those in Westland and Central North Island. All three Central North Island types were similarly assigned by both analyses. Collectively the results are more consistent with the hypothesis of monophyletic origin (i.e., arose from a single place), than that the disease arose from several areas independently, as suggested by Davidson (1976). I stress the preliminary nature of this deduction; a better assessment might be obtained by numerical taxonomic analysis of the DNA fragment patterns recorded by the electrophoresis photographs.

<table>
<thead>
<tr>
<th>Authors assignments</th>
<th>Disc. analysis assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Westland</td>
</tr>
<tr>
<td>Westland</td>
<td>12</td>
</tr>
<tr>
<td>Wairarapa</td>
<td>18</td>
</tr>
<tr>
<td>C. Nth. Is.</td>
<td>3</td>
</tr>
</tbody>
</table>
Summary of evidence about the origin of Tb in possums:

- Tb has been occasionally reported in captive possums for over 80 years.
- Tb has still not been recorded in wild possums in Australia.
- There were presumably innumerable opportunities for transmission of *M. bovis* during the long period of overlap of possums and cattle in Australasia.
- Advanced Tb lesions in New Zealand possums are usually obvious, even to the untrained eye.
- Tb did not occur in wild possums up to about the 1960s for, although advanced lesions are obvious, none were observed despite millions being skinned and examined by commercial hunters, control workers, and ecologists.
- There are now many genetically distinct types of Tb in New Zealand, but the evidence for phenotypic differences between the types is inconclusive.
- *M. bovis* in possums shows a high degree of genetic relatedness as defined by DNA typing.
- The most widespread type of *M. bovis* occurs in Westland, and Westland types are more closely related to those in Wairarapa than Central North Island.

These results are consistent with the hypothesis that Tb passed into possums in Westland during the late 1950s - mid 1960s, that genetic radiation was rapid, it spread rapidly to other districts by several agents, and is of monophyletic origin.

This hypothesis implies that Tb in possums and cattle should be managed on the principle that spread or re-infection will occur from existing loci. "Polyphyletic origins", as suggested by Davidson (1976), and tentatively by Collins et al., (1986), would conversely imply that new types of unpredictable genetic type and virulence, must be expected to evolve wherever possums and other Tb-susceptible mammals co-exist. This is an important hypothesis, and therefore should be investigated further.

Virulence of Tb in possums

After their trials with an Australian cattle strain of Tb (see above), and again using Victorian possums as test animals, Corner and Presidente (1981) compared infectivity and virulence of 10^4 *M. bovis* cells from a New Zealand possum (PAS, possum-adapted strain), with 10^8 *M. bovis* cells from a Queensland cattle beast (CAS, cattle-adapted strain). They concluded that New Zealand PAS produced a more rapidly progressive, severe disease and that "the greater virulence of ... PAS ... was due to differences between strains of mycobacteria and not the possums". However, the conclusion is based on very few samples, and different dose rates of PAS and CAS. There was no significant difference between numbers and severity of lesions produced by CAS and PAS. The results must therefore be regarded as inconclusive.

Julian (1981) summarised the outcome of experimental challenges of captive New Zealand possums with *M. bovis*. The onset of illness was rapid; possums became less responsive to stimuli and handling, lost condition, and died by the 14th day after the appearance of clinical symptoms regardless of the premonitory period (from P.J. O'Hara, et al., 1976, unpubl. MAF report). However, a rather different interpretation may be gained directly from O'Hara et al.'s original report. There, the authors state that possums were readily infected by subcutaneous injections of the order of 10^6 *M. bovis* cells.
Fig. 9. Distribution of Tb in cattle in Akitio County, Wairarapa, 1973 - 1985, and location and year in which Tb-infected possums were identified (redrawn from unpubl. data, F. Beckett, MAF).
Some possums infected by nasal installation, direct contact, or aerosol infection survived up to 100 days or more. In one trial, using two possums/group, they compared the virulence of 0.6 mg of a culture from a possum with 1.0 mg of a culture from a cattle beast, and concluded that: "at least our feeling that there is no real difference in virulence ... is backed by more data than can be marshalled by the protagonists of the 'enhanced virulence' hypothesis" and; "since prevalence rates are no higher than in cattle in the same environment, we infer that susceptibility to infection is no greater than in cattle". One must note however, that not only are these conclusions diametrically opposed to those of Corner & Presidente (1981), they too are based on inadequate data.

Furthermore, it should be pointed out that, even if the results of O'Hara et al.'s (1976) and Corner and Presidente's (1981) results were statistically valid, they cannot be assumed to resemble the likely course of Tb in wild possums. Newly captured possums are notoriously susceptible to post-capture "stress" diseases - even without a Tb challenge (Morgan & Peters, 1982). Furthermore, the doses administered were huge in comparison to those which are probably received by free-living animals.

The chronicle of an Orongorongo Valley (Wellington) possum which abruptly lost weight and died (Brockie, et al, 1987b) may be an example of inappropriate extrapolation of the results of the laboratory studies. The animal had resided for 3 years in the vicinity of a research trapping grid located at least 1.3 km from the nearest known infected possums. The authors concluded, having cited Julian (1981), that "it seems more likely that the infection was transmitted by (other) possums, wild pigs or deer", shortly before it died. Alternatively, if Tb is not as virulent as supposed, or if it may remain quiescent in healthy possums for several years (as occurs in some other hosts, including humans), an isolated case could relate back to an event several years before it is noticed by investigators. The topic clearly needs further investigation.

**Agents of spread of Tb**

If PAS had a monophyletic origin, the observed spread needs explaining on two levels: within a district (pers. comm.s. for Akitio Country, Wairarapa, by F. Beckett; and Central North Island by T.J. Ryan); and the leaps across "clean country".

The data for Akitio Country are a good example of detailed information on local spread. Tb had been identified in both cattle and possums by 1975 (Fig. 9). Over the following decade, it occurred among cattle herds progressively further to the east and north-east, and *M. bovis* was isolated from neighbourhood possums within about a year.

Generally, dispersal of Tb from the earliest known sites in Wairarapa, Central North Island, and Northern Westland, appears to be within the range of the normal traffic of possums and other wild and feral animals within their home range, and the movements of cattle around farms. Possums typically range over an area of less than 1 km radius (summarised in Green & Coleman, 1986), but juveniles occasionally disperse up to 10 km (Clout & Efford, 1984), or even up to 42 km (R.E. Brockie, pers. comm.). During these movements they overlap, socialise, and shelter in the same nests as other possums (Kean, 1967; Kean & Pracy, 1953; Ward, 1977; Green & Coleman, 1987). Transmission between possums is strongly indicated by observations remote from cattle, e.g., in 1983, a transect of the Hauhungaroa Range, Central North Island, showed an incidence of 2% of Tb in the middle of the bush (P. Livingstone, pers. comm.)
Fig. 10. Known spread of Tb in possums in Central North Island since 1975 (redrawn from unpubl. data, T.J. Ryan, MAF). The situation east of Lake Taupo is unclear because there are few cattle.
Taupo Tb Area

line - Exponential curve fitted through 1975 - 1987 data points.

\[ \text{km}^2 = 1913 \times 1.104 \text{yr}^{-1974} \]

Fig. 11. Exponential curve fitted to estimates of the spread of Tb in Central North Island possums (refer Fig. 10).
Several of the distant outbreaks (e.g., Westland; McKenzie Basin, Upper Waitaki) are believed to be attributable to the carriage of infections in traded cattle and deer (Boland & Livingstone, 1986). In others, e.g., Abut Head, Westland, there had been no trade in livestock for about 6 years before Tb was positively identified in possums, but it had been suspected for about a decade (P. Livingstone, pers. comm.).

Other wild and feral mammalian reservoirs or vectors are also recognised. For Westland, Cook (1975a) recorded Tb in goats, sheep, stoats, cats, and rats, and Stockdale (1975) extended the list by including horses, pigs, dogs, feral and wild cattle, deer, ferrets, and hedgehogs. Cook (1975a) noted that dead possums at Hohonu were scavenged by rats, stoats, ferrets, feral cats, hawks, wekas, blowflies, wasps, and other possums. Tb was not, however, cultured from hedgehogs (even though the lesions looked tuberculous; P. Livingstone, pers. comm.).

Tb has also been recorded elsewhere in New Zealand in pigs (Ek dahl et al., 1970; Brockie, et al., 1987b) and deer (O'Hara & Hellstrom, 1979; Boland & Livingstone, 1986). With such a suite of potential hosts and/or vectors, it will probably be impossible to identify the source of most outbreaks with any degree of certainty.

L.T. Pracy (pers. comm.) and Davidson (1976) have suggested that Tb could also be transported in infected possum carcasses by possum hunters. Possum hunters are numerous (there are about 18,000 registered cyanide users). Many of them move between blocks and even districts during the seasons. Some poison along roadsides, poach allocated blocks, dump skinned carcasses in secluded places, or feed them to their dogs. Commercial hunters are therefore the least controlled but most mobile potential vector for transmitting organisms between possum populations. The management of hunting may therefore be a vital component of an overall strategy for the control or eradication of Tb in livestock.

Rate of spread of Tb

Loci of Tb infected possums are identified by epidemiological trace-back studies undertaken whenever cattle persistently remain tuberculous despite repeated tests and the disposal of reactors by slaughter. Assuming that the lapse between occurrence and identification is reasonably constant, the rate of spread can be estimated by successive plots of the known boundaries of infection.

For the Central North Island, maps of the distribution of Tb possums for 3-year intervals from 1975 to 1987 (Fig. 10, redrawn from T.J. Ryan, MAF unpubl. data) indicated that the disease was spreading exponentially at the rate of 10.4%/annum (Fig. 11; r = 0.9994), covering 200 km² in 1975, and 6900 km² by 1987. Extrapolation backwards suggests that Tb was present some years before it was detected.

The New Zealand-wide distributions recorded for 1976 and 1986 (Coleman, 1981; Boland & Livingstone, 1986) give an indication of the overall spread of Tb in possums. Areas were taken by digitiser from Fig. 7 and, for 1976, gave New Zealand totals of 2.51% and 2.86% for the North and South Islands respectively; for 1986, estimates were 13.65% and 12.03% respectively. The map supports the common opinion that in the principal areas - North Westland, Wairarapa, and Central North Island - radial spread from discrete foci resulted in amalgamation into large zones in which Tb occurred discontinuously.
Fig. 12. Logistic curves fitted to estimates of the distribution of Tb in possums in 1976 and 1986 (refer Fig. 7) and assuming:

1. That the 1976 and 1986 areas represent the free-growing phase of a logistic curve;
2. Tb-infected possums will eventually occur in 100% of the North Island and 87% of the South Island;
3. The logistic model is appropriate because, as infected possums spread, further spread is progressively more likely to be back into already-occupied areas.
Overall, the pattern of spread is characterised by progressively more loci being identified, up to 500 km beyond the 1976 boundaries. In addition to those mapped by Boland and Livingstone (1986), Tb is currently suspected or confirmed in possums at Fortification and MacLennan State Forest (but a tuberculous possum had been found there before 1972, P. Livingstone, pers. comm.), Southland (1 and 2, Fig. 7, C.J. Main, NZFS 1987, pers. comm.), Moa Creek to Outram (3, MAF, unpubl. data, 1988), Waiau-Clarence, North Canterbury (4, G. Allan, MAF, unpubl. data), Northern Tararua and Kaimanawa Ranges (in deer only, 5, 6, MAF unpubl. data, 1988), Wanganui River (7, P. Livingstone, pers. comm.), Tauranga (8, P. Livingstone, pers. comm.), and at Te Puna, east of Mercer (9, MAF update, unpubl. data, 1988).

Summarising the statistical data and the occurrence of new loci in the past 2 years, it seems reasonable to suggest that Tb in possums is spreading exponentially and that the present pattern is likely to represent the early phase of logistic growth. Using the logistic model, extrapolation predicts that Tb will occur in all North Island possum populations (not individuals) by 2024, and in all South Island populations by 2031 (Fig. 12).

Control of Tb

During the 1970s, intensive possum control campaigns were undertaken whenever persistent Tb was identified in cattle and also found in possums. Typically, the tactics used were a large-scale aerial poisoning operation over bush adjacent to infected farms, together with an intensive possum ground-baiting programme on the farms and bush edges. Concurrently, tuberculin testing of all cattle on the farms was intensified, and reactors were slaughtered.

Epidemiological investigations during the mid 1970s indicated that the infection of herds in "non-endemic areas" was probably due to the uncontrolled movement of stock from infected areas (Boland & Livingstone, 1986). "Movement control" was imposed in April 1977 under the authority of the Animal Health Act. Boland & Livingstone (1986) state that although this "greatly reduced the risk of infected cattle being introduced into clean herds, ... the restrictions had no effect on the incidence of infected herds or animals in situations where there is an opportunity ... to become infected from Tb possums". Because of the possum vector, "Animal Health Division has modified its goal of total eradication to one of cost-effective control in endemic areas". An "endemic area" was defined as one in which the Tb possums are associated with persistent Tb infection in cattle herds.

Of the 18 - 20 areas in which tuberculous possums have been identified, 12 are considered to be endemic. Of these, the West Coast, Wairarapa, and Central North Island are classified as major endemic areas.

The three major and two minor endemic areas (Kopuatai Swamp, Hauraki Plains; South Kaipara Heads, Northland) have been designated as Strategic Control Areas. In these, the endemic zone is surrounded by a "cordon sanitaire" buffer zone. Cattle within the strategic area are tested annually. Possums are now controlled as soon as persistent Tb is detected in the buffer zone (P. Livingstone, pers. comm). The priority objective is to restrict any extension of the endemic area.
Fig. 13a. The incidence of reactors and confirmed Tb in cattle south of Westport, and the effect of possum control (from Stockdale, 1975).

b. An assessment of the overall effect of possum control on the confirmed incidence of Tb in cattle in the Wairarapa during the 1970s (from Boland and Livingstone, 1986).

c. The incidence of Tb reactors on two Central North Island farms, illustrating the recurrent nature of infection if possum control is not sustained.
Effectiveness of control

Cattle surveillance/possum control programmes dramatically reduce the incidence of reactor cattle (Fig. 13a,b). At Block 1 in the Buller District (a 30 x 15km coastal strip south of Westport), 8.2% of the cattle were infected with visible lesions (12.5% reactors) in January 1970; by 1972, the infection rate had been reduced to about 3% by test-and-slaughter. Aerial poisoning in autumn 1972, followed by 3 years of sustained ground control, further reduced the rate to about 0.1% (Stockdale, 1975). For the Wairarapa endemic area, Boland and Livingstone (1986) assessed the results of herd testing combined with several possum poisoning programmes. A district-wide incidence of 2 - 2.3% infection among cattle recorded over 4 years before poisoning of possums began declined to about 0.3% 2 years after aerial poisoning (Fig. 13b).

However, with the exceptions of the Matiri area (Buller), Monument (Banks Peninsula) and Methven foothills (Canterbury) (P. Livingstone, pers. comm.), outbreaks have proved to be recurrent. Tb has again occurred in cattle at Hokonui, Southland (MAF, unpubl. data, 1988), a decade after a possum control operation appeared to have disposed of the problem (C.J. Main, pers. comm.). Other examples include: Taramakau Settlement, Westland, poisoned 1974 and 1986; Inanganaha Valley, Westland, poisoned 1974 and 1988; Western Bays, Lake Taupo, poisoned 1974 and 1985; Waimahora, Central North Island, poisoned early 1970s and 1987/88).

The records from two Central North Island farms illustrate the typical pattern as measured by the incidence of tuberculin reactor cattle. On both farms, the reactor rate rose abruptly during 1973–74, dropped by >90% after 1975 when possums were poisoned, increased again in the early 1980s, and declined yet again after the possum population was poisoned a second time (Fig. 13c, K. Crews, MAFQual, pers. comm. to G. Hickling, FRC).

These examples clearly show that although the combination of test-and-slaughter of cattle and possum control reduces the incidence of reactors to low levels, the need for Tb possum control will probably continue indefinitely.

Despite efficacy of individual Tb control programmes in endemic areas, Livingstone (1987, MAF unpubl. data) reported that the overall reactor rate in New Zealand cattle was stationary over the 3 years 1983/4, 1984/5 and 1985/6 (0.056%, 0.051%, and 0.058% respectively). In 1985/6, the total discovered incidence, including reactors and infected cattle found during slaughter, was 0.07%, but the incidence of slaughtered reactors from endemic areas was 31 times that from non-endemic areas. "The lack of progress in controlling Tb is because of the continued contact between cattle and infected possums" (Boland & Livingstone, 1986).
Fig. 14. Direct operational costs of possum control since 1975, the overall incidence of reactors, and herds under movement control (from Boland and Livingstone, 1986 and unpubl. MAF data).
It has been an expensive problem. The annual cost of control of Tb possums increased after the early 1970s until 1979, after which a 3-year lull and steady decline for the last half-decade reflects the current cost-effective control policy (Fig. 14). The direct possum control costs constituted only 15% of the total costs associated with Tb in the endemic areas during 1985/6, and 13% of those budgeted for 1986/7 (MAFQual, unpubl. data, 1987). Of $12.97 million expenditure in 1985/6 (1987$), 41% was charged to personnel costs (veterinary, laboratory, administration), 15% to operating expenses, and 28% to movement control, farmer compensation, and the disposal of tuberculin reactors. Similar proportions and totals were budgeted for 1986/7. Assuming the same policies and intensity of control continue to be applied as Tb continues to spread among possums (Fig. 12), the direct costs of Tb possum control could approach $15 million/annum by the year 2030. A proportional increase in compensation for reactors (towards $20 million p.a.), and lesser increases in administration costs, could bring total costs of the control campaign to about $80 million p.a.

Computer modelling of the problem (G. Hickling, FRC)

N. Barlow (MAFTech) and G. Hickling (FRC) are currently studying computer models of Tb control processes, by developing equations used by Anderson and Trewhella (1985) to simulate the epidemiology of Tb in badgers in the United Kingdom. This work is not yet complete. However, it suggests that after large-scale possum poisoning, which typically kills 70% - 80% (Section E), annual cropping of perhaps 20%-30% of the residual population can inhibit the recovery of Tb in the population. Proper identification and simulation of the "real world" situation in the models could eventually have a substantial impact on the Tb control programme.
Summary and prospects of progress (C.L. Batcheler)

The cardinal conclusions I drew from the available evidence are: wherever tuberculous possums have been implicated as the cause of a "persistent" problem, the combined veterinary and pest control force continues to be highly skilled and effective at reducing local incidence of Tb in livestock; but spread of the disease has continued unabated. The current sequential tactic of testing livestock for 2–3 years to ensure that an outbreak is persistent, then searching locally for evidence of macroscopic Tb lesions in possums then planning a possum control operation has failed to match the strategic need.

The inherent complexities of the problem suggests that improvements in the control programme must be based on utterly reliable information about the epidemiology of Tb in possums and other animals, and first-rate surveillance and control strategies and techniques. However, many of the opinions and conclusions assessed for this review proved to be based on fairly tenuous information; considerable areas of the work require urgent revision; and a massive injection of additional research and management resources is probably required.

In the short-term however, it seems that considerable improvement could be attained if all groups involved with control of Tb could be coaxed into some agreement. Of all aspects of the possum studied during this review, expressed attitudes about Tb and possums were the most polarised.

On the one hand, some farmer representatives were critical of MAF's policies and operations: e.g., "...whoever is the new Minister of Agriculture is going to have to look at a new method of control" (NZ Herald, 5 July 1984); "In the past the problem of bovine Tb had been swept under the carpet and had been compounded by the gross incompetence of the former Ministry of Agriculture and Fisheries" (Auckland Herald, 26 May 1988).

On the other hand, scientists have commented in such terms as: "Money spent on possum control is being poured down the drain so long as basic herd-management requirements (such as fencing back paddocks that border on bush, an end to pushing cattle into the bush during winter, and clearance of patches of scrub off paddocks) are not in place before the control is done". I first heard such views while on tour with a MAF veterinary scientist in Westland in 1974.

The Ministry of Agriculture and Fisheries makes other cogent points (MAF, unpubl. report, 1987). "For the vast majority of farmers in an endemic Tb area, bovine tuberculosis ... (entails) ... no direct cost ... there is no incentive to commit time and resources to helping to resolve the problem ... many farmers oppose (1080 control operations) ... they receive 95% (of assessed market value) compensation (for tuberculous cattle) and free transportation of reactors off the property ... some farmers object to their pest board rates being diverted towards maintaining the possum population at its post-poisoning low (level)" .... "Tuberculosis is only likely to be perceived as a real problem by farmers in these areas when it costs them money".

Such conflicting and polarised views can be viewed in several ways, depending on whether one is a farmer, manager, or scientist. Basically however, I came to the conclusion that they reflect the anger and frustration which one can associate with, on the one hand, the threat Tb in possums poses to farm incomes and, on the other, the probability that the Tb
epidemic in possums constitutes the most intractable, serious and complex epidemiological problem which confronts the New Zealand livestock industry.
C.4 EFFECTS OF POSSUMS ON CROPS AND PASTURE (P. Cowan)

Introduction

In their 1980 survey, APDC (1981) dealt with possum damage to pasture, crops, orchards, gardens, and vineyards. They concluded that damage was not significant in terms of overall productivity, although locally severe damage occurred to all types of produce. Damage was consistently more severe on properties adjacent to possum habitats, such as forest, scrub, and shelter belts.

Because of recent extensive development of horticulture in North Auckland, Bay of Plenty, and Nelson, responses were sought from Pest Boards and MAFTech in these areas about the current role of possums as pests of agriculture. Much of the recent horticultural development (particularly in the North Island) has taken place on smallholdings which, by virtue of their size alone, are more susceptible to the economic effects of pest damage. Their development has involved the conversion of land formerly in scrub, and many such areas are still surrounded by possum habitat and have been relatively recently colonised by possums.

The relative importance of damage varies depending on the stage of the particular crop. The effects of possum browsing in mature orchards may be insignificant compared with the same level of browsing on newly established trees. Browsing of leaves may be unimportant relative to the damage to mature fruit. Horticultural diversification into crops with a high unit return (e.g., Nashi) has resulted in a concern over damage levels which would be considered unimportant in other crops. Perception of the importance of damage also depends on the current state of the market; for example, damage to kiwifruit may be of little concern, given the current market surplus.

Two factors combine to preclude any adequate assessment of the importance of possum damage to agricultural production. Firstly, often no distinction is made between damage by possums and that caused by other animals (stock, rabbits, hares, birds, wasps). Secondly, as pointed out by Spurr and Jolly (1981), there is usually no measure of actual losses, and no assessment of the cost-effectiveness of control.

Damage to pasture

The Technical Advisory Committee noted in 1969 that "while there is no evidence that opossums compete seriously with livestock for pasture on a wide scale, locally opossum grazing appears serious enough for farmers to persuade Pest Destruction Boards to carry out intensive control. The effects of opossums on pasture should therefore be investigated before such intensive control can be justified" (Anon, 1969 in Spurr & Jolly, 1981). For example, Quinn (1968) described a farm where carrying capacity had been increased by about 1 ewe/ha after intensive possum poisoning, but he also noted that this case was "possibly exceptional" (Possum numbers feeding on pasture were estimated at 37–49/ha). Harvie (1973) analysed stomach contents of possums from the farm in question and others nearby, and estimated that pasture formed about 30% of the diet; she calculated that in the absence of possums, stocking rate could have been increased by 1.3 sheep/ha (Harvie, 1973; Fitzgerald, 1977).
There is no doubt that possums, particularly those living on forest/pasture margins, eat pasture (Gilmore, 1965; Harvie, 1973; Coleman, Green & Polson, 1985). In such habitats pasture species commonly comprise 20-50%, but not more, of the local diet. Diversity of diet is apparently important to possums. Possums eat a wide variety of plants from pastures, not only grasses and clover, but also many of the weeds and forbs present (Gilmore, 1965, 1967; Harvie, 1973; Coleman, Green & Polson, 1985). Gilmore (1967) recorded white clover, ryegrass and cocksfoot as most commonly eaten, along with the flowers of flatweeds; Coleman, Green and Polson (1985) found that 90% of pasture eaten by possums living close to the forest edge was clover. Pasture is most commonly eaten from late summer to early winter (Gilmore, 1967; Harvie, 1973; Coleman, Green & Polson, 1985).

Serious local damage to pasture can occur, particularly near forest or scrub margins (Quinn, 1968; Spurr & Jolly, 1981; APDC, 1981), or in areas where pasture production already limits stock numbers (R. Clarey, pers. comm.).

APDC (1980) recorded that 10 out of 72 pest boards considered that possums affected the stock carrying capacity of their pastoral land. However, they stated "Board personnel had difficulty at the time of the field surveys in substantiating this view, therefore Council considers further research should be conducted to define the extent of this reported problem."

Considering the parallel between the comment by APDC and that of the TAC some 10 years earlier, together with the lack of any action, and the perception of some Pest Boards that the problem remains, the time has perhaps come for a detailed assessment of pasture loss to possums based on measurements of yield, so that the need for control can be established and its cost-effectiveness evaluated (Spurr & Jolly, 1981).

Damage to Crops

Spurr and Jolly (1981) reviewed evidence of possum damage to farm crops. They concluded that there was localised serious damage to crops such as turnips, chou moellier and lucerne, particularly near forest or scrub crop boundaries. The 1980 APDC survey recorded damage to a wide variety of vegetables, cereals, grains, and seed crops, and more widespread damage to forage crops. They concluded, "On intensively farmed land ... damage to any kind of crop is of little significance", and, "Moderate to severe damage occurs in localized situations. Crops subject to such damage in most cases have been planted adjacent to indigenous and introduced cover types."

None of the Pest Boards or MAFTech stations contacted considered possums to be a serious pest of cash or forage crops. All Boards emphasised the sporadic and localised nature of the damage, and the relationship between damage and possum habitat.

Damage to horticulture

Possums damage almost all types of horticultural produce (Table 11), breaking branches, eating buds, and spoiling ripe fruit. The 1980 APDC survey generally recorded insignificant damage to commercial orchards, except where these lay adjacent to possum habitat. Pest Boards surveyed generally described damage as seasonal, localised and more prevalent on properties adjacent to cover. Individual growers on occasions suffered total
crop loss (B. Greaney pers. comm.), but local possum control by shooting or poisoning was usually sufficient to relieve damage.

<table>
<thead>
<tr>
<th>Fruit or Plant</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Avocados</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian Pear</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blackberries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blueberries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boysenberries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broccoli</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brussel Sprouts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabbages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cauliflower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Celery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrots</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citrus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptomeria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courgettes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eucalyptus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Flevo Poplars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feijoa</td>
<td>x</td>
<td>x</td>
<td>/</td>
<td>/</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grapes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kiwifruit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kumara</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lettuce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macadamia Nuts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passion Fruit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pepino</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Persimmons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peaches</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Plums</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Parsley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinus radiata</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pumpkins</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Melons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strawberries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Sweetcorn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salix matsudana</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>willow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Tamarillos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reports of possum damage to orchards in the North Auckland and Northland areas may, however, increase markedly in the next few years, given the recent rapid development of horticulture there, the abundant indigenous and planted shelter, and increasing numbers of possums which have colonised the area only within the last 10 years (G. Ward, B. Greaney, pers. comm.).

Possum damage in commercial gardens is similar to that in orchards. In terms of overall production, possum damage is of negligible importance, and responses from Pest Boards suggested no change from the situation in the 1980 survey.

In vineyards, damage by possums is of most concern during establishment, when breakage of branches and damage to buds has been of local concern. Damage is apparently of little current importance, as was the situation in 1980.

Commercial production of honey from native trees, in particular southern rata, appears to have been affected as possums spread and increased in numbers in Westland (Wodzicki, 1950). The massive damage by possums to West Coast rata forests (see Section C; Batcheler, 1983), and seasonally high levels of feeding by possums on the flowers of native trees (Fitzgerald, 1976) suggest that the initial impact of possums on the activities of apiarists has probably been sustained.

**Damage in urban areas**

Possums are found probably in all urban areas of New Zealand. They are a persistent nuisance, damaging garden plants and vegetables, disturbing sleeping residents, damaging paintwork by scratching, and fouling roofs and footpaths (APDC, undated). In addition, they do more serious damage to electricity and telephone connections by clambering about on the cables, causing short-circuits and occasionally, fires. Most power poles in New Zealand have a metal sheath to prevent access by possums.

**Control**

Possums are not generally considered as pests of agriculture, and so little forethought is usually given to the need for their control during agricultural establishment or development. In most instances, preventative control measures could easily be applied at critical times by the owners or managers themselves. Currently available control techniques and their use are adequately described in farming brochures (e.g., Nelson, 1981, 1982). Local pest boards also respond to requests for assistance with possum control, although the number of requests for help has fallen with the introduction of cost recovery and changes in local pest board policy (C. Cooper, G. Ward, pers. comm.). Most pest board operations for control of possum damage to crops are small scale, at individual farmer level, and dealt with by shooting, trapping or hand-laid poison. In urban areas, although commercial pest control companies trap and remove possums, most people either reluctantly attempt to deal with the problem themselves or ignore the problem in the hope it will disappear. If a possum is caught, there is the problem of its disposal. The urban possum nuisance is of sufficient concern (at least in Auckland) to support a business which hires out traps and collects any possums trapped.
C.5 EFFECT ON CATCHMENT PROTECTION PLANTATIONS (P. Cowan, K. Varcoe, B. Warburton)

Introduction

The poplars and willows introduced into New Zealand by the European settlers soon proved useful for shelter belts, local wood supplies, and slope stabilisation. After the passage of the Soil Conservation and Rivers Control Act in 1941, Catchment Authorities adopted poplars and willows for systematic use on eroding hill country, farmlands, and river stop banks. The main areas of concern were in Hawke's Bay, Poverty Bay, Wairarapa, Manawatu, Taranaki, and Marlborough.

Browsing on plantings of poplars and willows became commonplace by the mid-1940s, at the same time as possum populations increased in many districts (Wodzicki, 1950; APDC, 1980), and many plantings suffered heavy mortality. Young plantations were particularly vulnerable. Representations were made to Government for authority and additional funds to enable Rabbit Boards to kill possums, considered to be responsible for the damage.

In 1965, the East Coast Rabbit Board proposed to alleviate the damage in the Hawke's Bay-Poverty Bay districts by employing 100 trappers to eradicate possums. An inter-Departmental research group found that many factors were responsible for the death of trees, including bad planting practices, drought, insect damage, and damage by farm animals (particularly cattle) and wild animals (Chisholm et al., 1966). Only about 7% of the mortality could be attributed to possums. However, the group recommended that the catchment planting programme and control of possums be more closely integrated, and that less palatable plants (e.g., *Salix purpurea* and *Populus yunnanensis*) be used.

The poplar improvement programme

A poplar improvement programme was started. By 1972, more than 200 clones were under test at the Soil Conservation Centre, Aokautere, and nearly 1 million poles and wands (94% poplars and 6% willows) were being planted annually (van Kraayenboord, 1980, Wilkinson, 1987). But in 1973, two *Melampsora* poplar leaf rusts caused so much damage that most of the clones then in use had to be abandoned (Wilkinson et al., 1976, van Kraayenboord, 1980). A wide variety of new clones, new seed sources, and the intensive selection of disease-resistant material re-established the poplar programme. The aim was to produce clones of suitable growth form and vigour, which are resistant to rusts, possum browsing, insect attack and branch rubbing. Between 1974 and 1986, 12 poplar clones were released for general distribution, although only three are widely planted. Several hundred hybrid clones have been bred since 1980, and are now available for selection trials. The long term objective of the Soil Conservation Centre is to breed about 25 genetically dissimilar poplar clones for general use in New Zealand (Wilkinson, 1987).

The most widely used poplars are now cultivars Flevo and Tasman (palatable to possums), and Eridano, Yunnanensis, Trichocarpa, and the recently released Kawa (all possum-resistant). Use of possum-resistant clones has increased as they have become available (Table 12), but insufficient production still restricts their use by Boards. None of the commonly used tree willows are possum-resistant (Table 12). This is considered a major problem by many of the Catchment Boards.
TABLE 12. Numbers and varieties of poplar and willows grown by Catchment Boards in 1987 for pole production. [* possum browse resistant clones]. Data provided by Dr R.L. Hathaway, Soil Conservation Centre, Aokautere.

<table>
<thead>
<tr>
<th></th>
<th>1984 Numbers</th>
<th>1988 Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Poplars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flevo</td>
<td>213155</td>
<td>106875</td>
</tr>
<tr>
<td>Tasman</td>
<td>34384</td>
<td>62352</td>
</tr>
<tr>
<td>Eridano*</td>
<td>40890</td>
<td>88382</td>
</tr>
<tr>
<td>Yunnanensis*</td>
<td>16612</td>
<td>31028</td>
</tr>
<tr>
<td>Kawa*</td>
<td>0</td>
<td>22087</td>
</tr>
<tr>
<td>Trichocarpa*</td>
<td>17148</td>
<td>13540</td>
</tr>
<tr>
<td>Total</td>
<td>322189</td>
<td>324264</td>
</tr>
<tr>
<td>Total stools</td>
<td>406834</td>
<td>374087</td>
</tr>
</tbody>
</table>

Tree willows

<table>
<thead>
<tr>
<th></th>
<th>1984 Numbers</th>
<th>1988 Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Matsudana</td>
<td>114292</td>
<td>103001</td>
</tr>
<tr>
<td>Aokautere</td>
<td>156769</td>
<td>160475</td>
</tr>
<tr>
<td>Moutere</td>
<td>53814</td>
<td>53104</td>
</tr>
<tr>
<td>Tangoio</td>
<td>35049</td>
<td>37633</td>
</tr>
<tr>
<td>Total</td>
<td>359924</td>
<td>353633</td>
</tr>
<tr>
<td>Total stools</td>
<td>507101</td>
<td>454211</td>
</tr>
</tbody>
</table>

New cultivars of willows are being developed for slope stabilisation, gully and streambank protection, and windbreaks. Form, vigour, resistance to breakage and resistance to browsing are major selection criteria. Work has concentrated on *Salix alba, S. matsudana* and their hybrids. Browse resistant clones are being developed by crossing *S. alba* with bitter willows (e.g., *S. purpurea*), but as yet there has been no major breakthrough. Neither has there been success with attempts to hybridise poplars and willows to increase the salacin content of willows and decrease their palatability (R. Hathaway pers. comm.).

*Nature of possum damage*

Possums damage poplar and willow poles by browsing the foliage, removing the bark, and breaking leaders and branches. Foliage browsing during the first 3 years after planting often results in reduced growth rates and poor root establishment. Most browsing occurs in spring and early summer, and although poles may recover foliage later in the year, they are often weakened and more susceptible to other mortality factors. Barkbiting usually occurs in winter, and ringbarking of branches or leaders is usually fatal in young trees. Breakage of leaders and branches occurs at all tree ages, and browse-resistant clones also suffer damage. Malformed trees develop, with slow growth and impaired ability for catchment protection.
Financial cost of possum damage

None of the currently available clones of either poplars or willows are completely resistant to possum browsing, but about 400 000 willow and poplar poles are planted annually, and a large number of wands and poles. Current costs/planted pole are about $7-8 (R. Hathaway, pers. comm.).

There are few available estimates of losses specifically attributable to possums. In Hawke’s Bay – Poverty Bay, Chisholm et al. (1966) reported 7% mortality of poles from possum browsing, with a further 21% suffering light to moderate damage. In the southern North Island, possums damaged a minimum of 10.6% of poles, killing 2.1% (Edwards, 1974). Several Catchment Boards reported similar or greater (15-20% of poles killed) possum damage (Jolly & Spurr, 1981). Donald (1982) found that 44% of poplar and willow poles he monitored in Hawke’s Bay were damaged, with 77% of the damaged poles being attacked by possums; damage to willows was greater than to poplars. Jolly (1980) recorded up to 51% of poles damaged by possums in various trials on Banks Peninsula. Thomas et al., (1984) reported that about 87% of an experimental planting of poplar poles in North Canterbury were browsed by possums during the spring flush, with about 35% of poles ultimately suffering damage to more than 50% of their foliage. In addition, 59% of poles had barkbiting damage, and 68% had broken leading shoots causing malformation of trees and reduction in their growth.

The overall annual costs to Catchment Boards of possum damage, assuming an average 20% loss, have been estimated at between $320 000 and $800 000 (R. Hathaway, pers. comm.; Thomas et al., 1984).

The 1980 APDC survey of possum damage to catchment plantings attributed much of the historical concern with possum damage to the coincidence of large-scale erosion control programmes and the buildup in possum numbers colonising those areas, particularly in the central North Island. The general conclusion from the 1980 survey was that possums were not now a serious threat to catchment plantings, although damage was locally severe at times. The report also emphasised the role of other agents, particularly farm stock, in the mortality of plantings.

Control methods

The merits of reducing damage to poles by attaching sleeves to the trunks to prevent possums climbing (Jolly, 1980) have been compared with the use of 1080 poison in the vicinity of plantings (Thomas et al., 1984). Expandable plastic sleeves proved highly effective and were less expensive than poisoning possums over a sufficiently large area to obtain effective control of damage for several years.

However, because of lack of commercial availability and additional costs, sleeve barriers for possum protection have not been widely used. Recently some Catchment Boards (e.g., Taranaki) have used printing plates – thin aluminium sheets available at about $0.40 each – as sleeve barriers. Such sleeves have been used successfully by some boards (e.g., Waikato), but others report that they tear in the wind and promote fungal growth on the trunk of the pole which can cause ringbarking (B. Dove, pers. comm.). Recently, a low cost smooth plastic pole protector has been developed; it is claimed not to collect flood
debris, and to provide no purchase for horns, hooves or possum claws (Acorn Plastics Ltd brochure, 11.1.87). This sleeve is intended to replace the current Nelton stock protection sleeve, and in addition, because of its length (1.5-1.7 m) provide protection against possums. Its cost is comparable to that of the stock protection sleeve alone. Evaluation trials of the new sleeve are in progress (R. Hathaway, pers. comm.).

In addition to poplars and willows, many Catchment Boards also plant large numbers of seedling trees (Table 13) which are damaged by possums, occasionally severely. Soil Conservation Centre, Aokautere, has conducted palatability trials on eucalypts and a variety of shrub and native species to identify suitable possum resistant seedling species (Sheppard, 1974, Stace, 1987b).

Current North Island situation (P. Cowan)

There are twelve Catchment Boards in the North Island. During 1970-1985, 77% of all poplar and willow pole planting was done by only four boards – East Cape (30%), Hawke’s Bay (19%), Waikarapa (14%) and Rangitikei-Wanganui (14%). Information was obtained from the Catchment Boards, and from their replies to a survey conducted in 1986 by the APDC (P. Nelson, pers. comm.). The extent of catchment plantings, the varieties used and the extent of the possum problem differ greatly. The current extent of plantings and varieties used is summarised in Table 13.

### TABLE 13. Numbers of poplar and willow poles, and seedling trees planted in 1987 by North Island Catchment Boards.

<table>
<thead>
<tr>
<th>Catchment Board</th>
<th>Poplar and willow poles</th>
<th>Other plantings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northland</td>
<td>c. 35 000</td>
<td>?</td>
</tr>
<tr>
<td>Hauraki</td>
<td>1-3000</td>
<td>?</td>
</tr>
<tr>
<td>Auckland Regional Authority</td>
<td>6 000</td>
<td>60 000 seedling trees</td>
</tr>
<tr>
<td>Waikato Valley Authority</td>
<td>20 000</td>
<td>105 000 radiata seedlings, 30 000 eucalypts, 51 000 other seedling trees</td>
</tr>
<tr>
<td>Bay of Plenty</td>
<td>c. 1 000</td>
<td>70 000 seedling trees</td>
</tr>
<tr>
<td>East Cape</td>
<td>83 000</td>
<td>105 000 radiata seedlings, 3 000 other seedling trees</td>
</tr>
<tr>
<td>Hawke’s Bay</td>
<td>c. 50 000</td>
<td>120-160 000 radiata seedlings</td>
</tr>
<tr>
<td>Taranaki</td>
<td>10 000</td>
<td>25 000 other seedling trees</td>
</tr>
<tr>
<td>Rangitikei-Wanganui</td>
<td>37 300</td>
<td>400 000 radiata seedlings, 30 000 other seedling trees</td>
</tr>
<tr>
<td>Manawatu</td>
<td>40 000</td>
<td>28 465 other seedling trees</td>
</tr>
<tr>
<td>Wairarapa</td>
<td>45 300</td>
<td>384 000 radiata seedlings, 64 000 acacia seedlings, 25 000 other seedling trees</td>
</tr>
<tr>
<td>Wellington Regional Council</td>
<td>1-3000</td>
<td></td>
</tr>
</tbody>
</table>
Northland Catchment Board considered possums to be the only significant cause of pole damage, with about 20% of willows and 5% of poplars damaged; the worst areas were Otamatea, Hobson, and Whangarei counties. Hauraki Catchment Board did not consider possums a serious problem except for occasional outbreaks of locally severe damage. The Auckland Regional Authority estimated 5–10% of poplars and 10–20% of willows were damaged, costing about $10,000 annually. The East Cape Catchment Board recorded widespread damage by possums, mostly of only slight to moderate intensity, but with persistent problem areas; e.g., in 1984, up to 75% of poles were damaged in parts of Waikohu County. The Board considered that in many areas damage levels were only kept in check by the current activities of the Pest Board. Possum damage was generally not significant over the areas of the Bay of Plenty and Waikato Valley Boards, except in the area around Hamilton, where 15–20% of poles were damaged, and 5% killed. Hawke's Bay, Taranaki, Rangitikei-Wanganui, Manawatu, and Wairarapa catchment boards all considered possums a continuing problem over most of their areas. For example, in Taranaki, 31% of 107 properties where planting occurred in the last 3 years reported possum damage to poles. Particular problem areas were around Taihape, all along the foothills of the Ruahine and Tararua ranges, particularly around Alfredton and Dannevirke, and along the Rangitikei River and its tributaries. Several boards commented on the association between severe or persistent damage and nearby native forest or scrub.

Management of possum damage to catchment plantings involves various combinations of the following tactics by different Catchment Boards:

- Use of browse-resistant clones.
- Siting of plantings to reduce accessibility to possums (e.g., in wet or swampy ground).
- Encouragement of farmers to shoot or poison around plantings regularly.
- Possum control by local Pest Board. Catchment Boards provide a list of proposed plantings; the pest board endeavours to inspect these and undertake control if necessary, particularly on properties with a history of damage. Subsequent damage to plantings is noted during catchment board inspections and reported to the pest board for follow up.
- Use of private trappers, assisted by negotiated access to farms.
- Use of protective sleeves.

Current management is constrained largely by the unavailability of sufficient numbers and varieties of possum resistant poplars and willows, lack of cost-effective protective sleeves, and problems applying effective control. Because most catchment plantings comprise widely separated small groups of poles, extensive control operations by the pest boards, which can effect damage reductions for several years, are difficult to justify. Control thus usually consists of small-scale operations which need to be repeated regularly because of the rapid recovery of possum numbers when such control is relaxed.

Current South Island Situation (B. Warburton)

There are eight catchment boards in the South Island, within which the extent of catchment plantings, the varieties used and the extent of the possum problems vary considerably. A summary of the number of poles and wands planted in 1987, the varieties (clones) used, and an estimate of the possum problem, is provided in Tables 14 and 15.
<table>
<thead>
<tr>
<th>BOARD</th>
<th>ACTIVITY</th>
<th>POLES &amp; WANDS/YR</th>
<th>CONTROL</th>
<th>DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nelson</td>
<td>nil Farms Wither Hills Wairau Valley Wye Valley</td>
<td>nil 241400</td>
<td>nil Private hunters</td>
<td>nil 20% poles killed</td>
</tr>
<tr>
<td>Marlborough</td>
<td>Kekerengu Clarence Hapuku Kahutara Conway</td>
<td>8000 poles</td>
<td>Private hunters</td>
<td>15% with loss of vigour</td>
</tr>
<tr>
<td>N. Canterbury</td>
<td>Coastal plantations Waiau/Motunau Banks Pen.</td>
<td>4-5000</td>
<td>Sleeves</td>
<td></td>
</tr>
<tr>
<td>S. Canterbury</td>
<td>90% stream bank</td>
<td>600000 poles &amp; wands</td>
<td>Co-op with Ag. Pest Bd</td>
<td>$20000-$25000</td>
</tr>
<tr>
<td>Waitaki</td>
<td>90% stream bank 10% hillside</td>
<td>8000</td>
<td>nil</td>
<td>&lt;$1000</td>
</tr>
<tr>
<td>Otago</td>
<td>Lawrence-Waitahuna Kilmog-Seacliff</td>
<td>15000 poles 27000 whips &amp; wands</td>
<td>Farmers use sleeves &amp; spotlights</td>
<td>500 pole/yr killed</td>
</tr>
<tr>
<td>Southland</td>
<td>Hokonui &amp; Taringatura 80% stream bank 20% hillside</td>
<td></td>
<td>Encourage farmers</td>
<td>$450</td>
</tr>
</tbody>
</table>

The majority of the boards consider possums to be a minor problem when compared to the cumulative damage inflicted by wind, drought, floods, stock, and vandals. However some board plantings, e.g., in Marlborough and Otago (Lawrence area), have persistent and sometimes severe damage (Table 14). The extent of the damage is usually localised and increases near bush and scrub areas.

Although some poplar and willow varieties are palatable to possums, they are planted in preference to other less palatable varieties because of their greater rust resistance or vigour. In the Otago Board, some areas have historically had possum problems (e.g., Lawrence) and here, palatable clones such as Tasman are avoided and less palatable clones such as Yeogi I are used. Sleeves are widely used in North Canterbury and Otago.
**TABLE 15. Poplars and Willows planted by South Island Catchment Boards**

<table>
<thead>
<tr>
<th>Catchment Board</th>
<th>Marlborough (Blenheim)</th>
<th>Marlborough (Kaikoura)</th>
<th>North Canterbury</th>
<th>South Canterbury</th>
<th>Waitaki</th>
<th>Otago</th>
<th>Southland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Poplars</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Korean</td>
<td>900</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flevo</td>
<td></td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I154</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I214</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tasman</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eridano</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kawa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yunanensis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yeogi I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Willows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matsudana x alba</td>
<td>2000</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrub</td>
<td>2500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crack</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golden</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moutere</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glenmark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pohangina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Some Poplar varieties used but not specified by Boards.**
No routine control of possums is undertaken by any of the boards. Most boards consider private hunter pressure to be sufficient to limit possum damage. In Canterbury and North Otago, where possums are recognised as a problem, farmers are encouraged to attach sleeves. The South Canterbury Catchment Board co-operates with the local Pest Destruction Boards who occasionally carry out poisoning or shooting in the spring.

C.6 EFFECTS OF POSSUMS ON EXOTIC FORESTS (P. Cowan)

Introduction

As at 31 March 1985, the size of exotic forest plantations in New Zealand was 566 000 ha of State Forests (now almost entirely administered by Forestry Corporation trading as Timberlands) and 529 000 ha of privately owned forest. Of the privately owned forests, 77% were held by companies, 11% by private persons, 6% by local authorities, and 6% by other groups (NZ Forest Service, 1986) (NZFS). In recent years, State forest plantations have increased in area by about 20 000 ha annually, and private forests by about 30-35 000 ha annually. About 40% of the State forests and 50% of the private forests are less than 10 years old, and are more susceptible to possum attack than established forests (Clout, 1977; Keber, unpubl. report). Of the total area of 1 095 000 ha of exotic forests, 88% is planted in radiata pine, 5% in Douglas fir, and the rest in other conifers, eucalypts, or broadleaf species.

Possum damage to young pine trees had already been reported from Australian plantations before large-scale planting of radiata pine started in New Zealand (Wodzicki, 1950). The central volcanic plateau of the North Island contains New Zealand’s most extensive pine forests. At 31.3.85, Rotorua Conservancy contained 41% of the total area of State exotic forest, and 61% of the area of private forests; 69% of all State forests are in the North Island, and 88% of private pine forests. The central North Island pine forests were originally established in 1925-35, but had passed the age at which they were most vulnerable to possum damage before possums became widespread throughout the area (Clout, 1977; Pracy, 1974). Occasional reports of possum damage to a wide variety of exotic species were made during 1930-60 (Wodzicki, 1950; Clout, 1977). From about 1960, when the original forests were felled, there was a resurgence of planting on the volcanic plateau, including replanting and expansion into new areas. It was in these young stands, established from 1960 onwards in areas where possums were now widespread, that extensive damage to Pinus radiata was first recorded. Several surveys carried out during the early 1970s by the NZFS, New Zealand Forest Products Ltd (NZFP), and Fletcher Timber Ltd all recorded locally serious damage to radiata pines (reviewed in detail in Clout, 1977; Keber, unpubl. report). In a survey of exotic forest owners conducted in 1972 by the NZFS, 13/15 respondents considered possums of major or moderate importance as a pest (Bathgate in Orwin, 1972). Subsequently, large areas of both State and private exotic forests were treated by aerial 1080 poison operations to control possums.

By 1980, however, there had been a major reversal of attitudes to possum damage – it was now considered of minor importance, with no significant effect on the economics of timber production (APDC, 1980). Earlier reliance on large-scale aerial control operations had been replaced by a combination of small-scale operations in response to sporadic outbreaks of locally severe damage and the use of private trappers to reduce damage and to maintain a general lowering of possum numbers. The use of trappers was greatly promoted by the high prices of possum skins during the 1976-82 period (see Section D).
Damage to *Pinus* species

Possoms cause four major kinds of damage to pine trees:

- Browsing of terminal shoots of newly planted seedlings during the 1-2 years after planting.
- Barkstripping and chewing of cambial tissue, both basally and around the leader and top whorl of laterals, on trees of all ages but mostly on those less than 10 years old.
- Breakage of leader and top whorl of laterals, mostly on trees 5-15 years old.
- Cone loss from seed stands after trees mature, from about 8 years onwards.

Previous surveys (Clout, 1977; Keber, unpubl. report) noted that the nature of the damage varied with locality; e.g., browsing of terminal shoots on the Mamaku plateau, basal barkstripping in Kinleith, Kaingaroa, and Eyrewell forests, and leader breakage in Tauhara forest. Damage also varied seasonally, occurring mainly in winter and spring, particularly barkstripping damage. Damage was usually patchy, both in severity and location. It was often associated with nearby habitat providing suitable nesting for possoms, such as slash piles, pockets of native forest among the pines, or adjacent large tracts of native forest or scrub (Clout, 1977; Keber, unpubl. report).

Damage has been recorded on at least 12 species of *Pinus* - *P. ponderosa*, *P. palustris*, *P. muricata*, *P. nigra* var. *laricio*, *P. taeda*, *P. echinata*, *P. patula*, *P. caribaea*, *P. contorta*, *P. radiata*, *P. pinaster*, and *P. elliottii*. Possoms appear to prefer species such as *P. ponderosa*, *P. taeda*, *P. echinata*, *P. contorta*, *P. elliottii*, *P. pinaster* and *P. muricata* to radiata, but since 88% of all exotic plantings are of radiata pine, such preferences have little relevance to the problem as a whole.

Establishment of eucalypts as plantation species has increased in recent years, largely to replace native tawa as a hardwood resource; e.g., NZFP is establishing a 6500 ha eucalypt plantation within its Kinleith forests. Possoms have caused serious damage to newly planted eucalypt seedlings at times; NZFP have alleviated such damage by selecting unpalatable eucalypt species (B. Poole, pers. comm.; Stace, 1987b).

Various surveys of possom damage to radiata pine plantations were conducted during 1970-75 (reviewed in Clout, 1977; Keber, unpubl. report). They recorded locally severe damage (e.g., up to 39% of seedlings browsed; up to 90% of 2-3-year-old trees with barkstripping and 50% killed), particularly on blocks established on cutover native forest or adjacent to remnant native forest or scrub. But overall forest damage levels were less alarming - a 1973 survey of basal barkstripping on 2-3-year-old trees in Kaingaroa forest recorded only about 7% of trees damaged and 3% killed by possoms (Beaumont in Clout, 1977); surveys in Kinleith forest during 1974-75 of 3-5-year-old trees recorded 37% of trees damaged, with 7% killed, in one area, but only 5% damaged and 2% killed in another area (Clout, 1977). In the same forest, 8-39% of seedlings in various compartments were browsed but only 0.1-2.7% died (Clout, 1977). In Tauhara forest, possom damage was recorded on 5-10% of trees 4-9 years old (Keber unpubl. report).

Clout (1977) primarily examined the problem of possom damage in young plantations - seedling browsing and basal barkstripping. The overall low levels of seedling mortality recorded in his surveys, and the results from his simulated browsing experiments which
demonstrated compensatory growth, led him to conclude that "over large areas the incidence of damage is low. Where its incidence is high, the proportion of trees dying as a result is still low relative to the total number damaged", and, "Because both browsing and barkstripping are mainly problems of young stands, there is a large amount of scope for minimising losses by thinning. Only in stands where stocking is already poor because of losses from other causes is possum damage likely to have any serious impact."

Keber (unpubl. report) studied possum damage in Tauhara forest where the major problem was leader and lateral breakage on trees 5-10 years old. From simulated damage trials and damage surveys, he concluded that only leader damage had a significant effect on tree growth and form. From an economic evaluation of the problem, loss to possums was estimated at about 1-2% of the final crop value at rotation in the worst case. Costs of traditional control (blanket aerial poisoning, blanket roadside poisoning, spot poisoning) in most cases exceeded the benefits. Keber suggested that the use of alternative slash disposal techniques (to reduce suitable possum habitat) and the managed harvesting of possums for furs were the most cost-effective and least environmentally damaging means of dealing with the possum problem in exotic forests.

Control policy and methods

Comments were solicited from Forestry Corporation District Managers, the major private forestry companies (NZFP, Tasman Forestry, Carter Holt Harvey, P.F. Olsen, Baigent Industries), and the Selwyn Plantation Board and the Dunedin City Council on the nature and extent of possum damage in their exotic forests, and their current policy and methods for possum control.

Replies were received from 11 Timberlands managers. All replies were generally consistent on policy for possum control and opinion on the effectiveness of the current control strategy. General policy is to restrict possum numbers to levels where little or no damage occurs. Where visual inspection shows local severe damage, intensive control is carried out by directing efforts of private trappers to those areas, but if the problem persists, by follow-up operations using Timberlands staff or local Pest Boards. Possum control is, almost without exception, principally conducted by private trappers. The system under which the trappers operate varies from district to district. Access is arranged by contract, formal permits (renewable 3 monthly to yearly) for sole or shared access to blocks, or by tender for exclusive rights for trapping. Most Timberlands districts charge trappers for access to their forests. Payments vary; e.g., a per skin fee, charge for permit ($50-100 per 6 or 12 months), price by tender (which currently range from $100 to $2000), or fixed price by private negotiation. The wisdom of charging trappers, who are in effect saving Timberlands money which would otherwise need to be spent on control, remains to be seen.

All District Managers considered that their current control policy, using private trappers, was adequately keeping possums in check, with only isolated pockets of significant damage. Overall damage levels were low, and of no economic importance. In all districts, there were more possum trappers than available possum blocks, presumably because of the reasonable prices for skins at present and the high levels of unemployment in rural areas.

Responses from managers of privately owned forests were basically similar. Possum damage occurred in all forests, but was considered of little importance except for
occasional outbreaks of locally severe damage. Possum damage was monitored by inspection, at least annually, of all blocks during forest health surveys, from observations by various company employees (such as logging gangs, pruning gangs, and supervisors), and by reports from possum trappers themselves. There was no formal system for assessing costs of possum damage or needs for control; decisions were made reactively, based on visual assessment of damage and experience of managers.

Possum control was again largely conducted using private trappers. The degree of control over their activities varied widely. Some companies did little for trappers other than allow them access to their forests, whereas others used the trappers both for possum control and to monitor forest health. For example, at NZFP, Kinleith, the activities of all trappers are overseen by one individual. Trappers are issued with monthly permits, renewable on return of the previous permit with possum tally and notes of areas trapped. Trappers are issued with a copy of the company regulations and conditions, and their performance and adherence to these are checked at intervals. They are encouraged to call in to discuss problems (e.g., poaching) or observations of forest damage. Many of the current trappers have dealt with NZFP for several years, and there is a waiting list for blocks. From the tallies returned NZFP estimate that about 57 000 possums are removed annually from about 140 000 ha of Kinleith forests (G. Harrison, pers. comm.).

Unlike Timberlands, owners of private forest do not charge trappers for access. If necessary, trappers' activities are directed to problem areas. Use is also made of Pest Boards for persistent problem areas, or areas with limited access for trappers; the costs of such operations are usually shared.

The current management of possum damage in privately owned forest was generally considered satisfactory. This was primarily attributed to the sustained trapping pressure in recent years because of relatively high skin prices. It was generally appreciated that a fall in skin prices could result in a marked decrease in the trapping efforts of private operators. There would then be greater reliance on pest board or staff control operations.

Conclusions

Diminished trapping could have serious implications in two areas of exotic forestry. Changes in silvicultural regimes and increased plantings for clearwood mean that a final stocking rate of about 300 trees/ha may be reached when trees are only 8–10 years old. Trees are still highly vulnerable to possum damage at that age, and there is not the same scope to reduce losses in thinning or pruning as under systems of progressive reduction in stocking rate. Thus damage to a single tree is of more economic significance. The conversion of farmland to exotic forest in some areas is being done by planting grafted radiata seedlings at final stocking rates. Such a regime must be much more sensitive to possum damage than one which starts with 1100–1600 seedlings/ha.

There was little comment from any of the forest managers on need for additional research. "Adequate control is being maintained by constant pressure by private hunting".
Fig. 15a. Exports of possum skins since 1921 (crosses) and the average price per skin in 1987$ (circles), showing the trend of increasing exports, decline in long-term value of possum skins, and the sensitivity of exports to the average price in the preceding year.

b. Exports of skins (crosses) and price per skin (circles) in 1987$ for the period 1945 - 1966, and the numbers of tokens presented per year during the 1951 - 61 bounty period.
D. POSSUMS AS A RESOURCE

D.1 LONG-TERM PATTERN OF SKIN EXPORTS (C.L. Batcheler)

About 90% of the entire harvest of possums by private trappers is exported as dried skins, for which export totals have been kept since 1921. They show that, exports have totalled 43.7 million skins from 1921 to 1985, worth $527.5 million in 1987 values (Department of Statistics, pers. comm.).

The annual totals harvested fall into three characteristic levels associated, at least in part, with the three "management phases" outlined in the introduction: 0.2 million during the licensed trapping period (1921-46); 0.4 million from 1946 to the end of the bounty period (1951 to 1961) and; an erratic increase to a peak of 3.2 million in 1980, followed by decline to the current 1.5 to 2 million during the unlicensed harvesting - free market phase.

The annual totals and the relationship between mean price per skin and the CPI (Fig. 15a) shows that the real value of possum furs reached an all-time high in 1927-28, decreased until the mid 1950s, stabilised for about 10 years, increased again to a peak in 1977-80, and has since declined. The average real value per skin since 1970 is only one third of the 1927-28 peak value, and two-thirds of the average for the whole of the 64 year period.

High prices during the 1920s were undoubtedly influenced by the fact that virtually all possums harvested during the restricted season (under licence) were from "pre-peak" populations, taken at the best seasons for fur. They were from big animals in prime condition. Also, in the earlier years, a high proportion of the harvest was of an especially valued colour-phase called "Wairarapa" or "Monaro Blues" (L.T. Pracy, pers. comm.). This mainland Australian colour-phase has been swamped out by interbreeding with "greys" and "darks", and is now seldom seen.

Since the 1940s, the quality of skins has deteriorated in many areas. Populations peaked about 30 years after their release; the "wave" of liberations during the 1900s - 1920s was therefore followed by a "wave" of deteriorating condition after the late 1940s. Body size and skin size became smaller (e.g., Fraser, 1979); and the value is now inherently lower. Abolition of restrictions on the hunting season have been held responsible for many animals being taken when moulting (October to January, Pracy & Kean, 1963), or with mating season damage to pelts (e.g., Moresby, 1984; L.T. Pracy, pers. comm.). Changes in use of skins (see later) and import restrictions into some markets (e.g., U.K.) have undoubtedly also depressed recent prices.

The bounty period, 1951-61, provided two sources of income for the hunters; tokens and skins. The numbers and value of skins exported fluctuated widely both immediately before and just after the bounty period (Fig. 15b). By comparison, values remained relatively stable during the bounty period, but export numbers dropped from about 0.4 to 0.11 million skins in 1961.
Fig. 16a. Correlation of numbers of skins exported 1955 - 1985 against the export value index (redrawn from Keber, 1986).

Increasing numbers of bounty payments, trending from 25 000 to 1.4 million, were claimed for tokens over the 1951 - 1961 period. The combination of steady value per skin, declining export volume and increasing numbers of redeemed tokens indicates that as use of the bounty system increased, the better quality skins went for export, and the "rubbish" became tokens. Overall however, the total number of possums killed, for tokens and skins, had about doubled by 1961 but as is shown later, even the combined kill had little effect on the total possum population or their rate of spread.

From year to year, the numbers of possum skins exported are closely related to movements in the average price. When trapping was controlled by licensing, the number of licences declined in the year after a decrease in the price of skins (Wodzicki, 1950). A similar relationship still holds in Tasmania, where possum harvesting is operated under a licence system (P. Cowan unpub). The peak in exports in 1970 followed a rise in average prices in 1969. After dropping to an all-time low value in 1971, both value and the numbers exported increased to the 1980 peak. For the 1955-85 period, Keber (1986c) plotted the numbers of skins exported against the Export Value Index and the direct correlation confirmed that, "as prices go higher, more people enter the trade, and the core of professionals trap harder" (Fig. 16a). A similar relationship was calculated to determine the dependence of exports against the CPI for the period 1963 - 85. As expected, it confirmed the inference of Keber's result \( r = 0.92 \), Fig. 16b).

D.2 POSSUM FUR IN THE WORLD FUR TRADE (P. Cowan)

Introduction

The principal centres of the world fur industry are North America, Europe, the USSR, and, more recently, the Far East (Korea, Japan, China). New Zealand possum fur has a well established place on the world fur market, having been traded at auction since before 1920 (Wodzicki, 1950). New Zealand is currently the world's sole supplier, apart from a small number (about 200 000 annually) produced from Tasmania.

Possum fur is durable, soft, and long-haired, and is widely used. It has a reputation of being unreliable and variable in quality, and of being particularly prone to fur loss during dressing (fur slippage) (MacGibbon, 1986). Before 1970, most skins were sold at auction in London or New York, and were used either for coats or trimmings, or in the mill trade in the UK and USA to prevent thread breakage on the looms in silk and cotton mills (Wodzicki, 1950; Keber, 1986a). The latter use has ceased, and since about 1970 all possum furs have been used in the fashion industry as full coats, linings, or trimmings (Keber, 1986a). Today possum fur fills a place towards the bottom end of the market, being ranked low in comparison to fox, and having a predominance of low grade and damaged pelts (Table 16; Comer, 1985).

World production of farmed furs is dominated by mink and fox (about 95% of the total numbers); 32.8 million farmed mink and 6.2 million farmed fox furs were produced in 1986/87 (Anon, 1988). Production of farmed possum furs to date has been insignificant, at most probably 1-3 000 annually (B. Mercer, A. Mackie, pers. comm). When Kiwi Bear Ltd move to full production, they will produce about 25-30 000 cage-finished possum furs annually (R. MacGibbon pers. comm), still an insignificant contribution to world farmed fur production.
TABLE 16. Recent representative prices for various furs sold at auction (data from Fur Review, March 1988)

<table>
<thead>
<tr>
<th></th>
<th>Average Price</th>
<th>High Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NZ$</td>
<td>NZ$</td>
</tr>
<tr>
<td>Russian sable</td>
<td>197-534</td>
<td>210-820</td>
</tr>
<tr>
<td>Lynx</td>
<td>31-72</td>
<td>875-1343</td>
</tr>
<tr>
<td>Mink</td>
<td>29-147</td>
<td>64-344</td>
</tr>
<tr>
<td>Fox</td>
<td>71</td>
<td>62-344</td>
</tr>
<tr>
<td>Coyote</td>
<td>40</td>
<td>265</td>
</tr>
<tr>
<td>Beaver</td>
<td>28</td>
<td>172</td>
</tr>
<tr>
<td>Raccoon</td>
<td>13</td>
<td>103</td>
</tr>
<tr>
<td>Nutria</td>
<td>13</td>
<td>10-34</td>
</tr>
<tr>
<td>POSSUM</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>Muskrat</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Squirrel</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

TABLE 17. Numbers and values of possum skin exports to major markets during 1983-87 (R. Charlton, pers. comm.)

<table>
<thead>
<tr>
<th></th>
<th>83</th>
<th>84</th>
<th>85</th>
<th>86</th>
<th>87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number exported</td>
<td>1426 626</td>
<td>1409 677</td>
<td>1374 434</td>
<td>1896 996</td>
<td>2478 142</td>
</tr>
<tr>
<td>Number:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% exported to Korea</td>
<td>46.0</td>
<td>50.6</td>
<td>55.4</td>
<td>80.6</td>
<td>78.6</td>
</tr>
<tr>
<td>USA</td>
<td>25.7</td>
<td>13.7</td>
<td>9.9</td>
<td>6.2</td>
<td>5.2</td>
</tr>
<tr>
<td>UK</td>
<td>8.2</td>
<td>5.9</td>
<td>5.3</td>
<td>2.4</td>
<td>3.9</td>
</tr>
<tr>
<td>West Germany</td>
<td>12.1</td>
<td>14.3</td>
<td>17.6</td>
<td>5.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Canada</td>
<td>4.2</td>
<td>5.3</td>
<td>1.9</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1.4</td>
<td>4.7</td>
<td>6.9</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Total 97.6</td>
<td>94.5</td>
<td>97.0</td>
<td>97.6</td>
<td>96.5</td>
<td></td>
</tr>
</tbody>
</table>

| Total value NZ$ | 7897 915 | 7406 023 | 9276 463 | 12540 785 | 18811 382 |
| Value:         |        |        |        |        |        |
| % exported to Korea | 41.0 | 41.0 | 45.3 | 73.4 | 74.2 |
| USA            | 25.7 | 16.7 | 11.8 | 8.0  | 5.0  |
| UK             | 10.6 | 8.5  | 8.4  | 3.4  | 6.2  |
| West Germany   | 14.2 | 16.2 | 16.2 | 5.5  | 4.8  |
| Canada         | 2.1  | 3.3  | 1.3  | 0.1  | 0.1  |
| Switzerland    | 2.7  | 7.3  | 12.6 | 5.2  | 4.8  |
| Total 96.3     | 93.0 | 95.6 | 95.6 | 95.1 |      |
By contrast with farmed furs, exports of wild possum furs comprise a significant 6-8% of the world's total wild fur production. About 85% of wild possum furs, and the small number of farmed skins, are currently sold at auction in New Zealand, either through Wrightson-Dalgety, Dunedin, or New Zealand Fur Auctions, Lower Hutt. Each company holds six or seven auctions each year, with most furs being sold from September to December. Furs are graded into about 57 lots on the basis of colour (about eight varieties), sizes (four classes), and roughly on quality (see Table 19). Skins are sold in large lots, often of thousands of skins, containing a range of colours and qualities that is much wider than is acceptable in the sale of other furs (Pearson, 1984).

Recent developments in the possum fur industry

Before the early 1970s, few of the possum furs exported from New Zealand were auctioned here; they were mostly sold to exporters, overseas brokers, or sent direct to overseas auctions, principally in London or New York (Keber, 1986a). In the 1973/74 season, Dalgety fur auctions handled only 8.3% of furs exported. The size of their auction business increased rapidly, however, and by 1977/78 they handled 54% of skins exported. Since 1983 they have handled between 63 and 78% of annual exports of possum furs. Overseas companies, such as Hudson's Bay, which were formerly major dealers in possum furs, have now all but abandoned possum auctions (Keber, 1986a).

Auction sales during the 1970s were dominated by Dalgety Ltd. Since the early 1980s however, a second auction house, New Zealand Fur Auctions, has opened in Lower Hutt, and has captured about 36% of the market. NZFA operates on the principle of selling the complete catalogue at each auction, which is usually held immediately after each Dalgety sale. Buyers set the prices, there are no reserves or lots passed in, and all prices are obtained by bids from the floor. Dalgety Ltd used to operate a similar system, but in 1985, in response to low prices, they introduced a system of withdrawing lots from the sale if unsatisfactory prices were offered, and negotiating private treaty sales after the auction, or keeping lots until the next auction. For example, in the August, October, and December 1985 sales, only 47, 20, and 16%, respectively, of furs offered were sold at the auctions. This policy tends to prop up prices in a depressed market, leads to a more stable trade, and may increase returns to trappers. Buyers in general dislike the system, as the auctioneer acts to support the seller.

Formerly, most skins went to USA, United Kingdom, and Europe. However, Korea's share of the market has increased dramatically, from 10% in 1980 to 46-55% in 1983-85, and in 1986 and 1987 to 80.6 and 78.6% of total furs exported, as manufacturers took advantage of low labour costs there. Although most exports to Korea are of lower grade furs for linings and trimming, a garment industry using high quality furs is developing there. This is reflected in the increasing value of skins exported to Korea (Table 17).

Most possum furs are still exported as dried untreated skins, although the export of dressed and/or dyed skins has significantly increased recently. For the 3 years 1984-86, 511 299 possum furs were exported as dressed and/or dyed (9.8% of total exports), representing 15.9% of export value (Table 18). Two major New Zealand companies are involved in dressing and dyeing possum skins. Merchant Tanners Ltd dress and dye mostly 1st and 2nd grade skins, of which 80% go to Italy; they treat about 90 000 skins per year, of which about one third are dyed. Fur Dressers and Dyers Ltd export only dressed skins; they treat about 60 000 skins annually, mainly small 2nd grades, most of which go to the
USA, but some are used by New Zealand producers. Possum fur garments and toys are also manufactured in New Zealand. The domestic fur fashion market is strongly dependent on the tourist trade (mostly Japanese). Camargue Fashions, one of the larger producers, uses only about 10–15 000 skins a year, about 40% 1st grades for apparel, the remainder 2nd and 3rd grades for linings and trimmings.

<table>
<thead>
<tr>
<th>Numbers exported</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
</tr>
<tr>
<td>1985</td>
</tr>
<tr>
<td>1986</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>(%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value NZ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
</tr>
<tr>
<td>1985</td>
</tr>
<tr>
<td>1986</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>(%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average value NZ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
</tr>
<tr>
<td>1985</td>
</tr>
<tr>
<td>1986</td>
</tr>
</tbody>
</table>

Although the proportions of the various colours, grades, and sizes of possum skins offered for sale vary somewhat from auction to auction, production is reasonably stable (Table 19). About 30% of skins sold are large, 40% large/medium, 12% medium and 18% small. Sales of large and large/medium skins represent about 75–80% of the total export value (Table 20). About 17% of the larger skins are 1st grade, 29% are 2nd grade, and more than half are 3rd grade. About 16% of the total value of skins exported derive from sales of 1st grade skins, 24% from 2nd grade skins, and 38% from 3rd grade skins (Table 20).
## TABLE 19. Statistics on numbers and types of possum skins sold at Dalgety auctions 1981/82 and 1987/88 (S. Dyet, R. Charlton pers. comms.)

### Total skins sold (%)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>355 395 (29.7)</td>
<td>380 542 (32.8)</td>
</tr>
<tr>
<td>Medium/large</td>
<td>469 480 (39.3)</td>
<td>497 429 (42.9)</td>
</tr>
<tr>
<td>Medium</td>
<td>154 536 (12.9)</td>
<td>127 903 (11.0)</td>
</tr>
<tr>
<td>Small</td>
<td>215 725 (18.1)</td>
<td>152 634 (13.2)</td>
</tr>
<tr>
<td>Total</td>
<td>1 195 136</td>
<td>1 158 508</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Grade (Large + Medium/large only)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>153 692 (18.6)</td>
<td>133 493 (15.2)</td>
</tr>
<tr>
<td>2nd</td>
<td>243 493 (29.5)</td>
<td>246 886 (28.1)</td>
</tr>
<tr>
<td>3rd</td>
<td>427 690 (51.8)</td>
<td>497 592 (56.7)</td>
</tr>
<tr>
<td>Total</td>
<td>824 875</td>
<td>877 971</td>
</tr>
</tbody>
</table>

### Colour

#### 1. Large + Medium large

<table>
<thead>
<tr>
<th></th>
<th>7/81-4/82</th>
<th>4/87-2/88</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red brown</td>
<td>93 194 (11.5)</td>
<td>142 673 (16.3)</td>
</tr>
<tr>
<td>Dark brown</td>
<td>232 071 (28.7)</td>
<td>205 882 (23.4)</td>
</tr>
<tr>
<td>Red neck</td>
<td>48 752 (6.0)</td>
<td>43 332 (4.9)</td>
</tr>
<tr>
<td>Rusty</td>
<td>85 474 (10.6)</td>
<td>126 473 (14.4)</td>
</tr>
<tr>
<td>Pale</td>
<td>218 901 (27.1)</td>
<td>270 251 (30.8)</td>
</tr>
<tr>
<td>Grey</td>
<td>129 239 (16.0)</td>
<td>89 360 (10.2)</td>
</tr>
<tr>
<td>Total</td>
<td>807 631</td>
<td>877 971</td>
</tr>
</tbody>
</table>

#### 2. Medium + small + 4th

<table>
<thead>
<tr>
<th></th>
<th>7/81-4/82</th>
<th>4/87-2/88</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark</td>
<td>211 165 (37.2)</td>
<td>166 408 (38.2)</td>
</tr>
<tr>
<td>Light</td>
<td>357 063 (62.8)</td>
<td>269 771 (61.8)</td>
</tr>
<tr>
<td>Total</td>
<td>568 228</td>
<td>436 179</td>
</tr>
</tbody>
</table>
Fig. 17. Average price for four size grades of possum skins auctioned since March 1987 (see also Table 20).
TABLE 20. Average prices paid for large and large/medium 1st, 2nd and 3rd grade possum furs at Dalgety auctions, and % of total sale value contributed by the various grades of furs (R. Charlton pers. comm.)

<table>
<thead>
<tr>
<th>Auction date</th>
<th>1st Value</th>
<th>%</th>
<th>2nd Value</th>
<th>%</th>
<th>3rd Value</th>
<th>%</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/88</td>
<td>11.41</td>
<td>18.8</td>
<td>8.19</td>
<td>21.8</td>
<td>6.32</td>
<td>35.9</td>
<td>76.5</td>
<td></td>
</tr>
<tr>
<td>12/87</td>
<td>14.22</td>
<td>18.8</td>
<td>11.26</td>
<td>26.7</td>
<td>8.51</td>
<td>32.0</td>
<td>77.5</td>
<td></td>
</tr>
<tr>
<td>10/87</td>
<td>14.64</td>
<td>21.7</td>
<td>11.62</td>
<td>29.2</td>
<td>8.16</td>
<td>32.3</td>
<td>83.2</td>
<td></td>
</tr>
<tr>
<td>8/87</td>
<td>12.93</td>
<td>18.4</td>
<td>10.50</td>
<td>27.0</td>
<td>7.29</td>
<td>37.6</td>
<td>83.0</td>
<td></td>
</tr>
<tr>
<td>7/87</td>
<td>10.42</td>
<td>12.4</td>
<td>8.63</td>
<td>24.1</td>
<td>6.15</td>
<td>41.8</td>
<td>78.3</td>
<td></td>
</tr>
<tr>
<td>6/87</td>
<td>12.76</td>
<td>11.4</td>
<td>10.05</td>
<td>19.1</td>
<td>7.34</td>
<td>43.0</td>
<td>73.5</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>14.64</td>
<td>12.5</td>
<td>11.94</td>
<td>23.1</td>
<td>9.32</td>
<td>43.7</td>
<td>79.3</td>
<td></td>
</tr>
<tr>
<td>PRICE RATIO</td>
<td>1.72</td>
<td></td>
<td>1.36</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>95% CL</td>
<td>1.64-1.80</td>
<td></td>
<td>1.30-1.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Among the larger skins, the predominant colours are dark brown and pale. The dark colours (red brown and dark brown) comprise about 39% of the larger skins, similar to the 37-38% of "dark" skins among the smaller and poorer quality skins (Table 19). There is remarkable consistency among grades, not only in the pattern of change in price from auction to auction, but also in the relative pricing of the various grades. There were highly significant correlations among the prices of the various sizes (Fig. 17; Kendal coefficient of concordance $W = 0.76, P<0.01$) and qualities (Table 20; $W = 0.94, P<0.01$) of skins sold over the last seven auctions. The price ratio averages, using 3rd grade skins as a base also showed little variation among these auctions, as indicated by the narrow 95% confidence limits on the mean ratios (Table 20).

High prices paid for possum skins during 1977-81 and the establishment then of a number of possum farming enterprises led to the founding of the New Zealand Opossum Fur Producers Association in 1982. The NZOFPA was to represent all sectors of the possum trade in New Zealand. The number of persons involved in the industry is estimated at 4000, but with only about 100-150 full-time commercial possum trappers (Comer, 1985). NZOFPA currently has about 300 members. Despite its small size, it has been very active on behalf of the industry through submissions on a wide range of issues, and education and promotion through its publication, "Fur Facts". For example, NZOFPA hosted an Opossum Industry Review and Strategy Formulation meeting (Comer, 1985), it has made submissions on issues such as the use of gin-traps, published a "Code of Conduct for Trappers", conducted surveys of trappers attitudes and activities, and attempted to establish a quality control scheme.
D.3 POSSUM FARMING (P. Cowan)

Possum farming developed after the dramatic rise in the value of furs in the late 1970s, coupled with the general economic downturn and the rapid moves into farming diversification (Giles, 1981). To date, 58 licences to farm possums have been issued (B. Insull, pers. comm), various field-days have been held by MAF and other interested parties (e.g., see Goldschmidt, 1979), and numerous articles have appeared in the farming press describing developments in the potential for possum farming (e.g., Rennie, 1979; Giles, 1981).

The original concepts of farming possums - breeding selected animals in captivity, and rearing their offspring in individual cages or large communal units - proved economically unviable when skin prices declined in 1982 and problems of domestication were encountered. Stress-related disease and mortality, low reproduction rate, and lack of information on adapting and maintaining possums in captivity were the main problems (Rennie, 1979; Giles, 1981). Most of the possum farms started at that time were part-time "hobby" enterprises which quickly closed down in the face of unanticipated problems. Only two organizations made a significant input to possum farming. First, Tasman Forestry operated an experimental possum farm for several years in the early 1980s, under the direction of A. Keber (later involved in the establishment of Kiwi Bear Ltd). Second, the Ministry of Agriculture and Fisheries established a possum farming research unit at Ruakura in 1982, concentrating on reproduction (Fisk, 1985; Pearson & Ashby, 1987). The research of MAFTech at Ruakura continues under contract to Kiwi Bear Ltd. Other than Kiwi Bear Ltd, only three or four small farms are still attempting to breed possums.

Rather than attempting to breed possums, some farmers keep animals in captivity for 3-4 months until blemishes in the furs grow out (fur finishing or ranching). Ranched furs are sold separately at Dalgety auctions, and generally command a premium over a comparable wild skin; for example, in September, October and December 1981, 460, 190, and 242 ranched skins were sold, their total value exceeding that calculated from the average prices for wild skins by 22.8, 27.1, and 22.4%. The production of ranched skins has continued throughout the 1980s, but only 500-2000 were produced annually, until the recent advent of Kiwi Bear Ltd.

Possum farming legislation

The Department of Conservation, which administers the Wild Animal Act 1977, is responsible, under section 12 of the Act referring to the keeping of specified wild animals in captivity, for issuing permits for possum farming. Applications are considered at regional level, and issued after recommendation to the Director General, DOC. Possible environmental problems (e.g., effluent discharge, extension of known range) are taken into account. Permits require compliance with a number of regulations, such as standards for fencing and buildings and the marking of all farmed possums by tag, tattoo, or similar identification. Possum farmers are also bound by legislation contained within the Animal Act 1987 (care and treatment of animals) and the Meat Act 1987 amendment (use of possum carcasses).

The possum fur industry in New Zealand is protected against competition by regulations administered by DOC governing the export of live possums; no exports are allowed where
the purpose of export is for breeding for fur farming or resale, although limited exports of sterilised animals are allowed.

Economics of possum farming

The economic feasibility of possum farming was investigated by Chai (1984), with a model using inputs for capital costs, returns for furs, feed costs, and reproductive rates. Internal rate of return (IRR) was calculated and compared to a 10% commercial interest rate. Potential returns through investment in research were also estimated. IRR was highly sensitive to changes in skin price and reproductive rate. At 1984 prices, possum farming was profitable when females had one young per year only if skins were worth $55; with two young per year, the required return was $36 per skin. Chai (1984) concluded that under existing conditions and skin prices, possum farming was uneconomic. Future profitability depended on increasing reproductive output and improving quality and presentation of furs. An investment in such research was clearly profitable, especially as the market size increased.

Chai's (1984) evaluation was based, however, solely on returns from fur sales; carcasses were sold at $0.15/kg for pet food. The development of an export market for possum meat (see later) returning about $10 per carcass somewhat alters Chai's original conclusions. Considering total return per farmed possum, the venture could be profitable at lower reproductive rates and skin prices.

The economics of fur ranching have been investigated by Keber (pers comm), based on a pilot project for Tasman Forestry Ltd. At 1982 prices, with furs sold privately to avoid auction costs, the IRR's at fur values of $20 and $25 were 17 and 36%, respectively calculated via a discounted cashflow analysis over 20 years. The economics of fur ranching, although superficially more attractive than possum farming, are still greatly affected by fluctuations in fur prices. Ranched furs sold at auction in New Zealand have attracted a premium, but their price has still fluctuated in parallel with that of wild furs. B. Mercer, who has operated a small fur ranching business for the last 8 years commented (in litt. 12/3/88), "Last year my cage finished furs averaged $17, which ... is unchanged over the last 7-8 years with regard to price." Because ranched furs have been produced only in small numbers, and not marketed to advantage, the premium they command has not been sufficient to sustain small-scale operations.

Current possum farming

There are no fully commercial possum farms currently operating in New Zealand where animals are bred in captivity and reared through to culling for meat and fur. The full potential of possum fur is unlikely to be achieved unless possums can be selected and bred for desirable pelt characteristics. The principal obstacle to farming possums is their low natural rate of reproduction (Pearson & Ashby, 1987; Pearson, 1987a). Kiwi Bear Ltd have long-term plans to expand into possum farming; farming of possums selected for size, coat colour and fur quality offers the best return on investment (R. MacGibbon, pers comm; Pearson, 1987a). The production of farmed mink fur and the finishing of wild mink fur, which currently dominate the world fur market, both underwent experimentation and selection similar to current activities in the establishment of possum fur production (Pearson, 1987a).
There is at present only one large-scale commercial fur finishing operation in New Zealand, Kiwi Bear Ltd. This enterprise developed partly from the expertise of A and D Keber, who managed an experimental possum farm and finishing operation for Tasman Forestry Ltd, later developed the venture commercially as Tauhara Furs, and subsequently incorporated their expertise into Kiwi Bear Ltd when it was established in 1987. The Kebers have since severed their association with Kiwi Bear Ltd.

In parallel with the Kiwi Bear development, West Harbour Furs, Waiuku, recently expanded its fitch farming operation to include possum fur finishing, marketing through a subsidiary company, Southern Sable Ltd (Woodd, 1987). In late 1987, Southern Sable merged with Kiwi Bear Ltd, and both the possum and fitch operations were consolidated at Broadlands, near Taupo. The present possum fur finishing operation is still expanding towards a final production of about 3-5 000 pelts every 3 months. The company has licenced access to about 60 000 ha of exotic forest in Tauhara and Kaingaroa forests, and has four full-time trappers catching possums alive. The value of each trapped animal is assessed on its current worth and its potential return after 3 months' cage finishing. Animals for meat production have to be kept a minimum of 14 days (see later). Annual production should be about 20-25 000 pelts (R. MacGibbon, pers comm). The furs will be sold directly overseas, not through the auction system. Improved marketing, including production and promotion of finished fur garments using expertise of Southern Sable's master furrier, is seen as vital if they are to obtain the premium prices necessary to support the enterprise. Prices obtained from trial shipments suggest that $40-50 might be expected (Laurenson, 1987; Woodd, 1987). Fur finishing on a large scale will increase the numbers of top grade skins produced, influencing market perception of possum as a fur, and probably helping to elevate prices (MacGibbon, 1986).

Improve returns from possum farming and fur finishing

The returns from possum farming could be increased by research on:

- Increasing reproductive output of possums
- Improved husbandry of lactating females
- Artificial diets and conditions for early weaning
- Alternative maintenance diets
- Techniques to reduce capture stress, and stabilise social behaviour.
- Selection of individuals for size, coat colour, and fur qualities.
- Analysis of factors affecting fur growth and replacement.

MAF at Ruakura have been actively researching possum reproduction since 1982. Their work has concentrated on inducing females to produce young at regular intervals, and fostering such young to surrogate mothers, control of oestrus using progesterone, induction of multiple ovulation by hormone injection, and the potential use of melatonin to alter natural patterns of fur replacement (Pearson & Ashby, 1987; A. Pearson, pers. comm). Nothing is known about the nutritional requirements of lactating females, although their food intake probably increases about threefold during lactation, and milk production changes from <1 ml/day to >50 ml/day (P. Cowan, unpubl. data). Young are usually weaned at about 6 months; if they could be weaned on to an artificial diet at 4 months, reproductive output could be increased. Changes in the composition of possum milk during lactation (P. Cowan, unpubl. data), and the young possum's inability to control its body temperature before then (Gilmore, 1966) probably preclude weaning of young less
than 4 months old. Chai (1984) identified significant savings of green feeds over pellets or mash diets, and MAFTech are currently also investigating alternatives to lucerne as a maintenance diet. Capture stress may result in animals losing up to 20% of their body weight immediately after capture, and requiring up to 7 weeks to recover (Pearson, 1987a). Information is needed on optimum group sizes for mating and holding - at present, damaged pelts and even deaths are common from fighting or stresses induced by group housing of what is basically a solitary animal.

The greatest long-term potential for possum farming lies in the breeding of selected individuals. Production of large-sized skins could be enhanced by selection of suitable breeding stock. Possums vary greatly in size around New Zealand, with a north to south trend towards larger animals, and dependent on whether they were derived from mainland Australian or Tasmanian stock (Triggs, 1987); possums on the west coast of the South Island are generally larger than average (Cowan, 1988). Improved nutrition of lactating females results in faster growth of young and an earlier attainment of suitable size for harvesting (Pearson, 1987a,b). Although nothing is known of the genetics of coat colour in possums, true-breeding colour morphs could probably be established using wild stock from selected areas of New Zealand; e.g., on the west coast of the South Island, there are areas with only dark-furred possums, whereas on the sand-dune country around Wanganui, only grey-furred animals occur (Cowan, 1988).

Whether the current colour gradings used by the fur trade represent true-breeding colour morphs remains to be established. Occasional colour mutants (e.g., albinos) occur in wild populations, and could provide another basis for development of selective breeding. Fur quality depends on many factors, including fur density, evenness, colour uniformity, length and amount of guard hair, and the general silkiness of the fur. All these factors have proved amenable to improvement by selection in other farmed fur animals, and there is no reason why similar improvements could not occur in farmed possums. Research is being directed at characterising seasonal changes in pelt quality and its controlling factors through study of hair growth, development, and moult patterns (Nixon, 1986). At the current stage of the possum farming industry, priorities lie with increasing reproductive output, and improving husbandry techniques.

Possum fur finishing has benefited greatly from expertise developed by the New Zealand fitch farming industry, particularly in animal husbandry. It is no coincidence that Kiwi Bear Ltd is a joint possum and fitch operation. Labour-saving techniques used in large-scale fitch farming have been directly transferable to possum fur finishing.

To date, fur finishing has mostly concentrated on adult animals because of their ready availability. However, because the moult is diffuse and prolonged (Nixon, 1986), possum fur usually consist of a mixture of old and new fibres. The highest quality pelts are thus likely to be produced by rearing and cage finishing of wild-born young less than a year old. Whether the longer holding period and associated increased costs would be offset by increased skin price is not clear (Pearson, 1987a). The economics of Pearson's (1987a) flow model for management of a possum fur finishing operation could be revised using information gained since Chai's (1984) analysis.

There is much scope for increasing returns from all types of possum furs by revising the grading system. Compared to other furs, the current grading of possum skins is rather crude, based as it is almost entirely on faults and not on quality (MacGibbon, 1986).
Possum furs are graded into six main colours (Table 19); generally dark brown and grey furs fetch the highest prices because they do not have to be dyed before use. Colour gradings are not always obvious. Pales, for example, appear grey until the fur is parted to show a brownish tinge near the base of the fur (S. Dyet, pers comm); regardless of the variable amount of discoloration, all are classed as pales not greys. Two colours, red neck and rusty, may simply represent furs stained with a rust coloration common on the fur of many mature males, and associated with testosterone concentrations in the blood; much of the rust coloration can be removed simply by washing in water (Oldham, 1986). Within any colour grade, fur colour is still variable, and lots auctioned in New Zealand are often regraded into matched lines for resale (MacGibbon, 1986).

First grade skins, regardless of colour, also vary greatly in quality. Promotion of possum fur as a quality product would require splitting the current first grade into at least four quality grades, as with fitch, mink and a number of other wild furs (MacGibbon, 1986; Pearson, 1987b). In addition, it may be necessary to grade farmed and finished furs separately from wild trapped furs, primarily because of lack of quality control on wild furs.

Industry Review

Comer (1985) identified five priorities for action in formulation of an industry strategy. A New Zealand Opossum Industry Board was envisaged operating in a similar manner to the NZ Game Industry Board; its function was to maximize returns from the possum. The NZOFPA currently acts by default as such an organization, but represents only a small number of possum trappers, and action to organize the possum industry is needed.

The need to improve the poor quality of wild possum furs was seen as a top priority. NZOFPA in 1981 attempted to establish a marketing scheme with quality guarantee, based on a system of stamped skins. Trappers who agreed to abide by requirements for pelt handling and preparation were issued with a personal stamp for their skins; a 0.5% levy was to cover costs, and pay any claims from manufacturers or furriers. Stamped skins were sold separately at Dalgety auctions, but the scheme has not been successful because of the small number or participating trappers (which reflects the small number of trappers in NZOFPA) and the small number of stamped skins offered for sale.

For trapped furs, improvements could be achieved by better pelt handling, preparation, and presentation by the trappers themselves. This is largely a matter of education and enforcement, since the main causes of fur slippage are known. But there must also be a scheme for identifying quality furs, such as the NZOFPA scheme, an improved grading system, or a means of identifying skins prone to fur slippage (MacGibbon, 1986).

Farmed or cage finished furs are, naturally, of more reliable quality. This by itself commands a premium, but returns could be increased further by:

- Production of large numbers of skins (20-50000 annually).
- Separate sales of farmed and cage finished furs.
- Improved grading based on quality.
- Direct sales of matched lines of skins.
- Development and promotion of high quality possum fur products.
The market for possum furs is highly elastic – it reacts to current demand (price); as prices rise more skins are sent to auction. Prices are determined by overseas demand and are unrelated to efforts or costs of supply (Comer, 1985; Chai, 1984). Price smoothing could be achieved by such mechanisms as sale by tender, floor price schemes, supplier-controlled auctions, or added value schemes (Comer, 1985).

The current auction system is viewed with some ambivalence by New Zealand trappers (NZOFPA survey, Fur Facts, September, 1982). Trappers were satisfied because they considered they were getting a fairer deal than from private buyers, and the auction was a "proven" way of selling; dissatisfaction was mainly with price fluctuations, lack of control over the fate of their skins, complaints about grading, handling, and presentation, and delays in payment. A number of improvements were suggested, but the only changes have been the introduction of a North Island auction (by NZFA), and establishment of a system of reserve prices and lot withdrawal by Dalgety Ltd (although reserves are set by the auctioneer and not the trapper). The small number of buyers at recent auctions (with each buyer representing several clients) is also seen as acting strongly against the interests of fair prices for trappers.

Possum fur prices will always be subject to fluctuations, as with all other fashion furs, but the key to dampening these changes appears to lie with improved quality and marketing. There has been no large-scale, coordinated attempt from within New Zealand to promote and market possum fur overseas as a fashionable quality garment fur. With improved quality control, an expanded grading system, and a professional worldwide promotional campaign, the value of possum fur could be greatly increased.

The role of education should not be underestimated. Trappers and possum farmers need to improve pelt quality and presentation; New Zealand processors need to improve the consistency of grading, production of finished articles, and the image of possum fur; and overseas buyers and processors need to be convinced of the potential of possum fur as a quality item and as an alternative to more traditional furs. The future development of the possum fur trade should be assisted by the recent NZOFPA moves to join the International Fur Trade Federation. IFTF imposes a 0.6% levy at point of sale; most of the revenue is used by IFTF for fur promotion and research, with about 30% returned directly to New Zealand for such activities.

D.4 POSSUM MEAT

Unlike rabbit, possum meat has never been much eaten in New Zealand. However, trial shipments of the meat were made to the Asian market in the early 1960s, and apparently received with enthusiasm. After 1966, however, further exports were banned because of concern over poison residues and bovine tuberculosis (Keber, 1987).

With the development of possum farming and the possibility of carcass preparation under controlled conditions, the development of an export trade in possum meat to Asian countries has again been explored. The major force behind this move has been Tauhara Furs, and more recently Kiwi Bear Company.

Possum meat is sold in Asia as a "game meat"; such meats are traditionally eaten in the winter months. Meat sales are currently targeted at the Chinese community in Hong
Kong, but there is probably potential to expand into other Asian markets, such as Korea and Taiwan, or ethnic communities in non-Asian countries.

With MAF approval, given only after prolonged negotiation, Tauhara Furs made a trial shipment of frozen possum carcasses to Hong Kong in November 1985. They were exported as an inedible trade sample because no appropriate legislation existed in New Zealand for alternative classification (possums were not defined as animals in the Meat Act 1981). Two further shipments were sent soon after, another from Tauhara Furs and one from West Harbour Furs (now part of Kiwi Bear Company) (Keber, 1987).

Development of the market was halted abruptly when Hong Kong authorities refused to allow further imports of possum meat pending resolution of their concerns that: Possum meat was not eaten in New Zealand; was not officially classed as game or meat under any legislation (particularly the Meat Act 1981) and; although possums can be infected with bovine tuberculosis, there was neither certification of origin of the meat from Tb-free areas nor a specified quarantine period for disease detection.

These concerns have been answered by changes to the legislation related to the consumption of possum meat. The Meat Act 1981 was amended in December 1987 to include farmed possums (farmed = animals that have been in captivity for a set period). MAF prepared a protocol for procurement, slaughter, processing, packing, and export of meat from farmed possums, which also specified quarantine periods and inspection procedures (Keber, 1987). These actions have allowed the resumption of exports of dressed frozen possum carcasses to Hong Kong, with a further trial shipment of about 100 carcasses by the Kiwi Bear Company in February 1988.

Previous models of the economics of possum farming paid scant attention to the meat value of the carcass. For example, Chai (1984) considered only the use of the carcasses as pet food at $0.15/kg. Kiwi Bear Company in its prospectus projected a meat value of $10 per carcass ($6-7/kg), one third of the income from each farmed possum. Annual consumption of game meats (mostly goat, kangaroo, rabbit, venison, and wild pig) in Hong Kong in 1985 was 720 000 kg.

Initially, possum meat is likely to be directed to the restaurant trade to establish a market position, for example as "New Zealand Gouzili", similar to a current delicacy (Kiwi Bear Co. prospectus; R. MacGibbon, pers. comm.). The potential market for possum meat cannot be assessed at present, but has been variously estimated at 20-60 000 carcasses (35-90 000 kg) annually (R. MacGibbon, pers. comm.; Woold, 1987). Seasonal patterns of consumption of game meats in Asian countries may influence both the size and nature of the export trade; Kiwi Bear Company possum farm will produce carcasses at about 3-monthly intervals throughout the year.

Several research contracts are currently in operation between Kiwi Bear Company and MAFTech, Ruakura, and MRINZ, with direct relevance to the meat export trade. Research is directed at two main areas:

- Analysis of possum carcass composition and meat yield, and effects of captivity, husbandry and diet.
- Efficient and humane slaughtering and skinning methods.
The research needs of any commercial operation in this area are likely to be defined by the companies themselves. Kiwi Bear Company are, at present, the only large-scale possum meat producer.

There are two major threats to the further development of the export meat trade to Asian countries.

*Threat of Tb infections:* The continued spread of bovine tuberculosis through possum populations may result in resistance from importing authorities, and additional and costly farm management problems for New Zealand producers. Kiwi Bear Company currently harvests its possums from the Tauhara and Kaingaroa exotic forests which are Tb-free. They are, however, greatly concerned about the possible infection of possums in these forests (R. MacGibbon, pers. comm.).

*Foreign competition:* At present, the only other country capable of establishing a possum meat export market is Australia; Tasmania allows controlled harvesting of about 200 000 possums annually (Coulson & Heron, 1982). We know of no moves to establish possum farming in Tasmania, although success of Kiwi Bear Company might prompt such moves. Establishment of possum farming in Australia would probably come up against resistance from animal rights protests, which have had such a marked effect on the sales of kangaroo products. Potential development of possum farming elsewhere is greatly restricted by the current legislation on the export of live possums from New Zealand - export of live possums for breeding for fur farming or resale is prohibited (Wetere *in* Savage, 1985). Successful opposition to the relaxation of restrictions on the export of live possums was largely the work of NZOFPA through submissions to the Minister of Forests.
Fig. 18. A suggested outline scheme to identify national priority regions for possum control, as indicated by the concordance of National Parks, State Forest Parks and reserves, and areas considered to be important for preservation of indigenous vegetation, and Tb control.
E. CONTROL OF POSSUMS AND POSSUM DAMAGE

Introduction (C.L. Batcheler)

"Control" and "management" are commonly thought to be two distinct policies. However, "control" is any action necessary to ensure that the population density is consistent with the "management" objective. Management therefore presumes that the tolerable or desired density is known for the particular situation, and that a technique is available to achieve or maintain that density at acceptable cost.

At one end of the range of management options are such places as Kapiti Island and Codfish Island bird sanctuaries, or areas in which bovine Tb is an economically important problem, where the desired density of possums may be zero. Part-way along the range, are crops, conservation plantings, and commercial plantations which can usually tolerate some possums. At the far end are non-sensitive habitats where the impact of possums may be so small that no formal action is needed except to regulate the rights to hunt.

The indigenous non-commercial forests and scrublands are the most difficult group of habitats to deal with in the range of options. The costs of doing nothing may involve the loss of indigenous plant and animal species and communities, the loss of honey supplies for bee-keepers and the loss or change of landscape values. The problem is that the biological and economic costs are unknown and, unlike cultivated landscapes, the value of controlling possums in natural landscapes cannot easily be evaluated in cost/benefit terms.

The importance of possums to scenic and other non-commercial cultural values has not been addressed in the review, except by passing reference to damage in some indigenous forests (Section C). Integrating all these values into a national priorities scheme for the management of possums in every parcel of land would be quite beyond our resources. Nevertheless, a comprehensive attempt at it needs to be done.

Short of that ideal, the distribution and extent of land which is judged in some way to be worthy of protection from possums indicates the magnitude of the possum management task. The distribution and extent of National Parks, Forest Parks, and other protected natural areas (including Scenic Reserves, Ecological Reserves, Scientific Reserves, and Wildlife Refuges) measures the collective effect of a century of public and scientific opinion regarding areas most deserving of protection (Fig. 18, redrawn from Wassilieff and Timmins, 1984 and Dennis, 1987). There were, as at 1984, 1660 reserves which totalled 4.6 million ha, or 17% of New Zealand. We accept that these areas would be "prime candidates" for protection from damage by possums.

Areas of prime interest to other values are discussed in Section C, and are shown in Fig. 3 (aerial poisoning for protection of indigenous forests and Tb control), Fig. 5 (North Island indigenous forests), and Figs. 6 & 7 (Westland rata/kamahi). Superimposed on Fig. 18 (dotted outlines), they indicate that the following areas must be ranked highly for control or eradication of possums: Aupouri Peninsula - Hokianga; eastern North Auckland coastal pohutukawa; northern Coromandel - Great Barrier Island; Raukumara Range; Central North Island - Kaimanawa Range; Mt. Egmont; Wairarapa - Tararua - Rimutaka Ranges; Clarence - Waiar; Westland; Banks Peninsula; Hokonui - Catlins and; northern Stewart Island. The singular issue of Tb in possums involves some six other areas, mainly in the
South Island. Altogether, the regions delineated as priorities in Fig. 18 amount to 14% of the South Island, 23% of the North Island, and 18% of New Zealand.

E.1 LETHAL DEVICES AND PROTECTIVE BARRIERS

Traps and cyanide (C.L. Batcheler)

Like all wildlife exploitation, harvesting possums entails killing animals and removing the usable skins, organs or other valuable tissues. No matter what technique is employed, many people regard the practice as ethically offensive and unacceptable. Apart from the ethical dilemma, the issues are efficiency and humaneness of the techniques used.

Gin traps and cyanide poison are by far the most important methods of catching and killing possums. Moresby (1984) suggested from personal experience that, of commercial skins sold, 51% and 41% are taken by leg-hold traps and cyanide respectively. Shooting accounts for 6%; cage traps, kill traps, and snares account for the remaining 2%. Of these minor techniques, shooting is too labour demanding and likely to damage the skin; cage traps are exceedingly bulky and expensive; snares are useable in relatively few places and require expert knowledge of the behaviour of possums.

No detailed research has been done in New Zealand on the methodology and relative efficiency of traps and cyanide. It is therefore only possible to observe that both have their advocates and place, and the literature contains many tips on setting traps and bait stations, lures, and the associated bushcraft (e.g., Pracy & Kean, 1963; Moresby, 1984).

Of the two general methods, cyanide poisoning is considerably simpler to use, and is generally regarded as more humane. It kills quickly. Many lethally poisoned possums lose consciousness within a few seconds or minutes of eating or sniffing a bait - often with their nose at rest on the bait; most die within a few metres of the bait; the recorded time to death is 37 minutes or less (Bell, 1972). The principal drawback of cyanide is its tendency, presumably because of its characteristic almond odour, to induce poison-shyness if the possum approaches the bait in a tentative manner, or the cyanide is dissipated by rain. Although these characteristics are often mitigated by careful prefeeding before poisoning, the use of covered stations, or by removing "washed out baits", some hunters assert: "to retain cyanide while prohibiting the trap would, more or less, halve the efficiency of hunting operations and put many operators out of business" (in Reid, 1985) or; "many (hunters in Westland) couldn't make a go of it if traps were banned as poison-shyness is becoming a big problem" (in Reid, 1986). In short, leg-hold traps have many advocates.

Gin-traps, of which the Lanes Ace is the most commonly used brand in New Zealand, with scalloped jaws that grip the leg of the victim, have long been regarded as an outstandingly effective device. They are mechanically simple, robust and durable. They were the "standard" rabbit trap until rabbiting was decommercialised (1951). They are currently the standard possum trap. But they have long been condemned by animal welfare groups as inhumane and have been the subject of at least two petitions to Parliament seeking prohibition of their use.

Warburton (1981, 1982) compared the efficiency and apparent humaneness of six types of traps which might improve on the gin trap, yet inflict less suffering on the victims.
Humane considerations were defined for kill traps: "The target animal (should be) killed outright by destroying the spinal nervous system, or the animal is rendered unconscious and dies by strangulation while unconscious"; and for leg-hold traps: "the target animal is held ... so ... that no physical injury, pain or suffering, is caused to the animal until it is killed".

Warburton found that one alternative smooth-jawed leg-hold trap (Victor) was as efficient as the Lanes Ace. A second (Montgomery) was less than half as efficient. All the leg-hold traps inflicted injuries such as cut skin and broken leg bones (although many possums broke free of the Montgomery so their injuries could not be examined). Kill-traps tested were all less than half as efficient as the Victor and Lanes Ace. Two of them killed all their victims - probably by strangulation - by the time they were found the following day; one occasionally caught the victim across the chest, abdomen or rump. All caused more loss of fur than leg-hold trapping. All killed more wekas than did leg-hold traps (moreover, wekas caught in leg-hold traps could sometimes be released with minimal injury).

Warburton commented that the search for a humane kill-trap was not promising. In Canada, the Federal-Provincial Committee for humane trapping had, to 1978, tested 233 trap designs, all of which failed to produce the impact required to cause humane death in the range of animals likely to encounter them. Although the situation in New Zealand is simpler, with fewer target and non-target species to contend with, "the problem seems no nearer to resolution". However, trials with a recently developed American "soft-catch" leg-hold trap are in progress. These have shown that "soft-catch" traps cause fewer injuries than were found with Lanes Ace gin traps, yet are as efficient. The problem seems to be near solution (B. Warburton, pers. comm.).

The capture of non-target animals in possum traps is also a problem. Reid (1986) recorded the following non-target victims: kiwi, hawk, magpie, weka, robin, tomtit, morepork owl, small brown owl, pigeon, blackbird, thrush, quail, kaka, pig, goat, hare, rabbit, stoat, ferret, weasel, cat, hedgehog, and rat. Of these, the capture and maiming of kiwis causes most evident concern. From a questionnaire survey of possum hunters, Reid (1985) recorded that 5 times as many kiwis were trapped as were poisoned by cyanide, at rates of 1 per 12-18 000 traps set, 1 per 60 000 cyanide baits set, and 1 per 10 800 possums caught. In 1986, he reported that 183 kiwis were injured or killed in a survey sample which represented 475 man-years of hunting. He considered that 70-80% of caught birds were not seriously maimed. He suggested that the surveys revealed a responsible and caring attitude by most professional hunters, who took many precautions against catching kiwis, and that the losses were justified by the contribution of the hunters to preservation of the forest habitat. McLennan (1987) however, suggested that Reid's surveys were likely to be biased by selective or evasive responses of some hunters. He commented on the high proportion of kiwis with missing toes in a research area of scrubland in Hawkes Bay. He suggested that: The apparent risks to kiwi populations were not well enough known to warrant permissive attitudes and; all possible precautions should be taken, such as those at Kapiti Island where wooden above-ground sets were used to eliminate the risk to kiwis.

The advantages and risks to non-target species of commercial harvesting are thus an aspect of possum management about which much is suspected, but relatively little is known. A substantial research input is clearly necessary.
Mechanical barriers (P. Cowan)

Individual trees, telephone, and power poles have been protected against possum damage by metal sheaths fitted around the bole, either at ground level or part-way up. Meads (1976) demonstrated their value for protecting rata trees from possum browsing; similar protection saved fuchsia trees on Kapiti Island (P. Daniel, pers. comm.) and on Stewart Island (J.D. Coleman & C.J. Pekelharing, unpubl. FRC data). Sheaths have been used to protect rata trees on several North Island reserves. Jolly (1980), Nelson (1981) and Pracy and Kean (1963) describe a wide variety of sheath designs for tree protection. The efficacy of plastic and metal sheaths has been discussed for protection of catchment plantings (see Section C; Jolly & Spurr, 1981; Thomas et al., 1984).

Other techniques for control of mammals, such as the use of ultrasound or high-intensity lighting, have not been tested against possums.

Behavioural barriers (P. Cowan, L.R. Crozier)

These types of control methods aim to exploit or adapt the behaviour of the animal concerned. Although possums can swim, they appear generally disinclined to enter water (pers. obs.). No practical tests of the use of water barriers to restrict the movements of possums have been made, although there are many casual observations of rivers, drains, and water-filled ditches acting in that way. For example, Julian (1984) considered that the northwards spread of possums was restricted by the Awanui River and the network of drainage outfalls north of Kaitaia; the movements of radio-tagged possums in Hawke's Bay were limited by water-filled ditches, which were only crossed if a bridge was available (Brockie et al., 1987a); possums first crossed many rivers (e.g., Wairaurahiri River, Southland, Kokatahi River and Copland River, Westland) only after they were spanned by bridges (J.R. von Tunzelmann, L.T. Pracy, M.F. O'Reilly, pers. comm.). The barrier effect of rivers is so widely recognised that, wherever feasible, major control operations use them as block boundaries to minimise re-colonisation of the treated area.

Many investigations of the use of repellents for protecting orchards and plantations have been reported (see Knowles & Cooper-Benson, 1975). In New Zealand, repellents for sheep were tested by the Forest Research Institute (Knowles & Tahau, 1979). Rabbit repellents have been tested at the Soil Conservation Centre, Aokautere (Stace, 1986; 1987a). Egg-based repellent mixtures in acrylic resin adhesive or acrylic paint, thiopel, mutton fat and kerosene, and fish fertiliser with an adhesive, protected pine seedlings from rabbits and hares over a 7 month trial. Possum pen trials with the same repellents resulted in concentration of browsing on untreated seedlings (Crozier, 1987; Crozier & Ledgard, 1988). Soil and Water Conservation Centre, Aokautere, are also evaluating several adhesive-based products to deter possums from climbing and damaging poplar and willow poles (R.L. Hathaway, pers. comm.).

Recently, there has been interest in the large-scale use of electric fencing as a means of restricting possum movements. Unlike physical barriers, electrified wires create a barrier of pain or fear which, with experience, the animals learn to avoid. Various fence designs incorporating electrified wires have been used by possum farmers to contain free-ranging possums (Giles, 1981), though none are totally effective at preventing escapes. Electric fencing was evaluated by MAF Auckland in 1986, and is currently under test by DSIR for
MAF in the Central North Island. The use of electric fencing was proposed by MAF as an alternative to aerial 1080 poisoning in some areas for the establishment of buffer zones to control the spread of bovine Tb in possums. Although electric fences appear to be effective in restricting the movements of possums, full evaluation awaits a detailed cost/benefit analysis. Preliminary results indicate that electric fences may efficiently protect individual farms or crops.

E.2 COMMERCIAL HARVESTING (C.L. Batcheler, P. Cowan, B. Warburton)

The effect of commercial harvesting

Although four trials have clearly shown that commercial hunting techniques can be used to reduce or eradicate possums from forest areas up to 2000 ha (Batcheler et al., 1967; Cowan, 1985, 1987 unpubl. data; Coleman et al., 1980; Morgan & Warburton, 1987) there has been a long-standing debate as to whether and where commercial harvesting contributes significantly to the control of possums in New Zealand.

The total number of possums in New Zealand has been estimated as 60-70 million (Section A). The maximum sustainable yield (MSY) of possums - i.e., the maximum number which can be harvested without forcing the population into decline (Caughley, 1977) - has been variously estimated for native and exotic forest as 2 million (Clout & Barlow, 1982), 3.1 million (Barlow & Clout, 1983), and 3.2 million possums per year (Keber, 1985). For the whole of New Zealand, including farmland and scrubland, the MSY may be 5.3 million (calculated from Clout & Barlow, 1982), 8.2 million (calculated from Barlow & Clout, 1983) or 10.7 million (Keber, 1985). Harvesting at MSY would reduce current densities to about 60% of their present levels (Barlow & Clout, 1983).

Numbers of skins exported do not directly represent numbers of possums killed since trappers discard varying numbers of low grade or damaged skins, depending mainly on prices (Woodcraft, 1987). In 1982, a survey indicated that trappers discarded an average of 7% of their catch before skinning (NZOFPA, Fur Facts, September 1982). Therefore, making some allowance for discarded skins, the average of 2.5 million possums harvested during 1978-81 was of the order of the MSY for forest habitats, but was well below MSY figures for the whole of New Zealand.

Towards the end of the peak period (1978-81), Clout and Barlow (1982) reported that "some populations have been exploited hard enough to change their composition, and in many areas possum numbers have declined significantly: e.g., Kaingaroa State Forest, where the catch of possums per permit issued declined by 50%; there were many informal reports from possum hunters of declining populations (see also Keber, 1985); the 1979 National Possum Survey indicated that possums had declined in many areas (APDC, 1981, see Fig. 2); a higher proportion of small skins was sold after 1978."

Brockie (1982) demonstrated the effect of trapping in a block of indigenous forest in the Orongorongo Valley, Wellington. Where possums were hunted commercially, they were being held at about half the density that occurred in a contiguous research block where hunting was not permitted.

By 1980, the perceived impact of commercial operations in more accessible country persuaded the NZ Forest Service that non-commercial operations in exotic State Forests
were rarely warranted on silvicultural grounds (Miers in APDC, 1981). Such evidence and
the lack of pressures from farmers and catchment authorities for more effective control
suggests that, overall (except where Tb occurs), possum populations are being adequately
controlled in the more accessible country.

For more remote or heavily forested country, there are four broad lines of evidence to the
effect that commercial hunting is not effectively controlling populations:

- Although reduction of possum numbers and reduced skin sizes were observed in
  the 1979 National Survey, and were interpreted by Clout and Barlow (1982) as
evidence of over-harvesting, it seems equally or more likely that these trends were
due to widespread "post-peak collapse" of populations after the 1940s (see
  Section A).
- There are persistent reports of possum populations declining through malnutrition
  rather than hunting pressure, even in relatively accessible country: e.g., the report
  from a commercial hunter at Galatea (east of Kaingaroa Forest) who noted: "no
  great fortunes were made in these parts, as ... opossums on my block were dying
  from starvation" (Comer, 1985).
- Evidence of increasing numbers of possums and damage to the forests of North
  Auckland, Coromandel, Raukumara, West Taupo, and other accessible tracts of
  forest (see Section C; I.J. Payton).
- Evidence of continued widespread increase and spread of possum populations, and
  possum-induced dieback in Westland rata/kamahi forests, despite the absence of
  constraints on commercial harvesting (Rose et al., Section C).

Making more use of commercial hunting

Some observers have suggested that the effect of commercial harvesting could be enhanced
by State intervention and support measures for the industry.

Moore (1986) suggested that in addition to the price of skins, several other factors
influence the intensity of private commercial hunting. These include: A profitable density
of possums, restricted access, vehicle and foot access, travelling time, and available
accommodation. Keber (1986c) suggested that, because "violent fluctuations in price over
the past few years ... has discouraged stability of (hunting) effort", some consideration
should be given regulations which would facilitate the following:

- "Price support by a Government agency ... to achieve a pre-determined offtake.
- Price support by a Fur Board ... in the same manner as other Producer Board income
  stabilisation schemes.
- Support buying at auction by a Fur Board ... by bids ... against other buyers.
- Some investment by a Fur Board in marketing.
- Some type of tenure for proven operators ... so that critical areas have a constant
  offtake of animals."
Fig. 19. Linear and quadratic predictions of average prices required to achieve a commercial harvest of 10 million skins, the approximate MSY of the total New Zealand possum population. The data points are those shown in Fig. 16b.
NZOFPA is actively involved in negotiation with landowners and pest control authorities to obtain the maximum possible involvement of OFPA-registered hunters in possum control schemes. The Association suggests that preference for OFPA-registered hunters will give the prospective employer some assurance of the technical competence, code of ethics and accountability of the hunters, in exchange for improved hunting block tenure, protection against poaching, and the hunters' longer-term prospects of harvesting better quality furs (Moore, 1986).

A price support model

The evidence which shows that the numbers of skins exported depends on the average price has already been presented. In CPI terms, the skin export data for 1963 - 1985 suggest that the harvest would peter out if the average value dropped much below $5 per skin (1987 values, see Fig. 16b). Above $5, exports increased by 247,000 skins for each $ increase of average value. Using Keber's straight-line prediction model, an export target of 10 million skins (about the MSY of the NZ-wide possum population) would require an average price of $45 per skin. Alternatively, if the increase in commercial hunting were to follow a quadratic model, the harvest per $ would accelerate with higher prices, and a harvest of 10 million would eventuate at $31 per skin (Fig. 19). Using the 1985 base of 1.38 million skins, at $8.8 average, the straight-line and quadratic models require something in the order of $190-$310 million of extra financial returns to attract enough effort to harvest the MSY and reduce the New Zealand-wide population to around 60% of the present density. These costs would be equivalent to $8-$14/ha over the 23.7m ha of possum-occupied country in New Zealand.

Morgan and Warburton (1987) recently studied the effectiveness of subsidised commercial hunting at North Pureora (central North Island) to assess its effectiveness for controlling tuberculosis possums, and compare it with 1080 aerial poisoning. Five hunters were employed to control the possums on 1434 ha of indigenous forest. In a contiguous 7000 ha block, conventional 1080 aerial poisoning with cereal pellet bait was used. They found that both the hunters and aerial poisoning killed about 80% of the populations at risk.

In discussion of the North Pureora trial Morgan and Warburton (1987) pointed out that the hunters achieved half of their kill profitability, at an average catch rate of 8.2 possums/hr. If 9 possums/hr is accepted as a profitable rate of harvesting, the cost of subsidising hunters to obtain the same kill as obtained by 1080 poisoning would be $16.45/ha. If 6 skins/hr is acceptable, the required subsidy would be $4.92/ha. The income from skins taken in achieving the 80% kill, plus a subsidy of $16.45/ha, brought the estimated operational costs of hunting to the same level ($20/ha) as was entailed in 1080 poisoning in the adjacent block.

Higher populations may be tolerable in many protection forests than was required at North Pureora. In these forests, commercial hunters may be able to maintain populations at required densities with lower subsidies than those needed at Pureora. Regular harvests would maintain the populations at a more constant level than is achieved by large 1080 operations at longer time intervals. The desired population levels require accurate determination, particularly for the more vulnerable types of indigenous forest.

The export market for skins is unlikely to yield increased returns of the order required for commercial hunting to (theoretically) control possums throughout New Zealand.
Therefore, additional inputs must inevitably be derived from subsidies of some kind. But, as shown by the extrapolation models, the estimated NZ-wide totals are so large that it would be naive to expect subsidies to be politically acceptable except where priorities for conservation, Tb control, or other purposes are high enough to warrant State involvement.

Direct subsidies of individual "commercial/control" operations would therefore involve guarantees and checks on the performance of the hunters, and the costs of this monitoring must be included in the overall costs of the subsidised commercial harvesting option. At Pureora, the cost of pellet counting (the only accurate technique available) came to about $14,000. Thus the overall cost to the State of the subsidised commercial option was about $26/ha. Similar monitoring in the 1080 block brought the estimated total cost of the 1080 operation to $22/ha. However, the North Pureora hunting block was much smaller than the poison block, and the amount of sampling per unit of area diminishes as size of the block increases. If hunters were as effective over very large areas (>10 000 ha), the cost/effectiveness of hunting could compare favourably with 1080 operations. In addition, the hunters involved at Pureora acknowledged that their work could only be considered a viable Tb control option in other similarly accessible country. In less accessible, rougher terrain, the costs would be much higher.

Overall, we conclude that, at least in accessible country, commercial hunting is a viable means of managing and controlling possums.

E.3 LARGE-SCALE CONTROL OPERATIONS (D.R. Morgan)

1080 poisoning and its problems

When physical and economic boundaries limit the effectiveness of commercial harvesting, and an abrupt reduction of possums is required, the State agencies (APDC, NZ Forest Service to 1987, now DOC) have favoured the use of aerial poisoning with compound 1080 (sodium monofluoracetate) since the early 1960s. Phosphorus in hand-laid jam bait may be used, particularly where dogs are at risk; the efficacy of brodifacoum in cereal baits or a cereal/wax bait is currently being evaluated by MAFTech; cyanide is rarely used.

The usual aerial poisoning procedure, using fairly primitive carrot bait cutters and fixed wing aircraft, was to sow up to 40kg bait/ha, in the belief that each target possum would then find a lethal quantity of bait within a short compass. Such high application rates lead to the technically absurd situation where there was sometimes a greater weight of bait on the ground than of possums to eat it (Batcheler, 1982; Morgan et al., 1986). Nonetheless, many operations were believed to be highly effective.

But of 20 operations monitored during the 1950s to 1970s, one killed less than 50% of the possums, 10 killed between 50 and 80%, and nine killed more than 80%; the average was 75% (Batcheler, 1978). Of 11 operations monitored during the 1980s, one killed less than 50%, eight killed between 50 and 80%, and two killed more than 80%; the average was 71% (D.R. Morgan, unpubl. data).

With such variable effectiveness, poisoning has to be repeated every 5-15 years to contain a population at tolerable levels. After a 70% reduction, a possum population on average can be expected to recover to 90% of its former level in a minimum of 10 years: if the kill is 90%, recovery will take 14 years (Spurr, 1981).
Despite the 30 years' experience of applying vast amounts of highly toxic bait material to possum populations, and wide recognition of the importance of effective operations, little headway seems to have been made with the art of aerial poisoning from the 1950s to 1980s. Weather, condition of the animals, and other factors beyond the control of operators can adversely affect poisoning. However, some factors can be controlled; they include choice of bait materials, toxicity and uniformity of baits, and distribution and density of baits.

Acceptance of bait: Dislike of bait materials such as carrots and cereal pellets was once considered to be the most frequent and likely cause of failure. However, 13 of 14 acceptance trials using four "popular" non-toxic baits dyed with Rhodamine B have shown that at least 94% of possums ate bait regardless of the type encountered (Morgan, 1982; Field, unpubl. data; Morgan, unpubl. data; Thomas, unpubl. data). The only unsuccessful trial was one conducted in summer when natural foods were abundant. Typically therefore, palatability of bait does not appear to be a key problem. Development of new bait formulations is therefore not warranted on grounds of supposed poor acceptance of currently available bait types. However, as pellet baits now cost up to $2000/tonne, there is good reason for seeking cheaper alternatives.

Acceptance of poison 1080: The reputation of 1080 as a "colourless, odourless and tasteless poison" (McIntosh, 1958) has not survived close scrutiny. Pen trials have shown that some possums can detect and reject 1080 through both smell and taste; e.g., in one trial, carrot baits doped at 0.15% w/w were rejected by 28% of possums, and 0.2% w/w 1080 pellets were rejected by 34%. This aversion, and consequent survival, was eliminated in trials by inclusion of cinnamon or orange oils with the 1080 (Morgan, 1982; Morgan, unpubl. data).

Bait size and toxicity: Lack of uniformity of bait size is a general problem. Often as many as 90% of the bait particles present in a poisoning area were sub-lethal (particularly unscreened carrot bait) (Batcheler, 1982). Since possums quickly lose their appetite after consuming sub-lethal quantities of bait, a high proportion of sub-lethal baits leads to a high probability that individuals will survive. This probably increases if there is little or no more toxic bait in the immediate vicinity of the sub-lethal fragment already encountered (Batcheler, 1982; Morgan et al., 1986). This problem has been largely resolved by improvements in bait production machinery, sieving out small particles, and more consistent application of 1080 to baits (Batcheler, 1987; Hough, unpubl. FRC report). However, obsolete machinery and inferior standards of bait production are still being used in many possum control operations.

Bait distribution: Uneven distribution of bait is the most common limitation to efficient poisoning. Three operations, in which swathes of bait were present on 52%, 62%, and 79% of the blocks, gave kills of 62%, 70%, and 80% respectively. The kill clearly depended on the proportion of the ground sown with bait.

Aerial sowing trials also indicated that sowing rates can be reduced if coverage is improved. A helicopter and underslung bucket was used to carefully sow non-toxic rhodamine-dyed pellet baits at 3, 5, and 10 kg/ha on three 100ha blocks of a pine forest. Over 95% of the possums on all blocks found and accepted the bait. In a similar trial in which alternate 50m swathes were left untreated, a significantly smaller proportion of the possums took bait (Morgan, unpubl. data). Moreover, since bait was still imperfectly
distributed in all the blocks, further savings could be made if machinery was developed to sow bait uniformly at less than 3 kg/ha. Even such low application rates expose possums to 500–750 baits/ha, assuming good quality bait with an average weight of 4–6g.

Better distribution seems most likely to be achieved by using aircraft navigation guidance systems, which have improved the uniformity of fertilizer application over pine plantations (Hedderwick & Will, 1982), and the development of improved sowing equipment.

Assuming that such problems can be solved, the potential savings from improvements in bait quality and sowing would/should be compounding. If bait can be more uniformly spread, sowing rates can probably be reduced by at least 50%. If the interval between operations could be doubled, the long-term cost could perhaps be reduced by about 75%.

Alternatives to 1080 poison

Although 1080 has won general acceptance as the outstanding pesticide over more than 30 years of use, improved effectiveness and lower operational costs can be expected as a result of further research and development. For the present this seems to be the most likely way of improving possum control.

However, while New Zealand possum control continues to be based on chemicals, the development of many other vertebrate pesticides, particularly for the control of rodents, cannot be ignored. The anticoagulants Brodifacoum (Kaukeinen & Rampaud, 1986) and Bromadiolone (Poche, 1986) are potentially less hazardous to non-target species, and vitamin K is an effective antidote (Godfrey, 1984). Bromethalin (Jackson et al, 1982), an "oxidative decoupler", apparently poses little hazard to dogs, wildfowl, or fish. Reserpine, a sedative hypnotic, and Vacor (recently withdrawn from the US market, P. Cowan, pers. comm.), which inhibits niacinamide metabolism, are older poisons considered to be potentially suitable for possum control (P.J. Saverie, Denver Wildlife Research Centre, pers. comm.). If improvements in 1080 operations prove elusive, or if non-target poisoning becomes more problematical, these options should be considered as the next line of approach in chemical control. Evaluation of Brodifacoum for on-farm use has already begun at MAF Tech, Lincoln.

Other potentially useful forms of chemical control in the longer term are: Chemosterilants; pheromones (which may enhance bait consumption, Morgan, unpubl. data); and species-specific compounds designed to interfere with unique metabolic pathways in animal pests.

It is important to acknowledge, however, that New Zealand is unlikely to be able to afford the luxury of investigating new compounds merely for the sake of change. Proposals for new methods must be aimed at solving clearly defined deficiencies of existing procedures because, as found in toxicological research world-wide, the required investment to register a new compound are high, and the chances of successful product development are very uncertain. In our view, the only justification at present for evaluating alternatives to 1080 in New Zealand is to reduce the hazard to non-target species, particularly farm dogs.

Problems with poisons regulations (D.R. Morgan and B. Warburton)

Poison 1080: The Agricultural Chemicals (Vertebrate Pest Control) Regulations 1977 give legal authority to the use of 1080 and cyanide poisons in controlling possums. These
regulations are pursuant to the Agricultural Chemicals Act 1959. This act has now been replaced by the Pesticides Act 1979 (see Second Schedule) but under the Transition provisions (section 54) of the Act, licences for the use of poisons granted under the VPC regulations are deemed to have been issued under the Pesticides Act. It is important that the necessary amendments be made to the Pesticides Regulations 1983 to include the supply and use of 1080 and cyanide. This was obviously intended at the time of the enactment of the Pesticides Act 1979, as vertebrate pest poisons were the only substances listed in its first schedule.

The VPC regulations are adequately designed to protect human health. However, if landholders are to be encouraged to assist in possum control (in cases such as Tb control), it will be necessary to amend regulation 4. Under the current regulation, landholders are not "employed directly in the control of vertebrate pests" and cannot legally acquire 1080 poison (regulation 5) or use it, except under the supervision of an approved operator. "Self-help" schemes would require some amendment of regulation 4 to enable licensed operators to include users other than employees of state pest control agencies.

If, as an alternative to self-help schemes, landholders are encouraged to use 1080, or cyanide, under the authority of a licensed operator, they should be required to indemnify the authorising agency from any liability resulting from use of the poison as practiced in Australia.

A worthwhile addition to regulation 8 would be a practical 1080 mixing test as part of the examination for the operator's licence, as in Australia.

Cyanide: The use of cyanide is controlled by the Pesticides Act, under which it can only be used by a certified "approved operator". At present, about 18 000 people are licensed as "approved operators". The licence is "for life", and we are aware that the system is often abused. Such abuses would be better controlled if licences were revoked every 2-3 years and re-issued only upon application and payment of a fee. The fee should be sufficient to defray administration costs.

Valuable information about regional and individual uses of cyanide could be gathered if sales were collated by the governing authority (Pesticides Board) and made available for public use.

E.4 DISEASES, PARASITES, AND BIOLOGICAL CONTROL (R.E. Brockie)

Introduction

Mammalian populations are invariably infected by parasites and diseases, with varying consequences. The geographic distribution of hoofed animals throughout Africa today was probably set by a rinderpest pandemic last century (Pearsell, 1956). The effects of foot-and-mouth, rabies, and anthrax on mammals are well-known, but diseases and parasites are also major mortality factors in many lesser known situations. Lungworms are the main cause of death in North American bighorn sheep (Forrester, 1971), and in Sweden, sarcoptic mange controls the density of fox populations (Lindstrom & Morner, 1985). In Russia, roundworms control hare populations, tularemia and pasteurella control small rodents, and sarcoptic mange controls fox populations (Naumov, 1972). The effects of
parasites and diseases may be amplified by other factors, such as density and food shortage which explains the often erratic or periodic effects of infections.

Biological control has often been used successfully against plant and invertebrate pests, but there are few examples of such control of mammals. The most spectacular case was the introduction of myxomatosis into Europe and Australia. Myxomatosis initially reduced rabbit populations by up to 99% over large areas, and completely eliminated them from some small islands (Flux, in press). However, the virus failed to establish in some areas, and 20-30 years later, its virulence has attenuated, the rabbit's immunity has increased and, in some areas, rabbits are almost as numerous as ever. Cat flu (feline leucopenia) was successfully used to help control wild cats on Little Barrier Island and reduced wild cat numbers on Marion Island by 70% (van Reusburg et al., 1987). Unsuccessful attempts were made to control rabbits in Australia with chicken cholera last century and attempts to control rodents with pasteurella failed. These are the only examples we know of the use of diseases or parasites for biological control of mammal pests. Biological control using introduced predators has also been attempted (e.g., Uchida 1969a,b). In New Zealand, the introduction of mustelids was a vain attempt to control rabbits and hares, with disastrous consequences for the native fauna (King, 1984).

Possum parasites and diseases

**Australia:** Potkay (1977) and Presidente (1982, 1984) list the following parasites and diseases from brushtail possums in Australia: Murray River encephalitis; Salmonella; Staphylococcus; Toxoplasmosis; pneumonia (*Fusobacterium necrophorum*); thrush; the balcanica strain of Leptospira; Sarcocystis; Coccidia; 21 species of nematode; 2 species of tapeworm; 1 trematode; 11 ticks; 8 mites; 10 lice; 7 species of fleas. Brushtail possums have also been experimentally infected with bovine tuberculosis, foot-and-mouth disease, Chargas disease (*Trypanosomiasis*), and kalar-azar (*Leishmaniasis*).

**New Zealand:** Possums in New Zealand are hosts to far fewer parasites and diseases than in their native Australia (Table 21). These include a viral infection (Whataroa fever); bovine tuberculosis; Yersinia; Golden Staphylococcus; the balcanica strain of Leptospira; an unidentified Coccidia; three species of ringworm; lung infections due to fungus (*adiospiromycosis*); six species of roundworm; the tapeworm *Bertiella*; three species of fur mite; and the sheep liver fluke. New Zealand possums have also been experimentally infected with human influenza virus, hydatids, and the dog ascarid.

There is no evidence to link any of these parasites or diseases with the natural regulation of possum populations in either Australia or New Zealand. The only possible exception is the unsubstantiated suggestion that populations of ring-tailed possums in Tasmania were decimated in the late 1940s by an unidentified disease (Green, 1973).

Prolonged and detailed studies have been made on possum population dynamics in a wide variety of habitats, and over a wide range of densities in both Australia and New Zealand (see Section B). In all these studies, the populations were thought to be limited by food supply, social interactions, or the availability of den sites. Population control has never been attributed to diseases or parasites as for some other mammal species. Indeed several New Zealand and Australian authors have commented on the rude health of possum populations and the small load of parasites. Given that possums are ubiquitous in urban areas, it is also fortunate that few of their parasites and diseases are transmitted to people.
Large numbers of *Bertiella* tapeworms and fur mites sometimes infect animals in late winter or early spring when possums are presumably weakened by starvation or exposure. *Bertiella* infection also is associated with reduced fat reserves (Warburton, 1983). Yersinia, Salmonella, Coccidia, and Adiopirosporomycosis appear in large numbers only in the crowded conditions of captivity (Hutton, 1979).

Wild possums appear well adapted to resist their Australian parasites and infections. Although additional possum parasites or infections might be brought over from Australia, these are unlikely to regulate possums in New Zealand any more than they do in their homeland.

**TABLE 21. Numbers of parasites and occurrences of major diseases of possums in Australia and New Zealand**

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ectoparasites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fur mites</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Lice</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Ticks</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Fleas</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td><strong>Endoparasites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protozoans</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Cestodes</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Trematodes</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Nematodes</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viruses</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Rickettsial infections</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Mycobacterium bovis</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Other Mycobacteria</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Leptospirosis</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+ present
- absent
* not recorded in Tasmania

*Bovine Tb in NZ possums*

When bovine Tb was first recognised as killing New Zealand possums, and the animals had little resistance to the infection (Julian, 1981, see Section C), some observers thought it might reduce their numbers. Twenty years later, although the prevalence of tuberculous animals may be locally high, we have no evidence of the infection reducing the densities of possum populations. Along the margins of the Hauhungaroa forest for example, where
up to 40% of animals were infected in some small areas, Barlow (1987) concluded that "M. bovis appears to have little measurable effect on the possum population".

This apparent failure can be explained by Anderson and May's (1979) model of infectious disease dynamics: To regulate a host population, the case mortality rate must be high relative to the intrinsic growth rate of the disease-free host population. This condition may not be met among possums with bovine Tb because the death rate from other causes outstrips that from bovine Tb. On Hawke's Bay farmland, for example, half the possums alive at any time disappear from "natural causes" within 4–8 months without any human intervention (R.E. Brockie, unpubl.). If the incubation or latent period for bovine Tb in possums exceeds 6 months, half the infected animals may disappear before the infection manifests itself, or before neighbouring possums can become infected - so reducing the rate of spread of the disease. In other words, starvation, social factors, or a shortage of den sites probably pre-empt Tb as the main mechanism for regulating populations.

Exotic infections

As no natural pathogens appear to regulate New Zealand possum populations, and possibilities of genetically engineered organisms remain remote, possible agents for biological control of possums must be sought elsewhere. A logical place to start would be with related marsupial species.

Koala chlamydia (Chlamydia psittaci serotype koala): Brockie (1986, tabled at TAC meeting 1987) outlined the case for introducing this pathogen to New Zealand. Since then, more information has been published on the infection in koalas, which further supports its potential as a control agent against possums.

- Its DNA characteristics set it distinctively apart from other serotypes of C. psitticae (Brown et al., 1987). The infection is specific to koalas but S. Brown thinks its pathogenicity might stretch to other marsupials.

- Because it is venereally transmitted between koalas, its spread to other species may be reduced.

- Although the infection is widespread in koalas throughout eastern Australia, it has not infected farm stock or other native animals. This reduces the likelihood of the infection spreading to non-target species if it was introduced to New Zealand.

- The infection impairs the reproductive capacity of koalas. Anderson and May's (1979) general epidemiological model shows that an infection which impairs its host's reproductive capacity is more liable to suppress population growth than an infection which kills its host outright.

Brockie (1986) suggested that the infection be tested on possums and non–target species in Australia before being evaluated for possible introduction to New Zealand. MAFQual have contracted S. Brown, World Koala Research Corporation, to undertake preliminary tests to establish the response of possums artificially infected with koala chlamydia.

If the koala chlamydia fails, 70 South American marsupials remain to be investigated as sources of biological control agents; for example, the South American opossum chlamydia
('Opossum virus *A didelphis*, 'Opossum virus *A caluromys*, and 'Opossum virus B') kill South American opossums and experimentally infected mice, but not experimentally inoculated guinea-pigs or pigeons (Rocca-Garcia, 1949, 1967).

South American marsupials harbour 21 species or strains of arbovirus (Potkay, 1977), some of which might also be investigated as potential biological control agents. The epidemiological parallels between these infections and myxomatosis, also of South American origin, give some cause for optimism.

Recent developments in molecular biology have raised the possibility of genetically engineered organisms for pest control. Advice was sought from J.D. Watson, Auckland Medical School. He thought that it would be impossible with present technology to alter the virulence, pathogenicity, or infectivity of bovine Tb or any other viral or bacterial organism to create a suitable agent for the biological control of possums. However, progress is currently so rapid in these fields of research, that such possibilities should not be discounted during the next 10 years.

* Caveat

Ecological disasters could be averted by conducting laboratory and field trials of prospective pathogens in their homelands - Australia and South America. Only after pathogens have been tested in those continents against possums and non-target species should consideration be given to their introduction to New Zealand. Even then, they should be introduced progressively onto small and then larger offshore islands, before being released on the mainland.

With so few examples to work from it is hard to predict the likely effects of new pathogens on the New Zealand possum, but if possums further threaten our indigenous forests and the 4 billion dollar cattle and venison industries, and poisons and traps fail to contain the animals, every possible remedy should be investigated.
REFERENCES


Batchelor, C.L. 1962. Record and perspective of the proceedings of the meeting to discuss the noxious animal problem in New Zealand, 1958. 48pp.


Forest Research Institute Report 1975 (p.72)

Forest Research Institute Report 1976 (p.71)

Forest Research Institute Report 1977 (p.65)

Forest Research Institute Report 1978 (p.64-5)


Ogle, Colin.; Wilson, Peter 1985. Where have all the mistletoes gone? *Forest and Bird* 16(3): 10-3.


