SRDC Research Project
Final Report

Cover Page:

Title of the Project:
An integrated pest management strategy for climbing rat in the far-north Queensland sugarcane production system

Project Reference Number:
QUT003

Name(s) of the Research Organisation(s):
QUT and BSES Limited

Principal Investigator's name(s), contact phone number, address and Email address:
Dr Susan Fuller, ph: 3138 2497, s.fuller@qut.edu.au
Faculty of Science & Technology,
QUT, GPO Box 2434,
Brisbane QLD 4001

Mr Brendan Dyer, ph: 4068 1488, bdyer@bses.com.au
BSES Limited
PO Box 566
Tully QLD 4854

A statement of confidentiality (if applicable):
N/A

Acknowledgements:
The project participant/s wish to acknowledge receipt of project funding from the Australian Government and the Australian Sugarcane Industry as provided by the Sugar Research and Development Corporation.

Australian Government
Sugar Research and Development Corporation

Thankyou also to BSES Limited for the support and encouragement received throughout the project, in particular, access to staff and field resources. Thanks to Peter Allsopp (BSES) for suggestions and editorial comment, and Steve Garrad (ex BSES Extension Officer) for help with grower introductions and site selection in the Silkwood district.

We especially wish to acknowledge the cane-growers and their families that agreed to be involved in this project and for granting access to their properties. In agreeing to the condition of not baiting their cane crops, a true assessment of the rodent population within sugarcane crops was able to be defined.

These studies were undertaken with the approval of the Queensland University of Technology Animal Ethics Committee (3775A) and Queensland Parks and Wildlife Service Scientific Purposes Permit (WISP02777505).

Body of the Report:

Executive Summary:

Two species of rodents (*Rattus sordidus* and *Melomys burtoni*) are currently the most significant vertebrate pests in the Queensland sugar industry. Comprehensive management plans exist for *Rattus sordidus*, but *Melomys burtoni* has a different biology, ecology and damage profile. An understanding of the biology and ecology of *Melomys burtoni* is central to the development of an integrated pest management strategy for this species.

Eight study sites were selected within the sugarcane production area between Tully and Silkwood in far north Queensland. Rodent trapping in cane was undertaken to determine the time and extent of colonisation and reproductive success of colonists after establishment. Data collection continued for 15 months; from February 2005 to April 2006. This intensive trapping phase allowed identification of environment/habitat correlates associated with colonisation, reproductive success and subsequent damage. Diet studies and damage assessments were undertaken to provide information on important organism/environment interactions (ie. the weak link in the dynamic cycle eg. reducing weed cover).

The field studies revealed that *M. cervinipes* are rarely caught in sugarcane and should not be regarded as a pest by the industry. However, numbers of *Melomys burtoni* within the crop are equal to numbers of *Rattus sordidus* once the crop canopy develops to near closure (≈83%). Both *M. burtoni* and *R. sordidus* are in higher numbers when sugarcane crops are grown adjacent to grasslands rather than closed forest areas. All age classes of both sexes of *M. burtoni* utilise sugarcane and weed/grass seed in their diet but, the protein from seed does not promote the same level of breeding that can be observed in *R. sordidus*. The highest proportion of *Melomys burtoni* reproduction occurred during the later stages of crop development and this corresponded directly with the highest proportion of juvenile recruitment. This has important implications in that due to a later colonisation period and lower breeding potential, strategies for management of *Melomys burtoni* are not likely to be the same as those that have led to effective management of *Rattus sordidus*. Moreover, damage assessments revealed that *Melomys burtoni* were responsible for damage to ~6% of stalks.

This research project has delivered the following outputs and outcomes:

- A greater understanding of the ecology and biology of *Melomys burtoni* within the cropping system of sugarcane
- Communication of outputs through grower participation, grower-oriented publications and at workshops, farm and field days as well as publications in ASSCT
- A Masters degree qualification for rodent ecologist, Mr Brendan Dyer, from BSES Limited.
- A scientific publication in the journal 'Wildlife Research'.

Estimated and actual benefits % Social: 60% Environmental: 20% Economic: 20%

Background:
Sugarcane stalks are susceptible to extensive damage from rodents universally (Tobin *et al*. 1990; Tobin & Fall 2004). This damage not only results in a loss in yield, but also a reduction in sugar quality arising from micro-organisms infecting the open wounds (Hood *et al*. 1970; Tobin & Sugihara 1992; Wilson & Whisson 1993). In Queensland, two native species of rodent, *Rattus sordidus* (cane-field rat) and *Melomys burtoni* (grassland melomys), are considered serious pests, potentially causing damage in at least half the sugarcane production area with an estimated annual loss of between AU$2 and AU$4 million (Wilson & Whisson 1993; Whisson 1996). However, a more recent estimate of 825 000 t lost in the 1999 and 2000 seasons was valued at AU$25 million (Smith *et al*. 2002).

There is a considerable body of knowledge regarding the ecology of *R. sordidus* (McDougall 1944a, b; 1946a, b; 1947; Wilson and Whisson 1993; Whisson 1996), but much less is known about *M. burtoni*. This is surprising because, in one such study (Redhead 1973), population numbers *M. burtoni* were at least as high as those of *R. sordidus*. Many investigations on rodents in Queensland sugarcane have centred on developing suitable rodenticides and baiting strategies (see Gard 1935; McDougall 1944c; Volp 1960; Hitchcock 1973; Hitchcock & Kerkwyk 1975, 1978; Redhead & Saunders 1980), which may be effective in the short term, but mortality-based strategies have limited effectiveness in the long term (Putman 1989). Control strategies that reduce rodent reproduction rates and immigration into the crop may achieve a more beneficial result. If so, an understanding of rodent population dynamics is fundamental to developing such a management strategy (Hussain *et al*. 2003; Tobin & Fall 2004).

The Integrated Pest Management (IPM) strategy developed for *R. sordidus* is based upon an understanding of their population cycle in sugarcane and the critical factors that determine the spatial and temporal distribution of rodent damage within districts (Wilson & Whisson 1993). Specifically, it involves population monitoring, in-crop weed control, harbourage (non-crop) management, and strategic use of permitted rodenticides. Monitoring of *R. sordidus* populations allows the potential damage to be estimated and the appropriate pre-emptive measures to be put in place. As a result, a non-breeding *R. sordidus* population may be baited after colonising the crop but prior to the onset of breeding, to minimise the potential for crop damage. Similarly, removing weeds and grasses (which provide the essential protein required for reproduction) can help suppress *R. sordidus* populations (and reduce crop damage by approximately 60%), as can decreasing the area of harbourage available, which in turn reduces the number of colonists in the following season (Wilson and Whisson 1993).

Despite a widespread acceptance of the reliability of the current IPM strategy for *R. sordidus,* the industry has expressed concern about the appropriateness of the strategy for *M. burtoni*. These concerns are important because it is clear that *M. burtoni* is increasing as a significant pest in the Central and Northern cane-growing regions of Queensland. Furthermore, there is additional unease that *Melomys cervinipes* (a closed forest species), may also be emerging as a significant economic pest resulting from the revegetation of harbourage areas, which stems from the *R. sordidus* IPM strategy.

Given that *M. burtoni* has a different biology, ecology and damage profile to *R. sordidus*, strategies to manage *R. sordidus* are unlikely to deal effectively with *M. burtoni*. Very little is known about the biology of *M. burtoni* (Watts & Aslin 1981) and research into the control of *M. burtoni* in sugarcane crops has been limited, so a separate management strategy for these rodents is yet to be developed (Allsopp *et al*. 1993). Furthermore, the pest status of *M. cervinipes* in sugarcane has never been clarified.

Objectives:

The project aimed to develop a practical, cost-effective and ecologically based management strategy to reduce both the economic and environmental impact of climbing rat (*Melomys burtoni*) in north Queensland sugarcane, through:

1. Providing an understanding of the population dynamics of *M. burtoni* in sugarcane growing areas of far north Queensland;

2. Identifying critical organism-organism and organism-environment interactions that give rise to the problem and that need to be targeted in a management strategy;

3. Identifying landscape factors that determine the spatial distribution of rodent damage within the sugarcane production system;

4. Integrating these findings into an integrated pest management strategy for *M. burtoni*; and

5. Extending this information to achieve change in farming practices.

Objectives 1, 2 and 3 have been fully achieved and while objectives 4 and 5 have not been finalised because Brendan Dyer did not complete his PhD program at QUT, progress has been made towards achieving them. In 2007, Brendan Dyer completed a Master of Applied Science at QUT, but subsequently withdrew from his PhD program in 2009, following a 1 year leave of absence for personal reasons. Because Objectives 4 and 5 have not been fully met, funds of $37546.39 remain unspent and will be returned to SRDC.

The following is a summary of key findings relating to objectives 1, 2 and 3 listed above and management implications relating to objective 4.

In this study, *M. burtoni* were found to feed on sugarcane and were responsible for damage to approximately 6% of stalks. In sites adjacent to closed forest, *R. sordidus* were found in higher numbers than *M. burtoni* in crop stages 2, 3 and 4. However in sites adjacent to grassland, numbers of *M. burtoni* increased in crop stage 4 and prior to crop harvest, were found in higher numbers than *R. sordidus*. *Melomys burtoni* colonised sugarcane at later stages of crop development than *R. sordidus*. Although the level of *M. burtoni* reproduction was lower than that of *R. sordidus*, the highest proportion of pregnant *M. burtoni* occurred during the later stages of crop development, corresponding directly with the highest proportion of juvenile recruitment. Importantly, significant crop damage does not occur until crop stage 5. Therefore, it is important to have any management efforts in place prior to crop stage 5, and possibly prior to crop stage 4.

Of the two *Melomys* species found in north Queensland sugarcane crops, only *M. burtoni* should be regarded as a pest. This rodent breeds and feeds within the crop, primarily after canopy closure. *Melomys burtoni* captures were roughly equivalent irrespective of adjacent habitat type, while *R. sordidus*, the traditionally recognized major pest of sugarcane crops, was found in significantly higher numbers in sugarcane adjacent to closed forest.

The Integrated Pest Management (IPM) strategy developed for *R. sordidus* is centred on the early stages of crop development and includes population monitoring, in-crop weed control, harbourage management, and strategic use of permitted rodenticides. The late colonisation and lower breeding potential of *M. burtoni* mean that the IPM strategy for *R. sordidus* will not be directly transferable to *M. burtoni*.

Monitoring for *M. burtoni* in the early stages of crop development may yield mature males, but will do little to help predict the potential for population build up or crop damage. Monitoring in the later stages of crop development would be preferable to indicate the increase in the proportion of female *M. burtoni* and reproduction, but access to the crop at the later stages of development is physically difficult. A baiting strategy conducted earlier in the crop development, in anticipation of damage, would not be considered best management practice as, at such time, there would be neither direct damage nor indicative population build-up. Bait longevity may also be compromised if applied at an earlier stage.

Our data suggests that movement of *M. burtoni* into the crop occurs over a relatively short period of time. This movement may be for utilisation of in-crop weed, not necessarily for providing seed-protein required for breeding, but for supplying cover and protection. As a result, weed control within sugarcane crops may be useful in controlling *M. burtoni*, as it is for *R. sordidus*.

Given that the population dynamics of *M. burtoni* indicate that management efforts should occur prior to crop stage 5 and, furthermore, control of *M. burtoni* at this stage in the development of the crop poses physical difficulties, it is suggested that one key management strategy for *M. burtoni* may be the management/manipulation of the adjacent habitat. Therefore, we suggest that in cane fields located adjacent to grassland, a careful program of grassland harbourage management including slashing and herbicide treatment, particularly during crop stages 3 and 4, may prevent a build-up of *M. burtoni* numbers in crop stage 5.

Methodology:

<u>Study 1) Historical Data</u>

The sugar industry, through BSES Limited and Cane Productivity Services (CPSs), routinely conducts rodent monitoring within sugarcane crops on an annual basis. A maximum of 125 sites were chosen between Sarina in central Queensland and Mossman in far north Queensland. Each site was monitored on three occasions between October 1st and March 31st annually using 20 snap-traps laid in two parallel transects placed 10 m apart and 10 m between each trap in sugarcane crops (total transect length equated to approximately 90 m). Traps were baited with cardboard soaked in raw linseed oil. Monitoring was carried out under a Scientific Purposes Permit (SPP) issued to BSES Limited by the Queensland Parks and Wildlife Service (QPWS).

The information gathered from each site included the sugar milling area/district, the monitoring round (e.g. 1, 2 etc), and date. Characteristics including the type of adjacent habitat and associated weed cover levels were recorded. In-crop characteristics were examined and recorded as percentage of in-crop weed cover, damage level assessment, the crop type and number of traps set.

Data recorded included the species trapped (*R. sordidus* or *M. burtoni*), the number of males and females caught, the percentage of mature females pregnant and number of embryo per pregnant female. Unidentified captures were recorded along with indeterminate sex of target animals. Traps that were sprung with no captures were recorded and resulted in a percentage trap success for each site monitored within that round of monitoring.

Five successive years of monitoring data equating to approximately 37500 trap nights from 1875 sites were analysed using partial correlations (Spearman's) and non-parametric (Kruskal-Wallis H) tests to investigate differences in capture rates (corrected for trap success) of *R. sordidus* and *M. burtoni* among the various site attributes. These site attributes included:

- in-crop weed cover, and adjacent habitat (habourage) weed cover - 0 (0%), 1 (1-25%), 2 (26-50%), 3 (51-75%) and 4 (76-100%);
- damage (0-4 as above);
- habitat type as - a (cane), b (closed forest), c (open forest), d (creek/drain) or e (grassland);
- mill area.

The analysis of the historical data was used to define the methodologies for field manipulation studies to be conducted within the adjacent habitats (see Study 3).

Study 2) DNA Sampling

Central to the understanding of any pest management problem is the accurate identification of the pest species concerned. Two species of *Melomys*, *M. burtoni* and *M. cervinipes*, may be encountered within the sugarcane production area of north Queensland. In many parts of their range, *M. burtoni* and *M. cervinipes* are sympatric, although they generally occupy different habitats (Taylor and Horner 1973; Baverstock *et al*. 1980; Smith 1985). In Queensland, *M. burtoni* prefers grasslands along the coast, sedgelands, open forest, woodlands and grassy patches within rainforests (Kerle, 1995). In contrast, *M. cervinipes* is known to inhabit rainforest in northern Queensland, extending its habitat in the south to include wet sclerophyll and coastal mangrove forest (Redhead 1995). Both species have been found in cane fields (McDougall 1944b; Watts and Aslin 1981).

Further to this overlapping range, body form in *M. burtoni* is similar to that of *M. cervinipes*. Although *M. burtoni* is on average smaller than *M. cervinipes*, both species overlap in their morphological measurements and both have four teats. This creates difficulties in identifying live specimens of both species in the field.

Given the overlap in range and habitat, similarities in body form and the difficulties associated with the field identification of the two *Melomys* species outlined above, the first objective of study 2) was to examine whether the readily measurable characteristics of weight and tail length could be used as diagnostic traits for field identification. The second objective was to confirm that the field identification of *Melomys* species based upon weight and tail measurements corresponded with that of the 'true' taxonomy assessed using DNA sequencing and phylogenetic reconstruction.

To this end, small ear-tissue samples (2 mm^2) were taken from live and snap-trapped *Melomys* species in the field, labelled and stored in 100% ethanol. DNA was extracted from 40 *Melomys* tissue samples using the salt-extraction methodology of Miller *et al*. (1988). Samples consisted of 20 field-identified *M. burtoni* and 20 field-identified *M. cervinipes* chosen from a total collection of 215 animals, and were stratified to ensure that all age classes from both sexes were represented. Laboratory analysis was outsourced and samples were analysed 'blind'. A fragment of the mitochondrial 16SrRNA gene of approximately 500 bp was amplified using primers (16Sar-L and 16Sbr-H) and polymerase chain reaction (PCR) conditions as outlined in Palumbi *et al*. (1991). PCR products were purified using a QIA-quick® PCR purification kit (Qiagen) and directly sequenced using ABI PRISM® Big Dye Terminators Version 3.1 Cycle Sequencing Kit on an ABI PRISM® 3700 DNA Analyser. Sequences were edited using BioEdit Version 5.0.9 (Hall 1999). A phylogenetic tree was constructed using the Neighbour-Joining methodology (Saitou and Nei 1987) and 1000 bootstrap pseudo-replicates in MEGA Version 2.1 (Kumar *et al*. 2001). *Rattus norvegicus* was included in the analysis as an outgroup (Genbank Accession number: NC_001665).

Study 3) Monitoring

Eight study sites were selected within the sugarcane production area between Tully and Silkwood in far north Queensland. Four sites had cane-fields adjacent to grassland whereas the remaining four had cane-fields adjacent to closed forest. Normal management practices (i.e. spraying/slashing) in-crop and on headlands were conducted for the duration of these studies, except that no rodenticide was applied.

All studies were initiated when the crop was fully developed with a closed canopy. Data collection continued through the harvest period and then through all subsequent stages of crop development until full canopy closure was again reached. The sampling covered 15 months; from February 2005 to April 2006.

Capture-release study

Every month, each site was live-trapped using Elliott Type 'A' folding mammal traps (100x100x330 mm). Two transects parallel to the adjacent habitat were placed at 2.5 and 10 m into the crop. Each transect consisted of 25 traps at about 5 m intervals (total transect length 120 m). Trapping was conducted over four nights each month, resulting in 200 trap nights per month. Traps were baited with cardboard previously soaked in raw linseed oil, proven to be attractive in previous studies (Wilson and Whisson 1993; Whisson 1996; Ruscoe *et al*. 1998).

Melomys species were all handled live, were not anaesthetised and were identified from morphological characteristics. On initial capture, each rodent was permanently marked by injecting a uniquely numbered 4D-ISO microchip (2x12 mm). Microchips were scanned using a Destron Technologies Pocket Reader™ . The capture location, recapture status, sex, reproductive condition, weight and tail length were recorded for each target capture and all animals were released at the point of capture. It was assumed that male and female *Melomys* species were equally trappable.

Snap-trapping study

The design (both in placement of traps and sampling occasions) for this study was identical to that of the capture-release study except that standard break-back rat traps were used instead of live-capture Elliot traps. Transects for this study were situated no closer than 50 m to those of the capture-release study. Snap traps were baited with cardboard soaked in linseed oil.

All target and non-target captures were recorded. Both species of *Melomys* were identified from morphological characteristics. The capture location, sex, weight and tail length were recorded for each capture. Each Melomys species was scanned for a micro-chip to determine if they had been trapped previously in the capture-release study. All *Melomys* species were dissected in the field to analyse stomach content and to assess reproductive condition (litter size per pregnant female). The proportion of cane-fibre, seed, non-cane vegetation and other material in each stomach was visually estimated to the nearest 10%.

Weed-biomass study

At each site, five 100 m long transects were laid parallel to the adjacent habitat at 1.0, 2.5, 8.5, 13.0 and 20.5 m into the crop. These transects were in the same cane-block as the capture-release study. Five quadrats (0.25 m^2) were chosen at random on each transect (i.e. total n = 25), on every capture-release event. Non-cane vegetation within each quadrat was harvested and total wet weight of biomass (g) and dominant weed species were recorded.

Damaged-stalks study

Five transects, 100 m long, were established parallel to the weed biomass transects and spaced at 1.5, 3.0, 9.0, 13.5 and 21.0 m into the crop at each site. The total number of cane stalks within each transect was counted and inspected thoroughly for rodent damage. A sugarcane stalk was classed as damaged regardless of whether it had one rodent gnaw or many, i.e. the degree of damage was not recorded. Stalk counts were undertaken during every sampling event when harvestable stalk was present.

Given the presence of *R. sordidus* in sugarcane crops, a method of eliminating the damage caused by this species from damage caused by *Melomys* species was required. Watts and Aslin (1981) described *R. sordidus* as a poor climber, and that damage to cane is confined to those parts which the rat can reach from the ground. Although *Melomys* species can damage cane at ground level, they are agile climbers. Thus, a conservative approach was adopted by considering only damage on the stalk at a height greater than 50 cm to be that caused by *Melomys* species, while ground-level damage was attributed to *R. sordidus*. This will have lead to an underestimation in total *Melomys* damage.

Outputs:

A) Increased knowledge of the ecology and biology of Melomys burtoni in sugarcane crops

<u>Study 1 Historical Data</u>

Results:

<u>Total captures across mill area</u>

Individual sugar mills within the Mackay, Herbert River and Innisfail-Babinda regions were combined for data analysis and simplicity in reporting. The regions listed as Plane Creek, Mackay, Proserpine, Herbert River, Tully, Innisfail-Babinda, Mulgrave and Mossman are here-after known as mill areas.

A Kruskal Wallis test was applied to examine the variation in total trap success across mill areas and a significant difference was apparent for both *R. sordidus* (H=139.435, df=7, p<0.001) and *M. burtoni* (H=111.319, df=7, p<0.001). Captures of *R. sordidus* were greater than those of *M. burtoni* across all mill areas (Figure 1).

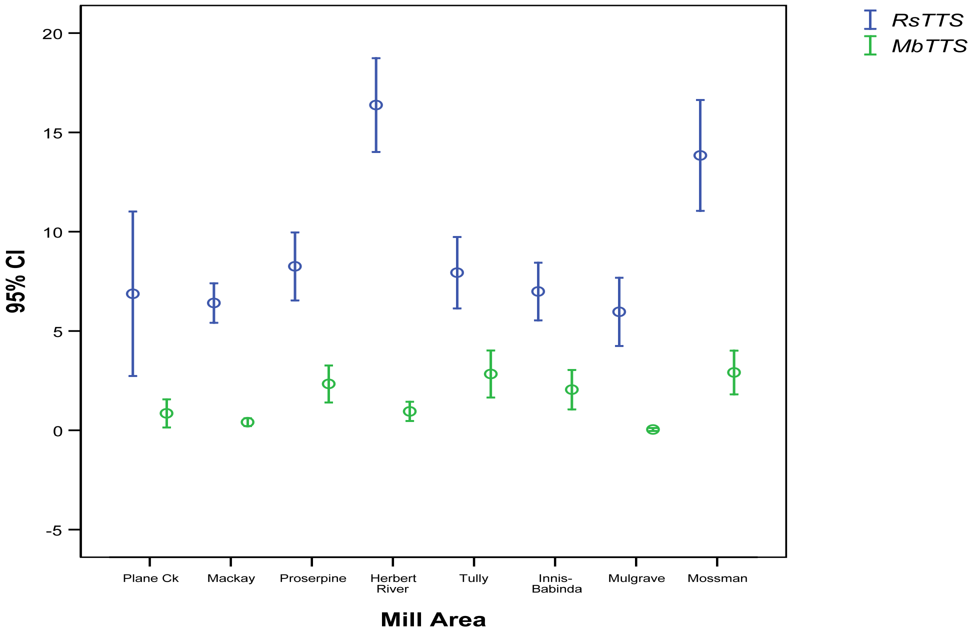

Figure 1

After combining Plane Creek, Mackay, Proserpine and Herbert River mill areas as the dry tropical zone and Tully, Innisfail-Babinda, Mulgrave and Mossman mill areas as the wet tropical zone, a Kruskal Wallis test showed the was no significant difference between these areas for *R. sordidus* (H=1.973, df=1, p=0.160), but there was a significant difference between the wet and dry tropics for *M. burtoni* (H=21.895, df=1, p<0.001) with a higher trap success for *M. burtoni* in the wet tropics (Figure 2).

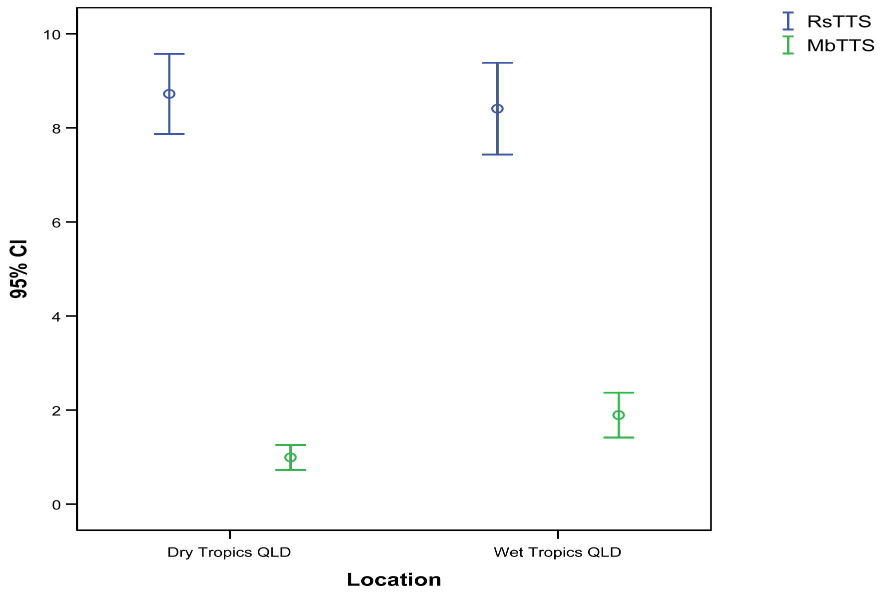

Figure 2

<u>*Rattus sordidus* across combined mill areas</u>

Monitoring occurs against five adjacent habitat types including, cane/cane, cane/closed forest, cane/open forest, cane/creeks/drains and cane/grassland. There was no significant difference among adjacent habitats for total trap success for *R. sordidus* (H=8.212, df=4, p=0.084), although the highest number of captures occurred in cane/cane. Nor was there a significant difference among adjacent habitat types for trap success of male *R. sordidus* (H=8.330, df=4, p=0.080), but a significant difference was found for females (H=10.177, df=4, p=0.038).

A non-parametric Spearman's test examined the relationship between total *R. sordidus* trap success and damage level in-crop. Damage was significantly correlated with *R. sordidus* trap success (r=0.259, N=1481, p<0.001). Damage also significantly correlated with the presence of in-crop weed cover (r=0.234, N=1481, p<0.001) and the presence of in-crop weed cover correlated significantly with *R. sordidus* trap success (r=1.000, N=1481, p=0.003). No significant correlation was apparent between damage and adjacent habitat weed cover (r=-0.050, N=1481, p=0.056).

<u>*Melomys burtoni* across combined wet tropics region</u>

A Kruskal Wallis test was used to examine the variation of *M. burtoni* trap success among different adjacent habitat types and there was a significant difference for total trap success of *M. burtoni* among these habitat types (H=13.739, df=4, p=0.008) within the wet tropics. Significant differences were found for both male (H=18.668, df=4, p=0.001) and female (H=15.276, df=4, p=0.004) *M. burtoni.* The highest captures of *M. burtoni* occurred in cane adjacent to open forest and grassland while the lowest captures occurred in cane adjacent to cane (Figure 3).

Damage did not correlate significantly with *M. burtoni* total trap success (r=0.003, N=1481, p=0.908) but was significant when tested against the level of weed in-crop (r=0.234, N=1481, p<0.001). Total trap success of *M. burtoni* significantly correlated with the level of weed cover with the crop (r=0.093, N=1481, p<0.001) and with the level of weed cover in the adjacent habitat (r=0.084, N=1481, p=0.001). The level of weed cover within the adjacent habitats varied significantly depending on the habitat type (H=377.870, df=4, p<0.001) with the highest weed cover available in open forest, creeks/drains and grassland, while the lowest levels are seen in closed forest and cane (Figure 4).

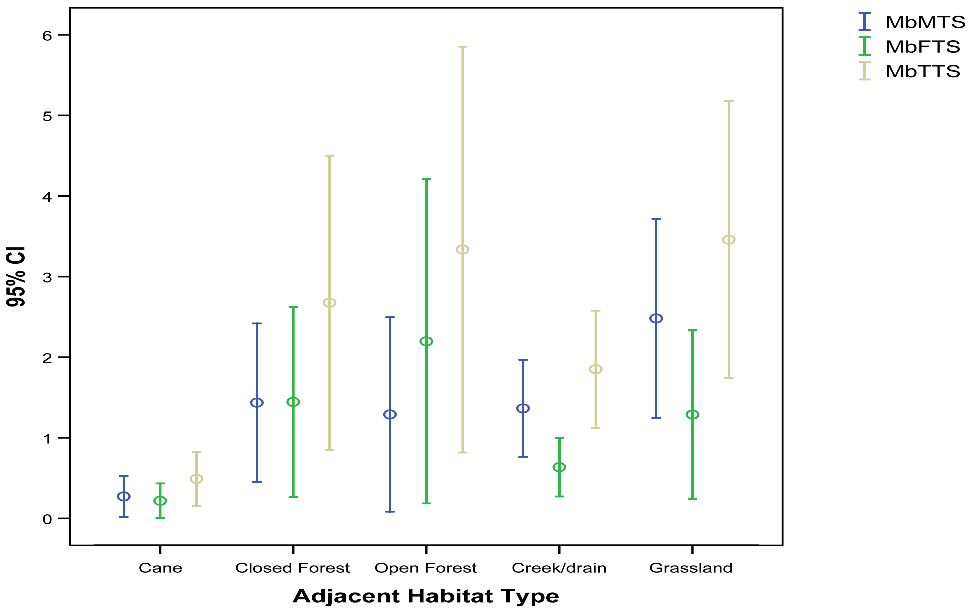

Figure 3

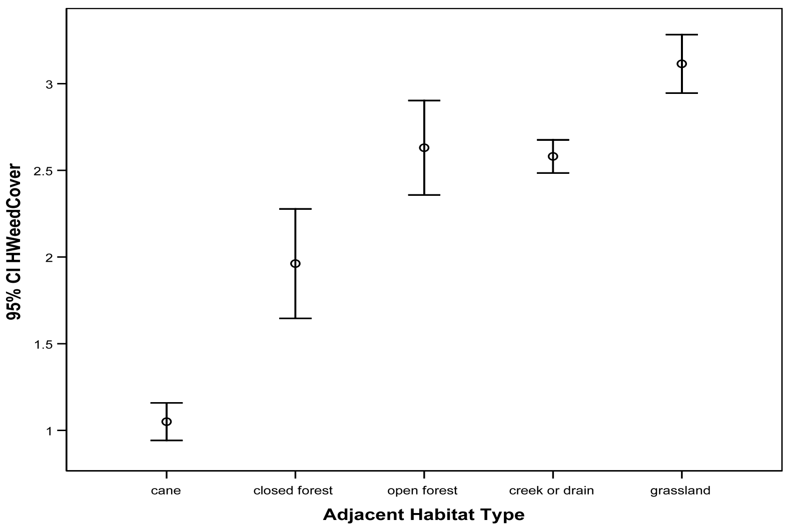

Figure 4

<u>*Melomys burtoni* across combined dry tropics region</u>

Analysis for *M. burtoni* within the dry tropics region was the same as that for the wet tropics region. Total trap success for *M. burtoni* did not vary significantly among the different habitat types (H=8.419, df=4, p=0.077), nor was there a significant difference among adjacent habitat types for *M. burtoni* males (H=2.721, df=4, p=0.606) or females (H=8.956, df=4, p=0.062). Overall captures of *M. burtoni* were lowest in cane and closed forest and highest in open forest and creeks/drains, however there is much variation the data (Figure 5).

Damage did not correlate significantly with *M. burtoni* total trap success (r=-0.015, N=923, p=0.643) but was significant when tested against the level of weed cover in-crop (r=0.201, N=923, p<0.001) and the level of weed cover in the adjacent habitat (r=-0.078, N=923, p=0.017). Total trap success of *M. burtoni* did not significantly correlate with the level of weed cover within the crop (r=0.050, N=923, p0.131) nor with the level of weed cover in the adjacent habitat (r=0.029, N=923, p=0.375).

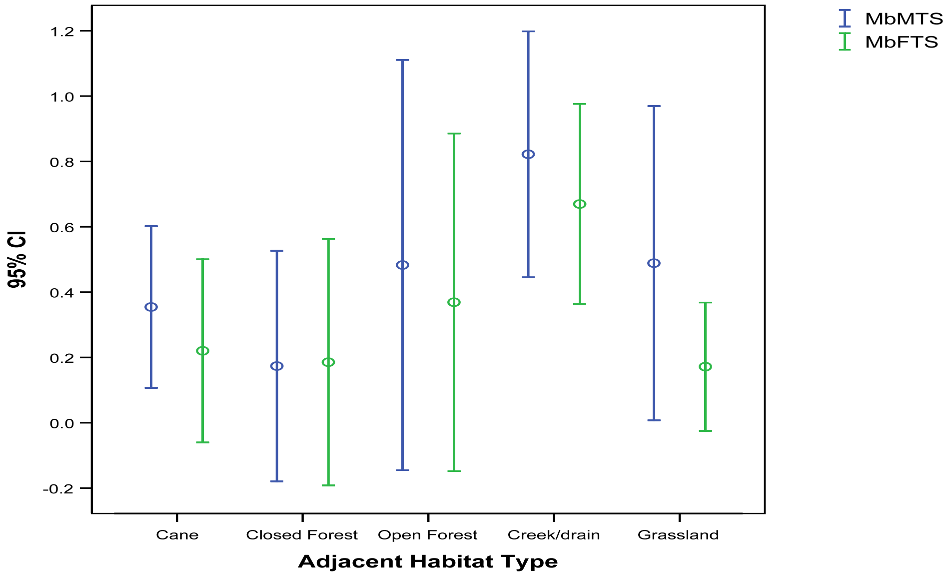

Figure 5

The level of weed cover within the adjacent habitats varied significantly according to the habitat type (H=218.212, df=4, p<0.001) with the highest weed cover available in both closed and open forest, creeks/drains and grassland, while the lowest weed cover levels were found in cane against cane (Figure 6).

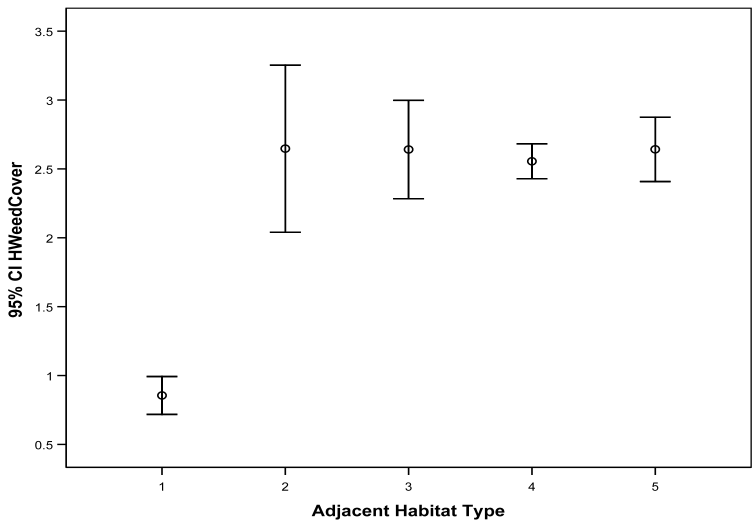

Figure 6

Discussion:

Wilson and Whisson's (1993) IPM strategy developed for *R. sordidus* focused on the early stages of crop development and included population monitoring, in-crop weed control, harbourage management, manipulation of adjacent habitats or land use, and strategic use of permitted rodenticides. From our results of the historical data analysis for *R. sordidus*, it is interesting to note that there was no significant difference among the different habitats adjacent to sugarcane and that sugarcane itself had the highest numbers of this species. The results do however support Wilson and Whisson (1993) in that total trap success for *R. sordidus* was correlated with in-crop weed presence. This presence of in-crop weed cover also correlated with the level of damage in sugarcane crops, and the damage level correlated with the total trap success of *R. sordidus*.

It was reasonable to expect that there would be significant variation in trap success for *M. burtoni* across mill areas but it is interesting that in combining mill areas into wet and dry tropics that trap success according to adjacent habitat type varied significantly in the wet tropics but not in the dry tropics. Capture numbers did vary between the wet and dry tropics however, the greatest captures in either area occurred in cane adjacent to open forest or grassland.

The level of damage varied significantly among the different adjacent habitat types, but on average was higher in the wet tropics when compared with the dry tropics. A significant correlation was found between *R. sordidus* total trap success and damage levels but not for *M. burtoni* total trap success and damage levels. Given that *M. burtoni* trap success correlated significantly with in-crop weed cover and in-crop weed cover correlated significantly with damage level, it would be hard to imagine that *M. burtoni* are not responsible for some of the damage recorded.

Both *R. sordidus* and *M. burtoni* are native animals and naturally inhabit grasslands. It is interesting to see that there is a significant difference between the wet and dry tropics within the sugarcane production system. When adjacent habitat in the wet tropics has high weed cover, the result is high *M. burtoni* trap success, whereas high weed cover in the dry tropics does not necessarily result in similar captures. Similarly to weed cover in adjacent habitats, a high level of weed cover within the crop also favours high *M. burtoni* trap success however does not equate to high trap success in the dry tropics.

Therefore, weed cover within the wet tropics tends to have an influence on *M. burtoni* within the sugarcane system but have little direct influence in the dry tropics. With the movement of *M. burtoni* at late stages of the crop cycle and the physical difficulties of management within the crop at that stage of crop development, a key management strategy for *M. burtoni* may be the management/manipulation of the adjacent habitat.

<u>Study 2 DNA Sampling</u>

Results & Discussion:
Results indicate that the morphological characteristics of weight and tail length used in field identification are significantly different when comparing individual species of both sexes and across all age classes. *Melomys cervinipes* of all age classes were heavier and had longer tails than *M. burtoni*. The characteristics of weight and tail length are simple enough for an animal biologist with field experience to use and have confidence in the identification of the *Melomys* species.

Blind-tested DNA examination of tissue samples confirmed that field identification based upon weight and tail measurements corresponded to the 'true' taxonomy of both species. Therefore, the morphological identification of *Melomys* species in the field using weight and tail measurements results in a reliable method of distinguishing between species.

<u>Study 3 Monitoring</u>

Results:
We caught 1792 *R. sordidus*, 1187 *M. burtoni* and 121 *M. cervinipes*. *Rattus sordidus* was the dominant species captured in crop stages 1 through to 4. While *M. burtoni* occurred in relatively low numbers initially; by crop stage 5, captures increased to 65% of total rodent catch in sugarcane adjacent to grassland and 35% of total rodent catch in sugarcane adjacent to closed forest. Captures of *M. cervinipes* constituted only a small proportion of all rodents caught (0.1% and 4% in sites adjacent to grassland and closed forest, respectively).

The relative abundance of the different rodent species was significantly influenced by crop stage ($F_{8,81}$=3.36, p<0.01) and adjacent habitat type ($F_{2,81}$=12.93, p<0.01), but no significant three way interaction was detected ($F_{12,81}$=1.37, p=0.20). In crop stage 1 few rodent captures were made, while in crop stages 2 and 3 *R. sordidus* were more numerous than *M. burtoni* and *M. cervinipes* in sites adjacent to closed forest. However, in sites adjacent to grassland, *M. burtoni* numbers increased in crop stage 4 and were greater in number than *R. sordidus* in crop stage 5. Conversely, in sites adjacent to closed forest, *R. sordidus* numbers were significantly greater than *M. burtoni* in crop stage 4, but not in crop stage 5 (Figure 7). Total rodent numbers in crop stage 5 were not significantly different between the two adjacent habitat types ($F_{1,23}$=0.27, p=0.61). Over all crop stages, *M. burtoni* numbers did not vary significantly according to different adjacent habitat type ($F_{1,38}$=0.07, p=0.79), while both *M. cervinipes* and *R. sordidus* were found in significantly higher numbers in sugarcane adjacent to closed forest ($F_{1,38}$=11.35, p<0.01, $F_{1,38}$=9.69, p<0.01 respectively).

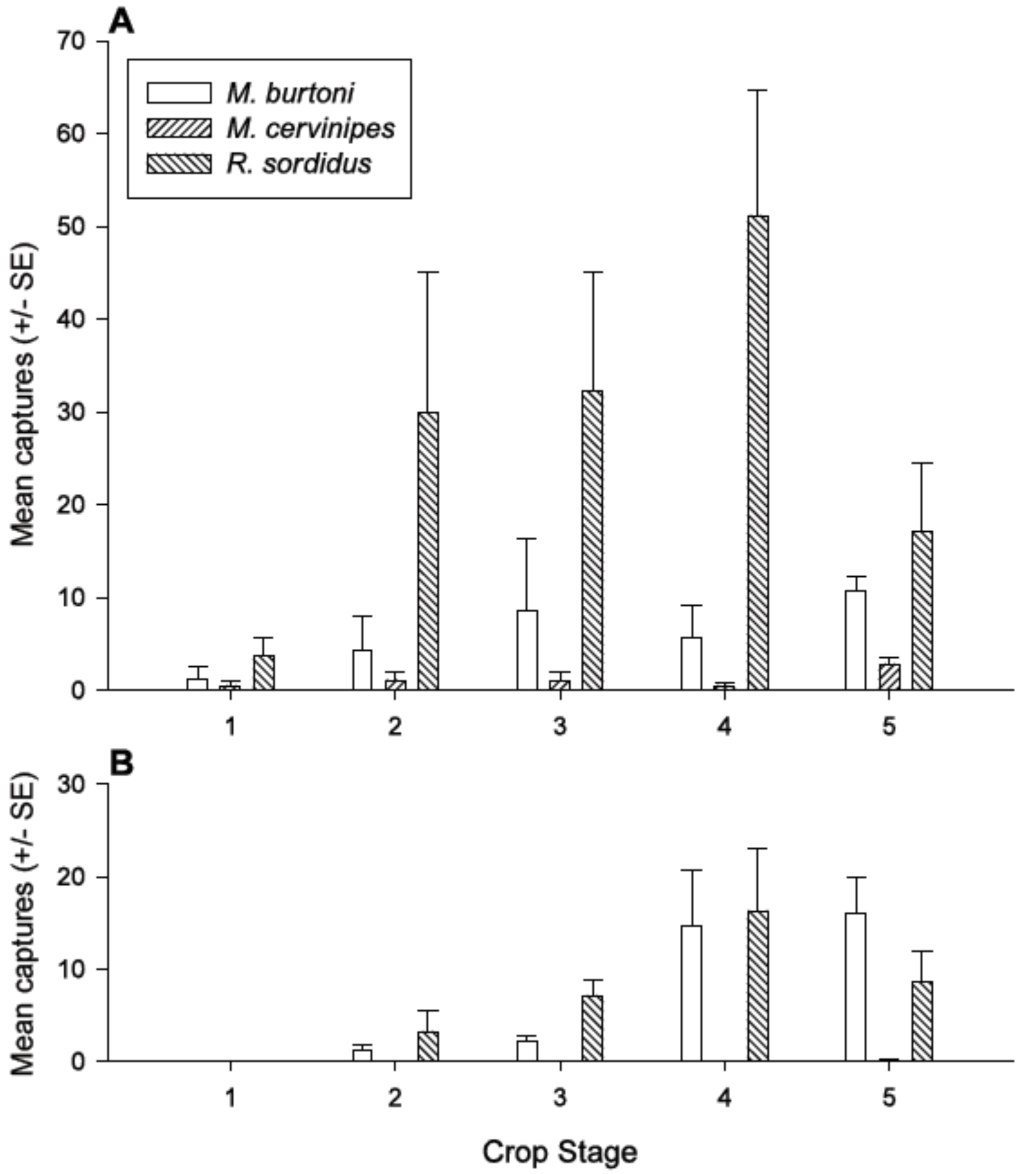

Figure 7: Mean captures (+/-SE), adjusted for trapping effort, of *Melomys burtoni*, *M. cervinipes* and *Rattus sordidus* at five crop stages in sugarcane located adjacent to A) closed forest and B) grassland.

Diet analysis

We dissected 183 *M. burtoni* (107 male, 76 female) and assessed their stomach contents for diet. Nearly all individuals (94.5%) were caught in either crop stage 4 or 5, thus only these individuals were included in the formal analysis for stomach content. Mean gut content percentages for all individuals caught were, respectively for males and females: 66 and 56% for seed, 21 and 37% for cane-fibre, and 13 and 6% for vegetation.

There were significant differences among the percentages of different stomach contents within crop stage 4 ($F=37.085$, d.f.=3, $P<0.001$), with a *post hoc* Tukey test identifying that the percentages of seed were significantly greater than sugarcane, vegetation and 'other' (i.e. unidentified) material. While the quantity of sugarcane was significantly different to 'other' material, it was not significantly different to the quantity of non-crop vegetation (Figure 8).

In crop stage 5 there were again significant differences among the percentages of different material in stomach contents ($F=108.5$, d.f.=3, $P<0.001$). The *post hoc* Tukey test identified that again seed was found in significantly greater amounts to sugarcane, vegetation and 'other' material. There was an increase in the proportion of sugarcane in this crop stage and it was found in significantly greater amounts to vegetation and 'other' material. There was no significant difference between vegetation and 'other' material, which were both substantially lower than seed content and cane-fibre (Figure 9).

We applied a Kruskal-Wallis test to examine the differences in the percentage of sugarcane and seed in stomach content for different *M. burtoni* age classes. There was no significant differences among age classes for sugarcane ($\chi^2=6.92$, d.f.=4, $P=0.140$) or seed content ($\chi^2=8.46$, d.f.=4, $P=0.076$).

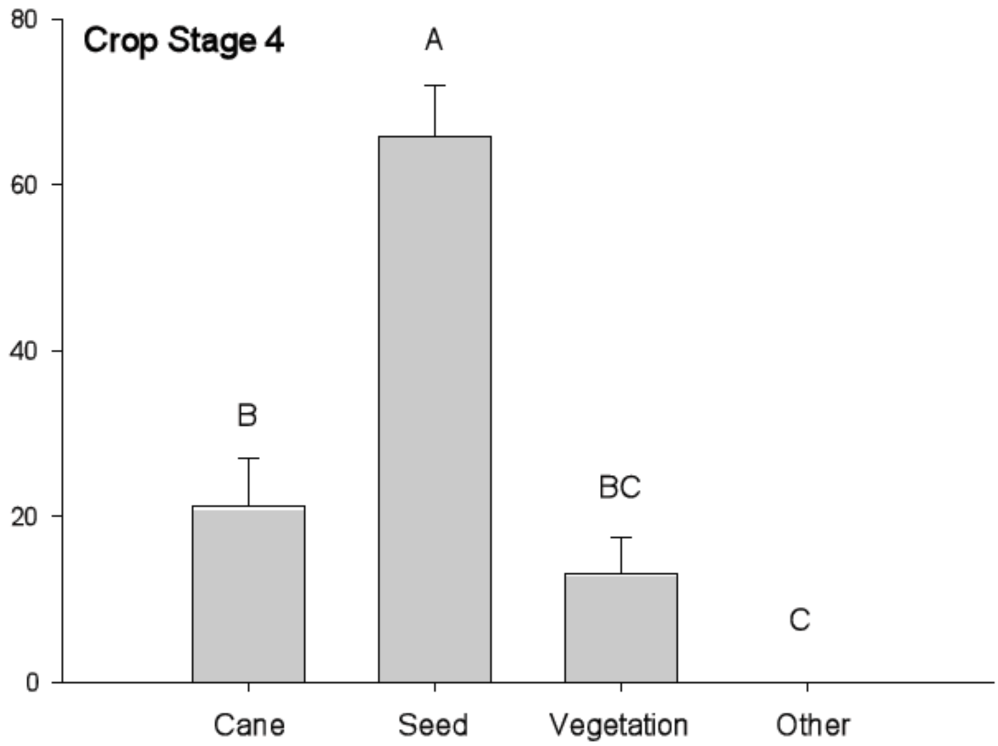

Figure 8: Mean (±SE) stomach content type in *Melomys burtoni* (n=36) within sugarcane crop stage 4. Columns headed by the same letter are not significantly different at $P=0.05$.

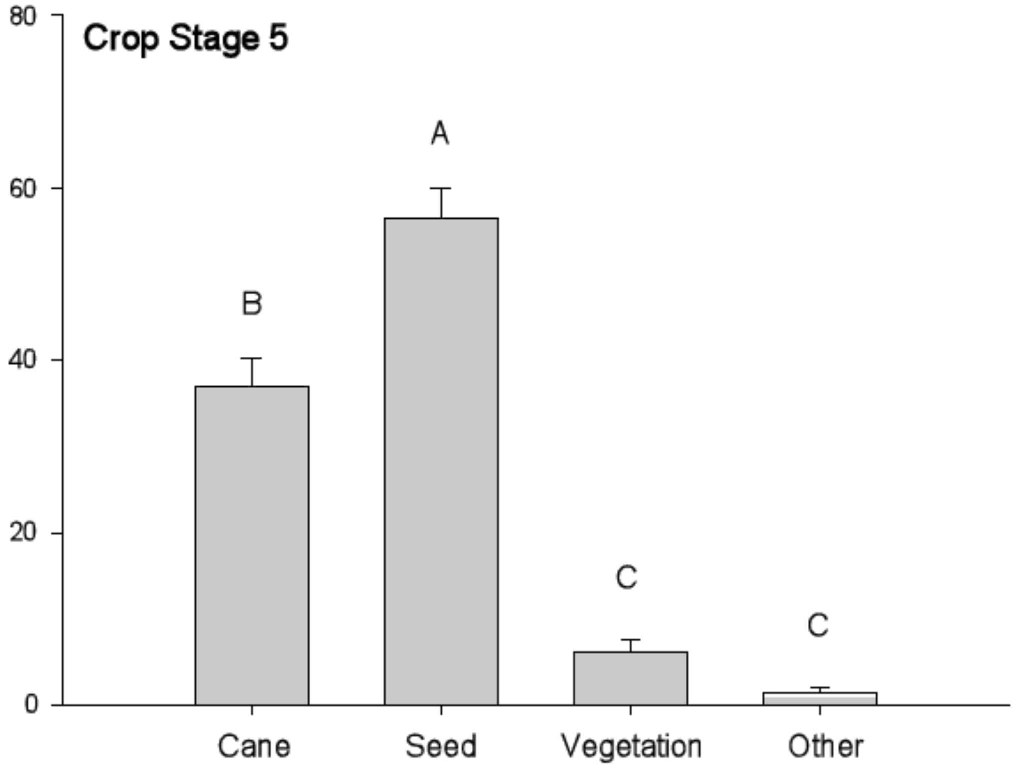

Figure 9: Mean (±SE) stomach content type in *Melomys burtoni* (n=137) within sugarcane crop stage 5. Columns headed by the same letter are not significantly different at P=0.05.

Sugarcane damage

As there were no harvestable sugarcane stalks >50 cm in height in crop stages 1 to 3, no damage was recorded within these stages, and only crop stages 4 and 5 were analysed. Damage attributable to *M. burtoni* became evident in crop stage 4 once harvestable stalks were present (0.4% of 35,999 stalks), but increased in crop stage 5 (5.6% of 220,208 stalks). A Chi-squared contingency test confirmed a significant difference in the proportion of damaged sugarcane stalk between crop stage 4 and 5 (χ^2=1716, d.f.=1, P<0.001).

Weed levels, sugarcane damage and rodent numbers

There was a significant, positive linear relationship (R^2=0.18, d.f.=1, P<0.001, y=6.24+0.18x) between stalk damage levels and *M. burtoni* numbers. The links between weeds and cane-stalk damage or *M. burtoni* abundance were less strong, with a weak, but significant positive linear relationship between the quantity of weed biomass and population numbers of *M. burtoni* (R^2=0.052, d.f.=1, P=0.037, y=6.74+0.05x). A very weak, but also significant positive linear relationship was found between the quantity of weed biomass available and the level of damage (R^2=0.060, d.f.=1, P=0.024, y= 0.02 + 0.06x).

Melomys burtoni demographics

There were 996 live captures of *M. burtoni*. The number of traps filled in any sampling event averaged 4.6%. The proportion of the snap-trapped population that was micro-chipped in the live trapping grids represented only 1%. Due to low capture rates of *M. burtoni* within crop stages 1-3, these sampling periods were pooled together for subsequent analysis and discussion.

Of the 996 live captures, 611 were initial captures within any sampling event (where details of individuals were recorded) and 385 were re-captures within any one sampling event and, therefore, released at point of capture with no further details recorded. The proportion of adult (mature) male and female *M. burtoni* varied across the different crop stages (χ^2=17.315, d.f.=2, P<0.001). A high proportion of males typified the population in crop stages 1-3 and in crop stage 4, but parity was attained in crop stage 5, when the proportion of mature female *M. burtoni* increased. The proportion of *M. burtoni* juveniles also varied significantly across crop stages 1-5 (χ^2=8.189, d.f.=2, P=0.017). The number of juveniles in the trappable population was stable at approximately 16% in crop stages 1-3 and crop stage 4, prior to a peak in crop stage 5 when they comprised 30% of the total population.

The proportion of female *M. burtoni* that were pregnant (live and snap-trapped combined) varied across all crop stages (χ^2=7.059, d.f.=2, P=0.029) with low breeding in crop stages 1-3 (1 individual, or 29% of mature female population), but increased in crop stage 4 (9, 42%), and again in crop stage 5 (26, 65%). Mean litter sizes (from dissections only) for crop stage 1-3, 4 and 5 were, respectively, 2, 2.6 ± 0.3 and 2.5 ± 0.1. The maximum litter size identified was five pups, but was encountered only in one female in crop stage 4. Overall, 15 females were found to be carrying three pups, 19 were carrying two pups, and one was carrying one pup.

Discussion:

Our study clarifies the pest status of *M. cervinipes* in sugarcane and shows that *M. burtoni* has a different biology, ecology and damage profile to *R. sordidus*. These results have implications for managing rodents in sugarcane.

Numbers of *M. cervinipes* remained low throughout all stages of crop development, although there was a small increase in numbers within crop stage 5. However, overall proportions were not significant when compared with *M. burtoni* or *R. sordidus* and *M. cervinipes* should therefore not be considered a pest of the sugarcane industry.

Wilson and Whisson (1993) developed the IPM strategy for *R. sordidus* in sugarcane by characterising the rat's colonising, breeding and dispersing population stages, the feeding and sheltering resources used by each stage, and then developing strategies which targeted those critical resources and ultimately lowered pest populations in the crop. Our results for *M. burtoni*, especially its late colonisation and lower breeding potential, clearly demonstrate that the population patterns of *R. sordidus* and *M. burtoni* in sugarcane are not the same and simply 'cutting and pasting' *M. burtoni* into the *R. sordidus* IPM strategy will not be appropriate.

Melomys burtoni colonises the crop much later than *R. sordidus*. Monitoring for *M. burtoni* in the early stages of crop development may yield mature males, but will do little to help predict the potential for population build up or crop damage. Monitoring in the later stages of crop development better indicates the increase in the proportion of female *M. burtoni* and likely reproduction. Access to the crop at the later stages of sugarcane development, however, is physically difficult. Nevertheless, a baiting strategy conducted earlier in the crop development, in anticipation of damage, would not be considered best management practice as, at such time, there would be neither direct damage nor indicative population build-up. Additionally, bait longevity may also be compromised if applied at an earlier stage.

Rattus sordidus has one of the highest reproductive potentials of any native Australian *Rattus* species (McDougall 1946a; Taylor and Horner 1973; Wilson and Whisson 1993). Mean litter size was lower for *M. burtoni* than *R. sordidus*, suggesting population eruptions of *M. burtoni* would be less intense. Nevertheless, numbers of *M. burtoni* were higher than *R. sordidus* in crop stage 5 in sugarcane adjacent to grassland, suggesting that *M. burtoni* may be migrating into the crop.

In contrast to previous research on *R. sordidus* (Wilson and Whisson 1993), the number of *M. burtoni* found in crop stages 4 and 5 was only weakly related to weed and damage levels. While in-crop weeds provide the nutritional requirements needed for breeding in *R. sordidus* (Wilson and Whisson 1993), it cannot be inferred that this is the case for *M.burtoni*. An increase in weed biomass in-crop could initially provide the preferred food type of *M. burtoni* (grass and weed seed; Watts 1977), or extra cover providing an alternative and extended habitat for early colonisation of sugarcane, rather than being a nutritional requirement for breeding.

The major components in the diet of *M. burtoni* were similar to that of *R. sordidus* and included seed and cane-fibre. Seed was found in greater quantities than cane-fibre and, although the quantity of cane-fibre in *M. burtoni* stomach contents increased in crop stage 5, it never reached the proportions that were found in *R. sordidus*. Therefore, it appears that there is no distinct diet switch, such as has been reported for *R. sordidus*. This may explain why damage levels for *M. burtoni* (5.6%) are lower than the levels found by Wilson and Whisson (1993) for *R. sordidus* (9%). It is possible that sugarcane is only a secondary food source for *M. burtoni*, resulting from diminishing supplies of their preferred food resource, as population numbers increase in crop stages 4 and 5 and competition occurs for this preferred food resource. Nevertheless, assuming that the average profit return to the grower is valued at AU$25/tonne of sugarcane, and approximately 75 tonnes/hectare grown in the Tully district alone (BSES unpublished data 2009), a damage level of 5.6% could equate to a potential loss of AU$105/ha, a level that warrants management.

If *M. burtoni* do not require in-crop weeds for breeding, then perhaps they are moving into sugarcane from their natural habitat in search of new territory. This may explain the male bias in early crop stages. Numbers of *M. burtoni* increase significantly in crop stage 4, but remain male biased until crop stage 5 when equal numbers of males and females are found. In addition to this, the largest proportion of juveniles is evident in crop stage 5, and it is possible that juveniles are migrating into the crop, rather than being the offspring of a population breeding within the crop.

Given that the population dynamics of *M. burtoni* indicate that management efforts should target crop stages 4 and 5, but direct control of *M. burtoni* in the crop at this stage is restricted by physical difficulties, we suggest that one key management strategy for *M. burtoni* would be the manipulation of the adjacent habitat. Rodent control via habitat manipulation has been successful for pocket gophers in apple orchards (Sullivan and Hogue 1987), rats in rice fields (Drost and Moody 1982), and of particular relevance to the current study, a 65% reduction in rodent damage in Australian macadamia orchards that was achieved following slashing and herbicide application to remove all adjacent non-crop habitat over 10cm in height (White *et al.* 1998). Therefore, we suggest that in cane fields located adjacent to grassland, a careful program of grassland harbourage management including slashing and herbicide treatment, particularly during crop stages 3 and 4, may prevent a build-up of *M. burtoni* numbers in crop stage 5.

Finally, although *R. sordidus* was not the focus of the current study, some interesting information has arisen. In particular, one segment of the IPM strategy for *R. sordidus* suggests that where possible, grassland habitat should be converted into closed forest. However our results suggest that *R. sordidus* are more numerous in sugarcane located adjacent to closed forest, and is a more significant pest relative to both the *Melomys* species in this context. Any future modifications to the IPM strategy for *R. sordidus* should take these results into consideration.

Outputs:
B) Communication of outputs through grower-oriented publications and workshops, as well as publications in both ASSCT and scientific journals.

During this project, Brendan Dyer has:

- Completed a Master of Applied Science degree at QUT in November 2007 entitled 'The biology of the grassland melomys (*Melomys burtoni*) (Rodentia: Muridae) in Far North Queensland Sugarcane Crops'.
- Attended the SRDC student forum (Media Skills) at Condong on 18th and 19th February, 2008.
- Attended the SRDC student forum (Writing for Scientific Publication) at Brisbane, 17-21 November 2008.
- Powerpoint presentations were made to Tully growers in April 2008 regarding the latest Melomys research. Almost 40% of the district attended.
- Presented a poster entitled 'The biology of the grassland Melomys (*Melomys burtoni*) (Rodentia: Muridae) in far north Queensland sugarcane crops' at the 30th Conference of the Australian Society of Sugarcane Technologists (ASSCT) in Townsville in April 2008 and at the Australasian Vertebrate Pest Conference in Darwin in May 2008.
- Awarded Best Agricultural Poster Paper and Presentation, Australian Society of Sugarcane Technologists 30th Annual Conference, Townsville, 2008.
- Powerpoint presentations and poster at the BSES Mackay field day in May 2008.
- Attended and presented at the 2nd Qld Pest Animal Symposium in Cairns in October 2008.
- Newspaper article 'Climbing rats in sugarcane lead to new methods in management' Tully Times, 20th May 2010, B. Dyer.
- Attended and presented at the 2011 Conference of the Australian Society of Sugarcane Technologists (ASSCT) Mackay.
- Dyer B, Clarke A, Fuller SJ. (2011) Population dynamics, diet and pest status of the grassland melomys (*Melomys burtoni*) in north Queensland sugarcane crops. *Wildlife Research* 38, 330-337.

Intellectual Property and Confidentiality:
None

Environmental and Social Impacts:
None

Expected Outcomes:

- Growers will have a management tool for managing rodents in a sustainable farming system
- Growers will have a reduction in damage to their crop and therefore will have an increase in overall yield of crop
- Growers will realise an increase in CCS
- Efficiency of harvesting will increase and decrease food resources remaining in fields for rodent survival
- Millers will have an increased supply of can to the mill
- Millers will be able to increase the quality of sugar
- Fewer rodents moving in and out of cane fields decreases the health issue of leptospirosis
- Foster targeted continuing education and retention of human capital in the industry

Future Research Needs:
- Integrate these findings into an integrated pest management strategy for *M. burtoni*; and
- Extend this information to achieve change in farming practices.

Recommendations:
- The IPM strategy for *M. burtoni* should be communicated to the industry through grower participation, grower-oriented publications and at workshops and farm and field days.

List of Publications:
- Dyer B, Clarke A, Fuller SJ. (2011) Population dynamics, diet and pest status of the grassland melomys (*Melomys burtoni*) in north Queensland sugarcane crops. *Wildlife Research* 38, 330-337.
- Dyer, B.C., Fuller, S.J. Williamson, I. (2011) Historical Analysis of Rodent Dynamics and Damage Using Queensland Sugarcane Industry Monitoring Data. *Proceedings of the Australian Society of Sugar Cane Technologists* **33**, (CD ROM) X pp.
- Dyer, B. (2010) Queensland Sugarcane Industry Species Management Plan – Schedule A to a Memorandum of Understanding between the Queensland sugarcane industry and the Department of Environment and Resource Management. Technical Publication TE10007, BSES Limited, Brisbane.
- Dyer, B.C. (2007) *The biology of the grassland Melomys (*Melomys burtoni*) (Rodentia: Muridae) in far north Queensland sugarcane crops*. Masters Thesis, Queensland University of Technology, Brisbane, Australia.

  N.B. An electronic and hard copy of Brendan Dyer's Masters Thesis has been provided to SRDC.

References:

Allsopp, P. G., Chandler, K. J., Samson, P. R. and Story, P. G. (1993). *Pests of Australian Sugarcane*. Bureau of Sugar Experiment Stations: Indooroopilly.

Baverstock, P. R., Watts, C. H. S., Adams, M. and Gelder, M (1980). Chromosomal and electrophoretic studies of Australian *Melomys* (Rodentia: Muridae). *Australian Journal of Zoology* **28**, pp. 553-574.

Drost, D.C. and Moody, K. (1982). Rat damage in weed control experiments in rainfed transplanted rice. *Tropical Pest Management* **28**, 295-299.

Gard, K. R. (1935) The rat pest in cane areas. *Proceedings of the International Society of Sugar Cane Technologists* **5,** 594-603.

Hall TA (1999) BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic Acids Symposium **41**, pp. 95-98.

Hitchcock, B. E. (1973) An evaluation of aerial baiting for the control of rats in cane-fields. *Proceedings of the Queensland Society of Sugar Cane Technologists* **40**, 59-64.

Hitchcock, B. E. and Kerkwyk, R. E. (1975) Further aerial baiting trials against rats in cane fields. *Proceedings of the Queensland Society of Sugar Cane Technologists* **42**, 105-107.

Hitchcock, B. E. and Kerkwyk, R. E. (1978) Evaluation of new rodenticides in Queensland cane fields. *Proceedings of the Queensland Society Sugar Cane Technologists* **45**, 93-95.

Hood, G. A., Nass, R. D., Lindsey, G. D. (1970). The Rat in Hawaiian sugarcane. *Proceedings Vertebrate Pest Conference* **4**, pp. 34-37.

Hussain, I., Cheema, A. M., and Khan, A. A. (2003) Small rodents in the crop ecosystem of Pothwar Plateau, Pakistan. *Wildlife Research*, 30, 269-274.

Kerle, J. A. (1995) Grassland *Melomys – Melomys burtoni*. In: Strahan, R. (ed) *Mammals of Australia*. Reed New Holland, Sydney, pp. 632-634.

Kumar S, Tamura T, Jakobsen IB, Nei M (2001) MEGA2: molecular evolutionary genetics analysis software. *Bioinformatics* **17**, pp. 1244-1245.

McDougall, W. A. (1944a) An investigation of the rat pest problem in Queensland cane-fields: 1. Economic aspects. *Queensland Journal of Agricultural Science* **1**, 32-47.

McDougall, W. A. (1944b) An investigation of the rat pest problem in Queensland cane-fields: 2. Species and general habits. *Queensland Journal of Agricultural Science* **1**, 48-78.

McDougall, W. A. (1944c) An investigation of the rat pest problem in Queensland cane-fields: 3. Laboratory experiments on food intake and toxicity. *Queensland Journal of Agricultural Science* **1**, 1-32.

McDougall, W. A. (1946a) An investigation of the rat pest problem in Queensland cane-fields: 4. Breeding and life histories. *Queensland Journal of Agricultural Science* **3**, 1-43.

McDougall, W. A. (1946b) An investigation of the rat pest problem in Queensland cane-fields: 5. Populations. *Queensland Journal of Agricultural Science* **3**, 151-237.

McDougall, W. A. (1947) An investigation of the rat pest problem in Queensland cane-fields: 6. Controls and Conclusions. *Queensland Journal of Agricultural Science* **4**, 79-139.

Miller SA, Dykes DD, Polesky HF (1988) A simple salting out procedure for extracting DNA from human nucleated cells. *Nucleic Acids Research* **16** (3), pp. 127-142.

Palumbi S, Martin A, Romano S, McMillan WO, Stice L, Grabowski G (1991) *The simple fools guide to PCR (Version 2.0)*. University of Hawaii, Honolulu.

Putman, R. J. (1989). Introduction: mammals as pests. In: *Mammals as pests*. Putman, R. J. (Ed). Chapman and Hall, London, pp. 1-20.

Redhead, T. D. (1973) *A re-assessment of the rat problem in north Queensland cane fields, with emphasis on the ecology and reproduction of* Melomys littoralis (Lonnberg). MSc Thesis, James Cook University.

Redhead, T. D. (1995) Canefield Rat – *Rattus sordidus*. In: Strahan, R. (ed) *Mammals of Australia*. Reed New Holland, Sydney, pp. 661-662.

Redhead, T. D. and Saunders, I. W. (1980) Evaluation of thallium sulphate baits against rats in Queensland (Australia) sugarcane fields adjacent to different habitat types. *Protection Ecology* **2**, 1-19.

Ruscoe, W. A., Mather, P. B., and Wilson, J. (1998) Genetic structure in populations of *Rattus sordidus* in sugarcane growing districts of Queensland, Australia. *Journal of Mammalogy* **79** (2); pp. 612-623.

Saitou N, Nei M (1987) The neighbour-joining method: a new method for reconstructing phylogenetic trees. *Molecular Biology and Evolution* **4**, pp. 406-425.

Smith, G. C. (1985) Biology and habitat usage of sympatric populations of the fawn-footed *Melomys* (*Melomys cervinipes*) and the grassland melomys (*M. burtoni*) (Rodentia: Muridae). *Australian Zoologist* **21** (7), pp. 551-563.

Smith, M., Staples, L., Dyer, B., and Hunt, W. (2002) Incorporation of a zinc phosphide rodenticide into integrated pest management of rats in sugarcane. *Proceedings of the Australian Society of Sugar Cane Technologists* **24**, pp. 228-234.

Sullivan, T.P. and Hogue, E.J. (1987). Influence of orchard floor management on vole and pocket gopher populations and damage in apple orchards. *Journal of the American Society for Horticultural Science* **112**, 972-977.

Taylor, J. M. and Horner, B. E. (1973). Reproductive characteristics of wild native Australian *Rattus* (Rodentia: Muridae). *Australian Journal of Zoology* **21**, pp. 437-475.

Tobin, M. E. and Fall, M. W. (2004) Pest Control: Rodents [web document]. Available at: http://www.aphis.usda.gov/ws/nwrc/is/annpubs2005.html [28 August, 2006].

Tobin, M. E. and Sugihara, R. T. (1992) Abundane and Habitat Relationships of Rats in Hawaiian Sugarcane Fields. *The Journal of Wildlife Management* **56** (4), 816-822.

Tobin, M. E., Sugihara, R. T., and Ota, A. K., (1990) Rodent damage in Hawaiian sugarcane. *Proceedings of the Vertebrate Pest Conference* **14**, 120-123.

Volp, P. (1960) Rat bait trials in the Mulgrave area. *Proceedings of the Queensland Society of Sugar Cane Technologists* **27**, 155-158.

Watts, C.H.S. (1977). The foods eaten by some Australian rodents (Muridae). *Australian Wildlife Research* **4**, 151-157.

Watts, C. H. S. and Aslin, H. J. (1981) *The Rodents of Australia*. Angus and Robertson, Sydney.

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

White, J., Horskins, K. and Wilson, J. (1998). The control of rodent damage in Australian macadamia orchards by manipulation of adjacent non-crop habitats. *Crop Protection* **17**, 353-357.

Wilson, J. and Whisson, D. (1993) *The Management of Rodents in North Queensland Cane fields*. Queensland University of Technology, Brisbane.