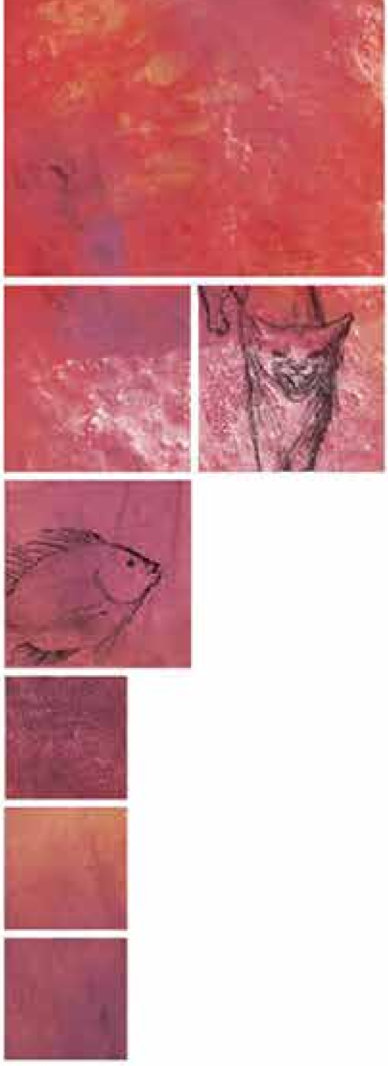

Surveillance and Forecasts for Mouse Outbreaks in Australian Cropping Systems

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Invasive Animals CRC

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

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Executive Summary

Outbreaks of house mice (*Mus domesticus*) cause substantial economic and social hardship, and pose a significant health risk to farmers. A 'real-time' national system for surveillance and forecasting mouse outbreaks (plagues) is required urgently. Real-time surveillance will help farmers apply mouse control early, and modify farm management before mice cause economic damage and social disruption in rural communities. In addition, reliable, real-time forecasts will help commercial operators secure adequate supplies of rodenticides to enable farmers to apply control in a timely manner. To be self-sustaining, a real-time national surveillance and forecasting system needs to provide immediate benefits to farmers. To be responsive and to have broad scale coverage, it needs to be based on information provided directly by farmers and the grains industry.

In 2012 a **national network for monitoring** mouse populations was set up in representative areas of all grain-growing regions. Mouse populations were monitored seasonally in typical grains farming systems in Western Australia, South Australia, Victoria, New South Wales and Queensland. Subsequently, the network was expanded in central New South Wales and in Yorke Peninsula and Eyre Peninsula in South Australia. Monitoring was conducted at (a) benchmark sites where regular surveys and research have collected detailed data for >30 years, (b) rapid assessment sites using low-cost quantitative techniques, and (c) sites where qualitative information was provided by farmers and agronomists. The monitoring provided data on the abundance of mice and their breeding status. This information was used in population models that have been developed progressively over the last 20-30 years to predict mouse plagues. Regular reports summarising the monitoring information and model-based forecasts were provided to the Grains Research and Development Corporation (GRDC), the National Mouse Monitoring Working Group (NMMWG) and farmer groups, and were disseminated widely via the Invasive Animals CRC (IA CRC) communications programme.

Qualitative assessments of mouse abundance were provided by farmers via a web-based platform and mobile phone app called *MouseAlert*. *MouseAlert* is a free, easy-to-use resource that was custom built to enable farmers to record their observations and obtain immediate access to status reports and information on mice for their local area. The *MouseAlert* phone app was launched in April 2015 with a special event, the 'National Mouse Census Week', to encourage use by farmers.

In parallel with collection of monitoring data, a new **region-specific model for forecasting** plagues of mice has been developed. In most cases, detailed predictions of abundance are not necessary and instead farmers need to know when large abundance fluctuations are likely to occur, especially at sowing and prior to harvest. In contrast to previous models for predicting mouse plagues, the new model translates current observations into consistent 'low', 'medium' and 'high' levels of mouse abundance. Then, using additional rainfall data, the model predicts the likelihood that mouse abundance will stay at the same level or change to a different level during the next season. These predictions are made for each 30 km x 30 km 'grid cell' within a grain-growing region. The model was implemented initially for south-eastern Australia using data from benchmark sites and rapid assessment sites.

Recommendations

This project has established a new national network for monitoring mouse activity throughout the grain growing regions of Australia and has developed a new region-specific model for forecasting mouse plagues. It has also modernised mouse surveillance and response capabilities, and automated methods to keep farmers informed about emerging mouse problems.

There are eight steps required to complete development and implementation of a real-time national surveillance and forecasting system for mice. This will provide farmers with the essential tools to monitor, and stay informed about, levels of mouse activity. It will also provide the grain growing industry with an early warning system for detecting and responding to regional-scale mouse plagues.

The eight steps are:

(1) **Continue seasonal monitoring**. Monitoring needs to be continued across the network of benchmark, rapid assessment and qualitative sites through the next mouse plague in at least one region in south-eastern Australia. Data from areas with high numbers of mice and, simultaneously, areas with few mice are essential to validate the new rapid assessment and qualitative methods across a full range of mouse population densities, and to complete tests of the spatially-explicit model for forecasting plagues. Future use of rapid assessment techniques should follow standard field protocols so that data can be compared between sites and monitoring sessions and to ensure data are suitable for use in new predictive models.

(2) **Select the best model for forecasting mouse plagues**. There are alternative statistical criteria for selecting the best model for forecasting mouse plagues. Further testing is required to confirm that the current best model, which correctly 'predicted' most periods of medium or high mouse abundance in the historical data from South Australia and Victoria, also performs well when mouse abundance is low.

(3) **Improve the model with additional environmental covariates.** The use of environmental covariates such as soil type might help to explain some of the variation in mouse abundance within regions. This step could be dropped *if* the best model from step 2 is good enough to meet farmers' requirements *and* there are sufficient monitoring data to provide widespread coverage across grain-growing areas. Monitoring with the current network is valuable (step 1) but does not have sufficient coverage to generate forecasts across the entire south-east grain growing region, or other regions: a high level of uptake of *MouseAlert* by farmers is essential.

(4) **Implement forecasts based on monitoring by farmers**. The new model for forecasting mouse plagues has been designed to use qualitative and/or quantitative monitoring data. It needs to be transitioned from predictions based primarily on specialised monitoring to predictions based on the knowledge and experience of farmers, i.e. information provided via *MouseAlert*, and it needs to be tested with data from farmers before, during and after a mouse plague.

(5) **Extend the forecasting model to additional regions.** The forecasting model road-tested in south-eastern Australia needs to be extended to cropping systems in the north-eastern and south-western grain-growing regions.

(6) **Training and delivery**. A dedicated training, extension and marketing programme is required to roll out the *MouseAlert* system to ensure sufficient uptake so that feedback to farmers motivates complete coverage across all grain-growing regions. Farmer networks and agronomists need to be brought online to ensure the full benefits of this system are delivered across grain-growing districts. This will require facilitation and appropriate district-wide training.

(7) **Automate delivery of forecasts via *MouseAlert*.** Delivery of routine forecasts requires software to be developed to automatically extract farmers' assessments from *MouseAlert* and rainfall data from the Bureau of Meteorology at pre-set periods, which will be added to current data used by the forecasting model. Then the software will need to re-run the model, provide updated forecasts and automatically feed them back to *MouseAlert* for reporting.

(8) ***MouseAlert* roll-out and maintenance**. The *MouseAlert* web site and mobile phone app needs to be maintained within an appropriate institution and updated as required.

GRDC has agreed to provide funds for the monitoring required for step 1. The additional testing for step 2 is being funded by Landcare Research and should be completed by mid-2016. Funds are yet to be obtained for the remaining steps.

Abbreviations

ACIAR: Australian Centre for International Agricultural Research

Biosecurity SA: Biosecurity South Australia

BRS: Bureau of Rural Sciences (now part of Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES))

CSIRO: Commonwealth Scientific and Industrial Research Organisation

GRDC: Grains Research and Development Corporation

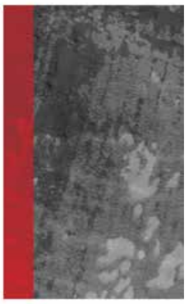
IA CRC: Invasive Animals Cooperative Research Centre

LHPA: Livestock Health and Pest Authority, New South Wales

NMMWG: National Mouse Monitoring Working Group

PIRSA: Primary Industries and Regions South Australia

Qld DPI: Queensland Department of Primary Industries



1. Introduction

1.1 Mouse plagues

Outbreaks of house mice (*Mus domesticus*), called mouse plagues, cause substantial economic and social hardship, and pose a significant health risk to farmers. Plagues have occurred in Australia for more than 100 years: some have been localised and others have extended over entire grain-growing regions (Singleton et al. 2005). There is some evidence that their frequency has increased in recent decades, possibly as a response to altered cropping systems and other changes in farm management. The review by Brown et al. (2010) highlighted the necessity of monitoring mice to predict when and where plagues are likely to occur. They recommended a nationally coordinated approach to monitoring, as well as maintenance of the skills base required to provide training in monitoring techniques, to assess monitoring data and to continue development of operational models for forecasting changes in mouse abundance.

1.2 Monitoring

There has been an *ad hoc* approach to monitoring trends in mouse abundance in the past. Monitoring has been achieved through a range of projects funded by GRDC, BRS, CSIRO, ACIAR and other sources. There are three very good long-term data sets from sites in South Australia (Roseworthy: Greg Mutze, Biosecurity SA), Victoria (Walpeup: Grant Singleton and CSIRO), and southern Queensland (Darling Downs: Steve Cantrill, Judy Caughley, Peter Cremasco, Julianne Farrell, Qld DPI), but detailed monitoring had ceased at all these sites prior to the current study. For a long period beginning in the early 2000s, mouse populations were relatively low because of the drought affecting Australia's grain growing regions. When the drought broke in 2010, mouse populations built up rapidly and caught many by surprise because little routine monitoring was being conducted in many areas and little expertise or capacity to understand what was happening existed within relevant organizations.

In previous mouse plagues, State agencies had implemented their own monitoring and reporting programmes based mostly on observations and subjective assessments. Observational data were gathered by regional staff such as district agronomists and LHPA rangers. These programmes were used to raise farmers' awareness of trends in numbers of mice and to assist in directing bait supplies to districts most in need. Commercial bait producers also maintained informal reporting networks for the same purposes. Monitoring in these circumstances tended not to be used in any predictive sense and mostly operated under emergency conditions only. In New South Wales during the mouse plague of 2010, resurrecting the previously used monitoring network was made difficult by declining agency resources. Currently there is no formal, government-funded monitoring of mice in Queensland, New South Wales or South Australia. The Department of Primary Industries in Victoria has a monitoring network, which involves approximately 150 sites and monthly monitoring of active mouse burrows at these sites at high risk times leading into autumn and spring. In Western Australia, the Department of Agriculture and Food has a PestFax service (https://www.agric.wa.gov.au/newsletters/pestfax) that provides reports on agricultural diseases and pests, including mice.

A nationally consistent monitoring network, matched to available resources, needs to be implemented so that it covers a broad cross-section of crop types, soils and climate in the major crop-production regions of Australia. Information gathered at low cost over large areas, backed up by strategically-timed, systematic monitoring, should provide early warning of increases in numbers of mice, and will provide the data essential for improving forecasts of mouse plagues in specific grain-growing regions.

1.3 Forecasting mouse plagues

A series of non-spatial regional models was developed previously to predict the likelihood of mouse plagues. These used detailed data collected from long-term monitoring sites in Queensland, South Australia and Victoria, and more limited data from other locations (Pech et al. 1999). Predictions (at least several months in advance) increase the time available for farmers and rodenticide companies to plan and conduct effective mouse control. The models vary in their data requirements, ease of use and accuracy. Some of the models were developed for specific crops and regions (e.g. Darling Downs, north-west Victoria). The most recent published assessment of the models for southern Australia tested their ability to predict outbreaks for a sample of nine local areas in Victoria and South Australia (Krebs et al. 2004). Currently the best models for these wheat production areas have a 70% success rate for predicting plague, and non-plague, years and 58% success rate for predicting the severity of plagues. The data required for the models include rainfall in key months (e.g. April to October; December) and an estimate of mouse abundance in spring. However the models were developed using data collected prior to recent farming innovations, such as minimum tillage, and they do not apply to crop types other than wheat. The most recent models for central Queensland are broadly similar to those for south-eastern Australia (Pople et al. 2014). The models for both south-eastern Australia and Queensland have very limited ability to generate useful forecasts across entire grain-growing regions.

1.4 Economic, social and environmental benefits of improved monitoring and forecasting

Farmers and their advisors are constantly seeking ways to improve the cost-effectiveness of farm enterprises. Previous research has shown how farmers can minimise economic losses from mice by taking advantage of early warning of plagues (e.g. Davis et al. 2004). Improved monitoring and forecasting will enable farmers to minimise the use and maximise the cost-effectiveness of rodenticides. Minimising use of rodenticides is likely to garner strong public support, given the limited public appetite for wide-scale use of poisons in the environment. Minimal use of rodenticides will also keep Australia ahead of the game compared to its international trading partners, who expect extremely high standards for food products. Products that are deemed environmentally friendly are more likely to command a premium price on international commodity markets. Also, increased awareness of mouse plagues will reinforce messages from health authorities about the potential risks of contracting rodent-borne disease such as leptospirosis.

2. Methods

2.1 Monitoring

A monitoring system was designed and implemented across the major eastern, southern and south-western grain-growing regions. The system has three levels of data collection: (a) qualitative assessments of mouse activity (from farmers and agronomists), (b) rapid assessment sites using indices of mouse abundance, and (c) benchmark sites where long-term trapping has been conducted and where forecast models have been developed (Figure 1).

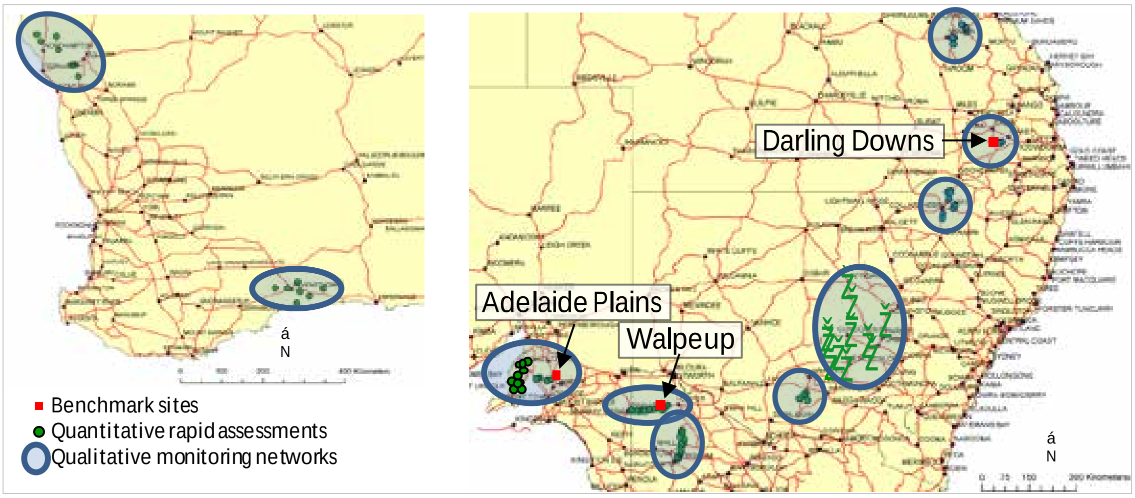


Figure 1: Approximate locations of monitoring in Western Australia, South Australia, Victoria, New South Wales and Queensland. Benchmark sites are at Adelaide Plains (Roseworthy), Walpeup and the central Darling Downs where there had been long term research and monitoring.

2.1.1 Qualitative assessments

Starting in 2012, qualitative data were collected by contacting key farmers and farmer groups in each region. In 2014 the *MouseAlert* platform became an additional method for collecting qualitative surveillance data. Initially *MouseAlert* was designed as web site (and a mobile optimized web site) that enabled farmers to contribute mouse activity data and obtain immediate access to status reports and forecasts on mice for their local area (Figure 2). In response to requests from farmers and to increase ease of use, *MouseAlert* was developed into a free, offline-capable phone app available in Apple and Android formats (Figure 3). *MouseAlert* was launched in April 2015 and promoted by a special event, the 'National Mouse Census Week', to encourage use by farmers.

(a)

(b)

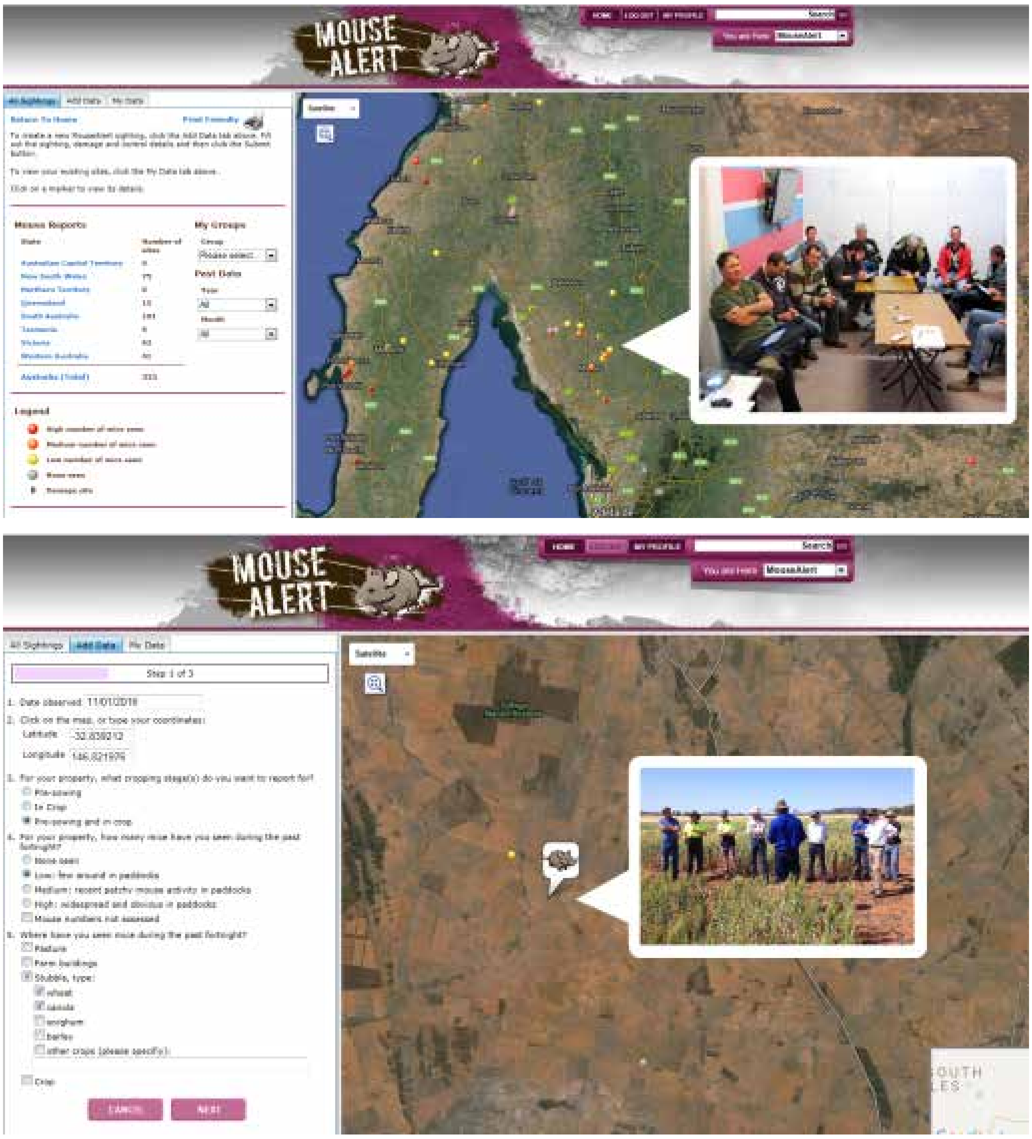


Figure 2: Screen-shots from the *MouseAlert* web site, with inset pictures of introductory sessions for farmers in (a) South Australia and (b) the Central West Farming Systems Group, New South Wales.

Figure 3: *MouseAlert* website, phone app and information card. Download from Apple and Google Play.

MouseAlert was designed primarily to collect and disseminate data on mouse abundance (or activity), which is recorded in the categories: low, medium and high abundance (Figure 4). These categories correspond to levels of concern to farmers: low mouse abundance implies no intervention is required; at the medium level, farmers should be vigilant for signs of activity or damage; and damage at sowing or prior to harvest is likely at high mouse abundance. *MouseAlert* has options for recording additional information on recent damage caused by mice and any actions to prevent damage. Additional options for eliciting input (such as push-prompts) and for providing feedback directly to farmers via the app have been discussed, and should be considered for future improvements, but these were not required as an output from this project.

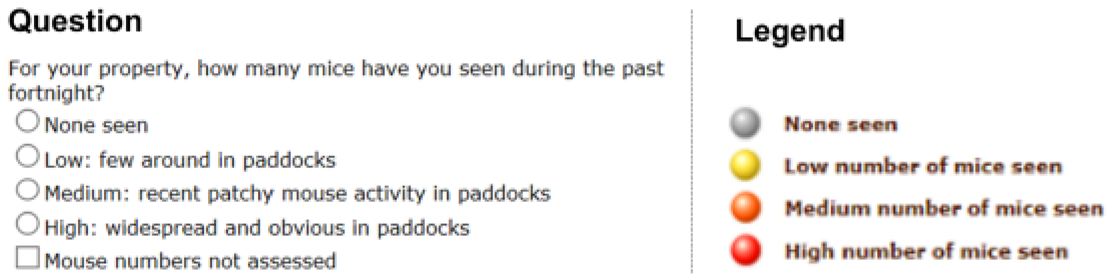


Figure 4: Mouse abundance (or activity level) categories used by farmers to record their observations in *MouseAlert*, and colour-coded categories used to re-display information to farmers checking local reports.

2.1.2 Rapic assessment sites

In March, June and October each year, rapid assessments of mouse activity were conducted at a total of 54 sites in the Geraldton and Ravensthorpe regions of Western Australia, the North Adelaide Plains and Yorke Peninsula in South Australia, the central Mallee and Wimmera in Victoria, and the Coleambally Irrigation Area in southern New South Wales. In each region, the minimum distance between sites was approximately 10 km to cover a range of farming systems and environmental conditions. Also monitoring was conducted at 10 sites around Moree in northern New South Wales and in three areas of Queensland (11 sites in the central Darling Downs, 7 sites in the Callide Valley and 7 sites in the Dawson Valley).

Active mouse burrows were counted along transects 100 m long by 1 m wide established in the main crop types: one transect at each of the Queensland and Moree sites, and two transects elsewhere (50 m and 20 m into the crop from the fence line). Each burrow was marked with talcum powder and revisited the following day to confirm that the burrow was active (Figure 5). Chew-cards were set on a parallel line of 10 cards spaced at 10 m intervals 20 m from each active burrow transect. This design allowed comparison of chew-card data with counts of active burrows. The chew-cards were set out overnight and the proportion of the card that was eaten was recorded when it was collected the following day. The cards (10 cm x 10 cm paper with a printed 1 cm grid) were soaked in canola or vegetable oil with a little linseed oil added. Each card was pegged to the ground. The beginning and end points of all transects were recorded on a GPS.

(a)

(b)

Figure 5: Rapid assessments of mouse activity were made by recording (a) damage to chew-cards and (b) active burrow entrances.

2.1.3 Benchmark sites

Monitoring sessions were conducted in March, June and October each year at benchmark sites in south-eastern Australia. For each session, live-trapping was used to estimate mouse abundance and index data were collected using the two rapid assessment techniques, chew-cards and burrow counts. At each site, 2 grids of 36 Longworth small mammal traps were established (6 x 6 traps, placed at 10 m intervals). These were located in wheat crops (or stubble) and the next most common crop type (e.g. canola) so that monitoring was in representative crop types. At each site, grids were located in adjacent paddocks 50 m into the paddock from the fence line. Additional lines of 15 traps spaced at 10 m intervals were placed along the fence line between the 2 trap grids and at the edge of one of the trap-grid paddocks but adjacent to a different habitat type, either road side verge or native vegetation patch. Each trapping session was for 3 consecutive nights.

Beginning in May 2013, trapping was conducted at up to 10 benchmark sites along a long-term 32-km transect in the central Darling Downs. Snap-trapping followed the protocol described in Pople et al. (2014), and additional 25 live-capture Elliott traps were set at each site. Seasonal monitoring sessions continued through to June 2015.

2.2 Models for forecasting mouse plagues

We extended dynamic occupancy models to estimate transitions between high, medium and low abundance states of mice. Data from the benchmark sites (live-trapping, chew-cards, burrow counts) and the rapid assessment sites (chew-cards, burrow counts) were continuous and may have over- or under-estimated the true abundance state. The new model has two main components: 1) a sub-model for biological processes, incorporating environmental covariates (e.g. rainfall) and prior knowledge of mouse population dynamics to estimate seasonal probabilities of transitioning between abundance states, and 2) a sub-model for the process of collecting surveillance data that accounts for uncertainty in how continuous data values relate to categorical abundance states (Figure 6). In this model, sites (i) are large 30 km x 30 km grid cells and can be grouped to make inference over wider regions using relevant environmental characteristics (e.g. cropping system; soil type) and primary drivers of population changes (e.g. summer/winter rainfall patterns; seasonality). Mice could become undetectable but not extinct in any grid cell. Grid cells were assumed to be independent, as individual mice are not expected to move over such large (30-km) distances. The grid cells were sampled over (k) repeated surveys in each season (t). Repeat surveys used multiple sampling techniques (q; e.g. trapping, chew-cards or burrow counts) and were repeated either spatially, if multiple locations were sampled within a grid cell, or temporally, in the case of multiple visits within a season, or both.

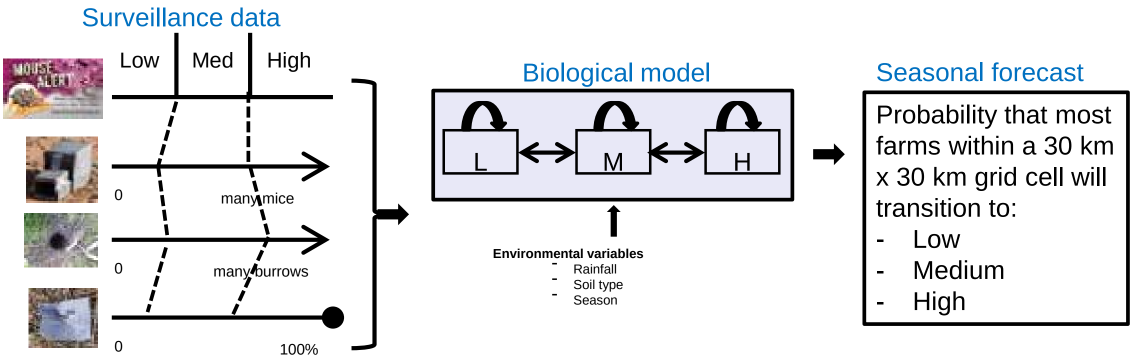


Figure 6: Schematic design of the new model for forecasting mouse plagues. Qualitative information (e.g. via *MouseAlert*) and quantitative surveillance data (using live-trapping, burrow counts, and chew-cards) provide an assessment of the current level of mouse abundance. The biological model uses environmental data (e.g. rainfall) to predict the likelihood mouse abundance will remain unchanged or will change to a different level of abundance.

Although changes in the numbers of mice were likely during a season as a result of breeding, mortality and migration into the sampling locations, these changes were assumed to be not large enough to result in a change in an abundance state (*N* = 0, 1, 2; corresponding to low, medium and high abundance respectively) within a season. Therefore, for the purpose of modelling major population fluctuations, abundance states were assumed to remain constant within a season for each grid cell, so that repeat surveys allowed estimates of the variation in detectability of mice.

In summary, model parameters are: $\psi^{[N]}$ = probability of remaining in the same abundance state (*N*) between seasons; $\tau^{[N_t, N_{t+1}]}$ = probability of transitioning to a different abundance state from season *t* to season *t* + 1; coefficients a_0 and a_1 for environmental variables, such as rainfall, that determine $\psi^{[N]}$; coefficients B_0 and B_1 for environmental variables that determine $\tau^{[N_t, N_{t+1}]}$; mean values $\mu_q^{[0-1]}$and $\mu_q^{[1-2]}$ for the 'cut-offs' in continuous data between states 0 and 1 and between states 1 and 2, respectively, using technique *q*; and standard deviations $\sigma_q^{[0-1]}$ and $\sigma_q^{[1-2]}$ for the cut-offs $\mu_q^{[0-1]}$and $\mu_q^{[1-2]}$, respectively.

Under a Bayesian approach, posterior distributions of model parameters were derived by updating initial parameter estimates with a Markov chain Monte Carlo (MCMC) algorithm, using data and prior distributions (Clark 2005). Before applying the model to real data, we tested its performance using a virtual ecologist approach with simulated data under a range of conditions represented by 11 scenarios. The 'standard' scenario assumed: *k* = 5 repeated surveys in each season; *q* = 2 techniques (trapping and chew-cards); $\alpha_0 = 2$, $\alpha_1 = -3$, $\beta_0 = -3$, $\beta_1 = 3$, $\psi^{[1]} = 0.1, \psi^{[2]} = 0.1, \tau^{[1,2]} = 0.2, \tau^{[2,0]} = 0.7$, for the biological process sub-model; and true cut-off distributions with means $\mu_q^{[0-1],True} = logit(0.33)$ and $\mu_q^{[1-2],True} = logit(0.66)$, for both techniques, and standard deviations $\sigma_q^{True} = 0.02$ for all cut-off distributions, for the observation sub-model. Other scenarios varied sample sizes (*k* = 2 in scenario 2, *k* = 10 in scenario 3), varying data inaccuracy levels, i.e. to represent 'messy' data (scenarios 4-7: increasing σ_q^{True} from 0.02 to 0.05 and 0.10 for both monitoring techniques and then only for one), skewed thresholds (scenario 8: the untransformed $\mu_{q=0}^{[0-1],True}$ changed from 0.33 to 0.15

and untransformed $\mu_{q=0}^{[1-2],True}$ changed from 0.66 to 0.3 for the trapping data, and untransformed $\mu_{q=1}^{[0-1],True}$ and $\mu_{q=1}^{[1-2],True}$ changed to 0.05 and 0.4 respectively for the chew-card data), biased expert opinion (scenario 9: prior cut-off means provided by experts shifted from the true means (μ_q^{True}) to 0.1 and 0.8 for the first and second cut-off, respectively, for trapping data and to 0.4 and 0.6, respectively, for chew-card data), and varied levels of missing data (scenarios 10 and 11: the effects of sampling only 80% or 60% of all site-season combinations). For each scenario, we generated 900 datasets and estimated model parameters using our MCMC algorithm (i.e. our model). For each scenario we estimated model performance by calculating coverage and relative bias for the 16 model parameters. Coverage for each parameter was calculated as the number of times the true value was contained in the estimated 95% credible intervals (CIs). Relative bias for each parameter was calculated by first estimating bias as the difference between the true and estimated values, and then dividing bias by the true parameter value as follows:

$$Bias(P_j) = \frac{\sum_{j=1}^{n}(P_j - P^{True})}{n}$$

and

$$RelBias(P_j) = \frac{Bias(P_j)}{P^{True}}$$

where P_j is the median estimated by the model for the j dataset, P^{True} is the true value used to generate the data, and n is the number of datasets for each scenario.

The new model was then applied to forecast mouse abundance for south-eastern Australia (Figure 7) using data from (a) the current study (2012 – 2015), (b) burrow-count monitoring in Victoria in 2011 (B Patterson, unpublished data), and (c) previous research at Walpeup in Victoria, Colleambally in New South Wales, and Roseworthy in South Australia (see Brown et al. 2002 and Singleton et al. 2005). For each grid cell, the model generates the likelihood mouse abundance remains the same or transitions to a different abundance state in the next season. Predictions are likely to most accurate for cells with more surveillance data (e.g. from rapid assessment sites). Predictions for cells with no surveillance data are estimated using a combination of readily available information (e.g. rainfall data) and predictions for neighbouring cells.

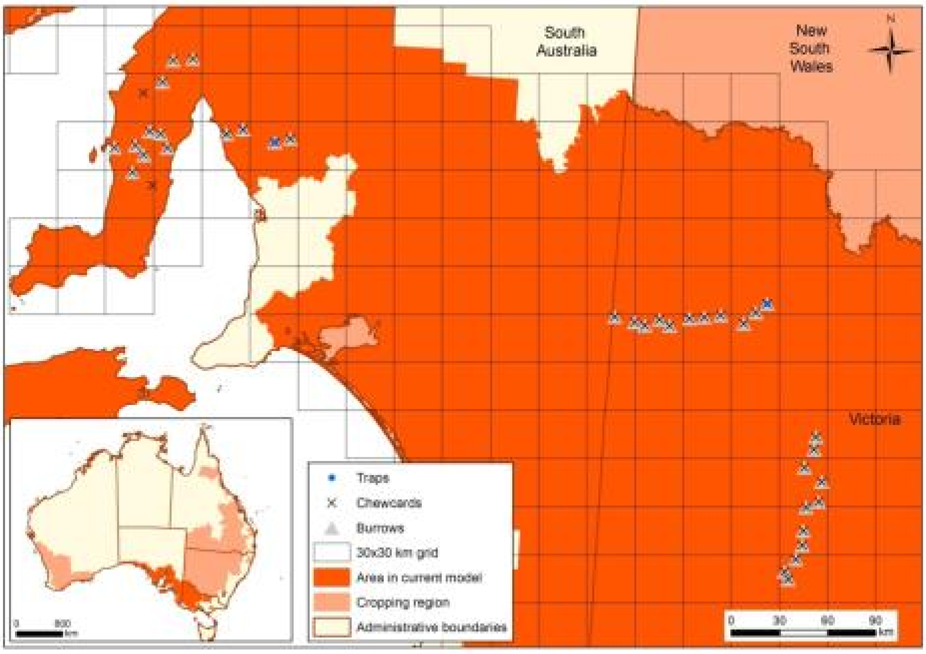


Figure 7: The new model generates forecasts of mouse abundance for each 30 km x 30 km grid cell. Forecasts use environmental data and estimates of current mouse abundance from the rapid assessment sites (chew-cards and burrows) and benchmark sites (where all monitoring techniques were used).

3. Results

3.1 Monitoring

Monitoring was completed seasonally at sites in Queensland, New South Wales, Victoria, South Australia and Western Australia. Following each monitoring session, a report was prepared on mouse activity and the forecast changes in mouse abundance in each grain-growing region (Appendix 1). These reports were provided to GRDC, the NMMWG and farmer groups, and were disseminated widely via the IA CRC communications programme.

The *MouseAlert* web site was developed in 2014 to supplement the network of monitoring sites. The MouseAlert mobile phone app was launched in April 2015, with financial support from PIRSA, and promoted during a special event, the ‘National Mouse Census Week’. This event generated a substantial increase in usage by farmers (Figure 8).

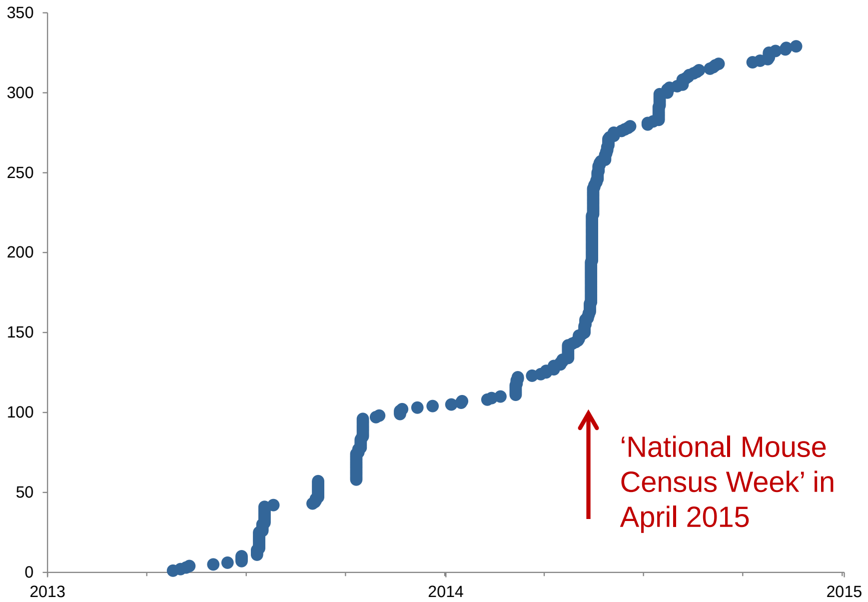


Figure 8: Cumulative number of *MouseAlert* records to October 2015.

3.2 Models for forecasting mouse plagues

Using test data, the model was successful at estimating parameter medians with a small (< 5%) relative bias for 169 of the 176 parameters (16 per scenario; 11 scenarios) in the performance evaluation (Figure 9). Relative bias under scenario 2 (k=2 within-season surveys) was close to -10% for the standard deviations of the medium to high cut-off distributions, $\sigma_{q=0}^{[1-2]}$ and $\sigma_{q=1}^{[1-2]}$. Under scenarios 5 (two messy datasets) and 7 (one messy dataset), relative bias was 6% for the low to medium cut-off means ($\mu_{q=0}^{[0-1]}$ and $\mu_{q=1}^{[0-1]}$) while under scenario 11 (40% missing data), the relative bias for $\tau^{[1,2]}$ and $\sigma_{q=0}^{[1-2]}$ was -5.5% and -6.5% respectively.

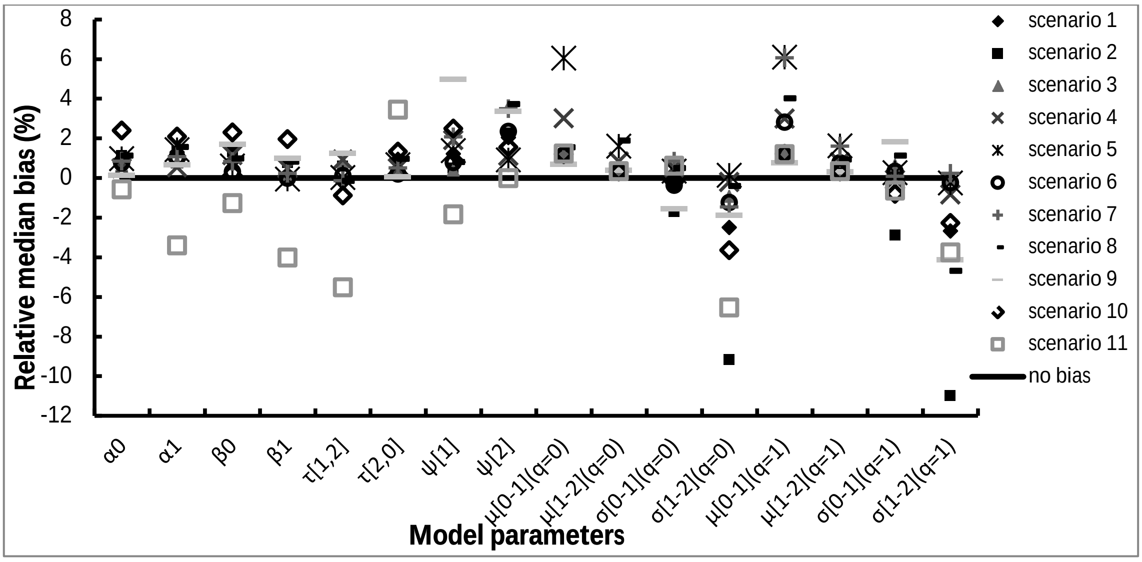


Figure 9: Percentage relative bias (difference between estimated and true model parameters) for 16 model parameters under 11 different scenarios testing a range of conditions including: 'standard' conditions (scenario 1), varied sample sizes (scenarios 2-3), varying levels of data accuracy (scenarios 4-7), skewed thresholds (scenario 8), biased expert opinion (scenario 9), and varied levels of missing data (scenarios 10-11). q = 0 for trapping data; q = 1 for chew-card data.

Coverage was close to the nominal 95% (within 5%) level for the eight biological sub-model parameters assessed under all scenarios except scenarios 6, 10 and 11, suggesting good precision (Table 1). Coverage for the eight parameters describing the observation sub-model was more varied. For the standard deviation parameters ($\sigma_{q=0}^{[0-1]}, \sigma_{q=0}^{[1-2]}, \sigma_{q=1}^{[0-1]}, \sigma_{q=1}^{[1-2]}$), coverage was good (within 5% of 95%) under most scenarios, and reasonable (close to 90%) under scenarios 2 (k=2 within-season surveys), 6 (one messy dataset) and 8 (skewed prior means for the cut-off distributions). However, for the means of the cut-off distributions ($\mu_{q=0}^{[0-1]}, \mu_{q=0}^{[1-2]}, \mu_{q=1}^{[0-1]}, \mu_{q=1}^{[1-2]}$), coverage was poor under all scenarios.

The generally good coverage observed suggests that model assumptions were met and that our model provides estimates of temporal trends with reasonable precision. The true means of the cut-off distributions were often outside the estimated 95% CIs although the relative bias was always positive and small, except when both datasets were messy (scenario 5). We expect the model will be used with Poisson-like data; thus the means of the cut-off distributions will often have a small positive bias.

Table 1: Percentage coverage defined as the percentage of datasets where the true parameter values (from simulated data) fell within the 95% Credible Intervals estimated in the model for eleven different scenarios. Values greater than 5% either side of 95% coverage are highlighted in bold. See the text for descriptions of scenarios and definitions of parameters; q = 0 for trapping data; q = 1 for chew-card data.

	coverage (%)															
	biological sub-model parameters:								observation sub-model parameters:							
	α_0	α_1	β_0	β_1	$\tau^{[1,2]}$	$\tau^{[2,0]}$	$\psi^{[1]}$	$\psi^{[2]}$	$\mu_{q=0}^{[0-1]}$	$\mu_{q=0}^{[1-2]}$	$\sigma_{q=0}^{[0-1]}$	$\sigma_{q=0}^{[1-2]}$	$\mu_{q=1}^{[0-1]}$	$\mu_{q=1}^{[1-2]}$	$\sigma_{q=1}^{[0-1]}$	$\sigma_{q=1}^{[1-2]}$
scenario 1	95.0	95.1	97.7	96.4	95.3	95.0	94.6	96.2	0.0	44.4	92.8	94.7	0.0	40.8	93.2	93.6
scenario 2	94.0	93.9	95.9	95.7	95.9	95.7	95.2	94.7	0.2	69.6	93.4	88.0	0.0	66.9	90.1	86.1
scenario 3	94.3	94.6	97.1	96.1	94.9	96.2	94.3	95.4	0.0	18.2	93.9	94.3	0.0	15.4	93.7	94.0
scenario 4	93.7	94.3	97.1	96.0	96.3	95.2	95.6	96.2	0.0	10.1	94.0	94.4	0.0	10.6	95.1	94.7
scenario 5	94.2	94.6	95.7	95.8	93.9	95.3	95.0	94.6	0.0	0.9	94.3	94.8	0.0	0.9	93.7	94.1
scenario 6	88.0	87.6	89.9	89.3	88.8	88.7	88.1	89.2	0.0	42.6	86.3	87.8	0.0	10.2	88.2	87.8
scenario 7	94.4	94.1	96.3	96.3	96.0	95.4	95.6	95.7	0.0	46.6	94.4	93.0	0.0	0.8	94.8	94.9
scenario 8	94.9	94.4	96.3	96.3	94.3	94.4	94.7	94.4	0.0	0.0	93.7	90.9	0.0	14.3	89.2	91.7
scenario 9	90.8	90.3	96.8	97.2	94.6	95.0	95.2	95.7	0.0	31.0	93.2	92.0	0.0	47.6	94.7	91.0
scenario 10	89.8	89.4	97.3	97.4	94.6	95.3	95.3	96.4	0.0	52.0	93.1	92.0	0.0	50.4	93.1	92.1
scenario 11	62.7	62.0	96.3	96.1	93.3	94.8	94.7	94.4	0.0	56.9	94.1	90.3	0.0	59.6	93.6	91.3

4. Discussion

4.1 Monitoring

Between 2012 and 2015, the monitoring network was gradually extended from the initial sites to include Yorke Peninsula and Eyre Peninsula in South Australia and the central west of New South Wales. This was in response to a combination of farmer interest and localized problems with mice, particularly in South Australia. Most quantitative monitoring was conducted by specialists with prior field experience. However, the rapid assessment techniques were used successfully by farmer groups in Western Australia and New South Wales. The generally low levels of mouse activity limited the opportunity to test the rapid assessment techniques across the full range of potential mouse densities. It is critical for future monitoring programmes that low-cost techniques such as chew-cards and burrow counts are validated by comparison with trapping data and that standard field protocols are followed to ensure data can be compared between sites and monitoring sessions.

The *MouseAlert* platform was designed specifically to meet farmers' likely need for information and the requirements of models for forecasting mouse abundance at local scales across entire grain-growing regions. Despite an initial slow start, a series of introductory training sessions in key grain-growing areas helped to communicate the benefits of using *MouseAlert* and show farmers how to use the system, and uptake rates increased markedly as a consequence. Usage rates also increased substantially during the 'National Mouse Census Week' in April 2015, which was promoted strongly by GRDC, the IA CRC and the project team. This event was timed to fit in with the main period of sowing for winter cereals when farmers might be more aware of signs of mouse activity. The data recorded via *MouseAlert* provided a level of spatial coverage indicative of what is necessary for national monitoring system and for generating region-specific forecasts of changes in mouse abundance. Nevertheless the total of number of *MouseAlert* records up to October 2015 represents a participation rate of <1.5% by farmers. The relatively low abundance of mice in most areas during 2014 and 2015 (apart from some relatively localized problems with mice, particularly in South Australia) might have contributed to the low participation rate by farmers in recording mouse abundance.

There is substantial scope for increasing usage of *MouseAlert* by the farming community. This requires a sustained promotion campaign by the grains industry. Stronger uptake could be helped by the use of automatic prompts to elicit recording of observations by farmers at key times in the year, e.g. prior to sowing and prior to harvest, however this is reliant on farmers having already registered in *MouseAlert* or having already installed the app on their mobile device(s).

The monitoring reports that were issued regularly between August 2013 and November 2015 (Appendix 1) appear to have been well received by most farmers. Preparation of these reports required expert knowledge to synthesise the monitoring information, generate forecasts (using previously published models) and provide region-specific advice to farmers. It is unlikely the data synthesis and the forecasts will be automated in the near future, which emphasises the need to maintain adequate levels of relevant expertise in the Australian scientific community.

4.2 Models for forecasting mouse plagues

Previous models for forecasting mouse plagues were developed using data mostly collected prior to recent changes to cropping systems, e.g. crop diversification and low-till farming. Although research at benchmark sites at Walpeup in Victoria, Roseworthy in South Australia and the Darling Downs in Queensland had generated highly valuable long-term data sets, model forecasts based on these data have very limited generality (Pech et al. 1999; Pople et al. 2014) and extrapolations beyond these locations need to be treated with caution. The new modelling approach developed in this project is designed to generate forecasts for localities at a 30 km x 30 km spatial resolution throughout each grain-growing region. The new model's forecasts will be expressed as the likelihood that mouse populations on farms within a grid cell will reach predicted levels of abundance. However, the model cannot make predictions at the farm or paddock scale: it is not yet feasible to quantify and include in a model the many factors likely to affect mouse abundance at this scale. To date, the model has been set up only for south-eastern Australia and it needs to be tested over several years with varying levels of mouse abundance. The model is designed to maximise use of data from the monitoring network, and incorporate other readily available, spatially-referenced data, such as rainfall. It is clear from the model's design that forecasts will be improved by multiple estimates of current mouse abundance within each grid cell; hence the need to promote the use of rapid assessment techniques and qualitative reporting via *MouseAlert*.

5. Conclusions and recommendations

5.1 Monitoring

From 2013 to 2015, this GRDC-funded project successfully designed and implemented a 3-tier monitoring system across Queensland, New South Wales, Victoria, South Australia and Western Australia. Throughout this period regular seasonal monitoring reports were supplied to the grains industry. Farmers' qualitative assessments and the techniques used for rapid quantitative assessments of mice have high potential value for recording spatial variability in mouse abundance within a region. Further collection of monitoring data from areas with high numbers of mice, and simultaneously with few mice, are essential to validate the new rapid assessment and qualitative methods across a full range of mouse population densities, and to complete tests of the spatially-explicit model for forecasting plagues (see below). Future use of rapid assessment techniques should follow standard field protocols to ensure data can be compared between sites and monitoring sessions and are suitable for use in new predictive models.

It was recognized very early in the project that direct support from farmers is the only feasible way to gather monitoring data at low cost across entire grain-growing regions. The *MouseAlert* platform, consisting of a web site, a mobile-optimised web site and a phone app, was developed for this purpose. *MouseAlert* has the added advantage of making monitoring information immediately available to farmers. A dedicated training and marketing programme is required to roll out *MouseAlert* ensuring sufficient uptake so that feedback to farmers motivates complete coverage across all grain-growing regions. The *MouseAlert* platform (web site and phone app) needs to be maintained within an appropriate institution and updated as required.

5.2 Models for forecasting mouse plagues

The new model for forecasting changes in mouse abundance takes advantage of decades of previous field studies and modelling research on mouse population dynamics. It has significant advantages over previous models because it is designed to use multiple sources of information, including data collected using rapid assessment techniques and qualitative data provided by farmers. In addition, it is designed to deliver forecasts for localities at a 30 km x 30 km spatial resolution throughout each grain-growing region.

Using test data, good coverage and small relative bias for most model parameters under several scenarios suggests that the model will perform well under a wide range of conditions. This modelling approach allows, for the first time, the use of rapid assessment data and expert opinion to forecast changes in mouse abundance at a landscape level.

The new model is not yet fully operational and its completion will require support for the necessary specialist expertise. The model performance could be improved iteratively over time as more monitoring data are collected in each region. The model needs to be validated using monitoring data collected through the next mouse plague in at least one region in south-eastern Australia. It needs to be transitioned from predictions based on primarily on monitoring using quantitative field techniques (trapping, chew-cards and burrow counts) to predictions based on the knowledge and experience of farmers, i.e. information provided via *MouseAlert*. Finally, the forecasting model road-tested in south-eastern Australia needs to be extended to cropping systems in the north-eastern and south-western grain-growing regions.

Acknowledgements

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Many farmers provided access to their properties, and the following farmer groups supplied monitoring data: Central West Farming Systems (New South Wales), Ravensthorpe Agricultural Initiative Network and Great Northern Rural Services (Western Australia), and Natural Resources Eyre Peninsula (South Australia).

The following people assisted with field-based monitoring: Alice Kenney, Marijke Welvaert, Cody Williams and Bridget Armstrong.

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Appendix

Examples of monitoring reports: (a) the first report in 2013 and (b) the final report 2015.

(a)

Invasive Animals CRC | CSIRO | GRDC Grains Research & Development Corporation | Landcare Research Manaaki Whenua

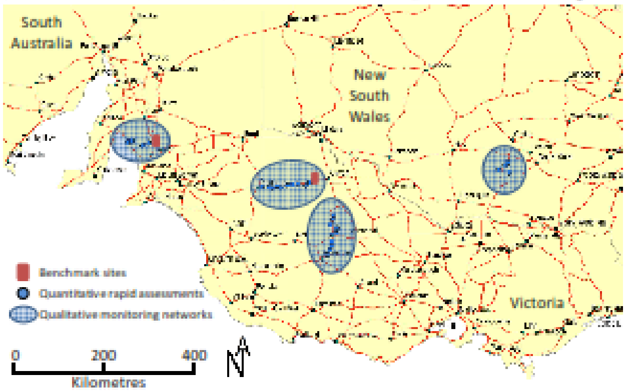
Monitoring mice in Australia – August 2013

Background

A new 3-year study to monitor and model mouse populations across the grain-belt of Australia started in October 2012 and is funded by the GRDC. The project is a collaborative project between Landcare Research (New Zealand), CSIRO Ecosystem Sciences and the Invasive Animals Cooperative Research Centre.

The aim of the project is to monitor mouse populations across the grain growing areas of Australia and develop predictive models to forecast outbreaks. It will also disseminate the results of the monitoring and predictions to farmers and industry through GRDC and other means so that everyone is aware of and better prepared for increases in mouse activity.

Mouse populations will be monitored in typical grains farming systems in Western Australia, South Australia, Victoria, New South Wales and Queensland at three key times each year, coinciding with important crop stages (eg at sowing of winter crops) and critical times in the build-up of mouse populations (eg commencement of breeding in spring). The monitoring will be used to collect information about the population size (abundance) of the mouse population, breeding status and overall activity. This information will be fed into mouse prediction models that have been developed over the last 20-30 years. These models were developed at long-term monitoring sites at Roseworthy (northern Adelaide plains, SA), Walpeup (northwest Mallee, Victoria) and the Central Darling Downs (southern Queensland).



Approximate locations of mouse monitoring occurring across South Australia, Victoria and southern NSW. Additional monitoring is located in the Central Darling Downs and Central Queensland and around Moree (NSW). Monitoring sites are currently being established near Geraldton and Ravensthorpe (WA).

Mouse monitoring

The monitoring of mouse populations will occur at 3 levels of intensity across 11 sites:

(1) **Benchmark sites** in the Adelaide Plains (SA), Northwest Victoria, and the Darling Downs (Qld), where long-term trapping has been conducted (>20 years) and where forecast models have been developed. Live trapping data will be collected at 3 key times a year and the data will be used in the models to predict the likelihood of outbreaks for those regions.

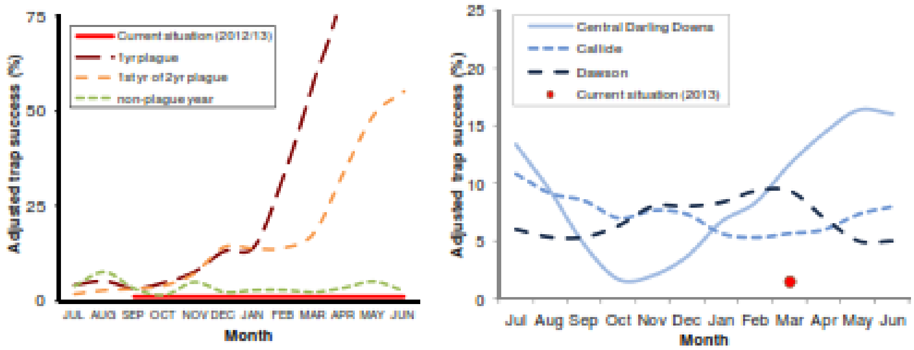
(2) **Quantitative rapid-assessment sites** in WA (Geraldton and Ravensthorpe), Victoria (Horsham and Walpeup), NSW (Riverina and Moree), SA (Roseworthy) and Queensland (Central Queensland and Central Darling Downs) where there will be two types of monitoring: mouse chew cards set out overnight (ten bait cards or canola squares at 10 m spacing along 100 m survey lines), and active burrow counts along 100 m survey lines. Monitoring will be conducted 3 times a year.

(3) **Qualitative monitoring networks** in all the areas with rapid-assessment sites plus Eyre Peninsula (SA) and Central West NSW where key farmers and agronomists are contacted to collect information about mouse activity in the region as well as any reports of the use of rodenticides.

Monitoring of mouse populations across Australia – August 2013 1

Current situation

Mouse populations have been low since monitoring commenced in October 2012. To get a sense of what is happening with mouse abundance, we plot the current mouse abundance against the historical data for outbreak (ie mouse plague) years and non-plague years.



Current monitoring of mouse populations in Victoria and South Australia (Left) and Queensland (Right) compared to outbreaks in the past.

Predictions of a future mouse outbreak?

Mouse populations are low across all locations. The models use information about the abundance of mice and rainfall over the growing season of the winter cereal crops. **For the Adelaide Plains and Northwest Victoria, the models predict that the chance of an outbreak in the remainder of 2013 is very low.** This should be good news for grain farmers in that they do not have to worry too much about mice for the remainder of the cropping season. However, since the winter has been relatively mild across southern Australia, we suggest that farmers remain vigilant as it is possible that there may be small pockets where the abundance of mice may be moderate/high, so ongoing monitoring is required. **For the Central Darling Downs, the long-term model predicts the potential for a problem next year is high.** The Darling Downs model has achieved a 78% success rate from these long-term predictions over the period of 1989 to 2003. More detailed predictions will be made after the spring (September/October) monitoring has been conducted.

Future activities

As part of this project we will be developing new models to forecast outbreaks of mice, incorporating different types of data (traditional live-trapping data, data from chew cards and active burrow counts, and qualitative information) across different scales to encompass areas not normally monitored for mouse abundance or activity. We will also explore the use of smartphone "apps" to collect information about mouse activity, which would improve forecast from the models. More information about this will be provided in the next mouse monitoring bulletin.

Further information

For further information about the monitoring or models, or if you have observed mouse activity in your area, please contact the people below:

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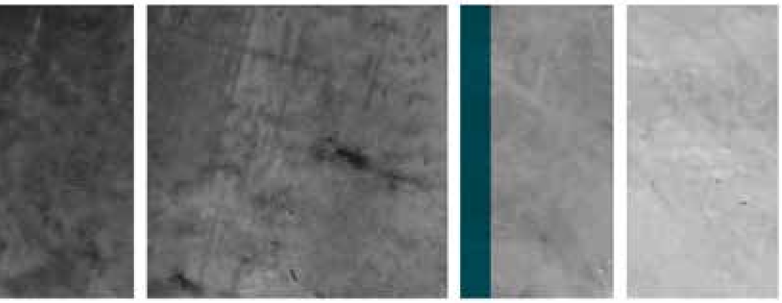

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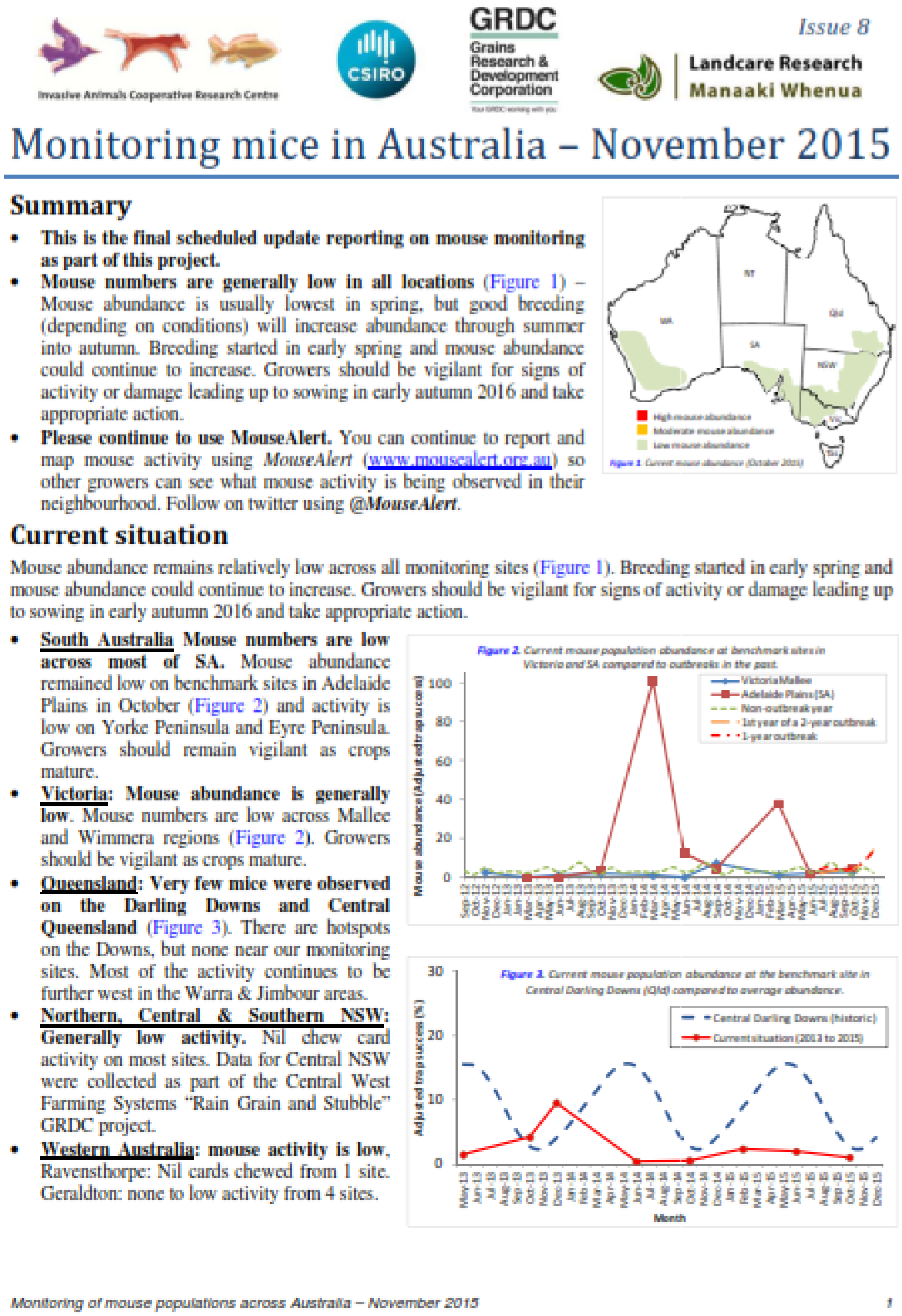


Issue 8

Invasive Animals Cooperative Research Centre

CSIRO

GRDC Grains Research & Development Corporation

Landcare Research Manaaki Whenua

Monitoring mice in Australia – November 2015

Summary

- **This is the final scheduled update reporting on mouse monitoring as part of this project.**
- **Mouse numbers are generally low in all locations** (Figure 1) – Mouse abundance is usually lowest in spring, but good breeding (depending on conditions) will increase abundance through summer into autumn. Breeding started in early spring and mouse abundance could continue to increase. Growers should be vigilant for signs of activity or damage leading up to sowing in early autumn 2016 and take appropriate action.
- **Please continue to use MouseAlert.** You can continue to report and map mouse activity using *MouseAlert* (www.mousealert.org.au) so other growers can see what mouse activity is being observed in their neighbourhood. Follow on twitter using @*MouseAlert*.

Figure 1. Current mouse abundance (October 2015)

Current situation

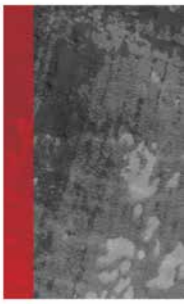
Mouse abundance remains relatively low across all monitoring sites (Figure 1). Breeding started in early spring and mouse abundance could continue to increase. Growers should be vigilant for signs of activity or damage leading up to sowing in early autumn 2016 and take appropriate action.

- **South Australia Mouse numbers are low across most of SA.** Mouse abundance remained low on benchmark sites in Adelaide Plains in October (Figure 2) and activity is low on Yorke Peninsula and Eyre Peninsula. Growers should remain vigilant as crops mature.
- **Victoria: Mouse abundance is generally low.** Mouse numbers are low across Mallee and Wimmera regions (Figure 2). Growers should be vigilant as crops mature.
- **Queensland: Very few mice were observed on the Darling Downs and Central Queensland** (Figure 3). There are hotspots on the Downs, but none near our monitoring sites. Most of the activity continues to be further west in the Warra & Jimbour areas.
- **Northern, Central & Southern NSW: Generally low activity.** Nil chew card activity on most sites. Data for Central NSW were collected as part of the Central West Farming Systems "Rain Grain and Stubble" GRDC project.
- **Western Australia: mouse activity is low.** Ravensthorpe: Nil cards chewed from 1 site. Geraldton: none to low activity from 4 sites.

Figure 2. Current mouse population abundance at benchmark sites in Victoria and SA compared to outbreaks in the past.

Figure 3. Current mouse population abundance at the benchmark site in Central Darling Downs (Qld) compared to average abundance.

Monitoring of mouse populations across Australia – November 2015 1



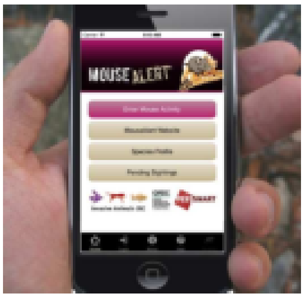
The 'Mouse Forecast'

Central Darling Downs (QLD): The density index for the mouse population is currently very low (1.1%). The probability of High density in May 2016 is 0.11, for **Moderate density is 0.62** and Low is 0.25. The Darling Downs model has achieved a 78% success rate from these long-term predictions over the period of 1989 to 2003.

Northwest Victoria: There is a low likelihood of an outbreak in autumn 2016 (probability of 0.17). The prediction for Northwest Victoria is dependent on rainfall in December. If December rainfall is low (eg 0 mm), then mouse abundance will remain low. If December rainfall is average (25 mm) then mouse abundance will increase to around 10-15% and could cause low levels of damage. If December rainfall is high (eg 50 mm), then mouse abundance will increase to 25-35% and could cause some damage at sowing.

Future activities

Please continue to report mouse abundance on your farm (presence and absence!) using ***MouseAlert*** (*www.mousealert.org.au*) on your smart phone, tablet or computer and to check what other mouse activity is being reported locally and regionally. You can now download the App for ***MouseAlert*** from the App Store or ITunes https://itunes.apple.com/au/app/feralscan-pest-mapping/id975407187. There are now more than 330 records despite low mouse numbers. We welcome any information at anytime. You can also follow progress on **Twitter** (*@MouseAlert*).



MouseAlert Smartphone app
www.mousealert.org.au

Background

This is an update on surveillance of mice across the grain-belt of Australia for September/October 2015. Mouse populations were monitored in typical grains farming systems in WA, SA, Vic, NSW and Qld during early spring 2015 (Sep/Oct). The monitoring provides data on the size (abundance) of mouse populations, their breeding status and overall activity. This information is used in models that have been developed progressively over the last 20-30 years to predict mouse outbreaks. Monitoring was conducted on (Figure 4):

- **Benchmark sites**: live trapping data collected for use in models in Adelaide Plains (SA), Walpeup (Vic) and the Darling Downs (Qld).
- **Quantitative rapid-assessment sites**: using mouse chew cards and active mouse burrows assessments on 86 transects across 11 sites.
- **Qualitative monitoring networks**: using data from farmers and agronomist in 11 sites.

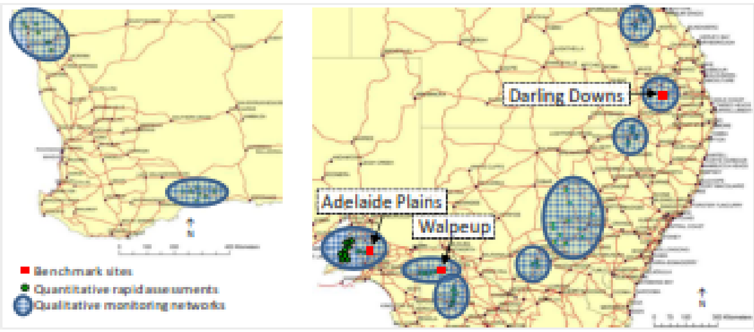


Figure 4. Approximate locations of mouse monitoring occurring in WA, SA, Vic, NSW and Qld.

This is part of a 3-year study funded by the GRDC to monitor mouse populations and forecast the likelihood of mouse outbreaks. The project is a collaboration between Landcare Research (New Zealand), CSIRO Agriculture and the Invasive Animals Cooperative Research Centre. The project will finish at the end of 2015.

Further information

For further information about the monitoring or models, or if you have observed mouse activity in your area, please contact the people below, or see www.mousealert.org.au.

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