

# Rodent management and cereal production in Asia: Balancing food security and conservation

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## Abstract

Rodents present a major problem for food security in Asia where smallholder farming families are particularly vulnerable. We review here recent developments in the biology and management of rodent pests in cereal cropping systems in Asia. The past decade has seen a strong focus on ecologically-based rodent management (EBRM), its adoption in field studies significantly increased rice yields (6–15%) and income (>15%) in seven Asian countries. EBRM principles have also been successfully applied to maize in China. We provide case studies on EBRM in Cambodia, on interactions between rodent pests and weeds, and on the importance of modified wetlands for biodiversity and rodent pest management. Knowledge on post-harvest impacts of rodents is increasing. One research gap is the assessment of human health impacts from a reduction of rodent densities in and around houses. We identify 10 challenges for the next decade. For example, the need for population modelling, a valuable tool missing from our toolbox to manage rodent pests in cereal systems. We also need to understand better the interactive effects of cropping intensification, conservation agriculture and climate change. Finally, new management approaches such as fertility control are on the horizon and need to be considered in the context of smallholder cereal farming systems and mitigating health risks from zoonotic diseases associated with rodents.

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**Keywords:** rodent pest management; Asia; rice; maize; population ecology; cropping intensification

## 1 INTRODUCTION

In his summing up of an international conference on rodent biology and management in 2006, C.J. Krebs<sup>1</sup> presented the following message: ‘...progress in ecologically based rodent management in agricultural settings in Asia and Africa is truly impressive. If there is a general message it is that we need a varied toolbox for rodent pest problems.’

Despite this report of impressive progress in our knowledge of managing rodent agricultural pests in developing countries, rodents still present a major problem for food security at a global level.<sup>2</sup> The focus of this review is Asia where smallholder farmers are particularly vulnerable.<sup>3</sup> The impacts on food security are even more pronounced in years when parts of Asia experience episodic population outbreaks of rodent pests.<sup>4</sup>

Ecologically-based rodent management (EBRM), a widely accepted paradigm for rodent pest management, builds on ecological, taxonomic and socio-economic studies to develop integrated ecologically-based approaches to rodent pest management.<sup>5–7</sup> A solid understanding of the species composition and the biology of the pest species in a specific agro-ecosystem enables the identification of optimal times, location and scale of action to develop management strategies that are cost-effective and minimize environmental harm by reducing reliance on rodenticides.

In this paper we review developments in our understanding of the biology and management of rodent pests in cereal cropping systems in Asia over the past decade. We cover progress in both

pre- and post-harvest management of rodents. Most of the research focus has been on rice production systems, therefore, we consider developing trends in rice production that are likely to add further dimensions to future studies of rodent pest management. The inter-linking of rodents and other pests and diseases of rice, plus the likely impact of rodents or the perceptions by farmers that may impede progress on the need to better manage rice landscapes to firstly, mitigate greenhouse gas emissions, and secondly, as important wetlands to preserve biodiversity, will be considered. We build on previous reviews that capture the

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'impressive' progress of EBRM in agricultural systems<sup>8,9</sup> since its reinvigoration in 1999.<sup>10</sup>

We will not cover rodent-borne zoonoses, which is a rapidly developing field of epidemiology after languishing until the late 1990s. Diseases such as leptospirosis, murine typhus, human plague, Lassa fever and scrub typhus are indeed major concerns in rural communities in Asia and Africa,<sup>11</sup> and a recent outbreak of pneumonic plague in Madagascar in 2017–2018 has led to a 'call for action'.<sup>12,13</sup> We simply make two points. Firstly, that the economic impact of the effect of rodent zoonoses on smallholder rural communities is not well documented and requires much more research effort. Second, that well designed studies that combine rodent ecology, crop production and epidemiology of potential rodent zoonoses in human populations in an agricultural landscape are a priority. Such research would support a laudable effort to include an agro-ecological approach to protect crops from vertebrate pests in an extended 'One Health' concept because of limited but promising evidence that such an approach reduces viral zoonoses.<sup>14</sup>

## 2 RICE AND RODENTS – AN IMPORTANT FOOD SECURITY ISSUE IN ASIA

Rice is the staple crop for most Asian countries<sup>15</sup> and rodents are a major pest in both lowland irrigated and upland rainfed rice cropping systems.<sup>16,17</sup> In the lowland systems that are the rice bowls of Asia, there is pressure to increase the intensity of rice production and to reduce post-harvest losses because of the imperative to provide food security to a rapidly growing human population. Indeed, FAO<sup>18</sup> estimates that rice production would need to be increased by 24% from 2005/2007 levels to provide food security for the projected 9 billion people in 2050.

### 2.1 Lowland irrigated rice systems

Intensification of annual cropping by transitioning from one crop of rice to two crops, two crops to three crops, or two crops of rice followed by a non-rice crop (e.g., maize or pulses), are all likely to increase the impacts of rodent populations on crop yields given the ability of the major rodent pest species in Asia to increase their annual breeding output when high quality food is available for more of the year. This includes *Rattus argentiventer* (most SE Asian countries),<sup>19–22</sup> *Rattus tanezumi* (Philippines)<sup>23–27</sup> and *Bandicota bengalensis* (Myanmar and South Asia).<sup>28–32</sup>

We review the literature on rodent ecology and management, including socio-economic studies, in cereal production in Asia over the past decade (Table 1). We selected this time frame because the last major review of the impacts of rodent pests in Asia, be it in the context of rodent population outbreaks globally, was in 2010.<sup>56</sup> We do not review specific post-harvest studies because a comprehensive review has been recently published (see Brown, *et al.*<sup>55</sup>). However, in section 2 we will provide some insights into a path forward for post-harvest management of rodent pests in intensive cereal production regions.

In this section we provide insights to what has emerged from the studies over the past decade. We consider some of the studies in more detail as case studies because of their interesting findings. An encouraging development is that there has been a stronger emphasis on obtaining quantitative estimates of economic impacts of rodents in rice cropping systems. In most cases these estimates are based on replicated field research with appropriate controls. The adoption of EBRM produced significant increases in yield (typically 6–15%) and/or increases in income (>15%)

(Table 1). There are two studies where the focus was on areas of high rodent impacts and the application of integrated EBRM options. In both instances, the yield and economic benefits from applying these actions are very encouraging. In Indonesia, Herawati and Purnawan<sup>52</sup> reported a mean yield increase from 1.6 to 6.4 t/ha for seven farmers within a 40 ha rice production area where best management practices for rodent pests were implemented. In Cambodia, Stuart, *et al.*<sup>54</sup> reported yield increases of 20 to 32% and increased income of 53 to 169%. We will consider the Cambodian study in more detail as a case study.

Although it is encouraging to have quantitative data on the benefits of EBRM from five Asian countries, some reported only on yield increases, crop losses or economic benefits. For *R. argentiventer*, crop losses to rice estimated immediately prior to harvest are known to under-estimate yield loss by 3–6 times.<sup>57,58</sup> We encourage future studies on economic impacts of rodent management actions to pay careful attention to the relationship between in-crop losses and estimated yield reduction, and to develop where possible estimates of benefit–cost ratios. Nevertheless, the published literature over the past decade indicate that the economic benefits are robust across countries and for different pest species (Table 1). In rice crops, *Bandicota* species are the main pests in Myanmar and Bangladesh, *R. argentiventer* in Indonesia, Vietnam and parts of the Philippines (but not Luzon), *Rattus rattus* complex in Laos, *R. tanezumi* in the northern part of the Philippines, and a combination of species in Cambodia and Thailand. There are reports from most of these countries in Table 1.

The intensification of rice-rice and rice-'other crop' systems in Asia, particularly Southeast Asia, often leads to asynchronous cropping within a local geographic area. Rodent pest species increase their reproductive output in response to the presence of a patchwork of crops in rice-cropping systems.<sup>41,59,60</sup> Two papers from Vietnam highlighted that the intensification of rice cropping in the Mekong River Delta, where three rice crops are often grown in one year, is another plus for more damage by rodent pest species.<sup>38,46</sup> In both instances the authors recommend that only two rice crops be grown each year, with a different crop grown when the third rice crop (Vu3) is grown. In addition, previous studies<sup>17,21</sup> highlight the need to avoid asynchronous cropping of rice if possible.

#### 2.1.1 Case study 1: ecologically-based rodent management (EBRM) in Cambodia

In Cambodia, an applied research study by Stuart, *et al.*<sup>54</sup> successfully brought together lessons learned from the previous 20 years of EBRM research in Southeast Asia to effectively manage rodent pests of rice, whilst at the same time reducing the use of hazardous rodenticides and electric fencing to protect crops from rodents. The authors of this study began by holding focus group discussions in two villages with rice farmers who had indicated that rodents were their main pest of concern. As previously demonstrated,<sup>35</sup> effective participatory adaptive research on EBRM includes discussions with farmers on understanding the rodent situation across the village rice-growing landscape, and then involving the farmers in decision-making to select the appropriate rodent management practices to implement and evaluate. These meetings were then followed by farmer participatory research involving the integration of several management methods that had been previously demonstrated elsewhere, for example, the Trap Barrier System (TBS).<sup>61</sup> The methods were carefully developed based on the ecology of the main pest species,

**Table 1.** Overview of selected papers from 2007 to 2020 on the ecology, behaviour and management of rodent pests in agricultural landscapes of smallholder farmers in Asia, plus a few papers on social and cultural dimensions of rodent pest management

Description of main topic	Country and Cropping System	Outcomes and Recommendations	Replicated field study; authors & year
Comparison of effects of EBRM compared to conventional management on population dynamics of rodent pest populations and level of damage	Indonesia; Lowland irrigated rice-rice	(i) EBRM led to 6% higher rice production over conventional farmer management practices; (ii) EBRM (synchronous cropping, trap-barrier system; 2-week community rodent control program within 2 weeks of planting, width of irrigation banks <30 cm, increased hygiene in villages and associated gardens) is an appropriate method to manage rodents in these rice systems	Yes – four replicates of treatment and conventional rodent management over a wet and dry cropping season; Jacob, <i>et al.</i> <sup>33</sup> 2010
Documentation of the effects of a large-scale media campaign on EBRM	Philippines; Lowland irrigated rice-rice	(i) A year after the media campaign, farmers who responded to the campaign increased yields by 0.7 t/ha compared to farmers who had not been exposed to the campaign. (ii) A media campaign with support from local leaders and extension specialists had greatest impact.	Yes – evaluated beliefs and management practices in nine villages Flor and Singleton <sup>34</sup> 2011
Assessed the effect on rodent damage, rodenticide use and economic impacts of participatory action research of EBRM that had a strong community focus and was led by local government extension staff	Vietnam: Red River Delta; Lowland irrigated rice-rice	(i) Adoption of EBRM decreased areas of rodent damage by 93%, reduced chemical rodenticide usage by 50%, increased profit of farmers by 20%; (ii) Farmers embraced collection action and changed their belief from rodents not being manageable to be able to do so through coordinated community management actions.	Yes – four agricultural cooperatives; initially two control cooperatives but these quickly adopted community management actions. Analyses therefore were based on before and after EBRM implementation, Palis, <i>et al.</i> <sup>35</sup> 2011
Knowledge, attitudes and practices of farmers on rodent pests and their management	Philippines; Lowland irrigated rice-rice plus coconuts	(i) Farmers applied wide range of practices to manage rats; all used zinc phosphide but generally late in the season; (ii) Most farmers believe that effective rodent control requires community action but only 31% did so in previous season; (iii) Recommend promotion of community action	Interviewed 150 farmers across 10 villages Stuart, <i>et al.</i> <sup>36</sup> 2011
Nest locations of female rodent pest species	Philippines; Lowland irrigated rice-rice plus coconuts	(i) All nests located above ground level and 67% in coconut groves; (ii) Nest sites had good ground and understorey vegetation; (iii) Coconut groves adjacent to rice fields to be targeted as part of an integrated ecological management approach	Radio-tracking study of nest sites Stuart, <i>et al.</i> <sup>37</sup> 2012
Combined a study on magnitude or rodent losses in each of the three annual crop seasons with crop and pest models to develop	Vietnam: Mekong Delta; rice-rice-rice	(i) Rodents cause losses of 10–16% per cropping season with highest losses in the third rice crop;	Combined 5-year data set on weekly reports of rodent damage to rice, two studies on rate of increase of

**Table 1.** Continued

Description of main topic	Country and Cropping System	Outcomes and Recommendations	Replicated field study; authors & year
management strategies of the main rodent pest		(ii) Crop models together with data on timing of damage to rice by rats and monthly rates of increase of rodent populations, indicate that best timing for rodent control is before the onset of the main breeding season (at maximum tillering).	rodent populations and APSIM-Oryza rice model. Brown and My Phung <sup>38</sup> 2011 Brown, <i>et al.</i> <sup>39</sup> 2011
Breeding ecology of two rodent pest species in rice	Philippines; Lowland irrigated rice-rice	(i) Onset of breeding for both species at rice tillering, highest breeding at booting and ripening of rice; (ii) Recommended community control of rats at sowing and maximum tillering, and synchrony of cropping	No replication – descriptive study for four cropping seasons Htwe, <i>et al.</i> <sup>25</sup> 2012
Population and breeding dynamics and habitat use of rodents in rice in the Mekong Delta	Vietnam: Mekong Delta; rice-rice-rice	(i) Population abundance highest after harvest and on large and medium sized banks of the rice crop; (ii) Management practices be conducted prior to seedling stage, vegetation on rice banks be kept lower than 10 cm to limit cover for breeding.	Yes – Two replicates My Phung, <i>et al.</i> <sup>40</sup> 2012
Landscape modelling to assess possible impact of cyclone Nargis on massive rodent outbreak	Myanmar: Ayeyarwaddy Delta; rice-rice	(i) Asynchronous planting after cyclone Nargis is likely cause of massive rodent outbreak 15 months post cyclone. (ii) Recommend synchrony of planting, rice varieties with similar maturation dates and good field sanitation.	Time series analysis using satellite imagery for monsoon crops 2007–2009; household surveys to validate remote sensing Htwe, <i>et al.</i> <sup>41</sup> 2013
Assessed effectiveness of reducing vegetation height along margins or rice crops and in adjacent coconut plantations	Philippines; Lowland irrigated rice-rice plus coconuts	Habitat manipulation by itself was not sufficient to manage rodent pest populations in rice-coconut systems	Yes – Two replicates of treatment and non-treatment Stuart, <i>et al.</i> <sup>42</sup> 2014
Effect of rodent management in rice crops; compared transplanting rice 30 days earlier <i>versus</i> traditional timing.	Bangladesh; Lowland irrigated rice	(i) The earlier transplanted rice crop with TBS captured four times more rats. (ii) Recommended use of TBS with an early planted crop to manage rodent pests in rice.	Yes – four replicates; with and without TBS; early and traditional time of transplanting Kabir and Hossain <sup>43</sup> 2014
Examine the potential of the effect of combining bromadiolone and cholecalciferol against <i>Bandicota bengalensis</i>	India; Laboratory study	A low concentration of bromadiolone (0.001%) together with cholecalciferol (0.005%) was effective based on clotting time and other blood parameters, and was recommended as the most cost-effective combination for managing this species.	Laboratory study Singla, <i>et al.</i> <sup>44</sup> 2015
Population and breeding dynamics and habitat use of rodents in five different habitats	Philippines; Lowland irrigated rice-rice; coconuts adjacent to rice; coconut groves; agroforestry	(i) Five species of rodent were captured with only one a major pest species in rice and coconut groves; (ii) The pest species had highest abundance from tillering to	Yes – three replicates across three crop seasons Stuart, <i>et al.</i> <sup>27</sup> 2015

Table 1. Continued

Description of main topic	Country and Cropping System	Outcomes and Recommendations	Replicated field study; authors & year
Assessment of an integrated management program in three provinces of upland Laos.	Laos; Upland rice	<p>ripening of rice with peaks in breeding from booting to just after harvest;</p> <p>(iii) Recommended two community campaigns; one at early stage and the other mid-season.</p> <p>(i) EBRM (sustained community trapping in fields; rodent-proof rice store; rodent hunting and improved sanitation in villages) plus bio-control using the protozoan <i>Sarcocystis singaporensis</i>;</p> <p>(ii) Rodent damage in rice fields was reduced from 11% to 4.3%; rice stores infested by rodents dropped from 86% to 3.5%. The predicted increase in yield was 55%.</p> <p>(iii) EBRM together with <i>S. singaporensis</i> were effective in managing upland rodent populations; now need forecast models of outbreaks.</p>	Yes – 18 villages (six in each of three provinces) were treated and 18 were non-treated. Jäkel, <i>et al.</i> <sup>45</sup> 2016
Assessment of farm-level economic impact of community action based on EBRM	Vietnam: Mekong Delta; rice-rice-rice	<p>(i) EBRM through community action (CA) built on traditional management practices with an ecological basis for promoting synchronous planting, improved field sanitation, when and where to conduct rodent management, and encouraging farmers to work together to apply actions at the same time.</p> <p>(ii) EBRM through CA increased rice yields by 0.43–0.45 t/ha (7–8%) and net income by USD67–69/ha.</p> <p>(iii) Recommended that farmers grow only two rice crops per year because highest damage is generally in second and third crops.</p>	Yes – two districts with one treatment (EBRM + CA) and one control village per district. Used difference-in-difference framework and propensity score matching Ngoc Ninh, <i>et al.</i> <sup>46</sup> 2016
Examined a range of animals and plants to determine their ecosystem service and disservice in rice and maize, <i>via</i> observations, farmer diaries and semi-structured interviews	Laos; Rice and maize	<p>(i) Rats caused high levels of damage to both maize (0.5–7.0%) and rice (8–12%) at most of the growth stages</p> <p>(ii) Rats were the most common animal collected for food but move to permanent maize cultivation increased use of rodenticides.</p> <p>(iii) Because farmers did not pay for rat-meat, but crop damage led to economic loss, then rats were seen more as an ecosystem disservice. They propose there is</p>	Yes – three villages and stratified sampling Rasmussen, <i>et al.</i> <sup>47</sup> 2016

**Table 1.** Continued

Description of main topic	Country and Cropping System	Outcomes and Recommendations	Replicated field study; authors & year
Spatial distribution of rodent damage; positive evidence of landscape of fear	Philippines; Lowland irrigated rice-rice	a spectrum from service to disservice and where rats are on the spectrum is likely to be location dependent. (i) Place traps or bait stations where rats spend more of their time foraging; (ii) Damage assessment <i>via</i> stratified sampling through to the centre of the crop	Yes – Four replicates Jones <i>et al.</i> <sup>48</sup> 2017
Social study to assess the effectiveness of six indigenous rodent management methods in Manipur	India; Rice (no details of cropping system)	The indigenous trapping methods, particularly traps, were adequate to manage rodent pests of rice instead of using rodenticides.	Surveys of farmers in 3 villages Ngaomei and Singh <sup>49</sup> 2017
Evaluated the effectiveness of a rectangular trap barrier system (TBS) (with or without a trap-crop) <i>versus</i> a linear TBS (LTBS) by comparing: (i) capture rates of different rodent species, (ii) the population structure of the main pest species	China: Jilin province; Maize (non-irrigated)	(i) The capture rates of different species were similar for the different TBS designs, and for the main pest species of maize at the site, <i>Apodemus agrarius</i> , the population dynamics, age structure and sex ratio were similar across the TBS designs. (ii) Recommended that L-TBS is a more efficient management option for maize (mechanized production) than rectangular TBS with or without a trap crop.	Yes – six replicates in year 1, eight replicates in year 2. Wang, <i>et al.</i> <sup>50</sup> 2017
Evaluated effectiveness of trap-barrier system to manage rodent damage to rice during a population outbreak of rodents caused by bamboo flowering	Bangladesh: Chittagong Hill Tract; Upland rice, one crop per year	(i) The rodent population density and amount of damage were not as high as elsewhere during the bamboo flowering. (ii) Rodent damage in TBS fenced fields was 0–0.26% and in unfenced fields was 1.8–3.2%. (iii) The TBS is effective but at these damage levels local governments may need to subsidise the cost.	Yes – Three villages and two seasons (years) Chakma, <i>et al.</i> <sup>51</sup> 2019
Evaluation of interaction between rodent and weeds in intensive lowland rice systems	Myanmar; Rice-rice	(i) A combination of EBRM and best weed management increased income by \$258/ha in the dry season and \$50/ha in the wet season. (ii) Concurrent best management for rodents and weeds is strongly recommended.	Yes – Four replicates and four treatments Htwe, <i>et al.</i> <sup>28</sup> 2019
Evaluation of effectiveness of EBRM at a large scale (40 ha); assessed impact on rice yield.	Indonesia; Rice-rice, lowland irrigated	(i) Six EBRM activities implemented early in cropping season (protect seed nursery with TBS; improved sanitation along crop margins; mass hunting (land preparation and early crop stage); (ii) Fumigation of rat burrows along crop margins during preparation of land for cropping; trap-barrier system (TBS) plus trap-crop planted 3-weeks early; linear TBS)	No - large scale pilot study 40 ha for two seasons; yield data collected from seven farmers. Herawati and Purnawan <sup>52</sup> 2019

**Table 1.** Continued

Description of main topic	Country and Cropping System	Outcomes and Recommendations	Replicated field study; authors & year
Spatial use in and around rice crops in presence and absence of intermittent irrigation; population changes and estimates of damage	Philippines and Indonesia; Rice-rice, lowland irrigated	increased mean crop yield from 1.9 t/ha to 6.4 t/ha. (iii) Concluded EBRM was highly effective; local government officials need to be trained on EBRM.	Yes – three replicates with AWD and non-AWD fields in both countries Lorica, <i>et al.</i> <sup>53</sup> 2020
Focus Group Discussions to select and then apply EBRM practices with trap-barrier system (TBS) plus trap-crop and/or linear TBS; tailoring the approach to village-specific community feedback. Assessed impact on rodent damage, rice yield and farmer income.	Cambodia, Rice-rice at recession rice sites, rice-rice-rice at irrigated sites	(i) EBRM included improved hygiene of crop margins, synchronous planting, community rat hunts at key times, community TBS and/or linear TBS. (ii) Rodent damage was 6% at treatment sites <i>versus</i> 22–34% at control sites. (iii) Rice yields were 20–32% higher and 53–169% increase in income and Benefit–Cost-Ratio of 3:1 to 11:1	Yes – two villages, three replicates of 5 ha per village Stuart, <i>et al.</i> <sup>54</sup> 2020
We have not included studies on post-harvest impacts in rice because they were reviewed in Brown, <i>et al.</i> <sup>55</sup> in 2020.			

the local conditions and the farmers' willingness to test them at a community level (5 ha) as most farmers had field sizes of less than one hectare. In one village, two rice crops were planted per year, one rain-fed crop in the wet season and another irrigated crop in the dry season. The latter was planted on a lake margin as the lake waters receded. EBRM in this village involved the use of a linear TBS (LTBS) along the edge of the rice fields and carefully targeted anticoagulant rodenticide use. In the second village, rice was grown intensively with three crops per year and the EBRM approach involved a community TBS plus trap crops (CTBS) as well as a LTBS alongside potential rodent refuge habitat. Other important EBRM activities such as synchronous planting, community rat hunting and field sanitation at key times were also conducted in both village treatment areas.

As a result of the EBRM approaches that were tailored to the local conditions, rodent damage was reduced by 84–99% and incomes were increased by 53–169% as compared to non-treatment farmers who continued business as usual. The study was thus a great success, and many farmers adopted the technology following the end of the project. However, most of these farmers decided to use a TBS around their entire field rather than strategically place LTBS at targeted locations or implement CTBS. The authors were informed by the farmers (Stuart, pers. obs.) that this approach ensured the greatest level of protection to their rice as the risk of rodent damage was high enough to compensate for the added costs of more fencing. This, after all, was the approach they had previously applied when using electric fencing that also surrounded their whole crop. Thus, even though the study is a

good example of the economic benefits of EBRM, it highlights the challenges of changing farmer mind-sets and conducting EBRM at a community level. However, the response is highly positive because the adoption of EBRM replaced the illegal action of using electricity to protect their crop from rodents. The use of electricity presents a lethal health risk to humans, livestock and companion animals.

### 2.1.2 Interactions between non-pest and pest rodent species

There is evidence that native rodent species may be able to compete with invasive rodent species in less-disturbed natural ecosystems, especially if the native species became residents first in a particular location.<sup>62</sup> A number of recent studies conducted in Northern Luzon, Philippines, indicate that non-pest native rodent species will recolonize regenerating forest habitat, displacing potential pest non-native species.<sup>48,63,64</sup> Non-native species (*R. tanezumi* and *R. exulans*) were confined to heavily disturbed habitats, where the diversity and abundance of native rodent species was low. These findings suggest that these invasive species are unlikely to become established in intact forests where native rodent species are present because it appears that 'natives have competitive superiority'.<sup>64</sup> This idea merits further investigation.

### 2.1.3 Case study 2: the interactions between rodent pests and other cereal pests

In Asia, research on the management of pests of cereal crops has an extensive literature covering insect, disease, weed and rodent pests.<sup>65,66</sup> However, there have been a dearth of studies that have

examined potential benefits of integrating rodent ecology and management with the management of other cereal pests. We present a case study of rodent and weed interactions in intensive rice cropping systems as an example of why such interactive research is important.

The impacts of rodents on rice crops and food security have been discussed in section 1. Weeds arguably have the highest contribution into losses to cereal production globally.<sup>67,68</sup> Herbicides and hand weeding provide management options for smallholder farmers, however, crop losses for rice remain around 10%.<sup>67</sup> There have been undocumented reports that where weed infestation of crops is high, rodent densities also tend to be high.<sup>69</sup> Likewise, where there has been high rodent damage to rice that opens the crop canopy, weed infestations appear to be high. In a replicated study in the fields of farmers in Myanmar, there were four treatments: rodents were excluded but not weeds, weeds were managed but not rodents, both rodents and weeds were managed, and neither were managed. Each of the 16 plots (4 treatments x 4 replicates) were 0.25 ha. The study was conducted across both dry and wet cropping seasons.<sup>28</sup> The study reported additive negative effects of rodent and weeds on crop yield, with the combined effect highest in the dry season. A clear recommendation from these findings is the need for concurrent weed and rodent management, especially during the early crop stages of rice production.<sup>28</sup> Such an interaction between weeds and rodents may not be unexpected but prior to this study, quantitative data were lacking.

Further research is urgently needed to quantify the interactions between rodents and other cereal crop pests, so that cost effective integrated management options can be developed and promoted. Why the urgency? The trends for increased intensification of rice cropping, moving from one rice crop to two, and two to three per year, is highly likely to increase the impacts of pests on yield and indeed rodent pests may exacerbate the losses caused by other types of pests and diseases. Moreover, increased impacts of cereal pests associated with climate change<sup>70</sup> and extreme climate events<sup>41</sup> are likely to provide unexpected interactions between insect, weed, and rodent pests and also crop diseases. The better we understand these possible interactions then we will be in a stronger position to anticipate them and to provide integrated management recommendations to assist smallholder farmers.

#### 2.1.4 Widespread geographic adoption of EBRM, including lowland non-irrigated crops – wheat and maize

Given that rice is by far the main cereal staple in Southeast Asia,<sup>15</sup> it is not surprising that most of the published literature on rodent management in agricultural systems has concentrated on rice (Table 1). In the decade beginning in 2009, there have been an impressive number of papers published on EBRM in China. Part of this focus is related to an increased awareness in China of the risks associated with environmental pollution and threats to non-target biodiversity from the use of pesticides such as rodenticides.<sup>50,71</sup> The trap-barrier system (TBS) was initially promoted by Lam<sup>72</sup> to protect irrigated rice crops in Malaysia and later was modified to include an early planted 'trap-crop' to attract rodents to the multiple-capture traps set into the rectangular fence/barrier to protect rice-cropping systems in Indonesia,<sup>61</sup> the Philippines,<sup>73</sup> Vietnam<sup>74</sup> and elsewhere in Southeast Asia.<sup>8</sup>

In China, wheat and maize are also important cereals. The TBS in a rectangular and linear form has been used successfully in wheat, maize, rice and other crops, resulting in increases in grain yield.

Apparently, the TBS is widely adopted in cropping systems in China but most of the publications are in Chinese (see Wang, *et al.*<sup>50</sup>). This development of greater adoption of EBRM of rodent pests in China and in non-rice crops is indeed a positive development. Moreover, the TBS has been successfully adopted as a tool for EBRM in rice crops in Eastern Africa.<sup>75</sup> Although the geographic spread of EBRM over the past decade is impressive, and impacts at a local scale have been reported,<sup>34,35,54</sup> quantitative data on the number of farmers who have adopted EBRM and the area of coverage at a district, region or provincial level is limited. More such data are required to influence policy makers to increase support for EBRM.

## 2.2 Upland rainfed systems

Over the past decade there has been little progress except for better understanding of the life cycle of specific species of bamboo and the role they may play in rodent outbreaks. However, the lessons learned from the outbreaks in Chittagong in Bangladesh, Mizoram in India, and Rhakine and Chin States in Myanmar are well covered in Singleton, *et al.*<sup>56</sup> In Bangladesh, there has been a first study to look at management options of rodent pests in the Chittagong Hill tract region.<sup>76</sup> This is to be commended given the logistics for field work in this region is challenging, and because many of the farmers rely on subsistence farming.

In the upland rice habitats of Laos, there has been one study of the social-economic aspects of rodent pests *via* farmer interviews,<sup>77</sup> and another impressive study that reported positive impacts from a combination of EBRM activities and the use of bio-control using the protozoan *Sarcocystis singaporensis*.<sup>45</sup>

In upland cereal systems, rodent impacts generally are episodic and severe.<sup>16</sup> Long term studies are desperately required in these farming systems to provide a data set that can be used to develop predictive models of rodent outbreaks. Long term data sets have provided the basis for models that have been successfully used in agricultural landscapes to assist with the timing of management of common voles, *Microtus arvalis*, in Germany,<sup>77</sup> and house mice, *Mus domesticus*, in Australia.<sup>78</sup>

## 3 POST-HARVEST IMPACTS OF RODENTS – A WAY FORWARD

In this paper, we have not systematically reviewed post-harvest impacts of rodents on cereal crops in Asia. Until the early 2000s there were very few publications on post-harvest losses. And these few papers provided general qualitative descriptions on losses and recommended management actions (*e.g.*, Meyer<sup>79</sup>) rather than quantitative data obtained from replicated studies with appropriate controls. Encouragingly, after a long lapse in research on this topic, there have been several quantitative studies in Southeast Asia and elsewhere since the 2000s. A recent review by Brown, *et al.*<sup>55</sup> provides a detailed coverage of recent studies on post-harvest losses by rodents to cereal crops in Asia and recommended management actions.

A clear message from recent studies is that for a particular region, generally the rodent pest species in grain stores differ from those in the field. Again, this emphasizes the need to understand the population ecology of the particular rodent species that are causing a problem. We cannot simply extrapolate from our knowledge of the population and breeding dynamics of a major pest species of rodent that causes pre-harvest losses to manage rodents that are feasting on the freshly harvested cereals in nearby grain stores.



Effective management of post-harvest rodent losses to cereals in stores include improved hygiene in and around the stores and nearby buildings, improved rodent proofing of grain stores that is affordable to smallholder farmers, community programs to highlight the best time to manage rodents (usually related to the breeding and spatial ecology of the pest species and the timing of harvest), and an awareness of social and religious factors that may influence the involvement of the farming community in proposed management actions. We provide two examples of the latter. Firstly, studies in Bangladesh and Myanmar indicate that the sharing within a community of kill-traps on a rotational basis can significantly reduce rodent losses.<sup>80</sup> However, in countries such as Myanmar where Buddhism is a dominant religion, the killing of animals is not readily accepted by farming communities. Second, a study in South Africa indicated that promoting a landscape of fear for rodents by encouraging predators such as cats and dogs, restricted the movements of rodents (decreased their access to grain stores), although the population density of the rodents was not affected.<sup>81</sup> In countries such as Indonesia where the Muslim religion is dominant, promoting dogs in villages would not be acceptable.

The review by Brown, *et al.*<sup>55</sup> highlighted the significant negative impact that rodent losses post-harvest can have on food security for smallholder communities. The progress of the past 10–15 years has been impressive in assessing the level of damage and the risks to food security. More now needs to be done to evaluate critically the effectiveness economically, environmentally and socially, of recommended management actions. One important component that is lacking from post-harvest studies is a quantitative assessment of the human health impact from a reduction of rodent densities in and around houses in rural communities in Asia. Given that rodents are carriers of many zoonoses<sup>8</sup> then we would expect there to be major health benefits.

#### 4 IMPORTANCE OF MODIFIED WETLANDS FOR BIODIVERSITY – WHAT DOES IT MEAN FOR RODENT MANAGEMENT?

The essence of the United Nations Sustainable Development Goal 2 is to reduce hunger by producing sufficient food in a sustainable manner. This in turn links with Goal 15 which emphasizes the restoration of terrestrial ecosystems and halting biodiversity loss.<sup>82</sup> In Asia, there are 52 million ha of lowland irrigated rice.<sup>15</sup> Wetland habitats are at grave risk globally and as a result there are great concerns on the rates of loss of biological diversity. In 2018, the RAMSAR Convention on wetlands highlighted the loss of 35% of wetlands globally since 1970<sup>1</sup>, and the Living Planet Report 2020 by the World Wildlife Fund<sup>83</sup> estimated that since 1970, there has been a 45% loss in vertebrate biodiversity in Asia and Oceania, and that more sustainable agricultural production is an important intervention to redress biodiversity loss. Rice agricultural systems provide important human-modified wetlands for wildlife,<sup>84–87</sup> particularly in Asia. The challenge then is to increase rice production using methods that are environmentally, socially, and economically sustainable, which importantly includes effective stewardship of water use, crop margins and non-agricultural lands in the associated landscape.

<sup>1</sup>Ramsar convention on wetlands 2018.

#### 4.1 Case study 3: what does increased water productivity mean for the management of rodent impacts in rice cropping systems?

Alternate Wetting and Drying (AWD), also known as controlled or intermittent irrigation, is a technique developed to increase water productivity (amount of food produced per unit of total water input) in lowland irrigated rice, and to save on water for other purposes, or for further distribution along the irrigation system.<sup>88,89</sup> Just as importantly, the implementation of AWD that allows the rice field to dry but maintain sub-soil moisture within 15 cm of the surface, leads to substantial reductions in methane gas emissions by as much as 73% in the dry season and 21% during the wet season.<sup>90</sup>

Rice farmers in Southeast Asia are hesitant to adopt this water-saving technology for fear the practice will lead to increased rodent pest activity, consequently exacerbating yield loss. Results of a study, which examined the effects of AWD on the population dynamics, habitat use, and damage levels inflicted on rice crops by *Rattus argentiventer* in Indonesia, and *R. tanezumi* in the Philippines, demonstrate that damage levels on standing rice crop were not affected by the water management scheme used, as shown by replicated damage assessments done on AWD and control fields. Rodent activity and movement, examined using spool-and-line tracking, also was not influenced by water level.<sup>53</sup> AWD also had no significant effect on the breeding performance and population dynamics of these species.

#### 4.2 Impact of rodent pests on efforts to promote eco-engineering and conservation agriculture in intensive rice-cropping systems

Like the AWD situation, farmer perceptions are important to maintain ecosystem benefits of crop margins. Firstly, the promotion of eco-engineering through growing plants that produce nectar along the banks of rice fields is used to increase biodiversity and thus attract predatory insects and arthropods. The rationale is that these predators will reduce the population density and impact of insect pests of rice.<sup>91</sup> The promotion of ecological intensification requires dense cover on the rice banks. Farmers can be hesitant to implement this practice because they perceive that such cover favors rodents (My Phung NT, pers. Comm.). If these habitats are targeted for community action for rodent management prior to crop establishment, which is recommended,<sup>74</sup> then a combination of early rodent management and the planting of nectar-producing plants can not only promote biodiversity but also has the potential to manage both rodent and insect pest populations.

Secondly, the edges of rice fields and associated riparian habitats favor non-pest rodent species as well as amphibian populations that have been documented to provide positive eco-system services in Asian rice cropping systems.<sup>13,92,93</sup> Again, we need to avoid perceptions that associated riparian habitats (*e.g.*, reed beds, irrigation canals, small dams and banks of rice fields) will provide a benefit to rodent populations that cannot be effectively managed. A balanced approach is required. This may not be too large a problem given farmers in Luzon in the Philippines reported that they perceive amphibians as beneficial because they eat pest insects and that a healthy frog and toad population provides a positive indicator that the cropping system is healthy for humans.<sup>94</sup>

Conservation agriculture in developed countries has altered the habitat use of some agricultural rodent pests, which then affects management recommendations.<sup>95</sup> Conservation agriculture is being promoted in Asia, but little is known about how this will influence the population dynamics and subsequent impact of

rodent pests. For example, no-till agriculture, which conserves soil and water, can allow rodent pest populations to increase due to the accumulation of crop residue (which provides additional food source and insulation from climate extremes) and the continuity of intact burrow systems in the cereal-legume fields of Washington, USA.<sup>96</sup> No-till and high biomass mulch caused insect and rodent pests to overwinter in conservation agriculture plots in South Africa, which would then feed on maize seeds and seedlings.<sup>97</sup> Wheat farmers in India reported an increase in rodent depredation in zero-tillage crops.<sup>98</sup> These examples indicate a possible conflict between conservation agriculture and rodent pest management. We urgently need field research on conservation agriculture and the effects of such practices on pest rodent population dynamics. We contend that if potential conflicts are anticipated then appropriate management actions can be developed.

## 5 RECOMMENDATIONS FOR THE WAY FORWARD

In an agricultural context in Asia there are insect and weed pests that potentially have a significantly larger impact on rice production than rodents. However, as pointed out by Schiller, *et al.*<sup>99</sup> rodent pests, particularly in outbreak years, are often of high concern to farmers because they are recognized as a pest that they have the least control over. In upland rainfed systems, managing rodent population outbreaks is still a huge challenge, however, in non-outbreak years, and in lowland systems, there has been good progress in developing strategies to reduce rodent damage.

There are some management recommendations that apply to most if not all systems. These include synchrony of cropping (planting within 2 weeks of neighbors),<sup>60</sup> conducting community management prior to the onset of breeding and when rodents are aggregated in specific habitats whilst the fields are in fallow, improving hygiene around villages and reducing spilled grain post-harvest. Our review further confirms that rodent management approaches are dependent on the respective ecology and population dynamics of the main agricultural pests, on particular rice systems, on coordinated community action, and on the culture and beliefs of rural communities in different countries. Progress towards tailoring management for specific systems and rodent species continues to make impressive progress. As highlighted by Krebs,<sup>1</sup> for progress to continue along this path we require a 'toolbox' of management options and this requires researchers to embrace current and future trends in agricultural production and to communicate clear messages on how rodent populations are likely to respond to these actions, and to obtain objective evidence from replicated field studies in the fields of farmers to provide advice on management strategies.

We identify the following challenges to tackle (not in priority order) to assist smallholder farmers in Asia to manage their rodent problems. From our interactions with colleagues in Africa, many of these challenges also apply with EBRM showing promise to help redress the rodent impacts on cereal production pre- and post-harvest.<sup>6</sup> Some of these challenges not surprisingly overlap with a recent global review that identified 10 essential questions for furthering our understanding of key population ecology processes associated with population cycles and outbreaks of small rodent populations.<sup>100</sup>

- We require better estimates of crop and post-harvest losses to rodents, and economic analyses of EBRM, including livelihood

benefits. This information is essential if policy makers are to be convinced of the need to broaden crop protection practices so that rodent management is more strongly integrated with recommendations for the management of agricultural pests and diseases.

- There is still a paucity of knowledge on the biology, behavior and population ecology of most rodent pest species in developing countries despite the impressive progress over the past 20 years. In an agricultural context, the current generation of rodent biologists in Southeast Asia come with a background mainly in entomology. In Asian countries, the curricula for plant protection are usually dominated by entomology, plant pathology and, to a lesser extent, weed biology. It is rare for courses to be available on vertebrate biology. We need to continue to advocate for the importance of managing rodent impacts in cereal systems and mentor young scientists with an interest in rodent biology and management.
- There is an urgent need for long-term data sets that would provide a solid foundation for developing predictive models for rodent outbreaks. These predictions are important in regions that suffer episodic outbreaks of rodent populations and need to trigger timely community management actions. Rodent management should be pro-active rather than reactive thus timely interventions are needed – population modelling is an important tool for our toolbox.
- We need to explore species interactions between invasive and native rodents. Is it possible to foster 'biotic resistance' in the fight against invasive rodents? Can 'rewilding' to restore more natural habitat within agricultural landscapes reduce rodent pest populations through interspecific competition with native rodent species?<sup>64,101</sup>
- Rodent communities – there is an important gap in our knowledge both in developed (see Parsons, *et al.*<sup>102</sup>) and developing countries on what is happening at the rural–urban interface and cropping systems–forest interface.
- Community action is the key to effective rodent management in Asian cropping systems where most farm holdings are less than 5 ha. It is encouraging to report that in our review of research from 2010 to 2020 there has been an impressive number that has a strong sociological component (Table 1). Capacity building of local extension specialists is vital to support smallholder farmers in developing effective community EBRM actions.<sup>34,35</sup>
- We need to be able to anticipate how rodents will respond to changes in intensive production to meet increased food demands and therefore evaluate the sustainability of such systems. For example, three rice crops per year in the Mekong River Delta, Vietnam, lead to increased rodent impacts yet three crops have been reported as less profitable overall than two crops per year.<sup>103</sup>
- Too little is known about conservation agriculture and the positive or negative effects of such practices on pest rodent population dynamics.
- New management approaches are on the horizon. One example is fertility control of rodent pests.<sup>104–106</sup> Another, although controversial,<sup>107</sup> is synthetic gene drive technology that may provide an opportunity to substantially influence the sex ratio of a rodent population.<sup>108</sup> As well as potential socio-political opposition to the environmental release of gene drive technology to manage rodent pests, another essential consideration is how will wild rodent populations in agricultural landscapes respond to new methods of control. Will all species respond the same?

• Climate change: A 46-year study of small mammal populations in the Boreal forest in northern Canada indicates that there have been long term shifts in the relative abundance of the four main species and marked changes in the energy flow in the herbivore populations contributed by the small mammals, and that these may be related to changes in the climate.<sup>109</sup> Unfortunately, we do not have long term monitoring of rodent populations in agricultural systems in Asia to assess effects of climate change at this level. However, the change of cropping systems associated with changes in climate and how rodent pest species respond to these changes needs careful study. An example is the Mekong River Delta where saline intrusion up the delta during the dry season is considerable and currently three provinces have greater than 80% of their cropland under salinity risk.<sup>110</sup> If salinity intrusion, coupled with flooding events, continues to increase because of climate change and sea level rise then that will likely lead to increased intensification of cropping of cereals and hence a likely increase in rodent impacts. Extreme weather effects can have indirect effects on rodent populations through changes in crop management. For example, Cyclone Nargis in the Ayeyarwaddy delta, Myanmar, devastated more than 738 000 ha of rice land.<sup>59</sup> Farming communities recovered at different rates and this led to an increase in asynchronous cropping and 15 months after the cyclone, there was a massive rodent population outbreak.<sup>59</sup> After such major climatic events, coordinated efforts are needed to avoid asynchronous planting. More quantitative data on the direct and indirect effects of climate change on rodent population dynamics is desperately needed to convince policy makers of the potential risks of rodent outbreaks for food security.

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## CONFLICT OF INTEREST

The authors declare that they have no commercial or financial relationships that could be construed as a potential conflict of interest.

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