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Author

Singleton, Grant R.

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ECOLOGICALLY-BASED RODENT MANAGEMENT INTEGRATING NEW DEVELOPMENTS IN BIOTECHNOLOGY

GRANT R. SINGLETON, CSIRO Wildlife and Ecology, GPO Box 284 Canberra, ACT 2601 Australia.

ABSTRACT: Chemical control is currently the primary driver of "Integrated Pest Management" (IPM) for rodents. This generally provides effective control in the short term, regardless of the rodent species. However, governments are concerned about the use of chemicals, especially when they are striving to provide clean and green food products for their domestic and export markets. In developing countries, the challenge is first to develop a good understanding of the ecology of the pest species and then assess the efficacy of using traditional and new methods of rodent control. This will enable adoption of management actions that are more environmentally sound and sustainable (environmentally and culturally). This approach is termed "Ecologically-Based Rodent Management" (EBRM). How EBRM operates in an operational sense is presented for two rather different geographic regions, research approaches and strategies for management. The first research approach is ecologically-based management of rodent pests in rice fields of Southeast Asia. As an indication of their impact, rodents are the greatest agricultural problem in Indonesia causing annual losses to rice production of 17%. I report on the development of a rodent management project in West Java, Indonesia. The initial phase of the research was developing an understanding of the population ecology and habitat use of the main pest species, the rice-field rat (*Rattus argentiventer*). These findings have been combined with local knowledge (of rodents and farming systems) to develop an ecologically-based management strategy of the rice-field rat at a village-level. The second research approach is biological control of house mouse populations in Australia. Mouse populations erupt into plague proportions in cereal-growing regions causing substantial economic and social stress to rural communities. We are examining whether mouse populations can be managed with fertility control either by a non-infectious agent delivered in an oral bait, or by infectious viruses as carriers of an infertility agent. Although the focus is often on the biotechnology aspect of this research, it is knowledge of the population ecology of mice and the epidemiology of mouse cytomegalovirus in field populations that will provide the critical context for this management strategy.

KEY WORDS: rodents, management, *Mus domesticus*, *Rattus argentiventer*, ecologically-based management

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RODENT MANAGEMENT—THE CURRENT REALITY

Despite a plea 50 years ago for an ecological approach to rodent pest management (Emlen et al. 1948; Barnett and Bathard 1953; Davis 1987), in recent decades the emphasis on rodent control has been prescriptive use of rodenticides, often regardless of the species. Therefore, the focus for controlling rodent pests has been to increase mortality through the use of rodenticides, without appropriate attention to other demographic processes or ecological compensatory mechanisms (see Singleton et al. 1999a).

Australia is a case in point where the battle against the depredations caused by outbreaks of house mouse populations (see Singleton and Redhead 1989; Caughley et al. 1994) has been led primarily by the use of rodenticides applied aurally over vast areas (Table 1). The most recent of these poisoning campaigns was conducted in New South Wales in 1999 despite the development of ecologically-based best practices for managing mouse populations in Victoria and southern New South Wales (Singleton 1997; Brown et al. 1998). The application of more than 500 tonne of zinc phosphide during the spring of 1999 is both impressive for the size of the operation and also of ecological concern given the high use of this poison. Unfortunately, a high reliance on rodenticides is generally the rule rather than the exception in many developed and developing countries.

Nevertheless, there is a growing demand, particularly in developing countries, for rodent control strategies that either have less reliance on costly chemical rodenticides or promote better use patterns. This is driven by a stronger awareness of the environmental risks associated with high rodenticide use, and increasing domestic and international marketing requirements for clean agricultural produce that is grown in an environmentally-friendly and sustainable manner. In an effort to turn around this rodenticide culture, there have been attempts to develop rodent IPM based on an understanding of the habitat use and population dynamics of rodent pests (see Wood and Liau 1984; Redhead and Singleton 1988; Whisson 1996; Brown et al. 1998; White et al. 1998; Leung et al. 1999) or the use of biological control (e.g., Lenton 1980; Singleton and Chambers 1996; Singleton et al. 2000a). Later in this paper, some of these studies will be considered in more detail.

The high use of zinc phosphide in Australia in recent years can be argued to be reasonably consistent with IPM principles. Singleton (1997) reviewed the progress of rodent IPM in Southeast Asia and Australia and highlighted five guiding principles that need to be met for effective rodent IPM. The management actions need to be: (1) environmentally sound; (2) cost effective; (3) sustainable—not only environmentally but also with regard to the ability of the users to sustain their actions

Table 1. Summary of broad-scale usage of rodenticides against house mice in Australia in the 1990s. The aerial application of strychnine cost about US \$6 per ha and zinc phosphide about US \$8 per ha (1999 \$ figures). Both poisons were mixed with grain and distributed at a rate of 1 kg/ha of prepared bait (1 tonne per 1,000 ha). Baiting was in winter unless otherwise indicated.

Region - Year	Poison	Area (ha)	Comments
South Australia - 1993	Strychnine	350,000	350 tonne ¹ 170 tonne applied in first two weeks of campaign that began in late July
Victoria - 1993	Strychnine	70,000	Wimmera Also 26,200 ha resown ²
New South Wales - 1994	Bromadiolone - Perimeter use	58,000	Murrumbidgee Irrigation Area Irrigated summer crops ³
Victoria - 1994	Strychnine	20,000	Wimmera
New South Wales - 1995	Strychnine	140,000	North Star, Croppa Ck, Moree 138 tonne, 194 farms in 8 days using 10 planes (Sept) ⁴
Queensland - 1995	Strychnine	250,000	Dalby - Goondiwindi ⁵ within 6.5 million ha region
Queensland - 1997	Zinc Phosphide	33,565	Central Queensland ⁶
South Australia - 1997	Zinc Phosphide	3,055	Mallee and Eyre Peninsula ⁷
Victoria - 1997	Zinc Phosphide	100,000	Wimmera and Mallee ⁸
South Australia - 1998	Zinc Phosphide	12,615	Eyre Peninsula and Yorke Peninsula ⁷
South Australia - 1999	Zinc Phosphide	2,185	Yorke Peninsula ⁷
New South Wales - 1999	Zinc Phosphide	510,085	Baiting in spring ⁹
Victoria - 1999	Zinc Phosphide	1,500	Wimmera ⁸

Sources:

¹Mutze (1998)

²Kearns (1994)

³Croft and Caughley—Farmers' Newsletter (1995) 144:40-41

⁴Data received from David Croft, Agriculture New South Wales

⁵Eldershaw (1995)

⁶Caughley et al. (1998)

⁷Data received from the Farm Chemicals Branch, Primary Industries Research, South Australia

⁸Data received from Ken Dowsley, Natural Resources and Environment, Victoria

⁹The NSW Agriculture Mouse Newsletter, Volume 7, 16 November 1999

a requisite level; (4) applicable on a large scale; and (5) politically and socially acceptable.

An underlying assumption is that the use of rodenticides is integrated with a monitoring system that indicates whether to bait or not. Given this assumption, returning to the broad scale use of zinc phosphide in Australia, it is only points (1) and (2) that would be in question. The environmental risks associated with the use of zinc phosphide are specific to each region, but were thought to be tolerable in central Queensland in 1997 during aerial baiting operations (Caughley et al. 1998). Economically, if farmers were willing to pay US \$8 per ha to apply the poison over > 500,000 ha in 1999, then at least the baiting operation was thought to be affordable. However, the cost-effectiveness has been assessed only in

the central Queensland study; the benefit-cost ratio was estimated by Caughley et al. (1998) to be 12:1.

ECOLOGICALLY-BASED RODENT MANAGEMENT

Recent reviews of "Integrated Pest Management" (IPM) of weeds and insects in the USA (National Research Council 1996) and the UK (Thomas 1999) highlight that the practice of IPM has generally not been consistent with its underlying philosophy, with there being too much emphasis on single technologies such as pest scouting and the use of pesticides. Both of these studies conclude that we need to adopt a more ecological approach to pest management, with a strong focus on the biology and dynamics of pest populations within particular agro-ecosystems.

IPM for rodents has parallels to developments with IPM for insects. Recent reviews of rodent IPM progress (Singleton 1997; Singleton et al. 1999a; Leirs et al. 1999) have concluded that there is a strong need to develop management strategies based on a sound understanding of the rodent species that needs to be controlled. As alluded to in the opening paragraph of this paper, this not a new idea, however, we have built on the earlier research to more formally describe the concept of ecologically-based rodent management (EBRM) (Singleton et al. 1999a). A common international interest in pursuing this concept led to the production of a book on EBRM with contributions from 61 authors drawn from 17 countries (Singleton et al. 1999b).

How EBRM operates in an operational sense will be presented for two rather different ecological systems, rodent species, and strategies for management. The first is the management of the rice-field rat (*Rattus argentiventer*) in lowland irrigated rice fields in Indonesia, with a focus on physical methods of control and modifications to farm management practices. The second is the management of the house mouse (*Mus domesticus*) in dryland cereal-growing regions of Australia, with a focus on biological control.

MANAGEMENT OF THE RICE-FIELD RAT IN INDONESIA

Definition of the Problem

In Southeast Asia, rodents, insects, and weeds are estimated to reduce the potential production of rice crops by 50%, with each thought to cause similar levels of pre-harvest losses (Geddes 1992; Thomas 1999). In Indonesia, rodents are economically the most important pre-harvest pest causing annual losses to rice production of 17% (Singleton and Petch 1994). If we could reduce these losses to less than 7%, then there would be enough rice to feed an extra 20 million Indonesians for a year—providing 60% to 70% of their energy requirements.

Ecologically-based Management

The Government of Indonesia is keen to develop strategies of rodent management that require minimal use of rodenticides. A three-year ecological study of rodent pests in rice-field habitats (see Leung et al. 1999) provided a sound basis for developing such a strategy. The study revealed that the rice-field rat (*R. argentiventer*) caused a majority of the damage to rice crops, that their breeding was strongly cued to the maximum tillering stage of rice crops, that rodent damage to crops is highest when there is a short fallow between crops (given there is generally a short fallow between the wet season and dry season rice crops, then the dry season crops suffer the largest losses), that certain habitats acted as source populations and others as sinks, and that much of the labor intensive control actions (e.g., use of sulfur for fumigating burrows; stalking rats at night and then clubbing them) where implemented too late and were having little impact on the level of crop damage. This ecological study was augmented by detailed radio-tracking studies on the movements and habitat use of rats (Brown et al. in press), on the timing of rat damage to rice crops (Singleton et al. 1998) and by experimental

studies of the benefit-cost of a barrier system with multiple-capture traps associated with a lure crop (Singleton et al. 1999c).

The findings of the above studies were used to develop a decision analysis/systems analysis approach (see Norton and Pech 1988) for the management of the rice-field rat. The appropriateness of different management actions was appraised through combining our ecological knowledge with that of agricultural extension staff (Table 2). The decision analysis was subsequently refined following consultation with farmers. The end result was the development of a village-level management program for the rice-field rat. In November 1999 this ecologically-based rodent management program was implemented at two villages in West Java, with two other villages set up as untreated controls. The rate of implementation of this management program and its economic impact will be monitored for two years. A similar study is in progress in the Red River delta of Vietnam.

MANAGEMENT OF MICE—INTEGRATING NEW DEVELOPMENTS IN BIOTECHNOLOGY

Definition of the Problem

A mouse plague is defined as a widespread eruption of house mouse (*Mus domesticus*) populations to densities greater than 750 mice per ha, and usually greater than 1,000 mice per ha. These mouse plagues occurred aperiodically with a frequency of one year in four prior to 1980, and approximately one year in two since then (Singleton and Brown 1999). The 1993 plague in southern Australia is the best documented one with minimum quantifiable losses of US \$42 million (Caughley et al. 1994), and an estimated US \$65 million in grain production saved because of aerial baiting. Since 1994, the area planted to grain crops has increased by >30% and production by 50%. Therefore, a future major plague is likely to cause losses of >US \$130 million. Added to this is the substantial social stress experienced by rural communities during plagues, with mice invading the living space of people, food stores, general businesses, and hospitals.

Fertility Control of House Mice

Current control of rodent pests generally relies on mortality agents such as poisons, physical control using traps, or habitat manipulation (e.g., destruction of burrows). These approaches often require continual application to cause long-term reductions in the impacts of the pest, are not sustainable because of cost or high labor involvement, and have an unacceptable environmental risk because they affect non-target species or contaminate crops. Also, many mortality control agents or actions are thought inappropriate because they appear to be unacceptably inhumane to rodent pests.

Another approach to rodent control is to reduce the recruitment of young into the population by affecting the fertility of the species. Rodent species such as mice that cause high economic losses in agricultural systems have a high innate capacity to rapidly increase their population density. Therefore, these species should be a prime target for fertility control. Moreover, fertility control addresses most, if not all, of the concerns associated with

Table 2. Decision analysis of practices for managing populations of the rice-field rat in rice agro-ecosystems in West Java, Indonesia. Decisions were based on a solid understanding of the population ecology of the rice-field rat. (After Leung et al. 1999). Timing: Early = land preparation to transplanting of rice seedlings; Mid = tillering to maximum tillering; Late = booting to harvest; Fallow; Suitability of practices: Y = yes; N = no; ? = unknown.

Management Practice	Timing	Feasible	Economic	Socially OK	Environment OK	Sustainable	Scale of Adoption	Scientific Basis	Priority
<u>Routine</u>									
Field sanitation	Early to Mid	Y	Y	Y	N?	Y	village	?	high
Synchronous seeding and planting	Early	Y	Y	Y	Y	Y	village	Y	high
Barrier system with traps and lure crop	All	Y	Y	?	Y	Y	village	Y	high
Reduce bund size within rice fields	Early	Y	Y	Y	Y	Y	village	Y	high
Encourage natural enemies of rats	All	?	?	Y	Y	?	district	?	high
Fumigation	Early to Mid	Y	Y	Y	N	Y	village	N	moderate
Digging burrows	Mid	Y	?	Y	N	N	village	?	moderate
Hunting at night	Mid	Y	N	Y	Y	N	village	?	low
Trapping with net	Fallow	Y	N	Y	Y	?	village	?	low
<u>Apply if high densities are forecast</u>									
Do not plant rice as the third crop		Y	Y	Y	Y	Y	farmer	Y	high
Remove rice straw after harvest	Fallow	Y	Y	Y	N	N	village	Y	high
Apply rodenticide	Fallow + Early	Y	?	Y	N	N	village	?	moderate
Pump water down burrow entrance	Fallow	Y	?	Y	Y	?	village	?	moderate

mortality control for managing rodents in agricultural systems (see Chambers et al. 1999a for review).

We are currently examining one approach of fertility control known as immunoncontraception for controlling mouse populations (Singleton 1994; Chambers et al. 1997, 1999a). The concept is based on an antigen (a reproductive protein) that generates an immune response, with antibodies in the female host blocking fertilization. In effect the goal is to develop an immunoncontraceptive vaccine. Such immunoncontraceptive approaches are potentially highly species-specific, are considered humane and are likely to be cost effective in the long term (Tyndale-Biscoe 1994). The focus is on generating fertility control by using either a non-infectious agent delivered in oral baits or infectious viruses as carriers of an infertility agent. The results thus far are promising; for example, it has been shown under controlled laboratory

conditions that a reproductive protein can be inserted into a mouse-specific virus and that mice infected with this recombinant virus become sterile for periods in excess of 150 days (see Chambers et al. 1999a for overview).

This is a multi-disciplinary research program involving molecular biologists, virologists, reproductive physiologists, immunologists, and population ecologists. Often the focus is on the biotechnology aspect of this research, however, it is the population ecology and epidemiology that will provide the critical context in the real world for this approach in mice. Our ecological research on immunoncontraception for mice in Australia has covered a number of different paths. Singleton et al. (2000a) have reviewed the rationale and progress of these population studies. For the sake of brevity, these studies are summarized in Table 3 with additional information provided on research in progress. It can be seen from

Table 3. An overview of the ecological studies, completed or in progress, that contribute to our understanding of the potential use of immunoncontraception (IC) to control house mice in cereal-growing regions of Australia.

Ecological Study	Main Focus and Outputs	Reference
Ecology of mouse populations that erupt into plague proportions	Mechanisms of mouse plagues	Singleton 1989; Boonstra & Redhead 1994
	Habitat and spatial use by mice	Krebs et al. 1995; Chambers et al. 2000
	Formal population models of mouse plague formation	Pech et al. 1999, In progress
Selection of possible viral vector for IC	Sero-survey of murine viruses	Smith et al. 1993
	Life history aspects of viruses found in the field	Singleton et al. 1993
Epidemiology of mouse populations and mouse cytomegalovirus (MCMV)	Seasonal and inter-annual dynamics of interaction between mouse populations and MCMV	Singleton et al. 2000b; Moro et al. 1999
	Contact rates between mice; transmission of MCMV	In progress
Proportion of population that needs to be sterilized	Simulate sterility via tubal ligation of 60% to 65% of females in confined populations of wild mice	Chambers et al. 1999b
	Pulse versus sustained sterility	In progress
Modelling interaction of mouse populations and IC	Proportion of mice required to be sterilized	Chambers et al. 1997
	Viral versus bait delivery	In progress
Epidemiology of recombinant MCMV	Level of sterility in mice	Singleton et al. 2000a
	Modes and rate of transmission; pathogenesis	In progress
	Species-specificity	Moro et al. 1999

this overview that there is a considerable amount of knowledge of the population ecology of mice and the epidemiology of mouse cytomegalovirus in field populations of mice required to provide the critical context for this management strategy. These studies also provide essential information for risk assessment analyses and informed public debate on the benefits and possible trade-offs of a novel biological control agent.

CONCLUSION

As with more traditional approaches to rodent pest management, the success of biological control based on biotechnological advances requires a strong ecological context during both its development and implementation phases. Therefore, the concept of ecologically-based rodent management is just as applicable to developing fertility vaccines delivered by viruses or non toxic baits for controlling mice in Australia, as it is to the control of rats in Southeast Asia using a combination of simple technologies and coordinated farmer participation. The key is to understand the ecological processes driving the dynamics of the pest populations.

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