# 1

# Introduction

Pests can be defined as organisms that cause harm: economic, environmental or epidemiological. Cherrett *et al.* (1971) defined a pest animal as one which is noxious, destructive or troublesome to humans. Woods (1974) qualified the definition to incorporate a requirement of causing economic damage. Today, vertebrates cause problems in agriculture: to crops, to livestock, in and around buildings and other equipment and by spreading diseases. Problems also occur in forestry, in conservation of plant and animal species and communities, in urban industry and in our own homes.

There are difficulties, however, in defining a pest (Harris, 1989). Is it that coyotes kill sheep or the number of sheep killed that causes coyotes to be called a pest? Answering this question is partly a social issue but also a scientific issue. This book is about the science of evaluating vertebrate pest control with particular emphasis on mammals and birds as pests; how to analyse whether populations of vertebrates really are pests and how to plan and assess what is achieved by pest control. It is not, however, about how to control vertebrate pests. For example, the book is not about how to control rats and mice, but describes how to determine if they are pests, and if so, how to estimate what is achieved by control.

Worldwide in scope, the book describes and critically reviews the literature on a range of analyses used in vertebrate pest research and management. The review draws on theories and analyses used in other scientific disciplines, shows their relevance to vertebrate pest control and how they are or can be utilised. In particular, predator–prey theory in ecology, and the theory of disease spread in epidemiology, are examined.

Statistical, economic and modelling analyses are described, with examples, that cover the spectrum of damage by vertebrate pests, and the methods used to control these pests. The analyses help identify the effects of pests, examine the ecological and economic levels of those effects and analyse the effects of control on the pest populations and their impacts. Hence, the book will assist in pest control decisions that have a scientific or economic basis. The details of the use of control methods, such as poisoning, trapping, shooting, fencing and habitat manipulation are covered in many references, for example, Timm (1983) and Breckwoldt (1983). The control methods used can be influenced by practical experience, as well as broader social, legal and technological factors. For example, the enthusiasm of some people for pest control may be related to some dark overtones in history reflected in the origin of the word 'pest' from the Latin word '*pestis*' meaning plague or contagious disease (Cherrett *et al.*, 1971).

A distinction between the effects of control on pests and on damage is fundamental to the book. I have observed that societies are more interested in the economics of damage control than the statistics of pest control. My reading of the literature is, however, that scientists have the reverse priorities. One implication for writing this book is that there is vastly more information available on the statistics of pest control than the economics of control, so the chapter 'Economic analysis' is thinner than I would have liked. There are simply fewer examples to write about.

The book is structured to answer several questions. Firstly, does the species of concern actually cause any damage (Chapter 2)? If it does, how can the effects of subsequent control be estimated, in terms of the level of impacts and abundance of the pest? This is described in Chapter 3. Is control economical? This question is addressed in Chapter 4. How can we model the population dynamics of pests and their damage? These are described in Chapter 5, while Chapter 6 describes how to model control, the process itself and its effects on pests and damage.

The conceptual framework used (Table 1.1) describes the variables estimated by research and the types of analysis. The variables estimated are usually one, or more, of the level of pest damage, pest abundance, pest population rate of increase or some other demographic parameter, such as sex ratio or age structure. There are three broad classes of analysis: statistics, economics and modelling.

The structure of the book is not by species or even by groups of species, for example rats, birds, ungulates, but by analyses and management topics. I could have structured the book according to pest species but that would have overemphasised the species rather than the analyses. Hence, the book is entitled *Analysis of Vertebrate Pest Control* and not *Vertebrate Pest Control*. The effect of the structure is to allow the reader to explore the use of a particular analysis on their species of interest and easily locate nearby a review of other uses of that analysis on other pest species. For example, information on statistical analysis of rat damage is close to a review of statistical analysis of bird strikes on aircraft. To aid readers, discussion of related topics is cross-referenced, both forwards and backwards, within the text.

There are six topics that are discussed in each of Chapters 2 to 6. The topics are predation of livestock, infectious diseases, rodent damage, bird strikes on aircraft, bird damage to crops and rabbit damage. In some chapters additional topics are discussed, such as predation of rock-wallabies by foxes in Chapter 3 and non-target effects of control in Chapters 3 and 6. The generic aspects of several particular methods of vertebrate pest control, such as poisoning, biological control and shooting, are discussed in Chapters 3 and 6.

Experimental design and sampling are emphasised in the discussion of statistical analysis. However, this is not a book on statistics. A knowledge of basic statistics and mathematics is assumed, but references are provided where more detailed analyses are used. I have tried to avoid using statistics solely as a line-fitting exercise without regard to the biology and practical application of what is being studied. Macfadyen (1975) expressed a similar concern in ecology. Emphasis is on the relevance and outcomes of statistical, economic and modelling analyses, rather than on the analyses themselves. Hence, detailed examples of analysis of variance or cost–benefit analysis are generally not provided. More details of the steps in and predictions of mathematical models are given, however, as fewer readers may be familiar with such details. The chapters on modelling are primarily about using mathematics to test hypotheses, not about mathematics itself. Hypothesis testing is needed in vertebrate pest control as it is needed in ecology (Macfadyen, 1975).

Table 1.1. *Variables estimated in studying vertebrate pest control and the analyses used to estimate damage or effects of control. The body of the table lists relevant chapters in the book*

| | Analyses | | |
|---|---|---|---|
| Variables estimated | Statistics | Economics | Modelling |
| Damage | Chapter 2 | Chapter 4 | Chapter 5 |
| Response to control | | | |
| (i) Damage | Chapter 3 | Chapter 4 | Chapter 6 |
| (ii) Abundance, rate of increase and other demographic parameters | Chapter 3 | Chapter 4 | Chapter 6 |

The book is a critical review of the literature. Hence, for the sake of balance I have included discussion of the strengths and weaknesses of studies. For example, some studies have used sophisticated experimental designs and others have used no statistical analysis. I have generally interpreted the lack of statistical analysis, particularly in manipulative experiments, as a study weakness, for reason that will be apparent within the book.

Pest damage and the effects of control can be studied by empirical and theoretical methods. The empirical methods are described first (Chapters 2, 3 and 4), then the theoretical methods, particularly mathematical models, are described (Chapters 5 and 6). The final chapter is a brief summary and outlook. The book is specifically written for research workers, academics, professional wildlife managers and undergraduate and postgraduate students with a focus on wildlife management. To accommodate this broad readership, the book is divided into chapters with differing levels of assumed prior knowledge. Chapters 2, 3 and 4 assume a minimum of mathematical knowledge. Chapters 5 and 6 are more mathematical and may be less accessible to some. I have tried to illustrate the ideas both graphically and in equations in Chapters 5 and 6. Some readers may be daunted by an equation yet easily grasp the idea when shown a diagram.

The analyses concentrate on populations of vertebrate pests rather than individuals. For example, the trapping of rats or foxes focusses the attention of the trapper on the individuals. Here, we are more concerned with the effects of trapping on a population of rats or foxes.

Research on vertebrate pests can be difficult because the animals range over large areas and the research is affected by the weather and other factors not under the direct control of the researcher. Some of those problems also occur in agricultural research (Dillon, 1977) so the similarities are examined. In particular, difficulties relate to the use of experimental design, statistical estimation, response variability, economics of research, differences between experimental and field results and making recommendations to farmers and wildlife managers. These topics are discussed in many sections of the book with suggested solutions.

The ‘conventional wisdom’ of vertebrate pest control is that if animals cause damage, then reducing animal abundance by control, will reduce damage. Deeper analysis is needed to examine this logic as this book is not about accepting ‘conventional wisdom’. For example, is the relationship between animal abundance and the level of damage linear or non-linear? If the relationship is linear then a reduction in pest abundance will reduce their impacts. If the relationship is non-linear a lot of control may not produce a substantial change in damage, but slightly more control will significantly reduce damage. The answer is embedded in the relationships between the level of control and the reduction in pest abundance and the level of control and the reduction in pest damage. The relationships may be easily extricated or may require very detailed study. Estimation of the relationships will allow scientists to answer questions such as: 'what level of control will reduce pest damage by 70%, or what level of control is needed such that the economic benefits of control exceed the economic costs of control?' Dyer & Ward (1977) described the need for more critical analysis and interpretation of control of bird pests, especially the relationship between bird abundance and the level of damage. Similarly, the level of control that maximises net economic benefits may, or may not, be obvious. These issues are addressed in this book.

Planning of vertebrate pest control is no different from planning other human activities. It involves deciding on objectives, alternative strategies, implementing one or more of those strategies and evaluating the results. If the results achieve the objectives then no further action may be necessary, but if the objectives are not attained then the actions or the objectives may need to be changed. A useful planning framework that is also suitable for vertebrate pest control was described by McAllister (1980). The framework, as applied to pest control, emphasises the need to evaluate alternatives and monitor the results. Each step needs some criterion as a basis for decision-making. Are alternatives selected on the basis of the highest pest mortality, lowest cost or highest benefits per unit cost? The mortality statistics are discussed in more detail in Chapter 3 and the economic criteria in Chapter 4. The strategies may be designed and evaluated by experience, laboratory and field testing, and by modelling. The latter is discussed in Chapters 5 and 6. The selection of alternatives can use pre-selected criteria. Dyer & Ward (1977) described flow diagrams for such decisions in the control of bird pests and their impacts.

Bell (1983) described a framework for planning and implementing options for field management of large mammals in African conservation areas. The discussion is useful although not specifically concerned with pest control. In management planning two types of decision were distinguished – technical and preferential. Technical decisions are those dealing with facts, such as how to design a trap to hold a certain size animal. Preferential decisions are those not based on fact but rather on opinion or preference, such as deciding whether to use lethal or non-lethal control methods. The information for making decisions was recognised as being inadequate. The decision to cull animals because of 'overabundance' implies two decisions – a preferential decision that acceptable limits to grazing or damage exist, and the technical decision that these limits have been exceeded. The analyses described in this book will provide inputs to such technical decisions.

Caughley (1981) identified four classes of 'overpopulation' of mammals. The first class was of animals that threaten life or livelihood. The second class was of animals that depress the density of favoured species. The third class was of animals that were too numerous for their own good, and the fourth class was of animals in systems off their equilibrium. The first two classes are those in which vertebrate pests usually occur. The analyses in this book will help determine whether 'overpopulation' means the animals are pests. For example, introduced reindeer (*Rangifer tarandus*) are abundant on South Georgia island (Leader-Williams, Walton & Prince, 1989) and have changed some of the native vegetation, but not caused any extinctions of species. That suggests they should be classified in the second class of pest. However, Leader-Williams *et al.* (1989) argued there was no scientific basis for active pest management, apparently as no species were threatened with extinction. This example illustrates the difference between technical decisions on how much control is needed, and the preferential decision on whether any control is needed.

A related question is should a pest be controlled or eradicated? Legislation may require eradication but it may not be economically feasible. The strongest ecological or economic arguments for eradication probably occur for pests on small islands or in small continental areas (Pimm, 1987). The decision to eradicate a pest should involve prior analysis and not be taken lightly. Coypu (*Myocastor coypus*) eradication from Britain was preceded by evaluation of a trial eradication in East Anglia (Gosling, Baker & Clarke, 1988), as described in section 3.17, and by simulation modelling of coypu dynamics and of the trapping effort needed (Gosling & Baker, 1987), as described in section 5.3.1. The subsequent eradication programme was based on trapping and trapper incentives (Gosling & Baker, 1989).

According to Kim (1983), eradication programs cannot be successful unless five conditions are met: (i) an appropriate control method exists, (ii) basic information on biology and ecology are available, (iii) defined natural barriers exist which stop pest movement, (iv) cost–benefit analysis of alternative actions has occurred, and (v) organisations are prepared. The conditions were based mostly on evaluation of eradication of exotic plant pests in northern America. The eradication of coypu in England met each condition, except (iv) – there was no cost–benefit analysis – so not all conditions are essential. Eradication of feral goats from New Zealand was not considered feasible because of the likelihood of domestic escapes (Parkes, 1990), so condition (iii) would not be met.

The five points of Kim (1983) can be reduced to one: the rate of increase of the pest population must be negative. A population must go extinct if its rate of increase stays negative. Extinction can be because of eradication (extreme control) or because the animal's habitat has insufficient resources as a result of human action. Methods for estimating rate of increase are described in section 3.4.

The decision to control or eradicate should be based on an assessment of the relationship between damage and pest abundance, as described further in Chapters 2 and 5. If the vertebrate species does not have a direct impact on human activities but influences it indirectly through its role as a host for a disease, then eradication should not automatically be an objective. Such a situation can occur with foxes and rabies. The maintenance of the infection depends on the abundance of the hosts and the contact rates between them (Bailey, 1975; May & Anderson, 1979). This is discussed in more detail in section 5.6.

To sum up, this book is about analyses used to study vertebrate pest control. Emphasis is on statistical, economic and modelling analyses and their application. Emphasis is not on the specific methods of vertebrate pest control or on the pest animals themselves. The first set of analyses, statistical analysis, is now explored. The estimation and statistical analysis of the type and level of damage is the subject of the next chapter.

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# 2

# Statistical analysis of damage

Imagine a scene of many square kilometres of semi-arid shrubland where an isolated population of 1000 goats is eating the local shrubs. The scene could be interpreted in many ways. In their native environment, or one long-managed for agriculture, the goats may be called indigenous or domestic animals respectively. In other parts of the world the goats may be called pests. What is the difference? It is the effect that the goats have on the shrubland rather than the goats themselves that can be annoying and may necessitate pest control. Hence, some scientific assessment of the effects of the goats is needed.

In a broader context, it is the damage of vertebrate pests that justifies their economic control. It is often the origin (indigenous or exotic) or legal status (declared pest) of a species that is the social justification for control. Non-native species are often labelled as pests without careful assessment of their pest status; are their effects really damage? The differentiation between the impact of a species and the species itself is fundamental to control and to the topics reviewed in this book. This chapter is concerned with estimating the damage of vertebrate pests. Emphasis is on the statistical aspects of design and sampling, with case studies used to illustrate the principles. Finally, there is a review of the analyses used.

For effective pest control it is fundamental to determine the pest status of an animal. Until this is established, a statistical or economic evaluation of damage is pointless. Judenko (1973) listed eight reasons for assessing the losses caused by pests: (i) establish the economic status of specific pests, (ii) estimate the damage or abundance level that justifies control, (iii) calculate the justifiable expenditure on control, (iv) estimate the effectiveness of control, (v) measure the effects of environmental factors on the loss of yield caused by pests, (vi) give information to manufacturers and distributors of pesticides to help them decide what actions should be taken, (vii) assess the public use of funds for current research, and (viii) direct future research and planning.

Auld & Tisdell (1986) expanded on points (iii) and (vii), by arguing that it is only rational to increase our knowledge about pests up to the point where the marginal benefit from research equals the marginal cost of obtaining that extra knowledge. Methods of estimating such marginal benefits and costs are described in section 4.2. Research into rodent control in Britain during the 1940s was criticised by Barnett & Prakash (1976) when they asked what the final effects of the rodent control were on food saved and abundance of rodents. They considered that few researchers had tried to answer such a question.

## 2.1 Types of damage

The damage by vertebrate pests is varied and the reported or alleged impacts are probably even more diverse. The impacts include effects on soil structure, soil erosion, water quality and runoff, alteration of plant species composition, changes in plant growth, biomass, reproduction and crop production, changes in animal populations and production, spread of human and livestock diseases, changes in ecosystem structure, and even species extinction. Pimm (1987), Brockie *et al.* (1988) and Ebenhard (1988) review damage caused by introduced pest species around the world.

## 2.2 Spatial and temporal variation

The damage by vertebrate pests can vary in space and time. Emphasis in vertebrate pest research is, however, often on the mean level of damage, but we need to examine the variation about the mean and the sources of such variation. This section examines the patterns in such variation.

Spatial variation is the frequency distribution of damage between areas at the same time. This variation can be examined at different geographic scales, such as within fields or forests, or in a district or county, or a region or country. The distribution may vary from negative exponential to normal to positively skewed (Fig. 2.1). Each unimodal (one-peaked) frequency distribution is an example of a more general exponential frequency distribution (Dobson, 1983). Bimodal (two-peaked) or multimodal (many-peaked) distributions could also occur (see section 3.1 and Fig. 2.1), though none have been reported as far as I know.

Dawson (1970) reported a positively skewed frequency distribution of damage to grain crops by sparrows (*Passer domesticus*) in parts of New Zealand, and Buckle, Rowe & Husin (1984) cited a study of rat damage to rice fields in Malaysia that showed a log-normal frequency distribution of damage. Negative exponential frequency distributions of damage have been reported for damage by feral pigs (*Sus scrofa*) in south-eastern Australia (Hone, 1988a), damage to sunflowers in North and South Dakota as a result of birds, particularly blackbirds (*Agelaius phoeniceus*, *Xanthocephalus xanthocephalus*) and grackles (*Quiscalus quiscula*) (Hothem, DeHaven & Fairaizl, 1988), and damage to grapefruit by grackles (*Quiscalus mexicanus*) in Texas (Johnson, Guthery & Koerth, 1989).

The pattern of spatial variation in damage is caused by, or correlated with, many factors, including the behaviour of pests or the characteristics of the environment. Harmon, Bratton & White (1983) reported that rooting by wild boar (*Sus scrofa*) in Great Smoky Mountains National Park in Tennessee was most frequent in gray beech forest at 1450 to 1800 m elevation. Rooting of the ground by feral pigs in mountain forests and woodlands in south-eastern Australia was positively correlated with elevation (Hone, 1988b).

Otis & Kilburn (1988) reported nearby marshes, roosting sites for birds, had the largest influence on blackbird damage to sunflowers in North and South Dakota and Minnesota. Glahn & Otis (1986) analysed, by categorical modelling, factors influencing blackbird and starling damage at livestock feeding operations in Tennessee. Blackbird damage was related to feeding of domestic animals, particularly pigs, on the ground, and the presence of a large

Fig. 2.1. Possible frequency distributions of spatial variation in damage by vertebrate pests. (*a*) Negative exponential, (*b*) normal, (*c*) positively skewed, (*d*) bimodal. In each example the *x* axis gives the level or extent of damage, and the *y* axis gives the number of sites with each level of damage (the frequency).