Habitat use by the Hastings River mouse, *Pseudomys oralis*

Kristy L. Graham, Grant L. Blackwell* and Dieter F. Hochuli

Institute of Wildlife Research, School of Biological Sciences, A08, The University of Sydney, NSW. 2006. Australia

*corresponding author.
The Department of Zoology, The University of Otago, 340 Great King Street, P.O. Box 56, Dunedin, New Zealand

Email: grant.blackwell@stonebow.otago.ac.nz Phone: (+64 3) 479-7986

ABSTRACT

The Hastings River mouse *Pseudomys oralis* is a rare Australian rodent with a patchy distribution in north-east NSW and southern Queensland. The micro-habitat requirements of the species are poorly known, although the majority of known records for the species are from areas with dense and complex ground cover and a high diversity of food-plant availability. The species is also thought to be at risk from exotic mammalian predators (feral cats *Felis catus* and red foxes *Vulpes vulpes*), and to be negatively associated with habitat edges, although this relationship has not been explicitly tested. This study investigates the micro-habitat use by *P. oralis* in a highly disturbed forest/pasture interface in Marengo State Forest, north-east NSW, as revealed by cotton spool-and line tracking. Individuals appeared to be significantly selecting habitat based on shrub-layer canopy cover in the 1-1.5 m height layer, with 76.1 % of the total spool line located under shrub-layer canopy compared to an environmental availability of 18.8 %. Shrubs (particular *Tasmannia stipitata* and *Leptospermum* spp.) were the most commonly selected cover type, followed by logs and head and butt residue. There were also significant trends in micro-habitat use at the ground level, with leaf litter, grass and logs were the most frequently used categories. These findings are discussed in light of current knowledge of the habitat requirements and management of *P. oralis*.

Key words: Edge effects, habitat selection, Hastings River mouse, *Pseudomys oralis*, spool-and-line tracking.

Introduction

The Hastings River mouse (HRM) *Pseudomys oralis* is a rare Australian rodent with a patchily recorded distribution in north-east New South Wales (NSW) and south-east Queensland. Although little ecological information is available about the species (Townley 2000), aspects of the morphology (Read 1993a; Keating 2000; Meek *et al.* 2003), diet (King 1984; Fox *et al.* 1994; Read and Tweedie 1996), reproductive behaviour (Meek 2002), home range (Townley 2000; Meek 2002), and habitat use (Gynther *et al* 1996; Read and Tweedie 1996; Smith *et al* 1996; Catling and Burt 1997; Meek 2002) of *P. oralis* have been described, and recently summarized by Pyke and Read (2002).

An understanding of the ecology of the species is essential for its conservation, especially with regards to protecting suitable habitat, as habitat alteration and fragmentation have been listed as a possible threat to the species (NSW NPWS 2003). A model for predicting the suitability of habitats for *P. oralis* has been drawn up as part of the Draft Recovery Plan for the species (NSW NPWS 2003) based on existing records of captures and habitat characteristics of these areas.

A three-stage process is used to determine *P. oralis* habitat under the current model (NSW NPWS 2003). Initially, a Geographical Information System (GIS) based landscape-scale model (Smith *et al.* 1996) is consulted to see if the survey location falls inside, or within two km of the boundaries of the predicted range of the species. If the location is inside the range, the broad habitat type is assessed for the presence of suitable habitat (wet or dry sclerophyll forest or woodland with a grassy or heathy understorey), and if present, within site features are used to predict suitable micro-habitat for *P. oralis* (Smith and Quin 1997). At the site scale, the amount of grass, sedge and rush cover, heath cover and species composition, and the presence of logs and holes are all scored in the model, with the total score providing the quality of habitat for the mice. Based on this rating there are legislative requirements for surveys of high and medium quality habitats, and restrictions are placed on activities such as development or logging if *P. oralis* is detected (NSW NPWS 2003). The micro-habitat model was built using the fairly limited information on *P. oralis* habitat use available at the time (26 mouse presence and 18 absence sites), and to date has not been modified or reassessed. A large number of surveys have now been completed for the species, particularly by Forests NSW as part of their pre-logging surveys. However, quantitative assessment of micro-habitat features has rarely been conducted (P. Meek pers. comm. 2004, Forests NSW), and the three-stage assessment process remains statistically untested. In an intensively studied population in the Marengo/Mount Hyland region in north-east NSW, captures frequently occur in areas such as mid-slope elevations and in areas lacking sedge and rush cover, which are predicted by the micro-habitat model to be of low habitat quality for the species (Meek *et al* 2003). However, Meek (2002) found that canopy cover as well as fallen logs, (either natural, or head and butt residues a result of logging operations) are also important to habitat use by *P. oralis*; broad habitat categories that are included in the current assessment process.

This paper examines the habitat use of *P. oralis,* captured at a forest edge at Marengo State Forest, north-east NSW. The study area falls outside the predicted geographic range of the species, as determined by proximity to forest edge, and is therefore deemed unsuitable habitat using the existing three-stage model. Habitat use at the shrub-layer and ground-cover scale was examined and compared with the habitat available in this forest edge environment. The preference of *P. oralis* for each habitat component was also investigated, to gain an understanding of the mechanisms by which the mouse could persist in predicted low-quality habitat.

Materials and Methods

Live trapping was undertaken at Marengo State Forest (30° 3' S, 152° 28' E) during August 2003. Grids were set up in areas where *Pseudomys oralis* had been captured during previous small mammal surveys (Graham 2003). A trapping grid (Grid A) was set up (AMG 441836E 66693405N) with three lines of eight Elliott traps (type A traps, Elliott Scientific Equipment Ltd., Upwey, Victoria), set at distances of 10, 25 and 50 m from the forest edge. Each line consisted of eight traps set 10 m apart (total length = 80 m), giving a total area for the grid of 0.4 ha. A second grid (Grid B) was marked 250 m to the west along the forest edge (AMG 441597E 6669486N) which was delimited by a fenceline. On this grid, 24 Elliott traps were set in three lines of eight, with a distance of 25 m between lines and 10 m between traps.

Traps were set for four consecutive nights from 9 to 13 August 2003 and checked between 0600 and 0800 each morning. Any captured *P. oralis* were kept in the trap in a cool dark place until dusk, and additional bait was supplied as a supplementary food source. At dusk, the weight, tail length, head length, foot length (in mm) and sex of each animal was recorded. Copper ear tags were used to identify individuals (Hauptner tags: Siepar and Co. Pty Ltd, Silverwater, NSW).

Spooling was carried out following the techniques outlined in Meek (2002; see also Boonstra and Craine 1986; Key and Woods 1996). The spools used were cotton bobbins (2.5 cm x 1cm) containing 250 m of cotton (Coates Australia, Pty Ltd). These were wrapped in electrical tape and the total weight was less than 4g. The spools were attached with Vet Bond (3M, Pymble, NSW) to the animal's skin between the shoulder blades just behind the skull. The fur was parted and the spool was glued directly onto the skin. The parted fur was also glued to the outside of the spool to ensure attachment and to reduce spool loss, as *P. oralis* is known to lose fur easily (Meek 2002). Animals were released at the capture site at dusk. The free end of the spool line was tied off immediately before the animal was released, and care was taken to be quiet and move away slowly when releasing the animal so as not to disturb its foraging behaviour. Nevertheless, the first five metres of the spool line was always discounted in the analysis, as in some cases these first five metres may represent flight and not foraging behaviour (Haby 2000).

The following morning the string was followed to the end and a description of the shrub-layer canopy cover and ground cover vegetation used was made for each section of traverse made by the animal (see below for categories used). A section was defined as a straight section of spool line with a new section starting when the animal turned a corner. Each corner was also tagged and the coordinates recorded using a hand-held GPS unit. For each section of the spool line, the percentage of the traverse in each shrub- and ground-layer habitat category was visually estimated to the nearest 5%.

Shrub-layer habitat characteristics largely consisted of shrub-layer canopy types, so cover was estimated separately for fern, grass (primarily *Lomandra* spp.), heath (primarily *Leptospermum* spp.), scrub (primarily *Tasmannia stipitata*), sedge (Cyperaceae and Juncaceae), log (fallen timber with a diameter > 10 cm) and vine (*Rubrus* spp.). The shrub-layer cover percentage was visually assessed to the nearest 5% at a height of 1-2m, the height that cover is most likely to be perceived by a ground-foraging species such as *P. oralis* (Meek 2002). Ground-cover variables include the types of ground cover that were used by *P. oralis* as it moved through the habitat. For each section of spool line, the actual cover type that the cotton lay upon was scored as the used habitat. The following categories were used: fern, litter, grass (Poaceae and *Lomandra longifolia*), log (on), log (in), log (under), rock, sedge, creek, herb (*Glycine* spp. *Oxalis* spp. *Viola* spp.), vine, earth, and moss. Log (on) was when the individual ran along the top of a fallen log; log (in) was when *P. oralis* ran into a hollow log and either out the same hole or out another hole in the log; and log (under) when the animal ran along underneath a log.

Available shrub- and ground-layer habitat was assessed at each trap site (24 traps per grid), after choosing a point five metres from the trap on a random compass bearing. A five metre transect was laid out from this point on the same bearing and the habitat was assessed along the transect using the same variables employed to score *P. oralis* habitat use.

Statistical Analyses

One-way ANOVAs (equivalent to Student's t-tests with two levels of the independent categorical variable; Sokal and Rohlf 1995) were used to assess differences in the total shrub-layer canopy cover used by *P. oralis* and the total shrub-cover available, and for each individual shrub-layer habitat category. ANOVAs were performed using PROC ANOVA in SAS Version 8.0 (SAS Inc 2000), after checking for homogeneity of variances using Levenes test (Quinn and Keough 2002). The differences between *P. oralis* habitat use and available habitat for categories that exhibited significant heterogeneity of variances were compared using Welch's test (Day and Quinn 1989), which uses adjusted degrees of freedom to protect against Type 1 errors (Sokal and Rohlf 1995). Due to the limited number of captures recorded during the study, the data from all spooling events were pooled to increase the sample size. This resulted in the inclusion of two spooling sessions from the same individual mouse, potentially reducing the independence of the data. However, the primary aim of the study was to gain an understanding of activity and habitat selection of a rare species in an unusual habitat, and consequently the decision was made to include all records in the dataset to allow the use of more powerful statistical techniques. It was anticipated that this would allow the identification of general patterns of habitat selection and highlight areas for future study.

The total distance travelled by each individual mouse was broken into 10 m sections. The first section of spool line (sections delineated by turns made by the mouse) to start after each successive 10 m section marker was taken as a sample of *P. oralis* habitat use. The average length of each spool line section was 3.82 m, and consequently a distance of 10 m between sampled sections was assumed to give independent samples of individual habitat selection. The data from the shrub- and ground-layer habitat assessments were analysed separately to investigate the importance of scale in determining habitat use. Vine was not included in the shrub-layer analysis as none was found in the habitat or used by *P. oralis.* Discriminant function analysis (SYSTAT 9.0, SPSS 1998) was used to compare the overall habitat used by *P. oralis* with the available habitat in each habitat layer. Discriminant function analysis is a constrained ordination technique which finds the axis through a cloud of points that best discriminates between *a priori* defined groups. This is achieved by maximising the between-group variance relative to within-group variance. The analysis derives linear equations that characterise the groups in terms of the original independent variables (Dillon and Goldstein 1984). The use of multivariate methods such as discriminant function analysis is recommended over univariate techniques for use in habitat selection studies where there are many correlated and potentially interacting factors (Reinert 1993). Prior to analysis, all percentage cover variables were arcsin transformed to meet the assumptions of the ANOVA and DFA analyses (Sokal and Rohlf 1995).

Results

A total of five *P. oralis* captures were recorded during the study, of which four were spooled (three on Grid A and one on Grid B). The average total length of spool line for the four mice was 164.4 m (median = 165.7, range 93.6 – 232.6 m), while each individual section was 3.8 m long on average (range 0.3 – 12.4 m). A typical spool line is shown in Figure 1. The individual crossed a creek line before heading away from the creek and appearing to engage in two bouts of foraging, where large numbers of short traverses were made in small areas. The animal then made a number of long straight movements, before recrossing the creek on a log. Shortly after, the spool line finished 186 m from the start of the line.

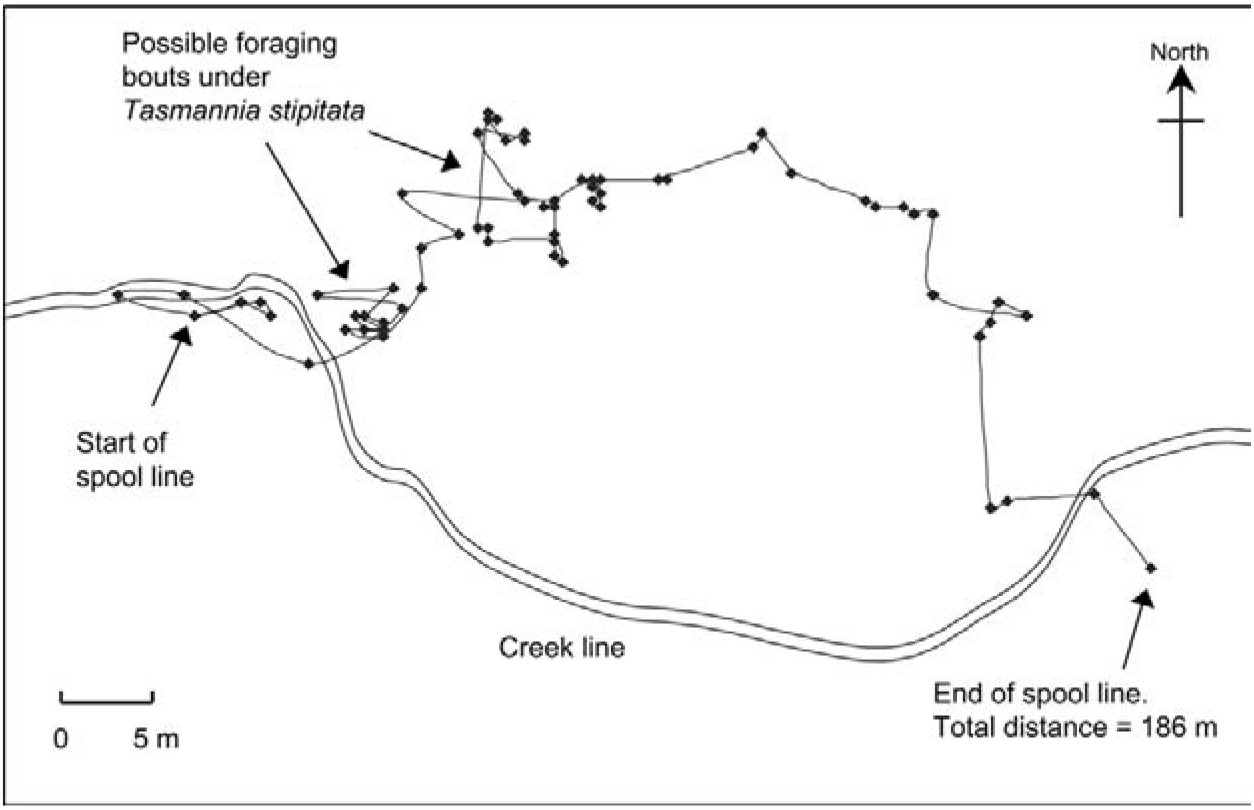

Figure 1. Diagrammatic representation of the spool line of *P. oralis* (4098) caught on Grid A at Marengo State Forest, north-east NSW.

Overall, there were no significant differences between the available ground-cover habitat on the two trapping grids (Pillai's trace = 0.246, $F_{8,39}$ = 1.59, $P > 0.05$). In addition, there was no significant difference in the total percentage shrub-layer canopy cover on the two grids ($F_{1,46}$ = 1.79, $P > 0.05$). However, there were some differences in the composition of this layer, with significantly more scrub present on Grid A (Grid A = 56.0 % of canopy cover, Grid B = 14.6 % of canopy cover; Welch's weighted variance ANOVA $F_{1,37.4}$ = 6.21, $P = 0.02$) and more sedge on Grid B (Grid A = 14.6 %, Grid B = 57.3 %; Welch's weighted variance ANOVA $F_{1,34.6}$ = 7.27, $P = 0.01$). Although they may be selected as cover *per se*, shrub-layer plants are not used as a foraging resource by *P. oralis*, and consequently the habitat assessments from the two grids were pooled for analysis.

Shrub-layer habitat use

When information from all spooled *P. oralis* was combined, the shrub-layer canopy cover type with the highest proportional use was scrub (Figure 2), consisting mostly of *Tasmannia stipitata* at a height of 1-1.5 metres. This cover was dense in parts, often constituting 80 – 100% of the cover on a spool line section. The second highest proportional use was in heath, which was generally found in moister areas.

Overall, the shrub-layer habitat selected by spooled *P. oralis* was significantly different from the available habitat (Pillai's trace = 0.435, $F_{6,103}$ = 13.20, $P < 0.001$). The raw and standardised canonical variables are shown in Table 1. The analysis correctly classified 78 % of the records (Jacknife estimate). The absolute magnitude of the standardised canonical variables indicates the contribution of each habitat category to the discriminant function. The percentage cover of heath, scrub and logs were the most important components of the discriminant function.

Overall, 76.1 % of the spool line was found under some form of shrub-layer canopy, which was significantly higher than the amount of canopy cover that was available in the habitat ($F_{1,108}$ = 64.21, $P < 0.001$). A similar pattern was seen with the individual categories heath, scrub and logs, where the mean percentage used by *P. oralis* was significantly greater than the mean percentage available (Table 1). The opposite pattern emerged for grass and sedge with a higher mean percentage occurring in the habitat than is used by *P. oralis* (Figure 2).

Ground-layer habitat use

Leaf litter was the micro-habitat category most frequently traversed by *P. oralis*, with 49.8 % of the distance traversed by each mouse being over litter. Logs were also regularly used, with the three classes of log use; log (on), log (in) and log (under) together comprising around 10 % of the total habitat use.

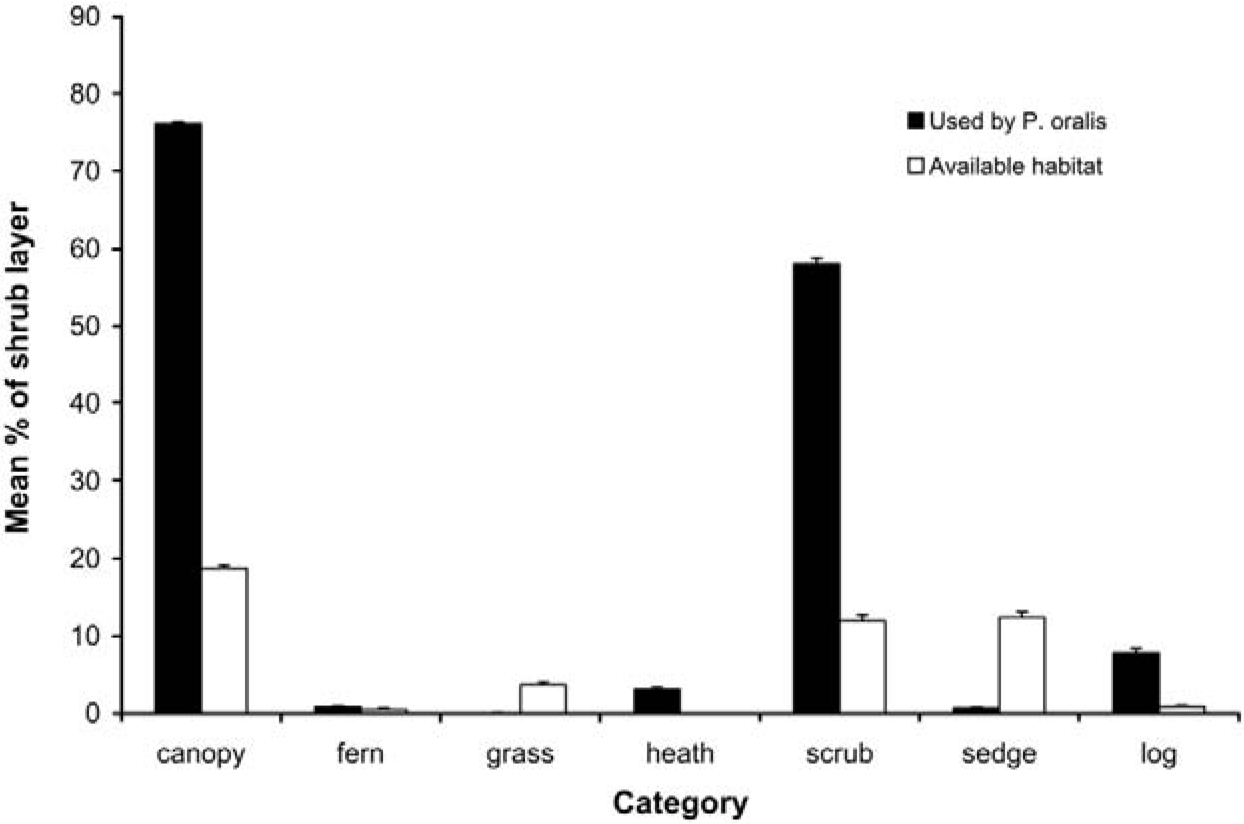

Figure 2. Shrub-layer cover type use by *P. oralis* at Marengo State Forest, NSW with respect to habitat availability. The distance spent under each canopy type is expressed as a percentage of the total distance each spooled animal spent under cover and is compared with the percentage of that habitat characteristic available in the area (n = 62 for habitat used by *P. oralis*, n = 48 for available habitat). Canopy was calculated by pooling the proportion of the spool line under all shrub-layer categories for P. oralis and the available habitat transects.

Table 1. Values of raw and standardised coefficients for the discriminant function analysis of habitat characteristics for macro-habitat used by *P. oralis* (n = 62) and available habitat (n = 48) at Marengo State Forest, NSW. F-ratios are for univariate comparisons between habitat used by *P. oralis* and available habitat. All tests are one-way ANOVAs unless denoted by superscript, in which case Welch's weighted-variance ANOVAs were employed.

Macro--habitat category	Raw canonical co-efficient	Standardized canonical co-efficient	Mean (SD) % of *P. oralis* habitat	Mean (SD) of available habitat	F-ratio (df = 1,163)
Fern	1.495	0.420	0.79 (9.45)	0.49 (5.32)	0.01^{ns}
Grass	-0.236	-0.076	0.06 (3.93)	3.70 (17.67)	3.37^{ns}
Heath	2.588	0.820	3.10 (16.76)	0.00 (0.00)	4.05^{*}
Scrub	1.662	1.105	58.00 (42.03)	11.98 (32.62)	$27.76^{**\,1}$
Sedge	-0.146	-0.063	0.63 (6.44)	12.39 (30.45)	2.75^{*}
Log	1.747	0.834	7.86 (30.29)	0.86 (8.09)	$15.84^{*\,2}$
Constant	-1.744				

[1]Welch's weighted variance ANOVA d.f. = 1, 151.6
[2]Welch's weighted variance ANOVA, d.f. = 1, 77.8

The mean percentage distances spent by spooled *P. oralis* in each micro-habitat are shown in Figure 3. Overall there were significant differences between the micro-habitat used by *P. oralis* and the habitat available (Pillai's trace = 0.579, $F_{12,97} = 11.11$, $P < 0.001$), with the discriminant function analysis correctly assigning 80% of the records to the correct group (Jacknife estimates). The percentage occurrence of litter, grass, sedge, fern and log (on) were the most important components of the discriminant function (Table 2). *Pseudomys oralis* used the litter category significantly more than it was available ($F_{1,163} = 7.98$, $P = 0.005$), and used grass (Welch's weighted variance ANOVA $F_{1,161} = 37.01$, $P < 0.001$) and rock ($F_{1,163} = 4.05$, $P = 0.04$) significantly less than they were available. There were no other significant univariate differences between used and available habitat, and there were no significant correlations between any of the macro- and micro-habitat variables (Spearman Rank Correlations, all $P > 0.05$).

Discussion

The patterns of habitat use of *P. oralis* in this study add to our understanding of the habitat requirements of this poorly known species. Other studies assessing habitat use of *P. oralis* have either not compared the habitat used with the available habitat (Meek 2002), or have

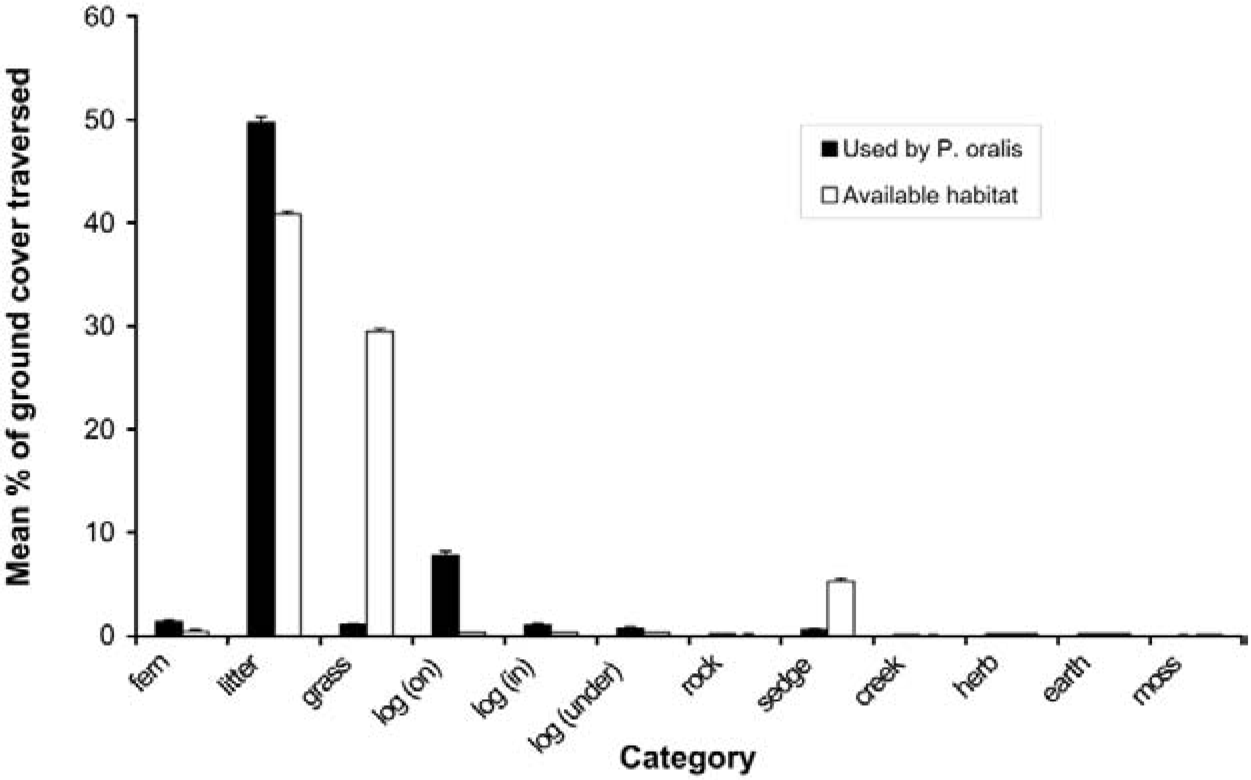

Figure 3. Ground-cover micro-habitat traversed by *Pseudomys oralis* at Marengo State Forest, NSW. The length of spool line on each ground cover type is expressed as a percentage of the total distance travelled and is compared with the percentage of that habitat characteristic available in the area (n = 62 for habitat used by *P. oralis*, n = 48 for available habitat).

Table 2. Values of raw and standardised coefficients for the discriminant function analysis of habitat characteristics for micro-habitat used by *P. oralis* (n = 62) and available habitat (n = 48) at Marengo State Forest, NSW. F-ratios are for univariate comparisons between habitat used by *P. oralis* and available habitat. All tests are one-way ANOVAs unless denoted by superscript, in which case Welch's weighted-variance ANOVAs were employed.

Macro--habitat category	Raw canonical co-efficient	Standardized canonical co-efficient	Mean (SD) % of *P. oralis* habitat	Mean (SD) of available habitat	F-ratio (df = 1,163)
Fern	3.431	1.037	1.33 (11.10)	0.43 (5.90)	2.79^{ns}
Litter	3.452	1.768	49.72 (32.15)	40.87 (12.54)	7.98^{**}
Grass	6.214	1.860	1.07 (5.30)	29.49 (12.98)	$37.01^{**\ 1}$
Log (on)	3.060	1.217	7.77 (24.96)	0.32 (0.80)	0.53^{ns}
Log (in)	2.863	0.738	1.00 (10.75)	0.32 (0.80)	0.001^{ns}
Log (under)	3.055	0.722	0.70 (8.98)	0.32 (0.80)	0.90^{ns}
Rock	3.615	0.260	0.01 (0.75)	0.01 (0.21)	4.05^{*}
Sedge	4.532	1.376	0.56 (6.16)	5.27 (12.46)	$3.55^{ns\ 2}$
Creek	-0.615	-0.038	0.02 (0.59)	0.01 (0.11)	1.64^{ns}
Herb	3.888	0.238	0.01 (0.42)	0.01 (0.32)	0.03^{ns}
Earth	1.082	0.106	0.06 (1.38)	0.04 (0.40)	2.70^{ns}
Moss	8.248	0.305	0.00 (0.00)	0.01 (0.32)	0.98^{ns}
Constant	-6.608				

[1.]Welch's weighted variance ANOVA, d.f. = 1, 161.
[2]Welch's weighted variance ANOVA, d.f. = 1, 162.6

investigated only the habitat characteristics of successful trap sites compared with surrounding habitat (King 1984; Read and Tweedie 1996). This study combines the benefits of both types of studies by comparing records of habitat use during foraging activity with quantification of the habitat that is available.

Habitat use by *P. oralis*

Canopy cover at a height of 1 – 2 m emerged as the most important habitat feature used by *P. oralis*. Specifically, heath, logs and scrub were selected as preferred macro-habitat. There did not appear to be specific selection for any particular species of plants, although the shrubs present in the area were mainly *Tasmannia stipitata*. Fern and sedge appeared to be selected against with more being available in the environment than was used by *P. oralis*. Early studies of the species identified associations between *P. oralis* and watercourses and bogs, as well as ground-cover species such as *Poa* and *Carex* (King 1984; Read 1993b). Most records of *P. oralis* in these studies were within 2 m of a watercourse, where sedge species provided the majority of cover used by the mice. Subsequently, other suitable habitats have been identified in midslope and upslope areas, with sedge plants deemed as less important features of suitable habitat in these areas (Read 1993b; Tanton 1995; Keating 2000; Meek 2002). Fern and log canopy cover have been found to be important in these habitats and were used extensively by *P. oralis* as cover during foraging (Meek 2002).

In the current study there were strong relationships between *P. oralis* and both dense shrub-layer canopy cover, and with some of the micro-habitat variables. The ground-layer habitat within each canopy cover was quite variable and not significantly correlated with any particular canopy type, and it was common to find many micro-habitats (e.g. grass, litter and bare ground) under one type of canopy. It appears from this study that the habitat selection of *P. oralis* is primarily for vegetation cover at the macro-habitat scale, consistent with the general patterns for small mammals (Knight and Fox 2000; Maitz and Dickman 2001; Williams *et al* 2002). Possible reasons for this may include the availability of nest sites or suitable foraging habitat as well as protection from predation (Knight and Fox 2000; Maitz and Dickman 2001). However, there was some selection exhibited at the ground-layer level, with litter used more and rocks and grass used less than available. Leaf litter may contain higher proportions of seeds, fungi and other food resources than other ground-layer habitat types, although this could not be determined from our data. Nevertheless, it appears that as a consequence of primary habitat selection at the shrub-layer, the ground-layer habitat use of *P. oralis* may be to be variable and unpredictable, but must presumably still allow the species to access sufficient food resources while foraging.

Interestingly, under the current three-stage assessment of suitable habitat for *P. oralis*, the current study site falls outside the predicted range of the species (at the first level in the assessment process), due to the site's proximity to the forest edge, and a modelled negative relationship between proximity to cleared land and mouse presence (NSW NPWS 2003). This relationship has been attributed to the negative impacts of edge effects, particularly exotic mammalian predators, on the species. As a consequence, habitat within two kilometres of extensive clearing is classified as unsuitable for the species, and Forests NSW is not required to undertake targeted pre-logging surveying in such areas (Integrated Forestry Operations Agreement, NSW National Parks and Wildlife Service 2003). The results from the current study, however, suggest that edge habitat may in fact be suitable for *P. oralis*, and the site-scale habitat use observed is in general agreement with the predictions of the existing micro-habitat model (Smith and Quinn 1997). Edge habitats are frequently characterised by higher light levels and increased density and structural complexity of ground and shrub-layer vegetation (Chen *et al.* 1992; Murcia 1995), conditions known to be suitable for *P. oralis* (Smith and Quin 1997; Townley 2000; Meek 2002; Pyke and Read 2002; NSW NPWS 2003), and found in the current study site. Additionally, *P. oralis* has a relatively broad diet compared with other Pseudomyiidae (Fox *et al.* 1994; Smith *et al.* 1996; Townley 2000; Pyke and Read 2002; NSW NPWS 2003), that may allow it to exploit the food resources present in edge habitat. The findings presented here suggest that within the general range of the species, the specific conditions at a site may be as or more important than geographical location in determining habitat suitability and presence of *P. oralis.* Our results, and the existence of a large dataset of recent positive and negative survey results for the species, suggest that the accuracy and applicability of the current GIS-based geographic range model should be reassessed.

Implications for management

The model used for *P. oralis* management first predicts occurrence based on the landscape-scale model, and then predicts the suitability of habitat focussing on ground cover types, including grass, sedge and rush, vegetation cover up to 75 cm, number of logs and holes and the number of specific species of heath (NSW NPWS 2003). The scores obtained in each of these categories are then summed and the suitability of the area for the species is determined. The results of this study and previous work in the same site suggest that more emphasis should be placed on the canopy cover at 1-2 m regardless of the species composition. In our study, this canopy level is dominated by shrubs, while in a second study in the same general area; the 1-2 m canopy was dominated by ferns, with a diverse ground cover layer of grasses, herbs and leaf litter present at both sites (Meek 2002). In both areas *P. oralis* used this habitat in preference to open areas. The availability of shelter sites such as hollow logs was also shown to be important for the species, as recommended in the micro-habitat model (Smith and Quin 1997), and were utilised during foraging. Consequently these should be retained in the model. Sedge and grass were actually selected against in this study with a greater percentage of cover of these types of plants being available than was used by *P. oralis*. This suggests that the previously described preference by the species for these plants may have partially been a result of early captures occurring near watercourses where sedges and grasses dominate. When *P. oralis* was tracked near a watercourse in the current study they did use sedge for cover, although overall the mouse was not found to select for this type of habitat. It should be noted however that the results of this study come from a small dataset of only four individual mice, and so care must be taken when extrapolating these findings to the species as a whole.

Clearly, the specific relationships between habitat requirements, individual behaviour and habitat availability require further clarification. To date, the vast majority of surveys for *P. oralis* have not included quantitative assessment of the available habitat as specified under the micro-habitat model (NSW NPWS 2003). Therefore, while there is qualitative information available on *P. oralis* habitat use, there is no empirical evidence with which to statistically test the accuracy and efficacy of the existing model. All future surveys should record habitat composition and structure, as specified by Smith and Quin (1997), to allow the validation and refinement of the current micro-habitat model.

Acknowledgements

The authors wish to thank Paul Meek from State Forests NSW for assistance with the project and the development of the spooling technique, and to Suzanne Bassett for suggestions on earlier versions of the manuscript and discussions on the project.

References

Boonstra, R., Craine, I.T.M. 1986. Natal nest location and small mammal tracking with a spool and line technique. *Canadian Journal of Zoology* **64:** 1034-1036.

Catling, P.C., Burt, R.J. 1997. Studies of the ground-dwelling mammals of eucalypt forests in north-eastern New South Wales: The species, their abundance and distribution. *Wildlife Research* **24:** 1-19.

Chen, J., Franklin, J.F., Spies, T.A. 1992. Vegetation responses to edge environments in old-growth douglas fir forests. *Ecological Applications* **2:** 387-396.

Day, R.W., Quinn, G.P. 1989. Comparison of treatments after an analysis of variance in ecology. *Ecological Monographs* **59:** 433-463.

Dillon, W.R., Goldstein, M. 1984. *Multivariate Analysis.* John Wiley and Sons, New York.

Fox, B.J., Read, D.G., Jefferys, E., Luo, J. 1994. Diet of the Hastings River Mouse (*Pseudomys oralis*). *Wildlife Research* **21:** 491-505.

Graham, K.L. 2003. Fauna responses to hard and soft edges in eucalypt forests. B.Sc (Honours) thesis, The University of Sydney.

Gynther, I., Townley, S., O'Reilly, P. 1996. New records of the Hastings River Mouse *Pseudomys oralis* from the Lamington Plateau, south-east Queensland. Pp. 30in *Australian Mammal Society Newsletter*.

Haby, N. 2000. Micro-habitat utilisation by the Southern Brown bandicoot, *Isoodon obesulus obesulus*, at Cox Scrub Conservation Park, South Australia. B.Sc (Honours) thesis, Adelaide University.

Keating, J. 2000. Factors affecting the distribution of two rare mammals at Grady's Creek, Border Ranges National Park, north-east NSW. B.AppSc. (Honours) thesis, Southern Cross University.

Key, G.E., Woods, R.D. 1996. Spool and line studies on the behavioural ecology of rats (*Rattus* spp) in the Galapagos Islands. *Canadian Journal of Zoology* **74:** 733-737.

King, G.C. 1984. Habitat utilized by *Pseudomys oralis* Thomas (Rodentia: Muridae). *Australian Mammalogy* **7:** 139-147.

Knight, E.H., Fox, B.J. 2000. Does habitat structure mediate the effects of forest fragmentation and human-induced disturbance on the abundance of *Antechinus stuartii*? *Australian Journal of Zoology* **48:** 577-595.

Maitz, W.E., Dickman, C.R. 2001. Competition and habitat use in native Australian *Rattus*: is competition intense, or important? *Oecologia* **128:** 526-538.

Meek, P.D. 2002. Radiotracking and spool-and-line study of the Hastings River Mouse *Pseudomys oralis* (Muridae) in Marengo State Forest, NSW. State Forests of New South Wales, Coffs Harbour.

Meek, P.D., McCray, K., Cann, B. 2003. New records of Hastings River Mouse from State Forests of New South Wales pre-logging surveys. *Australian Mammalogy* **25:** 101-105.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. *Trends in Ecology and Evolution* **10:** 58-62.

New South Wales National Parks and Wildlife Service. 2003. Draft Recovery Plan for the Hastings River Mouse (*Pseudomys oralis*). NSW NSW NPWS, Hurstville.

Pyke, G.H., Read, D.G. 2002. Hastings River Mouse *Pseudomys oralis*: A biological review. *Australian Mammalogy* **24:** 151-176.

Quinn, G.P., Keough, M.J. 2002. *Experimental Design and Data Analysis for Biologists.* Cambridge University Press, Port Melbourne

Read, D.G. 1993a. Body size in Hastings River Mouse *Pseudomys oralis* (Rodentia: Muridae) from new and old locations. *Australian Zoologist* **29:** 117-123.

Read, D.G. 1993b. Prescriptions for the identification of habitats of the Hastings River Mouse *Pseudomys oralis* (Rodentia: Muridae). Research Division Forestry Commission of New South Wales, Sydney.

Read, D.G., Tweedie, T.D. 1996. Floristics of habitats of *Pseudomys oralis* (Rodentia: Muridae). *Wildlife Research* **23:** 485-493.

Reinert, H.K. 1993. Habitat selection in snakes. Pp. 201-240 in Snakes: ecology and behaviour. (Eds R.A. Seigel and J.T. Collins). (McGraw-Hill, New York)

SAS Institute Inc. 2000. SAS Version 8.0 for Windows. (SAS Institute Inc: Cary, NC).

Smith, A.P., Phillips, C., Townley, S. 1996. Diet and habitat preferences of the Hastings River Mouse (*Pseudomys oralis*) (Rodentia: Muridae). NSW National Parks and Wildlife Service, Coffs Harbour.

Smith, A.P., Quin, D.G. 1997. Micro-habitat requirements of the Hastings River Mouse (*Pseudomys oralis*) (Rodentia: Muridae). NSW National Parks and Wildlife Service, Coffs Harbour.

Sokal, R.R., Rohlf, F.J. 1995. *Biometry: the Principles and Practices of Statistics.* W. H. Freeman, New York.

SPSS Statistical Software. 1998. SYSTAT Version 9.0 for Windows. (SPSS Inc: Chicago).

Tanton, M.T. 1995. Proposed forestry operations in the Tenterfield Management Area. Volume D. Environmental Impact Statement. Fauna Impact Statement. State Forests NSW, Sydney.

Townley, S. 2000. The ecology of the Hastings River Mouse *Pseudomys oralis* (Rodentia: Muridae) in northeastern New South Wales and southeastern Queensland. PhD thesis, Southern Cross University.

Williams, S.E., Marsh, H., Winter, J. 2002. Spatial scale, species diversity, and habitat structure: Small mammals in Australian tropical rain forest. *Ecology* **83:** 1317-1329.