HASTINGS RIVER MOUSE *PSEUDOMYS ORALIS*: A BIOLOGICAL REVIEW

GRAHAM H. PYKE AND DAVID G. READ


The distribution and abundance of the Hastings River mouse (*Pseudomys oralis*) have declined since the Pleistocene, and it is now one of Australia's rarest mammals. It was presumed extinct until rediscovered in south-east Queensland in 1969. Because of this past, and apparently ongoing decline, as well as the nature and extent of known or presumed threats, *P. oralis* is considered threatened with extinction. Like other 'threatened' species, *P. oralis* is presently the subject of a recovery process, which aims to improve its conservation status. Essential to the development of a recovery strategy for any species is a reasonable knowledge of its biology and the nature and extent of threatening processes. While there has been considerable recent interest in the biology of *P. oralis* and possible threats to its populations, there has not been a comprehensive and detailed review of its biology. The present review indicates that the necessary information for developing a recovery strategy for *P. oralis* is lacking. Progress has been made in understanding habitat requirements and developing the ability to predict its presence or absence, as well as knowledge of the biology of individuals. However, we presently have little understanding of the population biology or community ecology of the species. We do not, in particular, know what factors determine the distribution and abundance of *P. oralis*, nor how these factors operate. In this situation we can potentially provide some protection for *P. oralis* through strategies that avoid or minimise human impacts on habitat areas, but a strategy aimed at species recovery is impossible.

Keywords: *Pseudomys oralis*, review, threatened, species recovery.

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THE Hastings River mouse (*Pseudomys oralis*: Muridae) is one of Australia's rarest mammals. It has been recorded from only about 50 locations, at most of these only a single individual has been captured, and the total number of individuals captured throughout Australia is only about 400 (King 1984; Dickman and McKechnie 1985; King and Mackowski 1986; Read 1993a,b; Poole 1994; Gynther and O'Reilly 1995 and see below). This number is, however, slowly increasing as a result of the current relatively high level of survey effort.

The distribution and abundance of *P. oralis* have declined since the Pleistocene (Watts and Aslin 1981; King 1984; Tweedie and York 1993; Fox *et al.* 1994; Martin 1995; Kirkpatrick 1995). Subfossil remains with estimated ages of 8,000 - 17,000 YBP (years before present) indicate that the range of the species once extended both north and south of its present distribution (Ride 1960; Lampert 1971; Wakefield 1967, 1972; Flood 1972; Hope 1982, 1984, 1987; Fox *et al.* 1994; Himan 1994; Morris *et al.* 1997). In parts of these deposits the proportion of bones from *P. oralis* is relatively high, suggesting that the species was previously reasonably abundant (Ride 1960; Wakefield 1967, 1972; Schram and Turnbull 1970; Hall 1975; Hope 1982, 1987).

Some of the decline of *P. oralis* may have occurred since European settlement and *P. oralis* is presently thought to be under threat from a variety of factors, including predation by cats (*Felis catus*) and foxes (*Vulpes vulpes*), inappropriate fire regimes, logging and grazing (Tweedie and York 1993; Smith and Quin 1996; Dickman *et al.* 2000a,b). In addition, some populations have apparently disappeared during the last few years, suggesting a continuing decline (G. King, pers. comm.; Read 1988a; pers. obs.).

Because of the decline in *P. oralis* numbers and the nature and extent of known or presumed threats, it is generally considered to be threatened with extinction. It is listed as ‘Endangered’ under New South Wales (NSW) and Commonwealth legislation and as ‘Vulnerable’ in Queensland (Qld) (Meek and Triggs 1999). It is also listed as ‘Endangered’ in the Rodent Action Plan (Lee 1995).
Like other ‘threatened’ species, *P. oralis* is presently the subject of a recovery process, which aims to achieve an improvement in its conservation status. Under NSW, Qld and Commonwealth legislation a Recovery Team must be developed and this team must develop or arrange recovery strategies that will guide decisions and actions by government agencies in ways that will benefit this species. A Recovery Team for *P. oralis* has been in operation since 1992 and a Preliminary Draft Recovery Strategy has been produced but not yet released for public comment (A. Smith, pers. comm.).

Essential to the development of a recovery strategy is a comprehensive knowledge of species’ biology and the nature and extent of threatening processes. Only then may it be possible to develop positive habitat management strategies for the species and arrest or reverse its decline.

Since about 1986 there has been considerable interest in the biology of *P. oralis* and in possible threats to its populations. During this period there have been newly discovered populations (King and Mackowski 1986; Read 1989a,b,c, 1993c, 1994; Poole 1994; Gynther and O’Reilly 1995), studies of diet (Fox et al. 1993, 1994), habitat use (Read 1993c; Read and Tweedie 1996; Smith and Quin 1996), distribution (Mackowski et al. 1996) and population biology (Townley 1997), as well as numerous discussions of its biology and possible impacts of various human activities (especially forestry) (e.g., MRC 1992; MKES 1992a,b, 1993, 1995; Sinclair Knight 1992; Smith et al. 1992, 1994, 1995; Andrews et al. 1994; MGP 1994; AMBS 1995a,b; Ecotone Consultants 1995; Fanning 1995; Lim 1995; Martin 1995; SFNSW 1995a,b,c, 1996; Tanton 1995a,b,c, 1996). Earlier publications focused on its initial discovery (Thomas 1921; Tate 1951), its presence in sub-fossil bone deposits (Ride 1960; Wakefield 1967, 1972; Schram and Turnbull 1970; Flood 1972; Hall 1975; Attenbrow 1981, 1982; Hope 1982, 1984, 1987; Morris et al. 1997), its rediscovery in Qld (1969) and NSW (1981) after being presumed extinct (Kirkpatrick and Martin 1971; Hughes 1982; King and Chapman 1983), and subsequent surveys to locate further populations (Dickman 1984; Dickman and McKechnie 1985; Read 1988b,c, 1989c). This interest in *P. oralis* is ongoing, especially through the activities of the Recovery Team. *P. oralis* is also the subject of several current research projects (S. Townley, pers. comm.; A. Smith, pers. comm.).

Despite the interest in *P. oralis*, there is yet to be a comprehensive review of its biology. Here we review all available information on the biology of *P. oralis*; consider any implications for the recovery and/or management of the species and consider further research that could benefit the recovery process and our understanding of its biology.

### METHODS

In reviewing available information on *P. oralis* we considered about 150 documents (including unpublished documents), as well as observations made by one of us (DGR) during surveys carried out since 1987. In all cases, *P. oralis* surveys carried out by Read (1988b,c, 1989c) have involved one or more lines of Elliott traps, with trap-lines 5 - 30 m apart and with traps about 5 - 8 m apart along each line, baited with peanut butter and rolled oats and left *in situ* for up to 10 nights.

This review was developed using the strategy recommended in Pyke (2001). We divide our review into sections based on the level at which observations regarding the species are focused (i.e., species, individual, population, biological community), how these were made, and issues such as conservation and management of the species. Within each of these sections there are also sub-sections that reflect what is known about this species.

### Biological Review: Hastings River mouse *Pseudomys oralis*

#### Species biology

**Identification**

*Pseudomys oralis* is a relatively small mammal. It ranges from 55 – 110 g in body mass (Table 1; Kirkpatrick 1995; SFNSW 1995c) and from 125 – 170 mm in combined head/body length (Table 1; Hyett and Shaw 1980; Kirkpatrick 1995) with a tail length of 120 – 165 mm (Table 1; Hyett and Shaw 1980).

*Pseudomys oralis* may be distinguished from other mammals on the basis of its hair, bones or fur-colour along the tail and around the eye. It is rat-shaped and generally covered with short, soft hair. In adults, the body hair is brownish-grey above and buff to greyish-white below, the tail is clearly two-tone, being dark brown above and white below, and the feet are distinctly white. Descriptions are included in Thomas (1921), Hyett and Shaw (1980), Watts and Aslin (1981), Dickman (1984), Tweedie and York (1993) and Kirkpatrick (1995). Diagnostic external features which distinguish this species from other rodents found in sympatry are a narrow 1 mm band of black fur surrounding the eye, and a tail with black hair on the dorsal surface and white hair on the underside (Read 1993a; Kirkpatrick 1995). Even juveniles show these features and so can be distinguished from smoky-grey coloured juveniles of other species. Generally, the species is very similar to, and can easily be confused with, the commonly...
sympatric bush rat *Rattus fuscipes*. In addition to these diagnostic features, *P. oralis* also differs from *R. fuscipes* in its lack of 'rat' smell, its tendency to leave Elliott traps relatively clean and its relatively placid behaviour when captured (Read 1993a; Keating 2000). Female *P. oralis* differ from *Rattus* species in having four teats (Watts and Aslin 1981). *P. oralis* can also be distinguished from other mammal species on the basis of certain features of its hair (Brunner and Coman 1974), some of its teeth, including the larger molars, and differences in the shape and size of bones in the skull (Watts and Aslin 1981). In particular its dental formula is I 1/1 C 0/0 PM 0/0 M 3/3, and the manus and pes each have five toes (Hyett and Shaw 1980).

**Distribution**

The species was presumed extinct throughout Australia until it was re-discovered in south-east Qld in 1969 (Kirkpatrick and Martin 1971; Covacevich and Easton 1974; Denny and Press 1982; Hughes 1982; Kirkpatrick 1983) and north-east NSW in 1981 (Denny and Press 1982; Hughes 1982; King and Chapman 1983; Figgis and Mosley 1993; Kirkpatrick 1995). Since then there has been a slow but steady increase in the number of recorded locations for the species (e.g., Read 1993a) with its discovery at about 50 different 'trapping locations' (i.e., capture sites or groups of capture sites that are at least 1 km apart) (Table 2; Fig. 1). Bones of *P. oralis* have also been found in recent owl pellets and scats of dingoes (*Canis lupus dingo*) and *V. vulpes* (Table 3). Within this current range, *P. oralis* has a scattered rather than continuous distribution (Fig. 1), being absent from most areas, including many where there seems to be suitable habitat (Kirkpatrick and Martin 1971; Watts and Aslin 1981; King and Chapman 1983; Dickman 1984; Dickman and McKechnie 1985; York 1992; Cockburn 1992; MKES 1995).

Sub-fossil remains suggest that the distribution of *P. oralis* expanded about 17,000 YBP. At the Pyramids Cave and Clogs Cave deposits at Buchan, Victoria (Vic.) the sub-fossil record indicates an earlier period when *P. oralis* was absent with remains of *P. oralis* being only present in deposits that are 17,000 YBP or younger (Wakefield 1967; Flood 1972). No remains of the species have so far been found in deposits older than 17,000 YBP (Table 4). After this expansion *P. oralis* was relatively common in some locations, accounting for about 20% of the individual animals present in several deposit layers (Table 4).

The sub-fossil record also indicates that the distribution of *P. oralis* from 10,000 to 17,000 YBP was about twice what it is today. Bones of *P. oralis* have been found in sub-fossil cave deposits from 15 locations (Table 4), demonstrating that its distribution previously extended significantly further south, reaching at least Buchan in eastern Vic. (Ride and Davis 1997; Table 4; Fig. 1), and also further north, reaching at least Maleny in south-eastern Qld (Table 4; Fig. 1). Sub-fossil remains with estimated ages of 10,000 and 17,000 YBP have also been found at Jenolan Caves and Wombeyan Caves, NSW which lie outside the current known distribution (Table 4). The extent of the sub-fossil distribution as measured by the distance from Maleny, Qld to Buchan, Vic. is 1,300 km, whereas the present distribution from Lamington, Qld to Newnes, NSW is only 650 km (Fig. 1). The sub-fossil record also suggests that there has been a contraction in elevation range for *P. oralis*. While some sub-fossil records lie at elevations within the current range, many are at lower altitudes (Table 4).

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**Table 1.** Body measurements for *P. oralis*. (Read 1993a, 1994; Mackowski et al. 1994; NSWNPWS 1996).

<table>
<thead>
<tr>
<th></th>
<th>Adult (male)</th>
<th>Adult (female)</th>
<th>Sub-adult (female)</th>
<th>Juvenile (male)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean ± s.e.</td>
<td>n</td>
<td>Mean ± s.e.</td>
</tr>
<tr>
<td>Head/body mm</td>
<td>16</td>
<td>147.8 ± 6.3</td>
<td>36</td>
<td>146.0 ± 8.4</td>
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<tr>
<td>(range)</td>
<td>135 - 160</td>
<td></td>
<td></td>
<td>(125 - 165)</td>
</tr>
<tr>
<td>Tail mm</td>
<td>15</td>
<td>143.1 ± 11.2</td>
<td>30</td>
<td>148.6 ± 9.9</td>
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<tr>
<td>(range)</td>
<td>120 - 160</td>
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<td>(130 - 165)</td>
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<td>Head mm</td>
<td>16</td>
<td>40.4 ± 1.1</td>
<td>37</td>
<td>40.5 ± 1.5</td>
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<tr>
<td>(range)</td>
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<td>(36.7 - 43.7)</td>
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<tr>
<td>Hind foot mm</td>
<td>16</td>
<td>32.2 ± 0.9</td>
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<td>(range)</td>
<td>(30.5 - 33.5)</td>
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<td></td>
<td>(28.2 - 33.7)</td>
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<tr>
<td>Mass g</td>
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<td>83.0 ± 12.9</td>
<td>55</td>
<td>77.3 ± 11.8</td>
</tr>
<tr>
<td>(range)</td>
<td>(60 - 110)</td>
<td></td>
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<td>(55 - 112)</td>
</tr>
</tbody>
</table>

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*Note:* *P. oralis* has a scattered rather than continuous distribution (Fig. 1), being absent from most areas, including many where there seems to be suitable habitat (Kirkpatrick and Martin 1971; Watts and Aslin 1981; King and Chapman 1983; Dickman 1984; Dickman and McKechnie 1985; York 1992; Cockburn 1992; MKES 1995).
These declines in distribution and elevation range for *P. oralis* appear relatively recent and may have coincided with European settlement of Australia. Estimated ages of many of the sub-fossil remains of *P. oralis* are no more than 1,000 YBP (Table 4). In one case, remains of *P. oralis* were present on the surface of the deposit (Table 4) and hence were quite recent. In four other cases the remains of introduced mammal species were found together with *P. oralis* in the same top layer of the deposit, indicating that *P. oralis* and these introduced species occurred near these locations at or around the same time (see Table 4). *P. oralis* has also been found in relatively young midden deposits left behind by indigenous Australians (Bowdler 1970). The decline of *P. oralis* may be continuing as the species has apparently disappeared from five sites during the last 15 years (see Section C1). However, genetic evidence suggests that *P. oralis* was in decline before the arrival of Europeans (Jerry et al. 1998).

**Taxonomy and phylogeny**

The genera *Pseudomys*, *Mastacomys* and *Notomys* form a monophyletic group within the rodent Family Muridae (Watts et al. 1992). While the genus *Pseudomys* is apparently polyphyletic (Watts et al. 1992), boundaries among the different phylogenetic groups are presently unclear and the genus is not currently subdivided (Baverstock et al. 1981; Watts et al. 1992). The genus *Mastacomys* has been synonymised with *Pseudomys* (Watts et al. 1992), which is presently believed to contain 26 Australian species (Mahoney and Richardson 1988; Musser and Carleton 1993; Lee 1995; Kirkpatrick 1995; C. Dickman pers. comm.; S. Van Dyck pers. comm.). *P. delicatulus* is also found in New Guinea and is the only *Pseudomys* species found outside Australia (Lee 1995). Several species of *Pseudomys* appear to have become extinct since the European settlement of Australia (Lee 1995; Kirkpatrick 1995; C. Dickman pers. comm.).

*Pseudomys oralis* was described by Thomas (1921) on the basis of two specimens, one from the vicinity of the Hastings River, NSW and the other from an unknown locality (Watts and Aslin 1981). Both specimens were probably collected during the 1840s (Watts and Aslin 1981). There has been no...
discussion of geographic variation within *P. oralis* and no subspecies have been recognised.

**Sex/age/breeding categories**

Individual *P. oralis* can be sexed and categorised as juvenile, sub-adult or adult on the basis of external characteristics (Hyett and Shaw 1980; Watts and Aslin 1981; Read 1993a; Tweedie and York 1993; Kirkpatrick 1995). Other *Pseudomys* spp. grow through similar changes (e.g., Kemper 1976a,b; Watts 1979; Fox and Kemper 1982). Juveniles are a uniform smoky grey colour, adults have the colouration pattern described above and sub-adults exhibit a mixture of the two colour patterns. As sub-adults age, the juvenile colour pattern slowly gives way to the adult pattern. Males and females of all ages are similar in general appearance. However, adult males have visible testes or a developed scrotum, usually with dark pigmentation, and adult females have two pairs of teats in the inguinal position and none on the abdominal or thoracic regions (Hyett and Shaw 1980). In addition, some adult females have perforated vaginas. Juveniles and sub-adults lack such well-developed sexual characteristics but the sexes can nonetheless be recognised. In juvenile and sub-adult males the area between the genital papilla and anus is hairy with some dark pigmentation. Juvenile and sub-adult females have a narrow hairless and unpigmented strip of skin between the clitoris and anus and small undeveloped teats that are difficult to find amongst the fur.

Body size and mass increase markedly with age from juvenile to sub-adult to adult (Table 1; Read 1993a) and adult males are, on average, slightly heavier than adult females (Table 1; Student t-test, *P* < 0.05; see Keating 2000). However none of the other observed differences in body size between adult males and females is significant (Table 1; *P* > 0.05).

Individuals can be categorised as pre-breeding, breeding or post-breeding. Reproductive status of females can be categorised as pre-breeding ( imperforate vagina and small teats), breeding (perforate vagina and extended teats) or lactating (lactation evident from changes in skin around teats) (Keating 2000). Male reproductive status can be categorised as non-breeding (testes undescended) or breeding (testes descended).

**Habitat**

Information about what constitutes *P. oralis* habitat comes from the descriptions of a large number of authors. Some are based primarily on firsthand experience (Kirkpatrick and Martin 1971; Covacevich and Easton 1974; Denny and Press 1982; King and Chapman 1983; Dickman 1984; Dickman and McKechnie 1985; King and Mackowski 1986; Read 1988b; 1993b; Shields *et al.* 1992; HRMRT 1993; Tweedie and York 1993; Poole 1994; Lim 1995; Mackowski *et al.* 1996; Read and Tweedie 1996; Townley 1996; Gymnther *et al.* 1996; Catling and Burt 1997), while others represent a summary of existing views (Watts and Aslin 1981; Kinhill Engineers 1992; MKES 1992a,b; SFNSW 1995a,b; Kirkpatrick 1995; Tanton 1995a,b,c, 1996).

It is generally agreed that *P. oralis* habitat presently occurs between 250 and 1250 m elevation and usually consists of open forest in a gully and near a watercourse, with a dense understorey of grasses and/or sedges and with an abundance of potential shelter sites. *P. oralis* may occur within a variety of types of open and closed forest and woodland but is usually associated with open forest (Kirkpatrick and Martin 1971; Covacevich and Easton 1974; Watts and Aslin 1981; Denny and Press 1982; King and Chapman 1983; Dickman 1984; Dickman and McKechnie 1985; King and Mackowski 1986; Read 1988b; 1993b; MKES 1992a,b; Shields *et al.* 1992; HRMRT 1993; Tweedie and York 1993; Klippel 1992; Fox *et al.* 1994; MGP 1994; Andrews *et al.* 1994; Smith *et al.* 1995; SFNSW 1995a,b; Kirkpatrick 1995; Tanton 1995a,b,c, 1996). Other existing views (Watts and Aslin 1981; Kinhill Engineers 1992; MKES 1992a,b; Shields *et al.* 1992; SFNSW 1995a,b; Tanton 1995b; 1996; Fox 1994; Poole 1994; Lim 1995; Smith *et al.* 1995; SFNSW 1995a,b; Kirkpatrick 1995; Tanton 1995a,b,c, 1996; SFNSW 1995a,b; Kirkpatrick 1995; Tanton 1995a,b,c, 1996).
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<td>1040</td>
<td>19-22/2/1985</td>
<td>T. Tweedie</td>
</tr>
<tr>
<td>Mount Hyland NR</td>
<td>Hyland Ck*</td>
<td>1000</td>
<td>16/11/1987</td>
<td>D. Read</td>
</tr>
<tr>
<td></td>
<td>Hyland Ck</td>
<td>1000</td>
<td>24/11/1987</td>
<td>D. Read</td>
</tr>
<tr>
<td>Hyland SF</td>
<td>Maria Ck (Cpt.111)*</td>
<td>1020</td>
<td>20-24/9/1993</td>
<td>T. Tweedie</td>
</tr>
<tr>
<td></td>
<td>Merchin Ck (Cpt.111)*</td>
<td>1100</td>
<td>13-17/7/1993</td>
<td>T. Tweedie</td>
</tr>
<tr>
<td>Nymboida-Binderay NP</td>
<td>Charles Plain*</td>
<td>600</td>
<td>3-16/12/1990</td>
<td>T. Tweedie, D. Read</td>
</tr>
<tr>
<td></td>
<td>Edwards Plain FR*</td>
<td>620</td>
<td>3-14/7/1989</td>
<td>T. Tweedie, D. Read</td>
</tr>
<tr>
<td>Moonpar SF</td>
<td>E.W.B. Rd.</td>
<td>640</td>
<td>12/11/1993</td>
<td>D. Read</td>
</tr>
<tr>
<td></td>
<td>E.W.B. Rd.</td>
<td>640</td>
<td>11/11/1993</td>
<td>D. Read</td>
</tr>
<tr>
<td></td>
<td>Bicks River Rd.</td>
<td>680</td>
<td>15/9/1993</td>
<td>T. Tweedie</td>
</tr>
<tr>
<td></td>
<td>Bicks River Rd.</td>
<td>690</td>
<td>14/9/1993</td>
<td>T. Tweedie, P. Boglio</td>
</tr>
<tr>
<td>Muldiva SF</td>
<td>Mills Rd.</td>
<td>660</td>
<td>8/11/1993</td>
<td>D. Read</td>
</tr>
<tr>
<td>Carrai Rd.</td>
<td>TR 80004</td>
<td>540</td>
<td>2/1991</td>
<td>P. Catling, R. Burt</td>
</tr>
<tr>
<td>Carrai Crown Land</td>
<td>Sandy Ck</td>
<td>970</td>
<td>4/3/1993</td>
<td>A. Gilmore</td>
</tr>
<tr>
<td></td>
<td>Carrolls/Sandy Cks</td>
<td>990</td>
<td>20-27/8/1992</td>
<td>D. Read</td>
</tr>
<tr>
<td></td>
<td>Carrolls/Sandy Cks</td>
<td>990</td>
<td>20-27/8/1992</td>
<td>D. Read</td>
</tr>
<tr>
<td></td>
<td>Carrolls/Sandy Cks</td>
<td>990</td>
<td>20-27/8/1992</td>
<td>D. Read</td>
</tr>
</tbody>
</table>
Table 2. Locations and sites where *P. oralis* has been captured since its rediscovery in 1969. SF, State Forest; NR, Nature Reserve; FT, Fire Trail; FR, Flora Reserve; NP, National Park; TR, Timber Reserve; *, additional records within 200 m; **, additional records within 1 km; †, accuracy within 1 km. (HRMRT 1993; Mackowski et al. 1994; HRMMD 1997; AMR 1998; Bryant et al. 1999; NSWNPWS 1999; pers. comm. from I. Gynther, S. Phillips, S. Townley, A. Martin, P. Catling, T. Tweedie; D. Read, unpubl. data.

<table>
<thead>
<tr>
<th>Date</th>
<th>Predator</th>
<th>Location</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/1986</td>
<td>grass owl</td>
<td>Wardell</td>
<td>G. Holmes, pers. comm.</td>
</tr>
<tr>
<td>31/12/1983</td>
<td>masked owl</td>
<td>Carrow Brook</td>
<td>I. Cranwell, S. Debus, pers. comm.</td>
</tr>
<tr>
<td>1999</td>
<td>fox</td>
<td>Marengo SF</td>
<td>Meek and Triggs 1999; P. Meek pers. comm.</td>
</tr>
<tr>
<td>1998</td>
<td>fox</td>
<td>Grady’s Creek, Border Ranges NP</td>
<td>D. Charley pers. comm.; cited in Meek and Triggs (1999), Keating 2000</td>
</tr>
</tbody>
</table>

Table 3. Records of predation on *P. oralis* from owl pellets and canid scats. All sites are from NSW.

(Klippel 1992; MGP 1994; Smith et al. 1995; SFNSW 1995a,b; Tanton 1995b; Keating 2000). The species is typically (but not always) found near a watercourse or drainage line (Kirkpatrick and Martin 1971; Covacevich and Easton 1974; Dickman 1984; King 1984; Dickman and McKechnie 1985; King and Mackowski 1986; Read 1988a; Klippel 1992; MRC 1992; MKES 1992a,b; Shields et al. 1992; Sinclair Knight 1992; HRMRT 1993; Tweedie and York 1993; Andrews et al. 1994; Poole 1994; MGP 1994; Kirkpatrick 1995). Information about the habitat of *P. oralis* is also available from two quantitative studies of site attributes where the species is present (Mackowski et al. 1994; Read and Tweedie 1996). These studies included similar numbers of sites (31 in Mackowski et al. 1994, and 33 in Read and Tweedie 1996) but are not directly comparable as they differ in the choice of dependent and independent variables, the adopted statistical methods, and the temporal relationship between independent and dependent variables. Mackowski et al. (1994) adopted a
quantitative scale of female reproduction as the dependent variable and six independent variables (altitude, logging disturbance, fire disturbance, grazing disturbance, forest type and latitude). Read and Tweedie (1996) used frequency of similar plant species among sites. Mackowski et al. (1994) used multivariate biplot analysis, whereas Read and Tweedie (1996) used TWINSPLAN classification (Hill 1979). Mackowski et al. (1994) used historical information and previous survey records to derive their independent and dependent variables, whereas Read and Tweedie (1996) recorded dependent and independent variables at essentially the same time. Despite these differences, these two studies are generally consistent with one another and the qualitative descriptions summarised above. They lead to the conclusion that P. oralis tends to occur in forests with sedge/riparian zones or with grass/sedge understorey (Mackowski et al. 1994; Read and Tweedie 1996). Typically, these are moist hardwood forests (Mackowski et al. 1994).

However, both the qualitative and quantitative approaches to understanding P. oralis habitat-use are based on presence/absence of the species and do not provide any measure of habitat suitability or preference. Hence, while they may enable habitats to be ranked in terms of the likelihood of occupancy by P. oralis, they do not permit habitats to be ranked in terms of suitability, animal preference or animal density.

Within a site the nature and extent of available shelter apparently influence how individual P. oralis are distributed. Keating (2000) found that, across 250 trap locations at Grady’s Creek in the Border Ranges National Park (NP), there was a significant positive correlation between successful capture of P. oralis and the presence of shelter in the form of large rocks. At this level other variables relating to vegetation structure, floristics and topography were not significant (Keating 2000).

**Individual biology**

**Growth and development**

There is no information concerning rates of growth and development for P. oralis, and the nature and extent of any seasonal changes in body mass are unclear. If P. oralis is similar to the congeners P. novaehollandiae and P. gracilicaudatus, then it would be expected to have a juvenile period of about four weeks and a sub-adult period of about 10 weeks (Kemper 1976a,b; Fox and Kemper 1982). Keating (2000) found no consistent pattern in recorded mass changes for nine individuals over the period July-September. Larger sample sizes over longer periods may be necessary to detect any patterns.

**Reproduction**

From the few records available it appears that mating and gestation in P. oralis occurs between July and February, with most births occurring between July and March (Table 5). Males with descended testes have been recorded between July and January and most pregnant or lactating females have been captured between July and March (Table 5; Kirkpatrick 1995). Most births have been recorded during the period from July to March and post-lactating females have been captured in April (Table 5). Keating (2000) observed reproductively active animals between July and September.

There is little information available with regard to gestation period, lactation period and litter frequency for P. oralis. Gestation period is unknown but is probably 30 - 31 days, as for P. australis (Smith et al. 1972). Lactation period is similarly unknown but is probably about 30 days, as it is for other Pseudomys species (Watts and Aslin 1981). Number of offspring per pregnancy ranges from 1 - 4, but is usually 2 - 3, as determined by the few observations on litter size and number of embryos (AMR 1998; Read 1988a; P. Catling, pers. comm.; G. King, pers. comm.). Number of litters per female per year is unknown but, given the relatively broad span of time during which females breed each year and the simultaneous presence of both juveniles and pregnant females, it is possible that each female is able to produce more than one litter per year (AMR 1998; King and Mackowski 1986).

**General behaviour and activity patterns**

Pseudomys oralis is primarily nocturnal and apparently more active during late summer and early autumn than at other times. Radiotracking studies show that this species generally changes location only at night (Townley 2000b). In this respect it is similar to other Pseudomys species (Happold 1976a). Rates of capture success of P. oralis have been markedly higher during February and March than at other times (Table 6).

During periods of inactivity, individual P. oralis shelter in a wide range of sites, including hollows in and under fallen timber, hollows under the stumps or roots of live trees, cavities among rocks (SFNSW 1995c) and cracks in the soil (SFNSW 1995c; Keating 2000; D. Read, pers. obs.; S. Townley, pers. comm.). No general differences have been found between sites where individuals have been discovered, those to which individuals have been tracked, and those chosen by individuals immediately upon release (SFNSW 1995c; S. Townley, pers. comm.; T. Tweedie, pers. comm.; D. Read, pers. obs.).
Males Females

<table>
<thead>
<tr>
<th>Month</th>
<th>Captures</th>
<th>Descended testes</th>
<th>Juvenile &amp; subadult weight g (estimated month of birth)*</th>
<th>Captures</th>
<th>Pregnant or lactating</th>
<th>Births</th>
<th>Post-lactating</th>
<th>Juvenile &amp; subadult weight g (estimated month of birth)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>47</td>
<td>(Nov)</td>
<td></td>
<td></td>
<td>17 (Jan), 37 (Dec) 41 (Dec)</td>
</tr>
<tr>
<td>Feb</td>
<td>7</td>
<td>17</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>41 (Dec)</td>
</tr>
<tr>
<td>Mar</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>2</td>
<td>0</td>
<td>1*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>2</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>16</td>
<td>7</td>
<td>22</td>
<td>48</td>
<td>(Apr)</td>
<td></td>
<td></td>
<td>35 (June)</td>
</tr>
<tr>
<td>Aug</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td>12</td>
<td>2</td>
<td>16 (Oct), 25 (Oct)</td>
<td>23</td>
<td>(Oct)</td>
<td></td>
<td></td>
<td>35 (Sept)</td>
</tr>
<tr>
<td>Dec</td>
<td>2</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>23 (Nov)</td>
</tr>
</tbody>
</table>

Table 5. Breeding records for *P. oralis*. Data from MKES (1993); Mackowski et al. (1994); NSWPWS (1996); HRMMD 1997; AMR (1998); S. Townley and D. Read, unpubl. data. *Assuming similar growth rate to *P. gracilicaudatus* (Fox and Kemper 1982). a Individual captured in February and held in captivity. b Born in captivity.

<table>
<thead>
<tr>
<th>Time period</th>
<th>No. <em>P. oralis</em> captured</th>
<th>No. trap-nights</th>
<th>No. <em>P. oralis</em> captured / 100 trap nights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec – Jan</td>
<td>9</td>
<td>5,889</td>
<td>0.15</td>
</tr>
<tr>
<td>Feb - March</td>
<td>28</td>
<td>1,665</td>
<td>1.68</td>
</tr>
<tr>
<td>April - May</td>
<td>Not sampled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June - July</td>
<td>45</td>
<td>7,503</td>
<td>0.60</td>
</tr>
<tr>
<td>Aug – Sept</td>
<td>18</td>
<td>8,400</td>
<td>0.21</td>
</tr>
<tr>
<td>Oct - Novr</td>
<td>38</td>
<td>11,503</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Table 6. Seasonal pattern of *P. oralis* captures. Data from Mackowski et al. (1994); NSWPWS (1996); HRMMD 1997; Catling and Burt (1997); P. Catling, pers. comm.; D. Read, unpubl. data.

<table>
<thead>
<tr>
<th>Animal #</th>
<th>Sex</th>
<th>No. times caught</th>
<th>Range of intercapture distances (m)</th>
<th>Average intercapture distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>2</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>6</td>
<td>0 - 15</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>4</td>
<td>10 - 45</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>5</td>
<td>8 - 150</td>
<td>67</td>
</tr>
</tbody>
</table>

Table 7. Distances moved between successive captures of *P. oralis* by D. Read (see text for details).

**Movement**

Radio-tracking and recapture data indicate that during their night-time movements individual *P. oralis* often cover distances of ≥ 200 m while remaining within relatively small home ranges that are mostly < 2 ha. Radio-tracking of individuals reveals that they may move relatively large distances over periods of < 24 hr. (Townley 1992, pers. comm.) has found that, over 2.1 hr intervals, individuals move an average distance of 160 m (range: 44 – 321 m) and that the linear distance travelled by one individual in a single night exceeded 500 m. However, radio-tracking data indicate that home ranges are generally small with males having larger home ranges (i.e., area containing 95% of recorded locations) than females (male range: 0.69 – 0.83 ha; female range: 0.24 – 0.34 ha: mean values not presented, Townley 2000b). Furthermore, most recaptures, though on different nights, are within 100 m of where the previous capture occurred (Table 7; Townley 2000b; Keating 2000). Recapture data for individuals indicate that they sometimes move up to 150 m in a 24 hr period (Table 7; Read 1993c; Keating 2000), possibly from one edge of their home range to the other.
Foraging and diet

Faecal analyses indicate that *P. oralis* is essentially granivorous, feeding predominantly on seeds and fruit when they are present, but depending on leaves and stems in winter when seed and fruit are scarce (Fox et al. 1994; SFNSW 1995c). Fox et al. (1994) analysed 90 faecal samples collected from 42 animals in nine locations between November 1987 and June 1991 (29 samples during October - February; 61 samples during June and July). They found that, during the spring-summer (i.e., October - February), leaf and seed (including fruit) remains were equally prevalent (i.e., 45% vs 44%), whereas leaf material predominated in winter (i.e., June - July; 77% vs 12%). There were more insect remains in spring-summer than during winter (i.e., 7% vs 2%). For both seasons leaf and seed remains accounted for about 89% of items. Plant stem remains were uncommon in the faecal samples (summer: < 1%; winter: 7%) and other rare items included the remains of flowers, pollen, fern sporangia and fungi. There were no significant differences in diet either between locations or between males and females. Analyses by King (1984) of faecal material from a single individual yielded results consistent with those described above.

The analysis by Fox et al. (1994) also indicated that *P. oralis* tends to select leaves from plants which are relatively digestible and have a relatively high protein content, since plants with these properties are disproportionately represented in the faecal samples relative to their local abundance (Bernard 1990; Fox et al. 1994). In terms of individual species present in the faecal samples, Fox et al. (1994) identified leaf and stem material from *Juncus* sp. and the introduced *Taraxacum officianale* as well as seed remains of sedges and grasses of the genera *Juncus*, *Poa* and *Carex*. Observations of partly eaten plants along traplines where *P. oralis* was the only rodent captured also suggest that this species is relatively selective in its foraging. Along such traplines *Carex* sp. has been found with the most central and youngest growing shoot removed and with adjacent leaf shoots remaining (D. Read pers. obs.). Also along these traplines specimens of Cyperaceae have been found with only the distal three-quarters of the seed spike removed (D. Read pers. obs.). In addition, traps in which *P. oralis* individuals have been captured have generally had plants in the Cyperaceae or Juncaceae with maturing seed heads within 5 m, while traps that were more distant from such plants have been generally unsuccessful (D. Read pers. obs.).

Observations based on feeding by captive individuals are consistent with these conclusions, with animals feeding on seeds, fruit, leaves and stems of native plants (King and Chapman 1983; King 1984), as well as the peanut butter and oats mixture used as bait (Denny and Press 1982; Dickman 1984; King 1984; Dickman and McKechnie 1985; Read 1988a,b, 1989a,b; Shields et al. 1992; Tweedie and York 1993; York 1992; Andrews et al. 1994; Fox et al. 1994; Tanton 1995a; Catling and Burt 1997). Animals have also been successfully maintained in captivity on a mostly granivorous diet (Kirkpatrick 1995).

Other behaviour

Very little is known about conspecific interactions. Trapping and radio-tracking of *P. oralis* indicate that they have overlapping home ranges and hence do not defend exclusive territories (Townley 1997, 2000b). Like other *Pseudomys* species, communication between individuals probably includes threat squeals, distress calls, chirping, faint whistling calls, ultrasonic calls by nestlings and biological information left by scent-marking (see Happold 1976a, b; Watts and Aslin 1981; Kirkpatrick 1995). When first born, young *P. oralis* attach to their mother’s teats (P. Catling, pers. comm.; G. King, pers. comm.).

Population biology

Abundance and dynamics

Capture rates and density estimates for *P. oralis* indicate that, where this species occurs, its density is similar to other small mammal species. Targeted surveys carried out at sites where presence of *P. oralis* seems reasonably likely (geographic location, suitable habitat), have recorded capture rates similar to those for most other small mammal species. For example, during such targeted surveys carried out by Read (unpubl. data) at 14 sites, an overall capture rate of 0.59/100 trap-nights was achieved for *P. oralis*, while overall capture rates for other small mammals along the same traplines were 0.38 for *Melomys cervinipes*, 0.57 for *R. fuscipes*, 1.14 for *R. lutreolus* and 4.88 for *Antechinus stuartii* (Table 8; see also Read 1988a,b, 1989a,b; Read and Tweedie 1996). When small mammal trapping is carried out...
within areas known to contain *P. oralis* capture rates as high as 1.3/100 trap-nights have been achieved (e.g., Keating 2000). Catling and Burt (1994, 1995, 1997) report capture rates for 13 small mammal species caught in 34 areas that are predominantly between 0.1 and 1.5/100 trap-nights (i.e., 70/123 records).

Estimates of maximum *P. oralis* density, based on capture-recapture data, are similar to the maximum densities encountered for other small mammals. Townley (2000b) found a density of about 5/ha for *P. oralis* at Gamburgal, Qld, while densities of *R. fuscipes* are generally <14/ha (Watts and Aslin 1981; Wilson et al. 1986) and *R. lutreolus* ≤15/ha (Lunney 1995). In some instances much higher densities of *R. fuscipes* have been found (e.g., 40/ha - Wood 1971; 122/ha - Tasker et al. 1999). On average the density of *P. oralis* is about 2/ha (Keating 2000).

However, capture rates in non-targeted mammal surveys and estimates of population sizes indicate that across the broad landscape, populations of *P. oralis* are very rare and highly localised. During non-targeted surveys *P. oralis* is very rarely captured. Lim (1995), for example, reported the capture of just one individual after 5,400 trap nights (i.e., 0.02/100 trap nights), while Catling and Burt (1997) obtained one individual after 5,400 trap nights (i.e., 0.02/100 trap nights). In addition, many NSW small mammal surveys within the known geographic range of *P. oralis* have failed to capture the species (e.g., Barker et al. 1994; SFNSW 1996; NSWNPWS 1995).

Based on the numbers of individuals captured and recaptured, most *P. oralis* populations appear to be very small, possibly numbering <10 individuals (Mackowski et al. 1994; NPWSD 1996; HRMMD 1997). Sinclair Knight (1992) estimated that the population size at the Hyland SF site in NSW was about nine individuals. Townley (1997) estimated population sizes for several populations that were presumed to be relatively large and obtained estimates that ranged from 3 - 10 individuals (Billilimbra, NSW), to about 10 - 47 (Gambubal, Qld). Only at seven known sites (NSW: Mt Royal, Boundary Creek, Billilimbra, Grady’s Creek, Styx River SF; Qld: Gambubal, Lamington NP) have nine or more individuals been caught during a single trapping session (King and Mackowski 1986; Read 1989b; Williams 2000; J. Gyther, pers. comm.; S. Townley, pers. comm.; B. Cann, pers. comm.). At most sites the total number of *P. oralis* caught has been 1 - 5 individuals (HRMRT 1993; Mackowski et al. 1994; NSWNPWS 1996; Tanton 1996). Given the relatively high mobility of individual *P. oralis* (Townley 2000b), it is difficult to determine the boundaries of local populations but, given their apparently low sizes and the restricted extent of suitable habitat patches, these areas are likely to be quite small. The total population of *P. oralis* in Australia must also be relatively small, since only ~400 individuals have ever been caught despite extensive trapping effort within apparently suitable habitat (Tweedie and York 1993; Townley 1997; Keating 2000).

Five NSW populations of *P. oralis* have apparently disappeared since they were discovered (i.e., Werrikimbe NP; Boundary Creek; Blicks River Flora Reserve, Opossum Creek and Clouds Creek SF: Read 1988b, unpubl. data; HRMRT 1993). This is, however, difficult to substantiate because of the known mobility of individuals, the difficulty in capturing *P. oralis* even when it is present, and the lack of information concerning seasonal and year-to-year fluctuations in population sizes.

There is presently no information concerning the dynamics of *P. oralis* populations. Capture rates show a distinct peak during January/February (Table 6) and perhaps a smaller peak around July (Table 6; Keating 2000). This pattern of capture could, however, reflect changes in the behaviour of the animals as much as changes in their abundance.

### Regulating factors

Though there have been no studies of factors that may regulate *P. oralis* populations, a number of factors have been suggested. These include direct effects of fire (Andrews et al. 1994; Smith et al. 1994; Martin 1995; Tanton 1995a; SFNSW 1995a,b), predation (Andrews et al. 1994; Smith et al. 1994, 1995; SFNSW 1995a,b; Meek and Triggs 1999), availability of shelter (Smith 1996), and availability of food (SFNSW 1995a,b). Various human activities could also affect populations of *P. oralis* including logging (Tweedie and York 1993; HRMRT 1993; Lim 1995; SFNSW 1995a,b; Dickman et al. 2000a,b), burning (Martin 1995; Smith 1996; Tweedie and York 1993; Andrews et al. 1994; Smith et al. 1994; AMBS 1995a,b; SFNSW 1995a,b; Tanton 1996; Meeks and Triggs 1999; Dickman et al. 2000a,b), clearing (Smith et al. 1995; SFNSW 1995a,b), grazing (Smith 1996; Tweedie and York 1993; Andrews et al. 1994; AMBS 1995a,b; Smith et al. 1995; SFNSW 1995a,b; Tanton 1996; Meek and Triggs 1999; Dickman et al. 2000a,b), and introduction of feral animals (Catling and Burt 1995; Dickman et al. 2000a,b). It has also been suggested that there may be competition with other species for food, and that fire may also affect this species indirectly through its impacts on resources such as food and shelter (SFNSW 1995a,b).
The likely impact of predation on populations of *P. oralis* is unclear (Meek and Triggs 1999). The only known instances of predation have involved owls (species not stated) (Kirkpatrick 1995, C. l. dingo (NSWNPWS 1996) or *V. vulpes* (Meek and Triggs 1999)). *F. catus*, scats have been collected in the vicinity of *P. oralis* capture sites (Barker et al. 1994), but no *P. oralis* remains have been identified in them. Indigenous Australians may have occasionally collected *P. oralis* as food since this species occurs in a midden deposit alongside various human stone-tools (Bowdler 1970).

The likely nature of the impact of fire on *P. oralis* populations is also unclear (Meek and Triggs 1999). Most of the sites where Catling and Burt (1997) found this species had been recently burnt, which is consistent with the suggestion of Catling (1991) that this species is advantaged by frequent low-intensity prescribed burns. However, that fire may sometimes be deleterious to *P. oralis* is suggested by its apparent disappearance from two sites following fire (Werrikimbe NP: HRMRT 1993; Smith and Quin 1996; Boundary Creek in Forestland SF: Mackowski et al. 1994; Fanning 1995; Tanton 1995b; G. King, pers. comm.) and the observation of a relatively large population in an area that had not burnt for about 20 years (Keating 2000). *P. oralis* may also have disappeared from some sites in the absence of fire (e.g., Bloks River Flora Reserve: Read 1988b; unpbl. data) and there is no apparent relationship between fire and the level of reproductive activity found in a population (Mackowski et al. 1994).

The likely impacts of logging on *P. oralis* populations are also unclear. Sometimes higher captures have occurred at sites that have been logged in comparison with unlogged sites (MKES 1993; Shields et al. 1992; HRMRT 1993; Mackowski et al. 1994), but logged and unlogged sites are not necessarily similar in other respects and so any differences between them could be due to some factor other than logging. Mackowski et al. (1994) found that most sites where *P. oralis* had been captured were unlogged, and that relatively few had been heavily logged. However, they had no information on either the numbers before and after logging or with regard to sites that lack *P. oralis* but are otherwise essentially identical to the sites where it has been captured. Though *P. oralis* has sometimes been captured at sites that have been grazed (Tanton 1996; Catling and Burt 1997), the general effects of grazing on *P. oralis* are similarly unclear.

More quantitative investigation of relationships between breeding success and various disturbance factors has also failed to yield clear results. Mackowski et al. (1994, 1996), using biplot and correlation analysis, reported that disturbance through fire, grazing or logging was not related to the lack of breeding success for *P. oralis* and they concluded that logging, fire and grazing are not the agents responsible for its decline. However, their sample sizes were small and so further consideration of these potential interactions is warranted (Mackowski et al. 1994).

It is possible that the population density of *P. oralis* reaches a maximum at a particular seral stage of the vegetation, as do *P. gracilicaudatus, P. novae hollandiae, P. apodemoide, P. fumeus* and *P. shoaridgeri* (Catling and Newsome 1981; Fox 1982, 1990, 1995; Cockburn 1995a,b,c; Kemper 1995; Lock and Wilson 1999). If this were the case it would suggest either food availability or protection from predators, or both factors, are important in controlling the density of *P. oralis*.

### Population genetics

Patterns of mitochondrial DNA variation among current populations of *P. oralis*, as revealed by temperature-sensitive gel electrophoresis and sequencing, indicate the effects of both long-term evolutionary changes as well as relatively short-term anthropogenic effects. The nature and extent of genetic-based differences among present populations that are at least 200 km apart suggest that these populations have been separated for long periods of evolutionary time (Jerry et al. 1998). On the other hand, similarities between two populations that are currently only about 80 km apart suggest that, until recently, they had gene flow between them and were probably more extensive (Jerry et al. 1998). Fragmentation through human activities would seem to be the most likely cause of such recent curtailment of gene flow. There is presently some level of genetic variation amongst all *P. oralis* populations (Jerry et al. 1998).

### Community biology

*Pseudomys oralis* co-occurs with other mammal species and has always been found to be a minority species, accounting for about 5 - 30% of the small mammal community (e.g., Keating 2000). It has been captured in the same trap-lines as a number of similar-sized mammal species, most commonly *R. fusipes*, *L. lutreolus*, *A. stuartii* and *M. cervinipes* (Table 8; Keating 2000). For those sites where *P. oralis* has been captured and where the total number of small mammals captured is ≤ 13, *P. oralis* has comprised about 20% of total captures (i.e., 12/59; Table 8). For those sites where ≥ 20 small mammals have been captured, *P. oralis* has comprised about 5% of the total (i.e., 16/299; Table 8). However, at Grady’s Creek in the Border Ranges NP, NSW,
Keating (2000) found that *P. oralis* made up 29% of captured small mammals.

Presence of *P. oralis* is not associated with any clear variation in the community of other small mammal species. Relative captures of the above four mammal species were significantly different between traplines along which *P. oralis* was captured and nearby traplines where *P. oralis* was not captured (Table 8; \( G = 27.2, P < 0.001 \)). However, these species exhibited capture rates along traplines where *P. oralis* was also captured that were similar to rates along nearby traplines where *P. oralis* has not been captured (Table 8).

It is not possible to determine which mammal species co-occurred with *P. oralis* in the past. Bones of *P. oralis* have been found within the same sub-fossil deposit layer as a number of other mammal species (Table 4). However, as these deposit layers generally represent many years of deposition, these results can only be taken to mean that these species occurred in the vicinity of the deposit within such a period of time. Only if the species are found in the same sub-fossil owl pellet, is it possible to say that these species must have been in the area at exactly the same time. No information is presently available on the mammal species found in the same sub-fossil owl pellets as *P. oralis*.

There are no mammal species that should have been captured in the same trap lines as *P. oralis*, given their similar size, distribution, habitat and catchability, but have not. *A. swainsonii* might have been expected to be captured alongside *P. oralis* because its moist habitat is similar to some *P. oralis* habitats. However, the distribution of *A. swainsonii* is generally more coastal than that of *P. oralis* (Dickman 1995; Kirkpatrick 1995) and to date the two species have only been caught in adjacent traplines at Mount Royal, NSW (Read 1988b). In addition *A. swainsonii* is found in areas with much denser ground vegetation than *P. oralis* (P. Catling, pers. comm.).

The sub-fossil record suggests that *P. oralis* has replaced *P. higginsi* over time in some locations and that *P. higginsi* has completely disappeared from the mainland (Table 3). This may have been the result of a shift to warmer and drier climates in mainland south-east Australia (Galloway 1973) which favoured *P. oralis* over *P. higginsi*. Sites where *P. higginsi* and *P. oralis* both occur in sub-fossil remains probably became warmer and dryer at about 12,000 YBP (Wakefield 1972; Flood 1972; Harrison 1980; Kershaw 1995). Relative to *P. oralis*, *P. higginsi* occupies and is presumably adapted to cooler and wetter habitats including wet sclerophyll forest, rainforest, montane forest and alpine regions (Stoddart and Challis 1993; Green 1995; Monamy 1995).

**Research techniques**

Research techniques that have been developed or adopted for *P. oralis* relate to detection, capture/handling/release, marking, movements, diet and shelter. No special techniques have been used for observing *P. oralis*, either in captivity or in the wild (see Lehner 1996).

Either current or historical presence of *P. oralis* may be detected. Current presence of *P. oralis* at a site can be detected either through capture, their distinctive hairs left in hairtubes (see Scotts and Craig (1988) for a description of the hairtube technique), or through finding bones of the species in either fresh owl pellets or scats of mammalian predators (Tables 2, 3). Historical presence can be detected (Table 4) either through bones in sub-fossil deposits, apparently resulting from accumulation in caves or sites with similar shelter of regurgitated food pellets of roosting owls over long periods of time (e.g., Morris et al. 1997), or through food middens developed by indigenous Australians.

Some methods for detecting other mammal species have not so far worked for *P. oralis*. It does not leave behind distinctive faeces or tracks (Kirkpatrick 1995; SFNSW 1995c), and no fossil remains attributable to *P. oralis* have so far been discovered.

All captures of *P. oralis* have been made using Type A Elliott livetraps (33 x 10 x 9 cm) containing a food-bait (Denny and Press 1982; King 1984; Read 1988a, 1993a; Shields et al. 1992; York 1992; Poole 1994). Though trap-size is often unreported, no other trap size has been evaluated for capture of this species. Other trap types, including cage and pit-fall traps, may be ineffective in capturing this species as no captures in them have been reported. There has, however, been no comparative study of the effectiveness of different kinds of traps. In almost all cases where *P. oralis* has been captured, the food bait included peanut butter and rolled oats (Denny and Press 1982; Dickman 1984; King 1984; Dickman and McKechnie 1985; Read 1988a,b, 1989a,b; Shields et al. 1992; York 1992, Tweedie and York 1993; Andrews et al. 1994; Catling and Burt 1997; Tanton 1995a). In some cases, successful baits have included additional material such as honey (Dickman 1984; Dickman and McKechnie 1985), sultanas (Dickman 1984; Dickman and McKechnie 1985), vegetable oil (Read 1988a,b; Fox et al. 1994), bacon fat (Denny and Press 1982) and peanut oil (S. Townley, pers. comm.). *P. oralis* has also been captured using bait consisting of sweet potato soaked in vegetable oil.
information about movements of \( P. \, oralis \) comes from examining the remains of food consumed in the wild and from observations of food consumed by captive animals. Natural diet can be determined from examination of food remains in faecal material deposited by wild-caught individuals during capture (Read 1989a,b; Fox et al. 1993, 1994; Tweedie and York 1993). Captive diets have been examined by observing what food items captive individuals will eat (King and Chapman 1983) and what diets prove sufficient to maintain animals for about a year (Kirkpatrick 1995, pers. comm.).

Information about shelter site selection comes from observations of where individuals are found sheltering (S. Townley, pers. comm.) and of where they take shelter upon release (D. Read, pers. obs.; I. Gynther, G. King, S. Townley, T. Tweedie, pers. comm.).

Conservation and management

Pseudomys oralis is generally considered at significant risk of extinction, but there is variation in the term used to describe this risk, the definition of the category, and the criteria used to assign a category. It is, for example, considered ‘Endangered’ at a national and international level (Lee 1995; IUCN 1998), though there is variation in the criteria used and assessment against these criteria is highly subjective. It is considered by IUCN (1998) that there has been ‘a reduction of at least 50% in the total population size of \( P. \, oralis \) over the last 10 years or three generations (whichever is longer) and that the decline is continuing’, that this species therefore faces ‘a very high risk of extinction in the wild in the near future’ and its ‘survival is unlikely if causal factors continue operating’, and on this basis that it is ‘Endangered’ at an international level. It is listed as nationally ‘Endangered’ under the Commonwealth of Australia Endangered Species Protection Act 1992 (i.e., it is likely to become extinct unless circumstances or factors threatening its abundance, survival or evolutionary development cease to operate) and in the Australian Rodent Action Plan (Lee 1995). In the latter case both the above IUCN (1998) and that of Mace and Lande (1991) are used. According to Mace and Lande (1991), endangered species are those for which there is a 20% probability of extinction within 20 years or 10 generations, whichever is longer. Lee (1995) recognized that the assignment of \( P. \, oralis \) or any other Australian rodent species to the category ‘Endangered’, or any other similar category, is largely subjective. He considered \( P. \, oralis \) to be ‘Endangered’ because it has small populations and is under threat from logging, grazing and burning (Lee 1995).
There is more variation from one State to another in the conservation status assigned to *P. oralis*. In NSW it is considered ‘Endangered’ (i.e., it is considered likely to become extinct in nature unless the circumstances and factors threatening its survival or evolutionary development cease to operate), being listed on Schedule 1 of the NSW Threatened Species Conservation Act 1995. This listing was carried over from the previous listing under the NSW Endangered Fauna (Interim Protection) Act 1991. The stated reasons for this listing were that the population and distribution are severely reduced, threatening processes are severe, and it is an ecological specialist (Lunney et al. 2000).

In Qld it is considered ‘Vulnerable’ (i.e., its population is decreasing because of threatening processes; or its population has been seriously depleted and its protection is not secured; or its population, while abundant, is at risk because of threatening processes; or its population is low or localised; or its population is dependent on limited habitat that is at risk because of threatening processes) under the Queensland Nature Conservation Act 1992 and Nature Conservation (Wildlife) Regulations 1994. Dickman et al. (2000a) agreed with this assessment based on their view that, in Queensland, *P. oralis* presently has a stable total population size of 100 - 1000 individuals and occupies an area of 100 - 1000 km², which is 1 – 25% less than before European settlement. It is not clear, however, how they obtained these estimates.

Management of populations of *P. oralis* has mostly focussed on avoiding or minimising adverse impacts arising from forestry activities (including burning), with little attention being given to grazing and clearing for agricultural purposes (MRC 1992; MKES 1992a; Smith et al. 1992, 1994, 1995; Andrews et al. 1994; MGP 1994; AMBS 1995a,b,c; Drielsma 1995; SFNSW 1995a,b; Tanton 1995a,b). Those areas that contain recorded capture locations of *P. oralis* are managed differently from other areas that are considered to contain potential habitat for the species, but where it has not yet been recorded.

In the case of forestry activities, management of *P. oralis* populations involves three stages. Before any logging or other forestry activities occur within the known range of *P. oralis*, the quality of potential *P. oralis* habitat must be assessed as high, moderate or low (NSWNPWS 1999). Targeted surveys are then carried out for *P. oralis* within those areas of high or moderate quality habitat exceeding 1 ha, using standardised trapping procedures and a minimum of 100 traps on each of at least four nights (i.e., 400 trap nights) for each 50 ha of habitat (NSWNPWS 1999). Finally, different prescriptions for forestry activities are adopted depending on the assessed quality of the habitat and whether or not *P. oralis* has been captured within or near these areas.

In situations where there are either capture records for *P. oralis* or there is high quality *P. oralis* habitat, the adopted prescriptions for forestry activities involve attempts to avoid impacts, rather than to minimise or mitigate them. In NSW, forestry activities are excluded from within 200 m of any recorded location of *P. oralis* and from all areas assessed as high or moderate quality *P. oralis* habitat within 800 m of any recorded location (NSWNPWS 1999). Forestry activities are also excluded from within 100 m of any area that is assessed as being of high quality habitat for *P. oralis* (NSWNPWS 1999). However, current forestry prescriptions do not address the issues of burning and grazing, which are both routine and permitted activities within State Forests. In addition there is presently no available information concerning the effectiveness of these forestry prescriptions in avoiding adverse impacts on *P. oralis*.

Little progress has been achieved in terms of recovery of *P. oralis*, despite the fact that its recovery has, for several years, been an explicit goal under Commonwealth, Queensland and NSW legislation. A Recovery Team for *P. oralis* was formed in 1992 and given the task of preparing a Recovery Plan for the species. A Draft Recovery Plan for *P. oralis* is currently in preparation (A. Smith, pers. comm.). Most of the sites where *P. oralis* occurs are within State Forests rather than National Parks or their equivalent (Table 1; Keating 2000), and *P. oralis* is not included in the relatively recent listed conservation protocols for timber harvesting in NSW State Forests (NSWNPWS-SFNSW 1996, 1997). It has been recommended that populations of *P. oralis* that occur within NSW State Forests and appear to be > 4 individuals should be monitored (MGP 1994, Smith et al. 1995). However, it is not clear how this would be achieved or what resulting consequences there might be.

**Captive husbandry**

There is little available information regarding captive husbandry of *P. oralis*. The species has twice been maintained in captivity and on each occasion the diet of captive animals was noted (King 1984; Kirkpatrick 1995). The maintenance requirements for captive *P. oralis* may be similar to those reported by Watts (1982) for hydromyine rodents in general and other species of *Pseudomys* in particular. There is, however, no available information in terms of other aspects of the captive husbandry of these animals.

**Future research**

Knowledge regarding the biology of *P. oralis* is generally scant and further research will be necessary.
if populations are to be protected and managed successfully, and if a strategy for recovery is to be developed and implemented. It will be especially important to determine what factors control the distribution and abundance of the species and how these factors operate, as only then might threats to populations be reduced, or opportunities for population enhancement be undertaken. Such factors may include human-related impacts on populations due to logging, grazing, burning and feral predators, including possible interactions amongst these variables (MRC 1992). An understanding of population dynamics of the species and of the parameters that influence it will also be necessary, along with quantitative assessments of the risk of localised extinction for populations in different circumstances and under different management scenarios. Population genetics studies may also help in evaluating the relative conservation significance of separate populations and the development of a genetic component to any recovery strategy (Jerry et al. 1998).

There is also much still to be learnt with regard to the general biology of P. oralis. We have very little present knowledge concerning internal anatomy, physiology and behaviour of the species and how these features change in time, place and during the life of an individual. With respect to some features it may be reasonable to assume that P. oralis is similar to other closely-related species. Physiology has, for example, been investigated in the closely-related P. australis (Baverstock and Watts 1974). This will not, however, be easy as other Pseudomys spp. are also poorly studied and some biological aspects are known to vary considerably across the genus, since members of the genus occur in diverse habitats across Australia (Watts and Aslin 1981; Stoddart and Challis 1993; Strahan 1995).

DISCUSSION

Our review indicates the benefits of pooling knowledge from those experienced with a rare species like P. oralis. In the absence, however, of reliable information regarding the factors that control the distribution and abundance of P. oralis, it will be difficult to develop strategies for mitigating the effects of negative human activities on P. oralis populations. Recovery strategies for this species may therefore have to begin with protecting known populations from potentially adverse human activities, conducting further studies concerning the impacts of these activities, and carrying out further targeted surveys in the search for presently unknown populations of the species.

The relative rarity of P. oralis will make it virtually impossible to evaluate the impacts of human activities through direct experimentation. Instead it is likely that such evaluation will have to rely on studies, that consider relationships between aspects of P. oralis populations and past history in terms of various human activities (e.g., Mackowski et al. 1994, 1996), and on studies that explore the basic biology of the species. From the latter it should be possible to deduce the likely impacts of human activities.

The management of fire in and around P. oralis populations is likely to be particularly difficult to resolve because it may be an inappropriate fire regime (i.e., fire frequency, intensity and seasonal timing) rather than the presence or absence of fire that has adverse impacts on the species. As already noted, the presence of fire has been found to be associated with positive, negative or neutral impacts on P. oralis. The challenge will therefore be to determine fire regimes that are beneficial to the species.

The production and implementation of Recovery Plans for animals and plants that are ‘threatened’ is a slow process. Under State and Commonwealth legislation there are a large number of ‘Threatened’ species, each of which requires a Recovery Plan. It seems surprising, however, that few Recovery Plans have so far been published (e.g., painted burrowing frog Neobatrachus pictus) (NSWNPWS 2000) and Plans, such as that for P. oralis, can take over eight years before they are placed, in draft form, on public exhibition.

The present review can, we believe, contribute to the development of a recovery strategy for P. oralis, as it indicates what is known about the biology of this species, the basis for this knowledge, some of the gaps in our knowledge, and how we might remedy them. From a starting point such as this, a recovery strategy would be expected to include a determination of possible actions and decisions that might benefit the species, a cost-benefit analysis of these alternatives, and the establishment of priorities for the allocation of funds and other resources towards the implementation of these alternatives. We hope that all of this will lead to some improvement in the conservation status of P. oralis.

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REFERENCES


CATLING PC AND BURT RJ, 1995. Studies of the ground-dwelling mammals of eucalypt forests in...


PYKE & READ: REVIEW OF THE HASTINGS RIVER MOUSE


RIDE WDL, 1960. The fossil mammalian fauna of the *Burramys parvus* breccia from the Wombeyan Caves, NSW. *Journal of the Royal Society of West Australia* **43**: 4-80.


