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INTEGRATED MANAGEMENT OF RODENTS: A SOUTHEAST ASIAN AND AUSTRALIAN PERSPECTIVE

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Abstract. This paper discusses the concept of integrated pest management (IPM) and considers the progress that has been made towards effective implementation of IPM for rodent pests in agricultural systems in Southeast Asia and Australia. Unfortunately, progress with the management of rodents lags considerably behind IPM for insect pests and diseases of crops. Too often, recommended management practices lack scientific rigour, instead they are based on frequent reiteration of a concept which results in it being accepted as dogma. From a rodent management perspective, IPM in these regions is better described as perceived integrated management (PIM). Two case studies, one from Southeast Asia and one from Australia, are presented to demonstrate how replicated, manipulative field experiments with appropriate controls can redress this situation. The first study is on the rice field rat in West Java. The second study is on mouse plagues in southeastern Australia. In each case, the IPM programs are built around detailed descriptive studies of the population ecology of the pest species. The challenge lies ahead for rodent wildlife managers to not only develop effective rodent IPM but also to integrate these management actions with existing IPM programs of non- mammalian pests. From the perspective of a wildlife biologist, other pressing challenges for establishing effective and sustained control of rodents in Southeast Asia, were identified. These were the lack of appropriate tertiary training in wildlife management, the weak infra-structure for research on rodent pests, and the need to develop effective extension for programs on the management of rodents.

Key Words: Integrated pest management, rodent, mouse plagues, population ecology, Southeast Asia, Australia, *Rattus argentiventer*, *Mus domesticus*.

INTRODUCTION

Integrated pest management (IPM) is simply defined as the integration of a range of management practices which together provide more effective management of a pest species than if they are used separately. IPM has been the principal goal of the development of pest management for many years, although the chief goal of an IPM program is often not clear to practitioners involved in that program. A recent survey indicated that staff in the United States of America who coordinated the extension of a federal IPM program on insect pests were diametrically opposed to whether the chief goal of their IPM program was to reduce pesticide use; 20 thought yes and 23 thought no (GRAY, 1995). This highlights the need for managers of rodent IPM programs to learn from the mistakes of the past.

IPM had its genesis in the control of insect pests and plant diseases in agricultural environments where there was a strong move away from pesticides towards management of the agricultural system so as to promote methods which were least ecologically disruptive (SMITH & VAN DEN BOSCH, 1967). These methods include physical, cultural and biological control. A common approach for managing insect pests and diseases of crops is to promote the effect of predators and competitors through adopting actions which have a minimum impact on their natural role of limiting pest populations. These predators or competitors can be either endemic to a region or introduced as part of a biological control program aimed at establishing an alien organism in the region. At this point I wish to emphasise that rodenticides and biological control agents (if they can be successfully applied) should both be considered as integral parts of IPM of rodents. Too often views are expressed that a particular program is not IPM because poisons were used or their use was not reduced (GRAY, 1995), or once biological control is developed no further action will be required. Both views are incorrect and are old arguments. In the first instance, the use of rodenticides is consistent with IPM principles if the amount and/or frequency of applications of the rodenticide have been significantly reduced during the implementation of IPM (see BUCKLE, 1990; FIEDLER & FALL, 1994, for discussion). Although there is an equally acceptable view that IPM is not designed to reduce the use of chemicals for controlling pests, rather the goal is to reduce the impact of the pest with minimal impact on the environment (PETTY, 1973).

In the second instance, the coevolution of the biological disease agent and the host (the pest species) is likely to reduce the effectiveness of the biological control. Therefore, maintenance of effective control will require the action of the biological agent to be augmented by more traditional methods of management. This is the clear message emerging from one of the few successful cases of biological control of a vertebrate pest; the use of a myxoma virus to control rabbits in Australia (WILLIAMS *et al.*, 1995). Finally, the need to consider the use of either chemical or biological control in a broader ecological context is paramount given the toxicological effects of inappropriate use of chemicals and cases of biological control which not only have been ineffective but have caused worse ecological problems (*e.g.* the release of the cane toad in Australia and Hawaii).

There are many socio-political factors which influence the adoption rate of IPM (see KENMORE *et al.*, 1985; NORTON & HEONG, 1988 ; POSAMENTIER, 1988). The use of decision analysis (NORTON, 1982; NORTON & PECH, 1988) early in an IPM program helps to address these factors through understanding why farmers adopt particular management actions and ignore others. A decision analysis approach provides the platform for developing and extending management actions through matching science to the problem. I will not dwell on the socio-political influences on IPM, instead I will narrow the focus to the scientific approach to integrated management of rodents. Too often recommended management practices lack scientific rigour, instead they are based on frequent reiteration of a concept which results in it being accepted as dogma. Unfortunately, wildlife management in general suffers from the acceptance of hypotheses that are not supported by rigorous field data. SINCLAIR (1991) provides an elegant discussion of science and the practice of wildlife management.

Development of a regional or national IPM program requires not only rigorous scientific research but also implementation of basic management principles. From a research perspective, to focus simply on good scientific method is folly if the scale, setting (laboratory versus field studies) of experiments, and/or the management actions being examined are inappropriate (see also NORTON & PECH, 1988). A decision analysis approach helps marry research goals with management goals. From a management perspective, the strength of rodent IPM is dependent on the following principles:

(i) The management actions are environmentally sound – the use of rodenticides are minimised or targeted so as to reduce their impact on non-target species and, depending on the chemical, their entry into the food web (especially as a residue in the crop being protected).

(ii) The management actions are cost effective – this is of particular importance in developing countries where farmers have small holdings and little disposable income for management actions.

(iii) The management actions must be sustainable – this relates not only to actions being environmentally sustainable, but also to actions being consistent with the other demands on the end users. If the actions are too complex, too labour intensive or too difficult to integrate with their farm management system, then the end users are unlikely to either sustain their actions or maintain the requisite quality of actions.

(iv) The management actions must be able to be applied on a large scale – this is particularly important given the mobility of rodents and their ability to quickly colonise areas where crops are ripening and where rodent numbers have been reduced by local control actions.

(v) The management actions are politically advantageous – an action may be both feasible and desirable but is not adopted for local or national political reasons (see NORTON, 1988 for example).

In this paper the scientific approach to the integrated management of rodents will be demonstrated by drawing on two case studies of research currently being conducted in Southeast Asia and Australia. Both studies are aimed at critically evaluating IPM programs using replicated and controlled field studies.

CASE STUDIES

Case study 1: Rice field rat in Indonesia

The Rice field rat, *Rattus argentiventer* (Robinson & Kloss, 1916), is the most important pre-harvest pest in Indonesia (GEDDES, 1992). Rat damage to rice crops is the greatest agricultural problem in Indonesia causing annual production losses of approximately 17% (see SINGLETON & PETCH, 1994 for review), equivalent to reducing the potential value of the Indonesian rice crop by about US$ 1 billion.

The principal methods of rat control in Indonesia are varied, generally widespread and labour intensive. However, there have been few efforts to critically evaluate the effectiveness of these methods, either singly or in combination (Table 1).

An emerging and promising method of control is the use of a trap-barrier (TBS) to protect rice crops, which was first developed in Malaysia (LAM, 1988). The TBS consists of a rectangular or linear fence and multiple-capture traps inserted at intervals near the base of the fence. A mud mound, which protrudes above the irrigated water level, provides access to the traps. It works on the principle that rats enter the edge of the flood-irrigated crop, but cannot gain access to the rice because of the fence. Rats could climb over the fence but rarely do so. They swim along the fence, taking the line of least resistance, come to a mud mound and then enter the trap. Up to 129 rats have been caught in a single trap (260 x 260 x 620 mm) in one night (LAM *et al.*, 1990).

TABLE 1

An overview of what is known about the most common methods used by farmers for controlling the rice field rat in Indonesia

Method of rat control	*Level of adoption by farmers*	*Research on effectiveness*	*Potential as part of IPM*
Poisoning	Moderate; prefer zinc phosphide – cheap & see rat bodies	Yes – but best data on anticoagulants	High – depends on benefit-cost and availability
Trapping	High-labour intensive	None	Medium
Rat drives	Moderate – labour intensive but only when rat numbers are high	None	Low? – timing important
Electrocution	Low – high elsewhere in SE Asia	None	Low
Natural predators	Low – generally few birds of prey; snakes are hunted	None	Medium
Fumigation	High – labour intensive; using a sulphur gas	None	Medium – timing important
Trap-barrier	Moderate – usually with no traps; labour intensive	Yes, but no controls	High – depends on benefit-cost

The principle behind the TBS is simple and is now widely used in many countries in Asia. However, benefit-cost analysis indicates that rat damage would need to be higher than 30% in rice crops for the method to be cost effective (SINGLETON *et al.*, 1994; LAM YUET MING, pers. comm.). There have been various claims that the effectiveness of the TBS can be enhanced if the crop inside the TBS («trap-crop») is at an earlier stage, later stage, more aromatic, consists of seedlings (rice is transplanted into adjacent rows every two weeks) or is a combination of these treatments. In some instances these claims were backed up with data, but in each case there were inadequate control sites, usually no replication and limited economic assessment. Instead of critical evaluation of well formulated hypotheses, poorly substantiated claims were feeding off each other which led to the development of the dogma that «trap-crops» inside a TBS will provide general protection from rats for surrounding rice-crops. This dogma may indeed be correct but the data available were insufficient to provide farmers with a prescriptive approach to the type of trap crop, the size of the crop (and TBS) and how frequently they need to be spaced.

To redress this situation a project has been established in West Java, Indonesia, with replicated treatment and control sites, and rigorous assessment of the benefit-cost to farmers. From an IPM perspective, this study has been assessing also the effectiveness of fumigation of rat burrows using sulfur gas. Fumigation is the most common method of rat control used by farmers in this region.

Design of TBS and Fumigation study

The study is located at the Research Institute for Rice in Sukamandi, West Java. There are four treatments with two replicates per treatment. The treatments are a TBS with fumigation of rat burrows; TBS with no fumigation; fumigation only; no rat control. Each site is separated by a minimum of 500 m. The rice within each TBS (variety IR64) is transplanted 14-21 days prior to the surrounding crop (variety IR64). At sites without a TBS, a similar area is planted with rice 14-21 days prior to the surrounding crop.

Each TBS consists of a 50 m x 50 m square of 0.7 m high plastic supported by bamboo poles (1.2 m long) inserted 0.5 m into the ground, spaced 1 m apart and interconnected by string. The bottom 50-100 mm of the fence is buried. A live-capture trap is placed every 25 m (n=8), flush with and opening to, the outside of the fence. These are multiple capture traps (600 mm x 240 mm x 240 mm) with an opening of 100 mm in diameter at the base of one end of the trap leading to a wire cone 240 mm long, tapering to 50 mm in diameter. The traps are made of open wire mesh (gauge 1 mm and 12 x 12 mm squares). Holes are made in the fence to allow entry into the traps. There is raised earth above the water level at each entry point.

Rat burrows along the perimeter of each 5 ha site were fumigated using sulphur gas. The gas was delivered by a hand-operated fumigator which forced air over smouldering straw containing sulphur granules. Fumigation was conducted every 1 -2 weeks after the rice crop was at maximum tillering stage.

Damage caused by rats to rice tillers were assessed along 6 transects to the north and 6 to the south of the trap crop, every two weeks and for each treatment. The transects were within the trap crop, and 5 , 50, 100, 150 and 200 m from the trap crop. Each transect was 11.2 m long, following a transplanted row of rice. Every fifth hill (n=10) along each transect was assessed for number of tillers damaged by rats. In addition to cut tillers, yields were assessed from 10 x 10 m quadrats taken at each transect and at each of the eight sites during the week prior to harvest.

An overview of the outcomes from the first two years of the study is presented in Table 2. Briefly, the TBS provided good returns to growers when rat numbers were high relative to other seasons and most of the rat damage was during the generative stage of the rice crop (booting to harvest). Fumigation had little effect on rat damage to rice crops, resulting in a net cost to growers using fumigation for rat control. In one of three seasons, the TBS plus fumigation treatment resulted in better control of rat damage, and hence yield loss, than the use of a TBS alone.

TABLE 2

An overview of the effectiveness of a trap-barrier system (TBS), fumigation or TBS plus fumigation for controlling the rice field rat in West Java, Indonesia. The benefit-cost ratio was estimated from differences in yields between treated and untreated fields of rice. Where two values are given these are a direct and a more conservative estimate (see SINGLETON *et al., in press for details).*

Season	*Rat density*	*Time of main tiller damage*	*Benefit-cost ratio*		
			TBS	*Fumigation*	*TBS + Fum*
1995 Dry	High	Booting to harvest	20: 1 to 7: 1	Net cost	Additive effect
95/96 Wet	Low	Maximum tillering	7: 1 to 2: 1	Net cost	No effect
1996 Dry	Medium	Tillering	Net cost	Net cost	No effect

These results highlight the need for longitudinal studies of management practices with concurrent data on the population dynamics and ecology of rat populations, before a robust IPM program for rats can be developed for a particular region.

Case study 2: Mouse plagues in Australia

In southern and eastern Australia, populations of house mice, *Mus domesticus* (Schwarz & Schwarz, 1943), occasionally erupt with densities of >1,000 ha^{-1} occurring over thousands of square kilometres. These mouse plagues cause substantial economic losses, high levels of social stress, health risks to humans, and environmental problems through the heavy use of chemicals (see SINGLETON & REDHEAD, 1989 for review).

The occurrence of mouse plagues is aperiodic. On average there is 3 to 7 years between plagues depending on the region. It is difficult therefore to develop and critically assess management actions within a short time frame. Indeed, it is only recently that we have been able to obtain sufficient ecological data to determine key processes leading to the formation of mouse plagues (SINGLETON, 1989; BOONSTRA & REDHEAD, 1994; TWIGG & KAY, 1995) or to focus on key issues which must be addressed (KREBS *et al.*, 1995). Currently there is pressure from farmers and society to formulate IPM rather than continue with the current practice of remedial large scale use of poisons once a plague has developed.

In southeastern Australia, scientists and farmers have collaborated to identify what are likely to be the best practices available for managing mouse populations given our current knowledge. A demonstration study was established in two regions as part of a national program for establishing best practice for managing vertebrate pests (see BRAYSHER, 1993).

The respective contributions by scientists and end-users (farmers) to this program are summarised in Table 3. Meeting with farmers at the beginning of the study provided consensus on issues such as:

TABLE 3

Integrated management of mouse plagues in southern Australia – the marriage of science and end-users

Contribution by scientists	*Contributions by farmers*
1. Habitat use and population dynamics of mice – what, when & where to control; scale of operation.	1. Identify actions to target factors (identified by science) which limit mouse populations – how to control.
2. Monitor population numbers & breeding of mice – interpretation and forecasts.	2. Logistics of control operations. – practicality & cost – possible to incorporate in farm program – consistent with sustainable farming?
3. Rigorous evaluation of management actions, including benefit-cost.	3. Important role in extension – facilitate adoption by neighbouring farmers.

(i) recognition that an integrated management approach is required,

(ii) that we have a solid understanding of the dynamics and habitat use of mouse populations and, although there are many gaps in our scientific knowledge, we can formulate testable strategies for managing mouse populations,

(iii) that rodent management procedures will be adopted only if they do not compete with existing farm management practices.

Design of study on Best Practices for Management of Mouse Plagues

The study began in June 1995 and is being conducted in two regions of western Victoria, Australia. In the first region there are four farmers conducting identified best

TABLE 4

Actions to be taken in spring by growers who are trialing recommended best practices for managing mouse populations in southern Australia. Lists of activities are available for the other seasons

Recommended spring activities
1. Control the growth of grasses and weeds along fences – spray before their seeds are set (seeds of early grasses may trigger breeding by mice)
2. Graze pasture well to minimise seed set of grasses
3. Reduce ground cover for mice around silos and farm buildings
4. Mouse-proof grain and stock food storages
5. Bait farm buildings and key habitats (margins of crops) in late September and October
6. Monitor signs of mouse activity in different habitats; bait where activity is high

practice for managing mouse populations (experimental regime) and three farmers doing what they have been doing for decades (control regime). In the second region there are two farmers in each regime. The farms have been matched as far as practicable for soil type, climate and crops. All have only one growing season per year (winter-spring), with the principal crops being wheat, barley, field peas and canola (oilseed). The study area on each of the 11 farms is between 800 and 1,000 ha and there is a minimum of 5 km between farms.

A range of actions have been identified for each season. As an example, the actions for spring are listed in Table 4. The actions by individual farmers are monitored and these are contrasted with changes in mouse abundance (live-trapping every 6 to 8 weeks), plant biomass along fence lines (measured in spring and autumn), grain remaining in fields immediately after harvest and 3 months later, and the level of mouse damage to crops just prior to harvest and at planting. Costs on implementing management practices are being collated to enable a benefit-cost analysis of the study.

DISCUSSION

IPM or PIM?

What progress have we made with rodent IPM in Southeast Asia and Australia?

In Southeast Asia, there have been detailed studies of aspects of the biology of the rice field rat, *R. argentiventer*, and the Philippine rice field rat, *Rattus mindanensis* (Taylor, 1934), in and around rice crops, and the Malaysian wood rat, *Rattus tiomanicus* (Miller, 1900), in oil palm plantations, which have led to recommended IPM programs (FALL, 1977; WOOD & LIAU, 1984; RICHARDS & BUCKLE, 1986; BUCKLE, 1988; 1990, COLVIN, 1990). Apart from replicated and controlled studies of the efficacy of various rodenticides for managing rat populations (*e.g.* BUCKLE *et al.*, 1984; LAM, 1990) there have been few studies which have evaluated critically, under field conditions, the effect of individual management actions let alone whether two different actions complement each other, are synergistic, are not additive or possibly have a lower effect than either action by itself.

In Australia, there have been detailed studies of aspects of the biology of house mice in cereal growing regions and of the canefield rat, *Rattus sordidus* (Gould, 1858), in and around sugar plantations. For the mouse there have been manipulative, replicated field studies of the effect of parasites (*e.g.* SINGLETON *et al.*, 1995; SINGLETON & CHAMBERS, 1996), food quality (*e.g.* BOMFORD & REDHEAD, 1987) and rodenticides (*e.g.* MUTZE, 1993; BROWN *et al.*, 1997) on mouse populations. Apart from the case study described above, no studies have evaluated critically the interaction and consequences of two different management actions for controlling mouse populations.

For the canefield rat, there has been a replicated manipulative study of different tillage practices (WHISSON, 1996). This work has been taken a step further through examining the efficacy of tillage practices in combination with restricted and targeted rodenticide usage for managing canefield rat populations (J. WILSON, pers. comm.).

Therefore, from a rodent management perspective, IPM in Southeast Asia is better described as Perceived Integrated Management (PIM). The situation in Australia is little better.

The Way Forward - Manipulative Experimental Field Studies

The adoption of successful IPM for rodents requires rodent biologists to establish first descriptive population studies. Ideally, these would be capture-mark-release-recapture studies conducted every 3-6 weeks, with traps set in the principal habitats in the cropping landscape. Such studies of rodent pest species are an essential precursor for establishing which strategic management approaches would be the best candidates for IPM. If there are sufficient data (minimum of 3 years data for chronic pest species; longer periods for outbreaking species) then modelling of the population dynamics of rats may enable critical evaluation of key population processes, the dynamics of habitat use, and/or an ability to forecast population outbreaks. Unfortunately, the modelling approach has been seldom used because there are few long term population studies of rodent pests.

Once the best prospects for IPM have been identified, hypotheses need to be developed and then critically evaluated using replicated, manipulative field experiments with appropriate controls. The control (untreated) sites in these manipulative studies provide continuity of previous population studies and hence the basis of a long term data set. Typically, few studies move beyond the descriptive population phase.

Rodent wildlife biologists therefore need to establish a good baseline ecological study, from there develop best prospects for IPM, then critically evaluate these management methods using replicated manipulative experimental studies in the field.

This is the basic philosophy behind the IPM case studies presented for the rice field rat and house mice. The case study for the TBS is not an isolated study. As part of a multinational program on rodent pest management in Southeast Asia, the TBS approach is being evaluated critically also in peninsular Malaysia and in the Mekong and Red River Deltas in Vietnam. This is an exciting development because this collaboration provides an opportunity to contrast the effectiveness of a rodent management program under different landscapes, agricultural systems, climates and socio-political backgrounds.

CONCLUDING REMARKS

Much has been written about the implementation of IPM for insect pests and plant diseases (see KILGORE & DOUTT, 1967; REISSIG *et al.*, 1986). In Southeast Asia, the entomologists and plant pathologists have joined forces to develop multicountry IPM programs. Rodent IPM lags substantially behind and thus far there has been only cursory consideration of rodents in these programs (VAN ELSEN & VAN DE FLIERT, 1990). The challenge lies ahead for rodent wildlife managers to not only develop effective rodent IPM but also to integrate these management actions with existing IPM programs of non-mammalian pests.

From the perspective of a wildlife biologist, there are other pressing challenges for establishing effective and sustained control of rodents in Southeast Asia. First, the expertise in rodent biology needs to be strengthened; there are few tertiary courses in wildlife management in the region, with most practising rodent biologists having been trained as entomologists. This is of concern because the field techniques and analytical methodologies are markedly different for insects and rodents, as are their population dynamics (dealing with over-lapping generations with rodents), individual and social behaviour (more complex for rodents), and their population responses to climate, land management, diseases and predators. Second, the infra-structure for research on rodent pests is weak in most countries in the region. Third, the few research programs on rodent pests in the region focus primarily on single species. Generally, there are many rodent species living in or near rice fields. We need to be cognisant of the life history parameters of these species so that we can anticipate and monitor the possible emergence of one of these as a significant pest, if the population of the current primary pest species is managed effectively . Finally, effective extension of IPM programs has been difficult with insect pests (NORTON & HEONG, 1988). These difficulties are likely to be compounded for rodents because they have lived commensally with humans for centuries and there are many myths, taboos, rituals and customs linked with them. These vary from region to region, country to country. Once an IPM program has been shown to be effective, scientifically, in every likelihood there will be an even greater challenge to develop effective extension and adoption of the program. Recognition and then definition of these possible problems is an important first step and underlines a commonality between the scientific and sociological aspects of wildlife management – involve the end-users at the planning stage of studies, not after spending many years seeking and then defining what might be an inappropriate management program.

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REFERENCES

BOMFORD, M. & T.D. REDHEAD (1987) – A field experiment to examine the effects of food quality and population density on reproduction of wild house mice. *Oikos*, **48**: 304-311.

BOONSTRA, R. & T.D. REDHEAD (1994) – Population dynamics of an outbreak population of house mice (*Mus domesticus*) in the irrigated rice-growing area of Australia. *Wildlife Research*, **21**: 583-598.

BRAYSHER, M. (1993) – *Managing Vertebrate Pests: Principles and Strategies*. Australian Government Printing Service, Canberra, 58 pp.

BROWN, P.R., G.R. SINGLETON, B. KEARNS & J. GRIFFITHS (1997) – Evaluation of the cost-effectiveness of strychnine for control of wild house mouse (*Mus domesticus*) populations in Victoria. *Wildlife Research*, **24**: 159-72.

BUCKLE, A.P. (1988) – Integrated management of rice rats in Indonesia. *FAO Plant Protection Bulletin*, **36**: 111-118.

BUCKLE, A.P. (1990) – Recent developments in rice rat control. In: *Rodents and Rice, report and proceedings of an expert panel meeting on rice rodent control.* (Ed. G.R. QUICK), Manila, Philippines, International Rice Research Institute: 87-96.

BUCKLE, A.P., F.P. ROWE & H. ABDUL RAHMAN (1984) – Field trials of warfarin and brodifacoum wax block baits for the control of the rice field rat, *Rattus argentiventer*, in peninsular Malaysia. *Tropical Pest Management,* **30**:51-58.

COLVIN, A.C. (1990) – Habitat manipulation for rodent control. In: *Rodents and Rice, report and proceedings of an expert panel meeting on rice rodent control.* (Ed. G.R. QUICK), Manila, Philippines, International Rice Research Institute: 61-64.

FALL, M.W. (1977) – *Rodents in Tropical Rice.* University of the Philippines at Los Baños College, Laguna, Philippines, 39 pp.

FIEDLER, L.A. & M.W. FALL (1994) – Rodent control in practice: tropical field crops. In: *Rodent Pests and their Control.* (Eds A.P. BUCKLE & R.H. SMITH), CAB International, Wallingford, UK: 313-338.

GEDDES, A.M.W. (1992) – The relative importance of pre-harvest crop pests in Indonesia. Chatham, UK., *Natural Resources Institute Bulletin* 47, 70 pp.

GRAY, M.E. (1995) – Status of CES-IPM programs: results of a national IPM coordinators survey, *American Entomologist*, **41**: 136-38.

KENMORE, P.E., K.L. HEONG & C.A.J. PUTTER (1985) – Political, social and perceptual factors in integrated pest management programmes. In: *Integrated Pest Management in Malaysia.* (Eds B.S. LEE, W.H. LOKE & K.L. HEONG), Kuala Lumpur: 47-66.

KILGORE, W.W. & R.L. DOUTT (1967) – *Pest Control: Biological, Physical, and Selected Chemical Methods*. Academic Press, New York, 477 pp.

KREBS, C.J., D. CHITTY, G.R. SINGLETON & R. BOONSTRA (1995) – Can the Chitty hypothesis help explain house mouse plagues in Australia? *Oikos*, **73**: 429-34.

LAM, Y.M. (1988) – Rice as a trap crop for the rice field rat in Malaysia. In: *Proceedings 13th Vertebrate Pest Conference* (Eds A.C. CRABB & R.E. MARSH): 123-128.

LAM, Y.M. (1990) – Evaluation of four rodenticidal dust for the control of *Rattus argentiventer* in rice fields. *MARDI Res. J.*, **18**: 85-189.

LAM, Y.M., M.A. SUPAAD, P.M. CHANG, M.S. MOHAMED, C.S. GOH, & H. RADZI (1990) – An innovative approach for protecting rice against severe rat depredation. Proceedings of the 3rd International Conference on Plant Protection in the Tropics, 20-23 March, Genting Highlands, Malaysia. Vol. 2: 41-49.

MUTZE, G. (1993) – Cost-effectiveness of poison baits trails for control of house mice in mallee cereal crops. *Wildlife Research*, **20**: 445-456.

NORTON, G.A. (1982) – A decision analysis approach to integrated pest control. *Crop Protection*, **1**: 147-164.

NORTON, G.A. (1988) – Philosophy, concepts and techniques. In: *Vertebrate Pest Management in Australia: Decision Analysis/Systems Analysis Approach.* (Eds G.A. NORTON & R.P. PECH), CSIRO, Division of Wildlife and Ecology, Project Report No. 5 CSIRO: Melbourne: 1-17.

NORTON, G.A. & K.L. HEONG (1988) – An approach to improving pest management: rice in Malaysia. *Crop Protection*, **7**: 84-90.

NORTON, G.A. & R.P. PECH (1988) – *Vertebrate Pest Management in Australia: Decision Analysis/Systems Analysis Approach*. CSIRO, Division of Wildlife and Ecology, Project Report No. 5 CSIRO, Melbourne, 67 pp.

PETTY, H.B. (1973) – An applied insect pest management program and population threshold. In: *25th Illinois Operator Spray School Summary of Presentations*, University of Illinois, Urbana-Champaign: 63-68.

POSAMENTIER, H. (1988) – Integrated pest management, principles in rodent control. In: *Rodent Pest Management* (Ed. I. PRAKASH), CRC Boca Raton: 427-439.

REISSIG, W.H., E.A. HEINRICHS, J.A. LITSINGER, K. MOODY, L. FIEDLER, T.W. MEW & A.T. BARRION (1986) – *Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia*. International Rice Research Institute, Los Baños, Laguna, Philippines, 411 pp.

RICHARDS, C.G.J. & A.P. BUCKLE (1986) – Towards integrated rodent pest management at the village level. In: *Control of Mammal Pests*. (Eds C.G.J. RICHARDS & T.Y. KU), Taylor & Francis, London: 293-312.

SINCLAIR, A.R.E. (1991) – Science and the practice of wildlife management. *Journal of Wildlife Management*, **55**: 767-773.

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. & L.K. CHAMBERS (1996) – A large scale manipulative field study of the effect of *Capillaria hepatica* on wild mouse populations in southern Australia. *International Journal for Parasitology*, **26**: 383-398.

SINGLETON, G.R. & D.A. PETCH (1994) – *A Review of the Biology and Management of Rodent Pests in Southeast Asia*. ACIAR Technical Reports No. 30, ACIAR, Canberra, 65 pp.

SINGLETON, G.R. & T.D. REDHEAD (1989) – *House mouse plagues. In: Mediterranean Landscapes in Australia: Mallee Ecosystems and their Management*. (Eds J.C. NOBLE AND R.A. BRADSTOCK), CSIRO, Melbourne: 418-433.

SINGLETON, G.R., L.K. CHAMBERS & G.R. QUICK (1994) – *Assessment of the IRRI Active Barrier System (ABS) for rodent control*. Final report to ACIAR, International Rice Research Institute, Los Baños, Laguna, Philippines, 49 pp.

SINGLETON, G.R., L.K. CHAMBERS & D.M. SPRATT (1995) – An experimental field study to examine whether *Capillaria hepatica* (Nematoda) can limit house mouse populations in eastern Australia. *Wildlife Research*, **22**: 31-53.

SINGLETON, G.R., SUDARMAJI & S. SURIAPERMANA (in press) – An experimental fiels study to evaluate a trap-barrier system and fumigation for controlling the rice field rat, *Rathus argentiventer*, in rice crops in West Java. *Crop Protection*.

SMITH, R.F. & R. VAN DEN BOSCH (1967) – Integrated control. In: *Pest Control: Biological, Physical and Selected Chemical Methods*. (Eds W.F. KILGORE & R.L. DOUTT), Academic Press, New York: 295-340.

TWIGG, L.E. & B.J. KAY (1995) – The ecology of house mice (*Mus domesticus*) in and around irrigated summer crops in western New South Wales. *Wildlife Research*, **22**: 717-731.

VAN ELSEN, K. & E. VAN DE FLIERT (1990) – Development of a community-based program on integrated rodent management in Indonesia. In: *Rodents and Rice, report and proceedings of an expert panel meeting on rice rodent control*. (Ed. G.R. QUICK), Manila, Philippines, International Rice Research Institute: 109-114.

WHISSON, D. (1996) – The effect of two agricultural techniques on populations of the canefield rat (*Rattus sordidus*) in sugarcane crops of north Queensland. *Wildlife Research*, **23**: 589-604.

WILLIAMS, C.K., I. PARER, B.J. COMAN, J. BURLEY & M.L. BRAYSHER (1995) – *Managing Vertebrate Pests: Rabbits*. Bureau of Resource Sciences/CSIRO Division of Wildlife and Ecology, Australian Government Publishing Service, Canberra, pp. 284.

WOOD, B.J. & S.S. LIAU (1984) – A long term study of *Rattus tiomanicus* populations in an oil palm plantation in Johore, Malaysia. II. Recovery from control and economic aspects. *Journal of Applied Ecology*, **21**: 465-472.