Research Article

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Effects of harvesting and stubble management on abundance of pest rodents (*Mus musculus*) in a conservation agriculture system

Wendy A. Ruscoe,[a*] Peter R. Brown,[a] Steve Henry,[a] Nikki van de Weyer,[a] Freya Robinson,[a] Lyn A. Hinds[a] and Richard P. Duncan[b]

Abstract

BACKGROUND: The shift to more environmentally sensitive agricultural practices over the last several decades has changed farmland landscapes worldwide. Changes including no-till and retaining high biomass mulch has been coincident with an increase in rodent pests in South Africa, India, South America and Europe, indicating a possible conflict between conservation agriculture (CA) and rodent pest management. Research on effects of various crop management practices associated with CA on pest rodent population dynamics is needed to anticipate and develop CA-relevant management strategies.

RESULTS: During the Australian 2020–2021 mouse plague, farmers used postharvest stubble management practices, including flattening and/or cutting, to reduce stubble cover in paddocks to lessen habitat suitability for pest house mice. We used this opportunity to assess the effects of both harvest and stubble management on the movement and abundance of mice in paddocks using mouse trapping and radio tracking. We found that most tracked mice remained resident in paddocks throughout harvest, and that mouse population abundance was generally unaffected by stubble management.

CONCLUSION: Recent conversions to CA practices have changed how pest house mice use cropped land. Management practices that reduce postharvest habitat complexity do not appear to reduce the attractiveness of paddocks to mice, and further research into new management strategies in addition to toxic bait use is required as part of an integrated pest management approach.

Supporting information may be found in the online version of this article.

Keywords: rodent pest management; ecology; conservation agriculture; crop tillage; predation risk

1 INTRODUCTION

The shift to more environmentally sensitive agricultural practices over the last several decades has changed farmland landscapes. This includes the adoption of soil conservation practices, including zero-, no-, and minimum-tillage practices, whereby seeds are drilled directly into the soil with minimal disturbance, leaving stubble (residual stems and leaves) from the previous crop intact. Such conservation agriculture (CA) systems aim to enhance the sustainability of agricultural production by improving water storage, soil quality, organic matter and carbon sequestration, while reducing erosion and greenhouse gas emissions (see Page *et al.*[1] for review). For example, CA practices can increase water efficiency by maintaining vegetation cover, with reduced tillage decreasing evaporation and increasing infiltration by improving surface soil structure and facilitating deep water transport via the standing stubble.[2] The resulting increase in soil organic matter, particularly at the soil surface, improves soil structural stability, fertility, and biological diversity relative to conventional agricultural systems.[3,4] Similarly, soil macro-fauna benefit from CA systems, with earthworms, termites, and beetles, which burrow through the soil and/or break up plant residues, enhancing soil macroporosity (increasing water infiltration) and nutrient cycling.[5,6] These benefits have led to CA being practised in over 102 countries on over 205.4 M ha, covering approximately 14.7% of the global arable cropland (2018–2019 estimate), with its use increasing at a rate of 10.5 M ha per annum.[7]

There are, however, unintended consequences emerging with the adoption of CA, including an increased incidence of pests

* Correspondence to: WA Ruscoe, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Health and Biosecurity, GPO Box 1700, Canberra, ACT 2601, Australia, E-mail: wendy.ruscoe@csiro.au

a Commonwealth Scientific and Industrial Research Organisation (CSIRO), Health and Biosecurity, Canberra, Australia

b Centre for Conservation Ecology and Genomics, University of Canberra, Canberra, Australia

and diseases, though the economic impact is unknown. The residual crop stubble provides a cool, moist habitat that can favour the build-up of populations of slaters, millipedes, earwigs, and weevils, which have become increasingly common pests in broadacre crops over recent years.[8] In addition to invertebrate pests, no-till systems can favour a build-up of mammalian pests, notably rodents, leading to crop damage.[9–13] In conventional agricultural systems, a build-up of rodent populations is often prevented by postharvest ploughing that can destroy burrows, kill animals, and bury any remaining food and weed plants, leaving a relatively unattractive environment for small mammals. Managing rodent pests has become a significant issue in CA systems.[14–16] For example, common vole (*Microtus arvalis*) populations, which are resident in crops across Europe,[17,18] fluctuate in size in response to changes in food quality and quantity, and have benefited from conversion to no-till systems due to a lack of burrow disturbance and an increase in food availability from weeds retained in cropping paddocks.[12,15,19] Similarly, conversion to no-till agriculture in Argentina has allowed the nine-banded armadillo (*Chaetophractus villosus*) to increase in abundance in agroecosystems due to reduced disturbance and increased food availability from spilled grain and associated invertebrates.[11,20] Bandicoota rats (*Bandicota bengalensis*) have also showed higher crop infestations and caused more crop damage in CA rice fields compared to conventional tillage fields in India.[10] While the impacts of some pest rodents in CA systems has been revealed, research on which particular CA practices are supporting the increase in pest rodent populations is needed to anticipate, develop and implement CA-relevant management strategies.[14]

Increased cover due to retention of stubble in CA systems, may favour rodent pests by providing ongoing shelter. Open habitats are usually avoided by small mammals, and the amount of cover has been observed to affect behavioural decisions, such as micro-habitat choice,[21–25] feeding activity,[26] movement,[27] and hence reproductive output.[13,28,29] Foraging activity of African small mammals has been shown to change between crop and non-crop habitats across the crop growing season – being highly influenced by food availability and changes in the crop vegetative cover.[30] Changes in house mouse (*Mus musculus*) behaviour have been observed in response to changes in vegetation cover in Australia,[25,31,32] which has been attributed to perceived predation risk.[25,33] Specifically, greater habitat complexity at ground level (0–1 m) has been shown to support higher house mouse populations[25,31] and house mouse activity has been shown to shift to more protected microhabitats when perceived predation risk is high.[25] Mature crops such as cereals and legumes provide such an environment,[30] so changes in behaviour such as the reduction in home range size of ricefield rats, by almost 70%, consequent with the sudden reduction in habitat biomass, food or cover due to harvesting, is not surprising.[34] Similar outcomes have been observed in harvest mice (*Micromys minutus*),[28] common voles,[13] and root voles (*Microtus oeconomus*).[34]

Nevertheless, the multiple benefits of CA practices likely outweigh the disadvantages associated with increased pest incidence. This is particularly the case in dry Mediterranean-like environments where CA practices can minimise the risk of crop failure associated with low and irregular rainfall.[35,36] Unsurprisingly these practices have been widely adopted in Australia[37] which is the driest inhabited continent on earth with one of the highest between-year variabilities in rainfall which is only expected to get worse.[36,38] As in other countries, Australian crops are susceptible to pest infestations and there is a long history of house mouse outbreaks in Australian grain growing regions[39] where damage can be considerable.[40] Current house mouse management recommendations are based on work done before the widespread shift to CA and typically involve targeting mouse populations in refuge areas, such as fencelines, that provided suitable habitat following harvest and paddock ploughing.[41,42] The recent shift to CA practices, however, has changed the spatial and temporal dynamics of mouse populations.[43] Paddocks now appear to provide a year-round 'safe' environment for mice, the standing stubble providing at least perceived cover safety from predatory birds as well as feral cats and foxes that are present in the landscape. The implication is that mice are less likely to move out of paddocks following harvest if the soil is not disturbed and the standing stubble provides some cover, although this idea has not been explicitly tested. Understanding if and how mouse populations may be disturbed/reduced by manipulating the cover provided by standing stubble may help identify appropriate management strategies consistent with CA practices.

Here, we used the opportunity presented of a house mouse outbreak in eastern Australia in 2021 to examine whether habitat modifications could make paddocks less favourable to mice postharvest and prior to sowing the subsequent crop. We wanted to test whether reducing stubble cover postharvest (by increasing predation risk) could reduce mouse populations in paddocks. Farmers reduced cover height by using heavy machinery to flatten or cut up stubble while keeping roots intact and the soil surface relatively undisturbed. Cabling, chaining, rolling or slashing stubble are all methods used to remove invasive pest snails from crop stubble in southern Australian cereal growing areas[44] and they effectively reduce stubble to a height of < 5 cm. We used a replicated before-after design to examine how crop harvest and postharvest stubble management affected the population densities of mice and their individual movements. We expected that the negative effects of physical disturbance and a reduction in cover and habitat favourability associated with harvest would lead to:

- Mice emigrating from paddocks, and
- Reduced mouse abundance in paddocks following harvest.

In addition, we expected the additional reduction in habitat favourability associated with postharvest stubble management to:

- Further reduce mouse abundance in paddocks.

2 MATERIALS AND METHODS

2.1 Study area

Sites for this study were established in mature and subsequently harvested wheat and barley crops around Parkes, central New South Wales, Australia (33.1373° S, 148.1747° E) in November 2020. At the time, eastern Australia was experiencing the build up to what became a major mouse (*Mus musculus*) 'plague' in both cropping landscapes and local towns. The stubble management treatments implemented by farmers were in response to the growing mouse problem prior to the 2021 sowing season. Two farms with two paddocks ('sites') each were used for the Harvest Experiment ($n = 4$). These paddocks were also used for the Stubble Management Experiment, along with an additional farm with two paddocks ($n = 6$). The farms were 2–20 km apart while sites within farms were at least 300 m apart to be considered independent at the mouse-scale. The farms in this area practise

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'mixed farming' where cropped paddocks are often interspersed by unimproved livestock pastures.

2.2 Experimental treatments

We examined changes in mouse abundance and movement in response to two paddock-level treatments:

- *Harvesting* – Paddocks were harvested by the farmers as normal with all sites harvested within a few days of each other in early December 2020. Prior to harvest, crops were approximately 1 m high with near total canopy cover (Fig. 1(a)). Following harvest, the stubble remaining was approximately 20 cm high with approximately 30% canopy cover potentially providing some level of perceived safe harbourage. (Fig. 1(b)).
- *Stubble management* – Approximately 2 months post-harvest, stubble management was undertaken by farmers using either a prickle chain (Kelly Tillage, Australia), disc chain (Kelly Diamond Narrow; Kelly Tillage, Australia) or Ajust-A-Bar® (Martin Contracting Pty Ltd, Australia). All three methods, generically termed 'stubble rolling', involved a tractor pulling a set of chains or discs across the ground, resulting in the stubble being laid across the ground to a height of < 5 cm (Fig. 1(c)). There was some soil disturbance but not enough to impact mouse burrows.

2.3 Population monitoring

We carried out a pre-treatment survey of mouse populations on all sites prior to the treatments (harvesting and stubble management) being implemented, and a post-treatment survey following each treatment application. Preharvest trapping occurred in mature crops (November 2020) that were approximately 1 m tall (Fig. 1(a)). Post-harvest trapping occurred in December 2020 when the remaining stubble was approximately 20 cm tall (or 10 cm tall if narrow windrows were used to collect hay), with 10 days between the preharvest and postharvest trapping surveys. At two sites, pre-stubble management trapping occurred in January 2021 and post-stubble management trapping occurred in February, with 9 days between pre- and post-trapping surveys. For the remaining four sites, both pre- and post-stubble management trapping occurred in February 2021, with 10 days between pre- and post-trapping surveys.

Mouse populations were surveyed using capture–mark–recapture (CMR) techniques, based on 5-night live-capture data from traps laid out in a single grid within each site at least 100 m from the perimeter of the paddock. Sixty-four live-capture Longworth box traps (Longworth Scientific, Abingdon, UK) were placed on an 8×8 grid at 10-m spacing. Traps were baited with wheat grains and provided with bonded polyester (Dacron) for bedding. During each trapping survey, traps were checked and rebaited each morning and reset each afternoon. Captured animals were individually marked (Biomark RFID PitTags), and their weight, body length, and sex recorded before being released at the point of capture.

2.4 Population size estimation

We analysed the mark–recapture data to estimate the numbers of mice on each trapping grid at each survey, assuming that populations were closed during each trapping session. We used the method described by Royle *et al*,[45] which allowed us to model individual heterogeneity in detection probabilities implemented in a Bayesian framework via data augmentation (See Data S1 in Supporting Information for details). The outcome of the mark–recapture analysis was an estimate of population size on each grid at each survey, expressed as a posterior distribution specifying the probability that the number of individuals took a particular value, having accounted for variation in detection probability across surveys, grids and among individuals. From this we derived the best estimate of population size on each grid, at each survey, as the mean of the posterior distribution, along with two measures of uncertainty: the variance and 95% credible intervals (CIs) of the posterior distribution. A 95% CI denotes the interval in which we are 95% sure the true mean value lies. Density estimates (mice per hectare) were calculated as population size divided by the grid size (80 m $\times$ 80 m grid, including a 5 m buffer around the outside traps = 0.64 ha).

2.5 Analysis of population change

We used a replicated before-after design, comparing population size estimates before and after implementation of the two treatments. To test whether there was a change in mouse population size following each treatment, we modelled log-transformed estimates of mouse population size as a function of survey time (Pre-treatment *versus* Post-treatment). We incorporated the uncertainty in mouse population size estimates into the analysis by modelling the (log transformed) mean number of mice at the jth site during the kth survey (N_{jk}) as drawn from a normal distribution with variance that was a function of within-site-survey variation [the uncertainty in estimated population size, s_{jk}^2, which was

Figure 1. Photographs taken at various stages of crop and stubble (treatments) on our study sites: (a) preharvest, (b) postharvest and pre-stubble management, and (c) post-stubble management.

the variance in $\log(N_{jk})$ derived from the posterior distribution] and between-site-survey variation (unexplained random variation, σ^2, estimated in model fitting) as follows (Eqn (1)):

$$\log(N_{jk}) \sim (\text{Normal}\,(\beta_0 + \beta_1 s_{\text{Treatment}})) \quad (1)$$

where $s_{\text{Treatment}}$ is a dummy variable coded as 0 for a pre-treatment survey and 1 for a post-treatment survey, β_0 is the estimate of mean population size pre-treatment (on the log scale), and β_1 is the change in population size pre- to post-treatment (on the log scale).

We further tested whether there was a change in mouse capture probabilities following each treatment. We modelled the log-transformed capture probabilities as a function of survey time (Pre-treatment *versus* Post-treatment) in the same way as population estimates, described earlier.

2.6 Radio tracking

To further examine the behaviour of mice over the harvest period, 26 animals were radio-collared and released back into paddocks during the preharvest trapping session (November 2020). Adult mice were brought back to the field facility after capture in the morning trapping session and fitted with radio-collars. Collars were made from 2 mm wide cable ties with a cotton thread weak-link, and Lotek PicoPip Tag Ag379 radio trackers attached to the collar and weighed 0.70–0.76 g (3.8% of the average mouse weight) (see Robinson *et al.*[46] for details). Mice were released at their capture location in the afternoon. We used a Biotracker VHF Receiver and Liteflex 3-Element Yagi Antenna (Lotek, New Zealand) to locate collared mice. Nightly location fixes were taken between 20:00 h and 01:00 h. We estimated individual mice were less than 3 m away from an observer when the receiver signal strength was above 90%. We confirmed this signal strength indicated close proximity by sighting collared mice within a few metres on several occasions, at which point the VHF signal strength was over 98%. We took a single location fix during the day to establish the home burrow locations of mice. For animals we could not locate near the grid, team members walked in all directions for 500 m around the grid to locate mice that may have moved. On the final day of tracking, we searched for any transmitters which had been stationary for > 1 night and that we suspected had detached from mice. All animals that were collared and trapped on the grids during the postharvest, or subsequent trapping surveys, had their collars removed.

3 RESULTS

3.1 Effect of harvesting

Prior to harvest in November 2020 (austral spring), trapping at the four sites revealed that mouse populations were moderately high ranging from 150 to 425 mice/ha. Immediately postharvest, mouse population estimates appeared to decline at all sites, although at only one of the four sites (Site 4) was there a clear reduction in mouse density as evidenced by non-overlapping 95% CIs (Fig. 2).

Across all sites, there was an average 41% reduction in estimated mouse population size (range 20–63%), with a 96% probability that populations had, on average, declined (Fig. 3) though we acknowledge that this estimate was heavily influenced by one site. There was no change in capture probabilities between crops prior to *versus* post-harvest (Supporting Information Fig. S1).

3.2 Radio-collared animals

We successfully located the transmitter signals of 25 collared animals after deployment during the preharvesting trapping session.

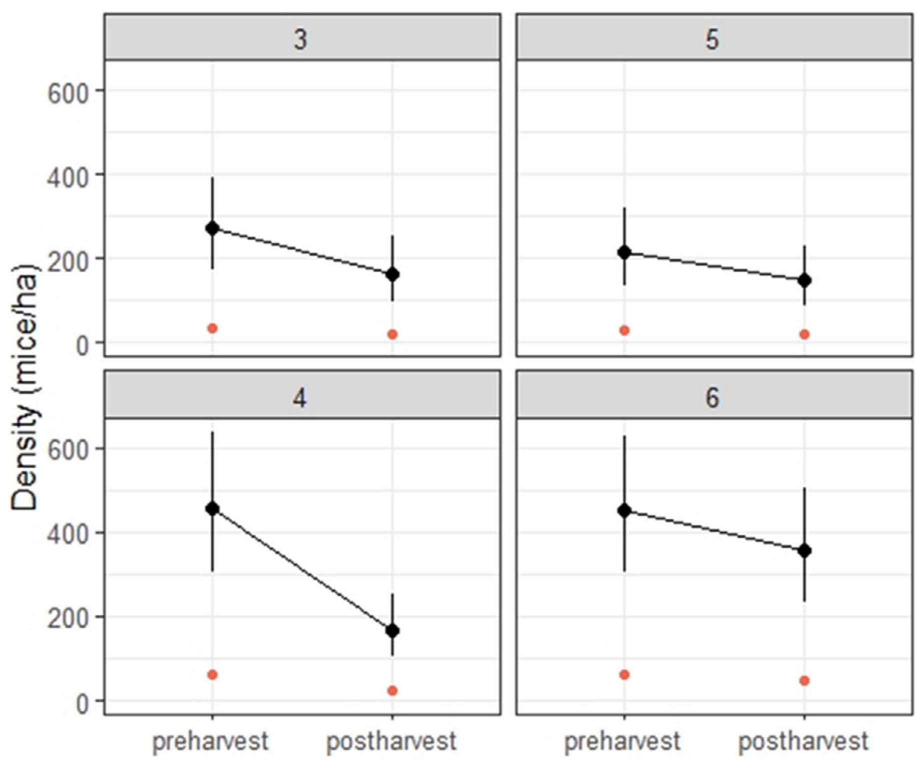

Figure 2. Mouse population densities (±95% credible intervals) estimated from CMR data (see Supporting Information Data S1) before and after harvesting (November and December 2020, four sites, black). The number of individual mice trapped at each survey are presented in red. Site numbers above.

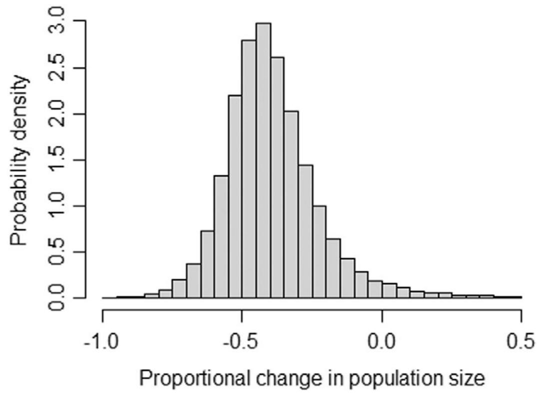

Figure 3. Histogram of the posterior distribution of treatment efficacy (the proportional reduction in mouse population size pre- to post-treatment) associated with harvest (November–December 2020, four sites). A proportional change of 0.0 would imply no change in mouse population size.

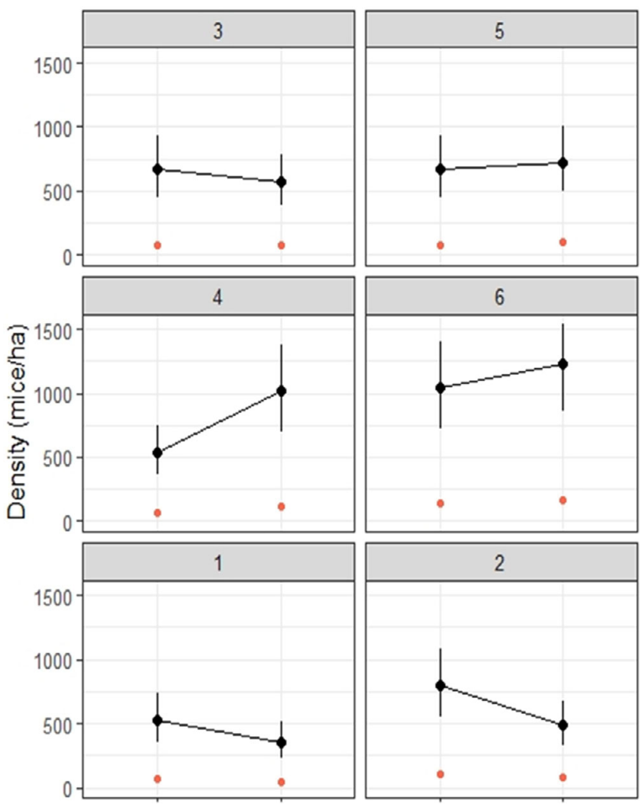

Figure 4. Population densities (±95% credible intervals) estimated from CMR data (see Supporting Information Data S1) pre- and post-stubble management (January–February 2021, six sites). The number of individual mice trapped at each survey are shown in red. Site numbers above.

We were unable to locate the transmitter signal of one animal the day after it was released, suggesting either the transmitter failed, or the animal had moved a long way from the trapping grid. When we returned to the sites postharvest, we found three collars on the ground, lost by mice at some point. Because we did not know when the collars had been removed, we excluded these animals from the analysis, leaving 22 animals we assumed were alive in the paddocks with functioning transmitters immediately prior to crop harvest.

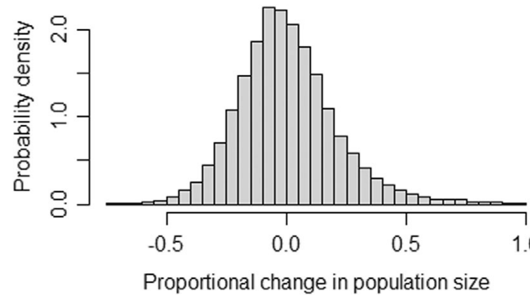

Figure 5. Histogram of the posterior distribution of treatment efficacy (the proportional reduction in mouse population size) associated stubble management (January–February 2021, six sites). Proportional change of 0.0 equals no change.

Following harvest, one animal was found deceased in a shallow burrow that we dug up, which was under a harvester wheel track. A second transmitter signal was tracked to another burrow under a wheel-track, but the animal and collar was not located but did not move, so this mouse was presumed to have also died at harvest. Of the remaining 20 animals with transmitters, only two animals could not be located on or near the trapping grids a week after harvest. Either these two animals had left the area (> 500 m), or their transmitters had failed in that time. Therefore, at least 18 of 20 (≥ 90%) of animals with transmitters that survived harvest remained resident (using burrows) in the paddocks.

3.3 Effect of stubble management

Mouse numbers were higher prior to the stubble management trial (late summer) than prior to or immediately following harvest (late spring/early summer) consistent with an increasing population. Population estimates in late summer indicated an average of up to 1200 mice/ha which is considered a 'plague'. Changes in mouse population sizes pre- to post-stubble management were highly variable (Fig. 4) with three sites showing an increase and three sites a decrease in numbers. Overall, there was no consistent trend, with an average 1.4% reduction in mouse population size following stubble management (Fig. 5). There was no change in capture probabilities a result of the stubble management treatments (Fig. S1).

4 DISCUSSION AND CONCLUSION

Our individual-level (fate of radio-tracked individuals) and population-level (mark recapture densities) estimates of population change indicated that mouse populations in paddocks decreased marginally because of harvesting. Two animals (9% of collared animals assumed to be alive on our grid at the time of harvest) died as result of being squashed in their burrows by harvesting machinery. We dug up the burrows and observed that these were long and shallow (10–20 cm deep) rather than deep, which may be a consequence of the soil type; the mice appear to excavate horizontal burrows in the topsoil rather than digging into the deeper clay base on these sites. Another two animals (9%) were not located in the paddocks following harvest and we assume they moved away more than 500 m although we cannot discount the possibility that they were taken by predators, or their transmitters failed but the animals were still on the grid (although we never trapped them again). Trials with the same batch of collars showed that the batteries/transmitters continued working for the manufacturer-stated 30 days[46] and another study suggested that small collars are more likely to fail very quickly (within a day or two, as one of our collars did) due to manufacturing faults rather than after a week or so.[47] Previous studies have reported up to 25% of radio-collared house mice being nomads (moving more than 300 m from their capture location within 3 days) in Australian agricultural paddocks[47] which suggests our 9% emigration estimate plausible. If we assume a combined 18% 'harvest loss' of collared mice, our estimate is similar to that reported by Jacob and Hempel,[13] though they attributed decreases in the density of common voles (*Microtus arvalis*) following harvest to decreased survival (21% mortality of radio-tracked individuals), rather than emigration.

There is limited information about how vegetation height might affect pest rodent populations in agro-ecosystems.[48] A recent study showed that the foraging activity of African small mammals was highly influenced by changes in the crop vegetative cover and food availability associated with seasonal growth.[30] Despite the common assumption that reducing vegetation height will be detrimental to small mammal populations, the evidence for this is mixed.[28] In another study, common vole density dropped after the harvesting of beans, but initially increased following the harvest of wheat in Germany.[16] Harvesting decreased CMR population densities in our trial by between 20% and 63% (average of 41%) but with uncertainty around the preharvest and postharvest population estimates (see Fig. 2). The average decrease is almost twice that of the radio-tracking estimate but was likely skewed by a much larger decrease in one of the four replicate paddocks. It is possible that the physical disturbance of harvest caused animals to become more trap-shy (neophobic) which could lead to a temporary decrease in trapability following harvest. It is also possible that a predator hunting on the one site where the population appeared to decrease substantially postharvest removed mice, or caused mice to change their behaviour, potentially reducing their movements and therefore probability of intercepting a trap. The impacts of predators on mice in Australian agricultural settings is unknown. Our population/density estimation accounts for heterogeneity in capture probabilities, and further analysis showed that there was no systematic change in capture probabilities due to either harvest or stubble manipulation suggesting animals were not becoming trap shy.

This postharvest decrease in density estimates was also higher than we expected given a previous study that (opportunistically used a long-term dataset) suggested that mice were not generally moving out of paddocks during the non-crop season.[43] The previous study did not assess the effect of the harvest process itself but compared trap success (surrogate for population size) in the paddock preharvest (generally November when the crops are maturing) with trap success in the summer when paddocks were in the non-crop phase; stubble or fallow (generally February). This 'non-crop' timing more accurately aligned with our Stubble Management experiment at which time our populations had increased from 200 to 400 mice/ha preharvest (November, late spring) to 500–1000 mice/ha pre-stubble management (February, late summer). If we had only assessed populations in November and February, we would not have measured the immediate effect of harvest and would have similarly concluded that populations did not decrease over the harvest/non-crop season. Spring and summer cover the main house mouse breeding season when populations generally increase to a peak in Autumn.[49] In a year that mouse numbers increased to high levels, our study shows that, while harvesting killed some animals and/or induced others to leave the harvested area, this effect was temporary and not sufficient to overcome the natural population increase due to breeding, and/or prevent re-invasion postharvest. Spilled grain that remains on the ground following harvest presents a bountiful food supply for mice with up to 200 kg/ha estimated from similar grain growing paddocks.[50]

Postharvest population estimates in December were 180–350 mice/ha but had increased to 550–1000 mice/ha 2 months later (pre-stubble management surveys), indicating an intrinsic rate of increase of 0.545 per month (equivalent to the population multiplying by a factor of 1.7 per month), well within previously reported rates of increase for Australian mice.[51,52] Cull rates of approximately 97% of the population have been estimated to prevent house mouse population increases.[53] Similar cull rates (91–95%) were found to be necessary to prevent rat (*Rattus rattus* and *Rattus norwegicus*) populations from increasing given the species maximum rate of population increase. The population reductions we measured following harvest were nowhere near these cull rates, and therefore would not be expected to prevent population increase while breeding was occurring. While population reductions less than 90% may be of benefit to delay peak population onset past the crucial re-sowing season, an average density reduction of up to 41% in this study did not stop significant population increases (reported in a study at the same sites undertaken 3 months later[54]) and may have resulted in compensatory survival, breeding, and/or emigration from adjacent unaffected higher density populations. These relationships require further investigation.

A range of habitat manipulation management practices have been trialled in Australia aimed at reducing the impact of mice on crops. These practices include mowing crop margins, harrowing, ploughing, livestock grazing, applying herbicides, deep seed-sowing, and providing alternative low-value food.[41,55] Our study was conducted in the initial phase of an outbreak, with stubble management aimed at reducing the suitability of paddocks to mice so that mouse densities would be reduced prior to sowing subsequent crops. Previously, studies have shown that mice will select habitats with higher complexity and vegetative cover to reduce predation risk.[29,31] We therefore may have expected mice to move out of our paddocks to adjoining non-manipulated paddocks and non-crop areas. Instead, we found that stubble management did not lower mouse densities (mouse numbers increased on three of the six sites) and we observed mice running both above and beneath the flattened stubble. Hence, stubble management that reduces cover to < 5 cm does not appear to have sufficiently altered the habitat to make it a worthwhile management practice for reducing mouse numbers in paddocks. The use of Giving Up Densities (GUDs)[26] may have revealed more about predation risk and foraging decisions by mice in the crop-scape and is an avenue for further research. Over the longer term, reduced cover might decrease mouse foraging efficiency due to perceived predation risk, which could in turn translate into reduced survival and fecundity, but these outcomes would take longer than our study to manifest. Having said that, the mouse population on these sites remained high 3 months after the present study (see a subsequent study on the same sites[54]) and the farmers reluctantly burned the stubble in the paddocks prior to sowing the next crop (April–May 2021) in a last-ditch effort to completely remove vegetative habitat and food (spilled grain and weed seeds) availability, to reduce mouse numbers.

While our stubble manipulation may have increased predation risk for mice, it may not have increased it enough to offset the benefit of abundant food available in the paddocks. This suggests that predation is not a strong regulating process in this system, and/or that the availability of food is more important. Options for managing mouse populations may be better directed to reducing food resources.[56,57] One way of reducing in-paddock food could be minimising the amount of grain left on the ground after harvest. This could be achieved by improving the efficiency of harvesting by reducing grain spillage and/or using 'seed destructor' machines to destroy spilled grain[58] which are being developed to deal with the seeds of herbicide-resistant weeds. Other ways to reduce the amount of spilt grain include grazing the crop stubble postharvest. While some farmers maintain livestock (mixed farming enterprises), in southern Australia the intensification of cropping is seeing many farmers remove old fences and combining paddocks to make way for the use of larger machinery and reducing non-crop areas they need to manage. A light tillage postharvest could potentially bury some remaining food sources making it harder for mice to find – this needs testing, but is unlikely to provide additional benefit via burrow disturbance.[15] Reducing alternative food may enhance the success of poison baiting programmes; toxic baits may be more readily accessible than spilt grain if a light tillage is done immediately prior to laying baits.

This study adds weight to the conclusions of a previous study suggesting that the conversion to CA in Australian dryland cropping zones has benefited pest house mice. Paddocks provide a begin environment year-round due to the lack of burrow disturbance and the provision of shelter for safe foraging. While the physical disturbance of harvest killed some mice directly, and may have prompted some to emigrate, the losses were not sufficient to demonstrate a consistent reduction in population sizes. Farmers attempted to make the postharvest paddock-scape less favourable to mice by reducing the complexity of stubble cover in the important 0–1 m height range hoping it would prompt emigration (to nearby unmanipulated areas). Whether 5 cm high cover is considered sufficient by mice for predator avoidance, or, predation risk in the system was so low as to not affect behaviour when cover was reduced to ground level, remains unknown.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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