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The spatial distribution of rodent damage in Australian macadamia (*Macadamia integrifolia*) orchards

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Abstract

The Black Rat (*Rattus rattus*), a global pest within the macadamia production industry, causes up to 30% crop damage in Australian orchards. During early stages of production in Australia, research demonstrated the importance of non crop adjacent habitats as significant in affecting the patterns of crop damage seen throughout orchards. Where once rodent damage was limited to the outside edges of orchard blocks, growers are now reporting finding crop damage throughout entire orchards. This study therefore aims to explore the spatial patterns of rodent distribution and damage now occurring in Australian macadamia orchards. We show that rodent damage and rodent distribution in these newer production regions differ from that shown in previous Australian research. Previous Australian research has shown damage patterns which were associated with the edges of orchard blocks however this study demonstrates a more widespread damage distribution. In the current study there is no relationship between rodent damage and the orchard edge. Arboreal rodent nests were identified within these newer orchard systems, suggesting rodents are residing within the tree component of the orchard system and not dependent on adjacent non-crop habitat for shelter. Results from this study confirm that rodents have modified their nesting and foraging behaviour in newer orchards systems in Australia. We suggest that this is a response of increased and prolonged availability of macadamia nuts in newer production regions enabling populations to be maintained throughout the year. Management strategies will require modification if control is to be achieved.

Keywords: *Rattus rattus*; Black Rat; spatial damage distribution; arboreal nests; rodent management.

Introduction

The Black Rat (*Rattus rattus*) has long been identified as a major pest in the global macadamia nut industry (Tobin, 1990; White et al., 1998). Studies in Hawaii and Australia, the two largest macadamia producers, have illustrated that *R. rattus* poses a significant economic threat to macadamia nut production with losses estimated to be as high as 30% of total yield (Campbell et al., 1998; White et al., 1997). Interestingly, the pattern of damage within Australian and Hawaiian systems has been shown to differ significantly (Tobin et al., 1997; White et al., 1997). This has resulted in distinct management recommendations for orchards in each country necessitated by the differing foraging and nesting strategies utilised by *R. rattus* populations in these two system (Horskins and Wilson, 1999; Tobin et al., 1997). Previous research on the spatial distribution of damage caused by *R. rattus* populations in Australian orchard systems showed high levels of damage around the orchard edge (up to 90% of first row crops (Elmouttie and Wilson, 2005)), with very little damage within the orchard interior (Horskins et al., 1998; White et al., 1997). This was suggested to be a result of the distinct fruiting and flowering seasons in Australian orchards, making *R. rattus* populations reliant on non-crop habitat resources adjacent to the orchard to maintain population densities (Elmouttie and Wilson, 2005). Rodents were found to forage into the orchard from these adjacent habitats when nuts were available within the orchard canopy (White et al., 1997). However, during periods of low nut availability, rodents remained in adjacent, temporally stable non-crop habitats feeding on resources within these habitats and nesting within extensive burrow networks (Horskins et al., 1998; White et al., 1997). Management strategies were therefore based around maintaining orchard hygiene, in particular the removal of adjacent habitats, as these were shown to be vital in maintaining population densities which resulted in high damage levels (White et al., 1998). This pattern of damage towards the edge of Australian orchards was different to the spatial distribution of damage in Hawaiian macadamia orchards. In Hawaiian orchards rodent damage was distributed much more uniformly throughout entire orchard systems (Tobin, 1992). In these orchards *R. rattus* populations were identified living within the orchard system (Tobin et al., 1996), utilising both arboreal nests and burrows within the orchards (Tobin, 1992; Tobin et al., 1996). Further studies demonstrated that rodents in Hawaiian orchard only occasionally used surrounding non-crop habitats (Tobin et al., 1996). The difference in foraging behaviour of rodents between Australian and Hawaiian orchards was suggested to be a consequence of the extended fruiting and flower season in Hawaiian systems, leading to a stable, year round, in crop food resource (Tobin et al., 1996). While studies by White and Horskins (1998) have formed the basis for rodent management in Australian macadamia orchards, in recent years, there has been a substantial expansion of macadamia production in Australia into new areas. Within these regions anecdotal reports from growers suggested that rodent damage is no longer restricted to the orchard edge. If this is the case, the management strategy of focussing solely on the adjacent non-crop habitat is unlikely to be useful in controlling these rodents. The aim of this study was therefore to investigate the temporal and spatial distribution of rodent damage and rodents in more recently established macadamia orchards in Australia. This study was used to aid in the development of more effective rodent management strategies in these areas.

Results

Damage distribution

The overall level of crop damage documented during this study was 8% of total yield, although damage reached 50% of yield at a single site. Contrary to previous studies in Australian orchards, damage was not higher at orchard edges and there was no difference in mean levels of nut damage at sampling sites extending into the orchard across the sampling period (χ^2 = 10.042, n = 2250, df = 9, p = 0.347). This pattern was found to be temporally consistent with no difference in rodent damage among sample sites during each of the sampling periods (March, χ^2 = 8.73, p = 0.463; May, χ^2 = 4.143, p = 0.900; July, χ^2 = 11.529, p = 0.241; September, χ^2 = 7.356, p = 0.600; November, χ^2 = 11.03, p = 0.274). Similarly, damage was generally consistent across seasons at each sampling site into the orchard. Although 2 of the 15 sites (site 2 (χ^2 = 20.895, p = 0.013) and site 12 (χ^2 = 18.204, p = 0.033)) were found to differ with distance into the orchard ($p < 0.05$), damage was not related to the orchard edge. Damage due to rodents was clumped each study site within each sample period (Table 1).

Rodent distribution

A total 105 rodents were caught during the study. There was no difference in trap captures at different locations across all study sites and all sampling periods (χ^2 = 5.051, n = 750, df = 9, p = 0.830). This remained consistent throughout the sampling effort, with no differences in mean trap captures across sampling sites within each sampling period (March, χ^2 = 7.257, p = 0.610; May, χ^2 = 5.198, p = 0.817; July, χ^2 = 8.102, p = 0.524; September, χ^2 = 6.386, p = 0.701; November, χ^2 = 8.14, p = 0.520). There were also no differences in trap captures among sampling periods for each sampling sites. Rodent captures were generally randomly spatially distributed across study sites with the exception of site 7 where rodents were uniformly distributed (Table 2). Dispersion estimates could not be generated for 4 sites due to low captures. There was a relationship between overall rodent distribution and nut damage (Rs = 0.156, n = 750, p < 0.001).

Nest and burrow distribution

Twenty arboreal rodent nests were identified across all study sites located between 20m and 117m from the orchard edge (Fig 2). A survey for rodent burrows in the study area identified 3 burrows at 45m and 88m from the orchard edge.

Discussion

The spatial distribution of rodent damage in this study differs significantly from previous research in Australian orchards (Elmouttie and Wilson, 2005; Horskins et al., 1998; White et al., 1998). Unlike previous studies that illustrated high levels of damage correlated with orchard edges, this study has shown that damage in newer plantings is not related to the orchard edge. Although damage was generally clumped no relationship was found between damage and location within the orchard (Table 1). This pattern was found to be consistent throughout the 2010 nut fall season suggesting that rodents may remain resident in orchard blocks. Previous research in Australian orchards showed that *R. rattus* populations were resident within adjacent non-crop habitats, and foraged into the orchards during periods of high nut availability (Elmouttie and Wilson, 2005). Rodent damage was a result of rodent populations being maintained by non-crop resources and foraging between adjacent non-crop and crop habitats (White et al., 1997). This behaviour led to a distinct edge related pattern of damage in Australian orchards with very little if any damage accumulating within the orchard interior (Horskins et al., 1998; White et al., 1997). In contrast, the current study has demonstrated no concentration of damage towards orchard edges suggesting that rodents are foraging throughout the orchard system. This is a significant result as previous research postulated that the spatial distribution of damage and foraging patterns of *R. rattus* populations were based primarily on food availability, and that non-crop habitats were utilised as a source of alternate food resources during periods of low nut availability (Elmouttie et al., 2009). These adjacent non-crop habitats were thus seen to be an essential habitat component for rodent persistence. In this study however, substantial levels of damage have been demonstrated to occur in the absence of adjacent non-crop habitats. Rodents in this study were also trapped throughout orchard blocks and were not related to orchard edges. Again, this contrasts with previous studies (Elmouttie and Wilson, 2005; Horskins et al., 1998; White et al., 1998). Note however that there is no concentration of rodents in other specific areas since dispersion estimates show that they were distributed randomly throughout orchard blocks (Table 2). Whilst trap success was used to show the distribution of rodents within these Australian orchard systems, it wasn't high enough to give any reliable indication of population abundance despite trap success being dependant on rodent abundance and activity. It was difficult to infer rodent activity using the sampling strategy of this study and as such, further research is needed to investigate the abundance or rodent populations within these new orchard systems. Arboreal nests within the orchard were found to be the dominant nest type within these orchard systems. Previous research in Australian orchards identified burrows within non-crop habitats as primary nest sites (Horskins et al., 1998). In this study however, burrowing was found to be limited. While low sample sizes precluded statistical analysis, the spatial distribution of nests (Fig 2), similar to the distribution of rodents and the damage they cause clearly indicates that these rodent populations are behaving in a manor previously undocumented within Australian orchard systems and are no-longer confined to the orchard exterior. Further research is needed to quantify the impact of these arboreal nests on the surrounding macadamia orchard and to identify how many individuals these nests are supporting. Increasing the resolution of damage estimates could also reveal any patterns of damage surrounding these nests and thus be useful in optimising control strategies. Taken together, the spatial distribution of rodents, of rodent damage and of nests within orchards indicate that more recently planted Australian macadamia orchards are no longer conforming to patterns that have been demonstrated previously (Elmouttie et al., 2009; White et al., 1997). Earlier studies postulated that seasonal conditions in Australia limited macadamia nut-in-tree availability, requiring *R. rattus* populations to forage for alternate food resources when nut availability diminished (White et al., 1997). This in turn led to a damage pattern which was biased towards the orchard edge. Such a profound change in the distribution pattern of damage suggests that the temporal availability of food

Table 1. Morisita Index for rodent damage in each study site within each sample period (NR - No Result). Note the majority of results show a clumped distribution.

Site	March	May	July	September	November
1	0.5243	0.7236	1.0000	0.7393	0.6896
2	0.5603	1.0000	0.8324	0.7372	0.6114
3	0.5282	0.7194	1.0000	1.0000	0.5805
4	0.5231	0.5191	0.5416	0.5621	0.5139
5	0.5356	0.6037	0.5918	0.6141	0.5212
6	0.5142	0.5365	0.5745	0.6769	0.5222
7	0.5519	0.5743	0.7591	0.5785	0.5793
8	0.5638	1.0000	NR	NR	1.0000
9	0.5767	0.6969	0.7419	1.0000	0.7413
10	0.5400	0.8198	0.5889	0.5912	0.5584
11	0.5801	1.0000	0.7875	NR	0.5872
12	0.5862	1.0000	0.7495	0.6463	0.5812
13	0.6597	1.0000	0.5745	0.6255	0.5329
14	0.6724	0.5188	1.0000	1.0000	0.5542
15	0.6285	0.5049	NR	0.7803	0.5887

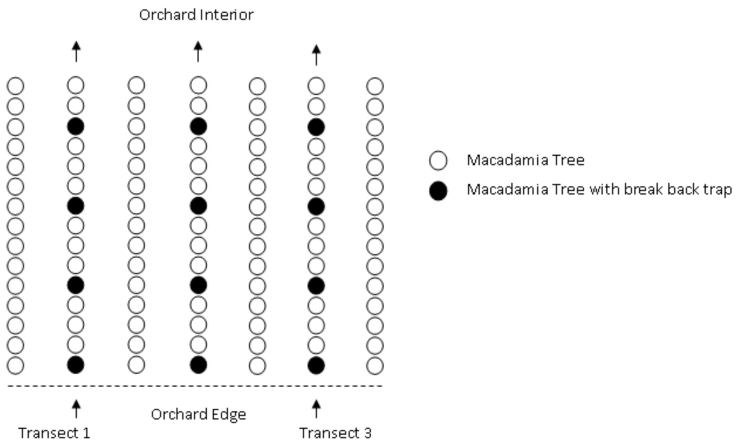

Fig 1. Representation of trapping grid design for all study sites throughout the 2010 nut fall season. The distance between sample points (black circles) along each transect is 16m.

resources has changed. Given the introduction of a range of new macadamia cultivars since previous studies were conducted, it may be that nut availability is being prolonged through the season, providing rodents with resources to maintain population densities within orchards. It is therefore possible that the pattern of damage observed in this study relates to the maintenance of rodent populations within the orchard, independent of external resources. Whilst the spatial distribution of rodent damage and nesting behaviours observed in this study has never before been documented within an Australian macadamia orchard, similar patterns have been recorded in Hawaiian macadamia systems (Tobin et al., 1997). Rodents in Hawaiian macadamia orchards commonly reside within the orchard system and were shown to construct arboreal nests (Tobin, 1995) and underground burrow networks (Tobin et al., 1996). Further, rodents in these systems are rarely associated with adjacent non-crop habitats. Similarly to this study rodent populations foraged throughout orchards with damage being uniformly distributed across orchard blocks. Rodent nesting and foraging behaviours within Australia's newer macadamia production regions appear to be similar to those found in Hawaii, and yet the extent of damage found in these newer systems is still significantly higher than previous Hawaiian systems. This study documented total rodent damage levels as high as 50% of total yield from just one study site throughout the 2010 nut fall season. This indicates that damage levels in these newer Australian orchards are similar to previously documented Australian research where damage levels were as high as 30% of the total yield (Horskins et al., 1998; White et al., 1997). In contrast the damage levels in Hawaiian systems are only 5-10% of the total yield (Campbell et al., 1998). This study has clearly identified that nut damage within newer macadamia plantings in Australia is no longer biased towards orchard edges as has been found in previous studies. Results from this study suggest that rodent populations in these regions are no longer dependent on the temporal stability of non crop habitats and can use within-orchard resources for a greater part of the year. These results have significant implications for the management of newer Australian orchards. The pattern of rodent captures and rodent damage within these systems suggested that rodent populations may be behaving in a similar fashion to those found within Hawaiian orchards. Within Hawaiian orchards rodent populations construct arboreal nests or burrows and feed on macadamia nuts for the majority of the year, as a

Table 2. Morisita Index for rodent distribution in each study site within each sample period (NR - No Result).

Site	Morisita Index
1	-0.3474
2	NR
3	-0.1755
4	0.0000
5	NR
6	-0.2059
7	0.5155
8	NR
9	NR
10	-0.1930
11	-0.0386
12	-0.1158
13	-0.2316
14	-0.2851
15	-0.2316

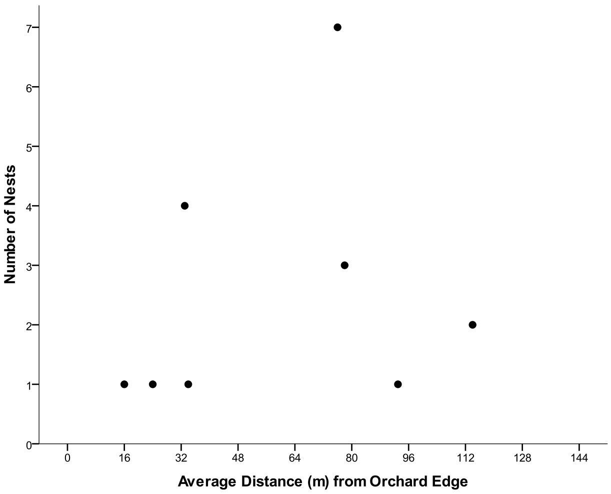

Fig 2. The distribution of arboreal rodent nests in relation to the distance from orchard edge for all orchards throughout the 2010 nut fall season.

consequence of the extended fruiting and flower season (Tobin et al., 1996). To manage these systems Hawaiian growers rely heavily on baiting and trapping regimes which can be focused on the areas where rodent damage is highest (Tobin, 1990). These management strategies are also most effective when used either before or after the nut fall season, when bait acceptance is greatest as the rodents preferred food source is in short supply (Tobin, 1990; Tobin, 1995). The current research suggests that, for Australian orchards, targeted trapping and baiting may be a useful additional strategy in addition to non-crop habitat control. Further, the apparent marked differences in the spatial distribution of damage in different regions of Australia suggests that management strategies may need to be region specific and that further research is required if long-term, cost-effective management strategies are to be developed.

Materials and Methods

Site description

The study was conducted over 5 farms in the Bundaberg production region of south-eastern Queensland, Australia. Each farm contained more than 20 individual orchard blocks. Orchard blocks consisted of a defined area of macadamia trees planted at the same time and of the same cultivar. Fifteen orchard blocks were selected for the study, with three orchard blocks being selected per farm. All orchard blocks were separated by a distance greater than 1.5km and by a range of habitats (including other orchard blocks, headlands, roads etc.) ensuring rodent populations could be considered independent. Within each orchard block a single study site was established from the orchard edge and ranging 144m into the orchard interior. Study sites were established in the middle of the orchard block such that only one edge was located adjacent to orchard headland (Fig 1). Each study site consisted of 10-20 year old macadamia orchard. All study sites were situated adjacent to highly modified non-crop habitats (headlands) as defined by White et al. (1997) to ensure that rodents trapped within study sites were not entering study sites from previously identified sources. A thorough survey of these surrounding habitats prior to data collection confirmed the absence of rodent burrows and other signs of rodent populations in the surrounding modified habitats.

Sampling design

Sampling commenced in March 2010 and occurred at bi-monthly intervals through to November 2010 encompassing the entire nut fall season. Within each study site three parallel transects were established from the orchard edge, extending into the orchard interior. Sampling locations were established on each transect at regular (16m) intervals creating a $256m^2$ sampling area with 16m x 16m grids. In total 30 sample points per study site were established (Fig 1). All orchard practices (harvesting, pruning etc.) continued throughout the experimental period with the exception of rodent baiting, which ceased across all farms 6 months prior to commencement of sampling and throughout the sampling period. Harvesting was carried out after sampling periods to ensure minimal disturbance to rodent behaviours. This sampling design allowed for a comparison of the pattern of damage between study sites.

Damage estimates

The Australian macadamia nut fall season begins in March and continues through September. During this period, nuts fall and are harvested from the ground. For the current study, samples were collected from the ground using one metre square quadrats at each sample location during each sampling trip. Quadrats were placed on the ground beneath the tree adjacent to each of the 30 marked sampling points within each study site. Counts of damaged and undamaged nuts were made within these quadrats. Rodents produce a distinct and clearly identifiable pattern of damage to macadamia nuts (Elmouttie and Wilson, 2005), and damaged nuts could be clearly identified. Damage counts were conducted at each study site within two days of each other during a sampling period. As experiments were conducted on commercial properties harvesting continued throughout experimental period. Thus damage estimates were based on a proportion difference between undamaged and damaged nuts and represented the damage that occurred over the two month period since the last sampling event.

Rodent distribution

Break back traps were used to assess the distribution of rodents across each study site. Thirty traps were placed within each study site. Traps were fixed in the lower canopy of the macadamia trees marked at each coordinate in the $16m^2$ grids. Traps were baited with cardboard soaked in linseed oil which was replaced daily. Trapping occurred over three consecutive nights in each data collection period (March, May, July, September and November). All captured rodents were removed from the site and placed in an on farm location as specified by the local grower.

Nest & Burrow Survey

A visual survey was conducted within each study site to identify both tree and ground nest locations. All trees within each study site were inspected for the presence of arboreal nests. Nests were identified using two criteria: (1) a dense clumping of dead leaves in the orchard canopy; and (2) a concentration of damaged nuts and leafy debris on the ground beneath. Nests location was recorded on the sampling grid. Burrows were identified as holes in the ground that had been obviously excavated by a burrowing rodent. Recent activity such as tracks and discarded nuts in and around burrows were used to identify active burrow systems.

Data Analysis

Data were not normally distributed and as such differences in nut damage and rodent distribution were assessed using the Kruskal-Wallis test and their relative position within the orchard system. The relationship between nut damage and rodent distribution was assessed using Spearman Rank Correlation. The Standardised Morisita Index (Krebs, 1989) was used to determine the spatial distribution of nut damage and rodent captures. The Morisita index of dispersion ranges from -1.0 (uniform distribution) to +1.0 (clumped distribution) with confidence intervals for a random spatial distribution in the range (-0.5, 0.5) (Morisita, 1962).

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