Reducing the impact of feral house mice in agricultural ecosystems

Peter R. Brown

CSIRO Sustainable Ecosystems, GPO Box 284, Canberra, ACT, 2601, Australia
School of Biological, Earth and Environmental Sciences, The University of New South Wales, NSW, 2052, Australia
E-mail: peter.brown@csiro.au

ABSTRACT

In Australia, the introduced house mouse, *Mus domesticus*, causes obvious and severe agricultural damage, particularly during mouse plagues where population densities may exceed 1,000 mice/ha. The aim of any pest control is to reduce the damage caused by the pest, not to reduce pest numbers *per se*. Management of mice is generally reactive, and much damage has already occurred by the time control methods are applied. Most of the time, mice are in low numbers and cause little damage to crops. There is limited understanding of how mice damage plants or how crops recover or compensate for damage inflicted by mice. However, it is known that wheat crops can compensate for damage early in the growth of the crop, but not in later growth stages. We need to know the relationship between the density of mouse populations and loss of yield at key phases of crop growth so that management targets can be established. I modelled mouse population density and the feeding requirements of mice in a crop simulation model, and estimated yield loss. A sigmoidal curve best described the data and showed that the density of mice at which 5% loss occurred was 42 mice/ha. Management therefore is required early and over large areas to reduce reinvasion and to keep mouse densities less than 42 mice/ha at sowing.

Key words: crop simulation model, management, mouse damage, wheat crop, yield loss

Introduction

The introduced house mouse, *Mus domesticus*, is one of Australia's worst vertebrate pests causing $35.6 million damage/year (McLeod 2004; Figure 1). Among 11 significant vertebrate pests in Australia, the house mouse was considered to have the greatest social impact, as it was one of two species to inhabit people's homes and spread diseases to humans (McLeod 2004; the other species is the black rat, *Rattus rattus*). House mice in Australia were likely to have come from England, the Netherlands or France with explorers and early European settlers (Singleton and Redhead 1990; Redhead *et al.* 1991). It is considered that the species of *Mus* is *M. musculus domesticus*, rather than *M. m. musculus*, which occurs further west in Europe (Sage *et al.* 1993; Payseur and Nachman 2005), and is referred to as *M. domesticus* (see Singleton and Redhead 1990 and Berry and Scriven 2005 for details).

Figure 1. House mice in a piggery during a mouse plague.

Domestic and feral populations of house mice have done extraordinarily well in Australia, inhabiting almost all available ecological niches. They have done particularly well in highly modified agricultural landscapes, where native rodents have faired poorly (Redhead *et al.* 1991). However, some native rodent species can form plagues in the arid interior of Australia after favourable climatic conditions (Newsome and Corbett 1975; Dickman *et al.* 1999). In Australia, feral mice do not have specific predators (although there is a range of predatory birds, mammals and reptiles that feed on mice); have no small mammal competitors in crop ecosystems; and do not have the full suite of diseases that their forebears have in Europe (Singleton and Redhead 1990; Tattersall *et al.* 1994; Singleton *et al.* 2005).

Despite the huge economic, social, and environmental costs associated with house mice, especially during mouse plagues, there is comparatively little known about the type of damage that they cause to crops or how crops might respond or recover from mouse damage. Furthermore, there is a paucity of information to allow for better timing of control or to indicate what targets should be set for control. The purpose of this paper is to review existing knowledge about the impacts of mice on agriculture, to examine current control methods, and to develop a model for the relationship between mouse population abundance and yield loss in wheat crops. I will highlight the importance of understanding how crops compensate for mouse damage in order to predict the best time to maximise financial returns to farmers. Such predictions will also allow the environmental consequences of large-scale baiting with rodenticides to be reduced.

Pp 8 - 15 in *Pest or Guest: the zoology of overabundance,* edited by Daniel Lunney, Peggy Eby, Pat Hutchings and Shelley Burgin. 2007. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

Damage caused by mice

A mouse plague occurs somewhere in Australia once every four years, but could be one year in seven for any particular region (Singleton 1989; Redhead and Singleton 1988; Mutze 1991; Singleton *et al*. 2005). These plagues are a significant problem to agricultural areas of Australia (Figure 2). It has been conservatively estimated that the 1993 mouse plague cost AUD$64.5 million to Victorian and South Australian farmers (Caughley *et al*. 1994). Within the wheat belt of southern and eastern Australia is a number of distinct regions defined by soil types, cropping systems and climate all of which experience mouse plagues. For example, on the Darling Downs in southern Queensland, winter and summer crops are grown on a continuous basis on self-mulching dark clay soils, whereas on the light sandy loam soils of the Victorian Mallee winter cereals are grown in the same paddock only once every 2-3 years. The mechanisms of plague formation in these regions differ markedly (see Singleton 1989; Cantrill 1992; Pech *et al*. 1999). Curiously, widespread mouse plagues do not occur in Western Australia, although localised outbreaks often occur (Plomley 1972; Chapman 1981).

Figure 2. House mice have an Australia-wide distribution, but mouse plagues generally affect the grain-growing regions of eastern and southern Australia (shaded area). Study sites in the Victorian mallee and Queensland Darling Downs are indicated.

Rodents cause damage to crops by consuming grain and plant material. They damage crops by digging out newly planted seeds or germinating seeds (Mutze 1998; Brown *et al*. 2003) (Figure 3a). Rodents also attack developing tillers/shoots (Figure 3b), and seem to focus their effort on the nodes of the developing tillers. Once the plant reaches the booting stage (when the panicle grows up the leaf sheath and swells), mice can attack the developing head inside the tiller. They do this by either climbing up the tiller to chew through it (if their body weight is small enough) or cutting the tiller near the base of the plant and feeding on it. Once grain starts to develop, rodents can chew through the tiller to access the grain or climb up the tiller. When mouse damage is severe, cut tillers and damaged grain is evident (Figure 3c).

Figure 3. Typical mouse damage (a) at sowing where seeds have been dug out of the ground, (b) tillering (note the characteristic 45° angle cut on the tiller) and (c) ripening stages of wheat, where mice have cut down tillers or heads and have stripped the grains to leave husks lying on the ground. (d) Mice build up in undisturbed vegetation on the verges of crops such as these fence lines.

Because of the nature of mouse plagues, the problems associated with high densities of mice and damage to crops tend to be acute. In outbreak years, the wheat crops may have little opportunity for compensation because feeding activity on the crop remains high. In this situation, farmers attempt to minimise losses by using readily available, fast-acting (acute) rodenticides such as strychnine or zinc phosphide. In other years when densities are low to moderate, mice cause no perceivable damage. To move from a reactive to a preventative management strategy, it is necessary to have a good understanding of the mechanisms that govern the development of mouse plagues and then to develop models that can forecast outbreaks. Substantial progress has been made in forecasting mouse outbreaks (Pech *et al.* 1999, Kenney *et al.* 2003; Krebs *et al.* 2004), but the best models are only 70% accurate (Krebs *et al.* 2004) and are region specific. These models rely on rainfall as a surrogate for food supply (Brown and Singleton 1999; Pech *et al.* 1999).

Few studies adequately summarise the impacts of mice on crops. Brown and Singleton (2002) summarised information on the damage caused by mice to different crop types relative to the density of mice. The available published data covered the full spectrum of damage (0.5-100%) and a wide range of mouse population densities (50-2,716 mice/ha), yet it was not possible to develop damage/abundance relationships using these data. There is a striking paucity of studies where rigorous data have been collected on both damage or yield losses and population densities of mice. This makes it difficult to understand the actual economic losses caused by mice or the relationship between the density of mice and damage to crops. These are essential elements for developing management guidelines.

Densities of mice in non-plague years are normally <50 mice/ha, sometimes as low as <5 mice/ha, but during mouse plagues, densities can reach in excess of 1,000 mice/ha (Singleton *et al.* 2001; Singleton *et al.* 2005): a 200-fold change (see Korpimäki *et al.* 2004 for discussion). The maximum density that has been estimated in crops was 2,716 mice/ha (Saunders and Robards 1983). Densities of mice during plagues can also be very high around intensive animal husbandry facilities such as piggeries resulting in high production losses (Caughley *et al.* 1994; Figure 1).

Methods for control of mice

The main method used by farmers in Australia to control mice is the application of rodenticides either aerially from small aircraft or by farm vehicles using fertiliser spreaders. Rodenticides are considered to be cheap and effective at reducing population densities of mice (Mutze and Sinclair 2004). It costs farmers approximately $10-15/ha to bait their fields using zinc phosphide (Brown and Singleton 2002; Mutze and Sinclair 2004). However, farmers are generally reactive in their actions and conduct control after crop losses have occurred. Much research has been conducted on examining the efficacy of various types of rodenticides to reduce population abundance of mice in Australia, particularly for the acute rodenticides of strychnine and zinc phosphide (Brown *et al.* 2002; Mutze 1998; Mutze and Sinclair 2004), but there has been little examination of how these rodenticides actually increase yields or reduce damage caused by mice. Furthermore, there have been some non-target impacts when applying rodenticides over large areas (Bird 1995; Brown and Lundie-Jenkins 1999; Brown *et al.* 2002). In general, if appropriate buffer areas around native vegetation are maintained there will be minimal risks to non-target wildlife, particularly granivorous birds (Brown and Lundie-Jenkins 1999).

Aside from rodenticides, there is a range of alternative methods to reduce mouse damage, particularly at sowing. Sowing seeds deeper and/or cross-harrowing after sowing reduces mouse damage by disguising the location of sown seeds (Brown *et al.* 2003). Spraying or grazing vegetation along key refuge and breeding habitats, such as fencelines, in early spring reduces the breeding success of mice and hence the level of their subsequent invasion of crops (Brown *et al.* 1998; Brown *et al.* 2004; Figure 3d). These practices are considered to be cost effective (Brown *et al.* 2004), but they have not been fully tested when mouse population densities are high.

In order for farmers to know when it is best to apply mouse control, they need to be able to estimate mouse densities, particularly before sowing. Developing simple methods that farmers can use to monitor mouse numbers in their fields has received some research, but a reliable method that can be applied across a range of densities is yet to be found. Pieces of card or paper (10 x 10 cm) soaked in vegetable oil have been trialled (Mutze 1998; Mutze and Sinclair 2004), but the results are variable, and a rigorous comparison with live-trapping mouse populations is required. An alternative method is to use the number of active mouse burrows in an area, but the effectiveness of this method depends on soil conditions and ground cover. Again, it needs to be evaluated.

Relationship between damage and abundance

The aim of any pest control is to reduce the damage caused by the pest, not to reduce pest numbers *per se* (Hone 1994). In order for this to be achieved, it is desirable to have an understanding of the relationship between damage caused to crops and abundance of mice so that management targets can be developed. It is also important to understand how individual plants or a crop can compensate for pest damage. Four theoretical models are provided in Figure 4 (adapted from Brown and Singleton 2002). These show how important it is to understand the relationship between mouse density and crop damage. This relationship influences management decisions and helps set thresholds for management. Obviously, when no mice are present, there should be no damage and no yield loss from mice. Furthermore, at some point when very high densities of mice are present, ~100% of the crop will be damaged. The models attempt to explain what happens in between these two extremes. For example, if Model II exists (straight line relationship), in order for damage to be reduced to an acceptable level, the mouse population density will need to be reduced by 90% (Figure 4b). If Model III exists (sigmoidal relationship), then a 60% reduction in mouse density will be required (Figure 4c). Other types of curves are possible, and it is likely that different relationships exist in different situations. The targets for management will vary, depending on the shape of the curve.

Many types of pests can affect the yield of crops, including insects feeding on plant tissue or developing grain (Bardner and Fletcher 1974; Sadras *et al.* 1999), slug damage to plant tissue (Hammond 2000) and cattle and other large herbivores trampling on crops as they graze (Goryñska 1981; Putman and Moore 1998). In many situations, the crop may compensate for this type of attack or injury, provided the damage is small or early enough for the crop to divert resources to recover from the attack (Bardner and Fletcher 1974; Buckle *et al.* 1979; Poché *et al.* 1981). However, it is not known whether wheat crops can compensate for damage caused by house mice.

In an experiment where wheat plants were hand-clipped at various stages of crop growth and at different intensities, Brown (2005) demonstrated that wheat crops could compensate for damage provided the damage was not too high or late in the growth of the crop. Up to 50% damage at sowing resulted in negligible yield loss at harvest, whereas damage just prior to harvest resulted in equivalent yield loss (Brown 2005). In response to the simulated damage, wheat plants increased grain production, the number of tillers or the survival rate of remaining tillers. This experiment demonstrated how wheat crops recovered or compensated from damage that mice would cause. However, the damage was applied at discrete times, not continuously as would be the case if mice were constantly eating the crop. The next step then is to either (1) intensively monitor mouse population abundance and resulting damage to crops, or (2) model the abundance of mice and damage to crops through knowledge of the diet requirements of mice over time and simulate the effects of this damage on yield loss of wheat. Attempts at the first approach have been unsuccessful (Brown and Singleton 2002), while the second approach has been conducted and is summarised below.

The modelling approach utilised mouse population data from a 21-year dataset (1983-2003) available from Walpeup, in the mallee wheat-growing region of northwestern Victoria (Singleton *et al.* 2001; Figure 5) and a diet study of mice from the same region (Tann *et al.* 1991). These data were used to calculate the amount of food eaten per mouse per day, and incorporate that into a crop simulation model called APSIM (Agricultural Production Simulation Model; Keating *et al.* 2003) along with daily weather details. The model was run initially without the effect of mouse grazing to estimate potential yields of wheat crops at Walpeup. The model was run a second time with mice destroying a given proportion of the crop each day. This enabled an accumulated grazing effect on the wheat crop and estimated percent yield loss (Figure 5). When mouse densities were low, there was little yield loss (14/21 crop years, mouse density <25 mice/ha; crop loss <5%), but during outbreaks of mice, yield loss was high (7/21 crop years, mouse density >100 mice/ha; crop loss >5%) (Brown *et al. in press*). When densities of mice were high at sowing and at emergence of the crop, the crop suffered significant yield losses (>5%). The best fit of the data was a sigmoidal relationship (Brown *et al. in press*), similar to Model III in Figure 4. The density of mice at which 5% loss occurred was 42 mice/ha.

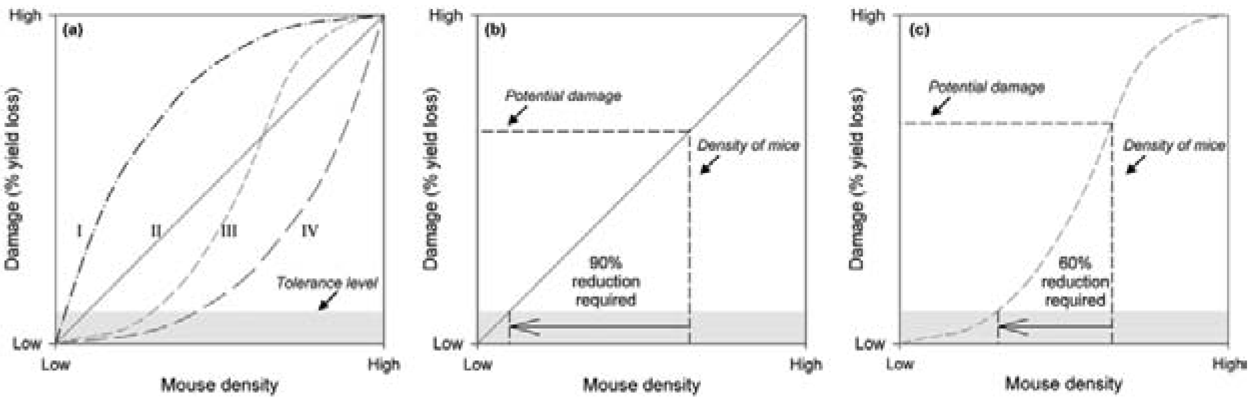

Figure 4. Potential models explaining the relationship between mouse density and damage to crops. The shape of the curve helps to set management targets. (a) Four potential models are shown along with what farmers might consider as an acceptable level of damage (tolerance level: ~5% yield loss). Type I shows sensitivity to rodent damage, where relatively high levels of damage occur at low rodent densities; Type II shows a linear relationship between rodent density and damage up to 100% yield loss; Type III shows a sigmoidal relationship where there is tolerance to damage or compensation of the crop at low densities of rodents, but as rodent densities increase, the level of damage incurred increases faster until a plateau is reached at 100% yield loss; and Type IV shows an exponential growth response where the crop can compensate for up to moderately high densities of rodents, but then the level of damage increases rapidly at high densities. (b) Example for model II with a moderate density of mice. A 90% reduction in mouse population density would be required so that damage was less than the tolerance level of the farmer. (c) Example for model III. A 60% reduction in mouse population density would be required.

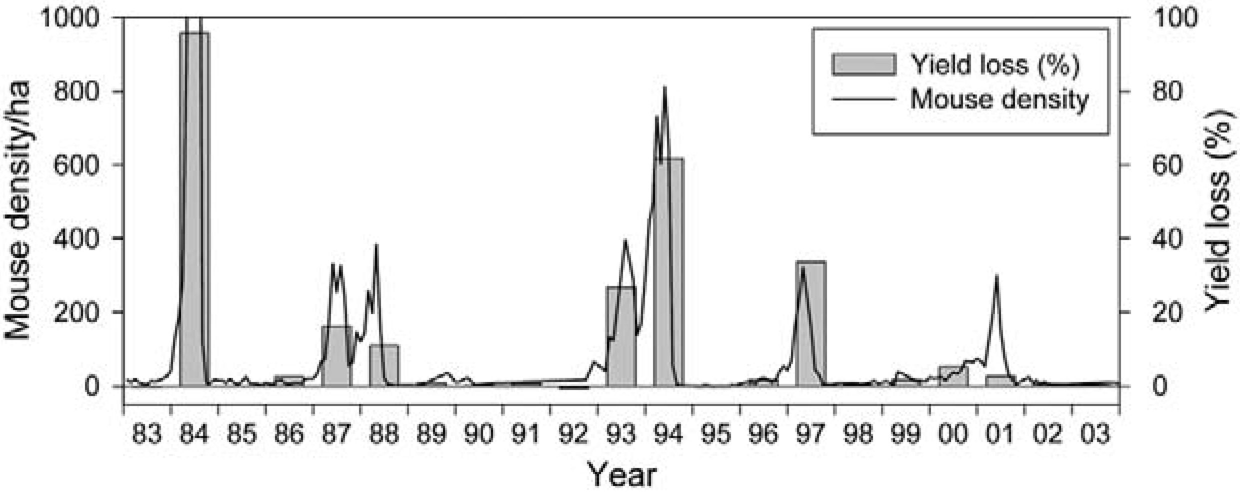

Figure 5. Density of mice/ha and predicted yield loss (%) from a 21-year dataset from Walpeup, northwestern Victoria, 1983-2003. Mouse density peaked at 2,200 mice/ha in January 1984. The daily grazing effect of mice was calculated from the density of mice and from the diet of mice. Data from Brown *et al.* (*in press*).

This basic APSIM model was used to examine the benefits in yield response after rodent control had been applied. An initial run of this model was conducted on the Walpeup population data from 1997 and data from a study by Brown *et al.* (2002). The initial mean density of mice from sowing to harvest was 88 mice/ha. Zinc phosphide was applied to a field prior to sowing to reduce the mouse density by 0, 50 and 95% (assuming no immigration from untreated areas or increases in density through breeding; Figure 6a). Crop yields were then compared to the yields in a field without mice. Predicted yields were 548.3 kg/ha (0% density reduction; 66% of the yield without mice), 913.8 kg/ha (50% density reduction; 111% of the yield without mice) and 833.1 kg/ha (95% density reduction; 101% of the yield without mice) (Figure 6b). There was an increase in yield with a 50% reduction in density of mice. The effectiveness of baiting was further manipulated: significant damage occurred both when the effectiveness of baiting was less than 20% and the mean density of mice was greater than 75 mice/ha (> 5% yield loss). Therefore, under the conditions experienced in 1997, any control method that reduced the density of mice by more than 20% (to mean densities less than 75 mice/ha) resulted in low levels of damage (potential yield gain). Further work is required to test this model under field conditions and to test its suitability for managing mice. It would be valuable to examine the impact of mouse control at different crop stages when densities are high and to monitor both the response of the crop and the mouse population to these control actions and therefore verify and validate the outcomes of the APSIM model.

In southern Australia, most damage to crops is to newly planted cereal crops at a time when population densities of mice normally reach a peak. The findings of the simulation highlight the need to conduct rodent control over large areas to limit reinvasion, and in the case of house mice in Australia, rodent control needs to occur before sowing, if densities are >100 mice/ha.

Do mice have a beneficial role in agricultural systems?

House mice play an important role in agricultural systems in Australia. They have obvious detrimental effects, which were outlined above, but they also could play a significant beneficial role in this agroecosystem. Mice are virtually the only small mammal inhabiting wide areas of crop land. From >250,000 trap nights in the wheat fields of the Victorian mallee over 21 years there was only one capture of a native small mammal (fat-tailed dunnarts *Smithopsis crassicaudata*) (G. Singleton *personal communication*). In the Darling Downs of southern Queensland, there have been some captures of the native rat *Rattus tunneyi*, but these were on grassy verges of crops (P. Brown *unpublished data*), and the Queensland Department of Natural Resources and Mines infrequently capture *S. crassicaudata* (J. Farrell *personal communication*). Native small mammals are often present only in small blocks of native habitat relatively close to fields used for cropping. These native bushland habitats are sink habitats for mice as they prefer the highly modified cropping areas.

Mice are food for native predators snakes, owls and raptors, but also introduced predators such as foxes and cats (Davey and Fullager 1986; Sinclair *et al.* 1990; Smith 1984). Since there are few other small mammals in this ecosystem, mice could be considered as a key food source for native predators. Mice are also predators of insects and arthropods (Tann *et al.* 1991) many of which cause damage to crops. There is strong evidence that mice are predators of plague locusts (*Chortoicetes terminifera*), and may be useful in reducing the detrimental effects that they cause (Story and Cox 2001). In natural environments, however, mice have a detrimental effect on invertebrates and lizards. After mice were removed from small plots, there were increases in the species richness of invertebrates and the capture rates of a small skink (Dickman 1999).

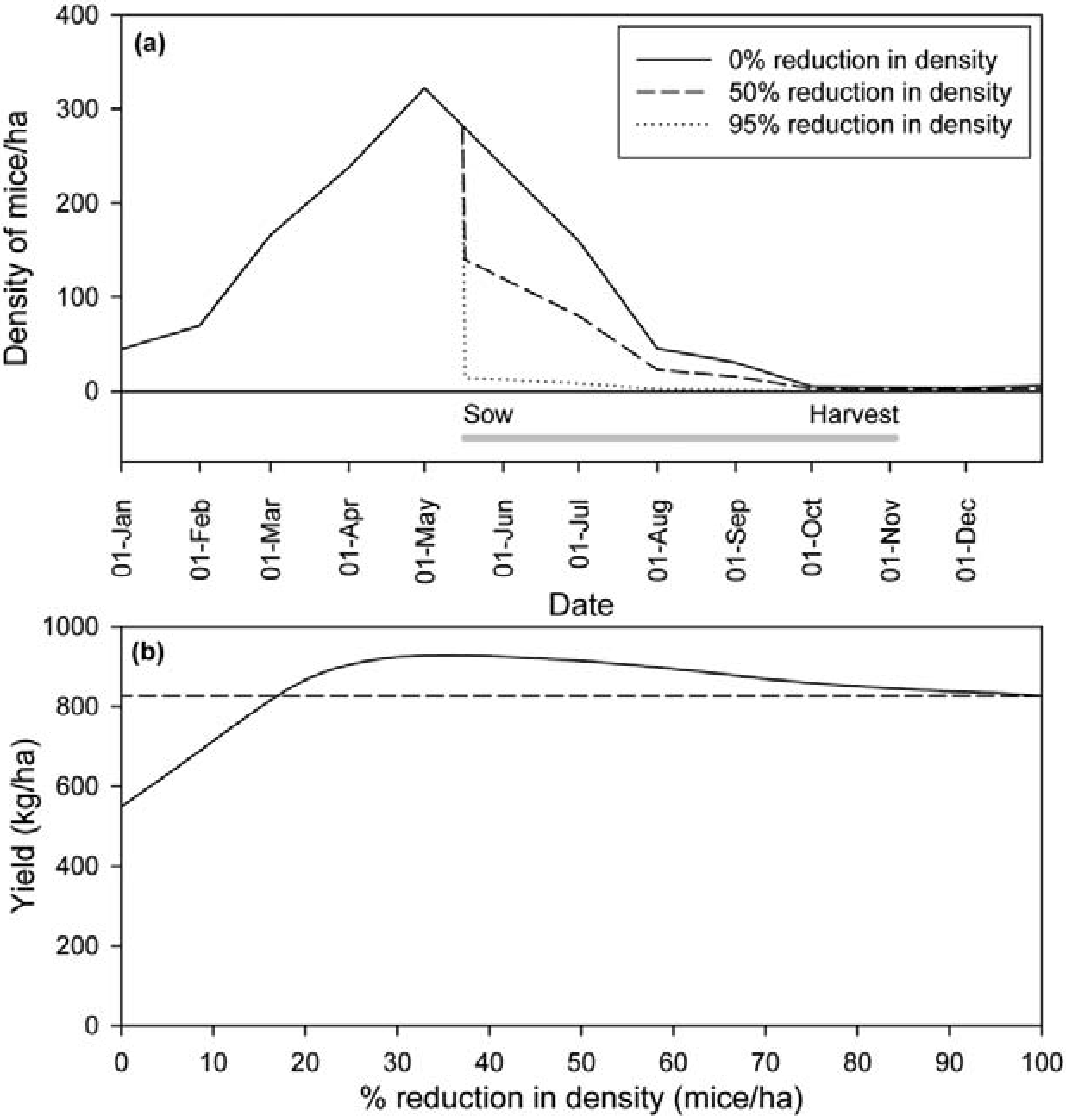

Figure 6. (a) Change in density of mice/ha at Walpeup in 1997 after simulated control achieved 0, 50 and 95% reduction in density, based on data from Brown *et al.* (2002). A wheat crop was planted on 17 May 1997 and was harvested on 3 November 1997. (b) Relationship between the percentage reduction in mouse density/ha and the resulting yield of wheat (kg/ha). The dashed line represents the yield (826.2 kg/ha) when no mice were present (ie when 100% of the mice were controlled). Mouse control would therefore need to be at least 20% effective in order to minimise yield loss.

There is some evidence that small amounts of damage may increase yield of crops. When densities of mice were low, there was a negative yield loss, indicating a yield gain as found for 1992 (Brown *et al. in press*; Figure 5). Over time, however, these potential yield gains would be outweighed by the enormous losses during mouse plagues, so the overall beneficial effect would be small.

Conclusions

For much of the time mice are in low population abundance and cause little damage to crops. However, during outbreaks or mouse plagues, severe economic, environmental and social impacts occur. House mice are part of a complex food web in Australia's highly modified agricultural areas, where few other small mammals are found, and as such, are important prey items for a range of bird and mammal species. Mice also feed on a range of food sources and may assist in reducing the impact of locusts, another significant agricultural pest. In some circumstances, however, it has been demonstrated that mice negatively affect species composition of native species.

In the past, management of mice has been reactive, and much damage has already occurred by the time control methods are applied. Historically, acute rodenticides such as strychnine and zinc phosphide have been used over large areas (up to 500,000 ha) to limit the damage caused by mice. Consequently, there have been large non-target problems. Recent research has been directed at developing and testing more environmentally benign control methods without having to rely on rodenticides. These farming practices result in less damage and higher yields. One of the fundamental aspects of reducing mouse damage has been an understanding of the relationship between mouse population density and yield loss, particularly for wheat crops. Through the development of a density/damage model, management targets can be set. Furthermore, there is now a better understanding of the importance of appropriate timing of control actions and the resulting impact of control actions on the yield of crops. This work also highlights the importance of monitoring mouse population densities and acting early to prevent damage.

Acknowledgements

I am grateful to Drs Grant Singleton and Peter Banks for their support and encouragement. The work reported here is the result of many years research with numerous helpers and assistants. Thanks to Dr Rudy Boonstra for his critical comments.

References

Bardner, R. and Fletcher, K.E. 1974. Insect defoliations and their effects on the growth and yield of field crops: a review. *Bulletin of Entomological Research* **64**: 141-160.

Berry, R.J. and Scriven, P.N. 2005. The house mouse: a model and motor for evolutionary understanding. *Biological Journal of the Linnaen Society* **84**: 335-347.

Bird, P.L. 1995. Off-target mortalities due to strychnine baiting during the 1993 mouse plague in South Australia. *Proceedings of the 10th Australian Vertebrate Pest Conference*. Hobart, Tasmania. Kings Meadows. Tasmanian Department of Primary Industries and Fisheries. Pp. 188-191.

Brown, P.R. 2005. The effect of simulated house mouse damage to wheat in Australia. *Crop Protection* **24**: 101-109.

Brown, P.R., Chambers, L.K., and Singleton, G.R. 2002. Pre-sowing control of house mice (*Mus domesticus*) using zinc phosphide: efficacy and potential non-target effects. *Wildlife Research* **29**: 27-37.

Brown, P.R., Davies, M.J., Croft, J.D., and Singleton, G.R. 2004. Can farm management practices reduce the impact of house mouse populations on crops in an irrigated farming system? *Wildlife Research* **31**: 597-604.

Brown, P.R., Huth, N.I., Banks, P.B., and Singleton, G.R. in press. Relationship between abundance of pest rodents and damage to agricultural crops. *Agriculture, Ecosystems and Environment*.

Brown, P.R. and Lundie-Jenkins, G. 1999. Non-target mortalities during aerial strychnine baiting of house mice. *Wildlife Research* **26**: 117-128.

Brown, P.R. and Singleton, G.R. 1999. Rate of increase as a function of rainfall for house mouse *Mus domesticus* populations in a cereal-growing region in southern Australia. *Journal of Applied Ecology* **36**: 484-493.

Brown, P.R. and Singleton, G.R. 2002. Impacts of house mice on crops in Australia - costs and damage. Pp. 48-58 in Human Conflicts with Wildlife: Economic Considerations edited by L. Clark, J. Hone, J. A. Shivik, R. A. Watkins, K. C. VerCauteren, and J. K. Yoder. National Wildlife Research Center, Fort Collins, Colorado. [Web address: http://www.aphis.usda.gov/ws/nwrc/symposia/economics/brownHR.pdf]

Brown, P.R., Singleton, G.R., Dunn, S.C., and Jones, D.A. 1998. The management of house mice in agricultural landscapes using farm management practices: An Australian perspective. *Proceedings of the 18th Vertebrate Pest Conference*. Pp. 156-159 edited by R.O. Baker and A.C. Crabb. University of California, Davis, California.

Brown, P.R., Singleton, G.R., Tann, C.R., and Mock, I. 2003. Increasing sowing depth to reduce mouse damage to winter crops. *Crop Protection* **22**: 653-660.

Buckle, A.P., Yong, Y.C., and Rowe, F.P. 1979. Yield response of the rice variety Improved Mashuri to simulated rat damage. *Malaysian Agriculture Journal* **52**: 135-144.

Cantrill, S. 1992. The population dynamics of the house mouse (*Mus domesticus*) in a dual crop agricultural ecosystem. Unpublished PhD Thesis, School of Life Science, Queensland University of Technology.

Caughley, J., Monamy, V., and Heiden, K. 1994. Impact of the 1993 Mouse Plague. GRDC Occasional Paper Series No.7. GRDC, Canberra.

Chapman, A. 1981. Habitat preference and reproduction of feral house mice, *Mus musculus*, during plague and non-plague situations in Western Australia. *Australian Wildlife Research* **8**: 567-579.

Davey, C.C. and Fullager, P.J. 1986. Changes in the abundance and distribution of raptors during a house mouse plague. *Corella* **10**, 52-54.

Dickman, C.R. 1999. Rodent-ecosystem relationships: a review. Pp. 113-133 in *Ecologically-based Management of Rodent Pests* edited by G. R. Singleton, L. A. Hinds, H. Leirs, and Z. Zhang. ACIAR Monograph No. 59. Australian Centre for International Agricultural Research, Canberra. [Web address: http://www.aciar.gov.au/web.nsf/doc/JFRN-5J473R]

Dickman, C.R., Mahon, P.S., Masters, P., and Gibson, D.F. 1999. Long-term dynamics of rodent populations in arid Australia: the influence of rainfall. *Wildlife Research* **26**: 389-403.

Goryñska, W. 1981. Method of determining relations between the extent of damage in farm crops, big game numbers, and environmental conditions. *Acta Theriologica* **26**: 469-481.

Hammond, R.B. 2000. Simulation of moderate levels of slug injury to soybean. *Crop Protection* **19**: 113-120.

Hone, J. 1994. *Analysis of Vertebrate Pest Control*. Cambridge University Press, Cambridge.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Champan, S., McCown, R.L., Freebairn, D.M., and Smith, C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18**: 267-288.

Kenney, A.J., Krebs, C.J., Davis, S.A., Pech, R.P., Mutze, G.J., and Singleton. G.R. 2003. Predicting house mouse outbreaks in the wheat-growing areas of south-eastern Australia. Pp. 325-328 in *Rats, Mice and People: Rodent Biology and Management* edited by G.R. Singleton, L.A. Hinds, C.J. Krebs, and D.M. Spratt. ACIAR Monograph 96. Australian Centre for International Agricultural Research, Canberra. [Web address: http://www.aciar.gov.au/web.nsf/doc/ACIA-5LN3SJ]

Korpimäki, E., Brown, P.R., Jacob, J., and Pech, R.P. 2004. The puzzles of population cycles and outbreaks of small mammals solved? *BioScience* **54**: 1071-1079.

Krebs, C.J., Kenney, A.J., Singleton, G.R., Mutze, G.J., Pech, R.P., Brown, P.R., and Davis, S.A. 2004. Can outbreaks of house mice in southeastern Australia be predicted by weather models? *Wildlife Research* **31**: 465-474.

McLeod, R. 2004. *Counting the Cost: Impact of Invasive Animals in Australia 2004*. 70 pp. Cooperative Research Centre for Pest Animal Control, Canberra. [Web address: http: //www.invasiveanimals.com/images/pdfs/Mcleod.pdf]

Mutze, G.J. 1991. Mouse plagues in South Australian cereal-growing areas. III. Changes in mouse abundance during plague and non-plague years, and the role of refugia. *Wildlife Research* **18**: 593-604.

Mutze, G.J. 1998. The 1993 strychnine baiting program for mouse control in South Australian grain crops. I. Efficacy. *Wildlife Research* **25**: 533-546.

Mutze, G.J. and Sinclair, R. 2004. Efficacy of zinc phosphide, stychnine and chlorpyrifos as rodenticides for the control of house mice in South Australian cereal crops. *Wildlife Research* **31**: 249-257.

Newsome, A.E. and Corbett, L.K. 1975. Outbreaks of rodents in semi-arid and arid Australia: causes, preventions, and evolutionary considerations. Pp. 117-153 in *Rodents in Desert Environments* edited by I. Prakash and P. K. Ghosh. Junk, The Hague.

Payseur, B.A. and Nachman, M.W. 2005. The genomics of speciation: investigating the molecular correlated of X chromosome introgression across the hybrid zone between *Mus domesticus* and *Mus musculus*. *Biological Journal of the Linnaen Society* **84**: 523-534.

Pech, R.P., Hood, G., Singleton, G.R., Salmon, E., Forrester, R., and Brown, P.R. 1999. Models for predicting plagues of house mice (*Mus domesticus*) in Australia. Pp. 81-112 in Ecologically-based Management of Rodent Pests edited by G.R. Singleton, L.A. Hinds, H. Leirs, and Z. Zhang. ACIAR Monograph No. 59. Australian Centre for International Agricultural Research, Canberra. [Web address: http://www.aciar.gov.au/web.nsf/doc/JFRN-5J473R]

Plomley, N.J.B. 1972. Some notes on plagues of small mammals in Australia. *Journal of Natural History* **6**: 363-384.

Poché, R.M., Haque, M.E., Main, M.Y., Sultana, P., and Karim, M.A. 1981. Rice yield reduction by simulated rat damage in Bangladesh. *Tropical Pest Management* **27**: 242-246.

Putman, R.J. and Moore, N.P. 1998. Impact of deer in lowland Britain on agriculture, forestry and conservation habitats. *Mammal Review* **28**: 141-164.

Redhead, T.D. and Singleton, G.R. 1988. An examination of the "PICA" strategy for the prevention of losses caused by plagues of the house mouse (*Mus domesticus*) in rural Australia. Pp. 18-37 in *Vertebrate Pest Management in Australia: Decision Analysis/Systems Analysis Approach* edited by G.A. Norton and R.P. Pech. CSIRO, Melbourne.

Redhead, T.D., Singleton, G.R., Myers, K., and Coman, B.J. 1991. Mammals introduced into southern Australia. Pp. 289-304 in *Biogeography of Mediterranean Invasions* edited by R.H. Groves and F. Di Castri. Cambridge University Press, Cambridge.

Sadras, V.O., Fereres, A., and Ratcliffe, R.H. 1999. Wheat growth, yield, and quality as affected by insect herbivores. Pp. 183-227 in *Wheat: Ecology and Physiology of Yield Determination* edited by E.H. Satorre and G.A. Slafer. Food Products Press, New York.

Sage, R.D., Atchley, W.R., and Capanna, E. 1993. House mice as models in systematic biology. *Systematic Biology* **42**: 523-561.

Saunders, G.R. and Robards, G.E. 1983. Economic considerations of mouse-plague control in irrigated sunflower crops. *Crop Protection* **2**: 153-158.

Sinclair, A.R.E., Olsen, P.D., and Redhead, T.D. 1990. Can predators regulate small mammal populations? Evidence from house mouse outbreaks in Australia. *Oikos* **59**: 382-392.

Singleton, G.R. 1989. Population dynamics of an outbreak of house mice (*Mus domesticus*) in the mallee wheatlands of Australia - hypothesis of plague formation. *Journal of Zoology, London* **219**: 495-515.

Singleton, G.R., Brown, P.R., Pech, R.P., Jacob, J., Mutze, G.J., and Krebs, C.J. 2005. One hundred years of eruptions of house mice in Australia - a natural biological curio. *Biological Journal of the Linnaen Society* **84**: 617-627.

Singleton, G.R., Krebs, C.J., Davis, S.A., Chambers, L.K., and Brown, P.R. 2001. Reproductive changes in fluctuating house mouse populations in southeastern Australia. *Proceedings of the Royal Society of London Series B* **268**: 1741-1748.

Singleton, G.R. and Redhead, T.D. 1990. Structure and biology of house mouse populations that plague irregularly; an evolutionary perspective. *Biological Journal of the Linnaen Society* **41**: 285-300.

Smith, P. 1984. Prey items of the sooty owl and the barn owl at Bega, New South Wales. *Corella* **8**: 71-72.

Story, P. and Cox, M. 2001. Review of the effects of organophosphorus and carbamate insecticides on vertebrates. Are there implications for locust management in Australia? *Wildlife Research* **28**: 179-193.

Tann, C.R., Singleton, G.R., and Coman, B.C. 1991. Diet of the house mouse (*Mus domesticus*) in the mallee wheatlands of north-western Victoria. *Wildlife Research* **18**: 1-12.

Tattersall, F.H., Nowell, F., and Smith, R.H. 1994. A review of the endoparasites of wild House Mice *Mus domesticus*. *Mammal Review* **24**: 61-71.