

Ecology and habitat of a threatened nocturnal bird, the Tasmanian Masked Owl

By

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Submitted in fulfilment of the requirements for the
Degree of Doctor of Philosophy



University of Tasmania
Hobart, Tasmania, Australia

August 2012

Declarations

This thesis contains no material which has been accepted for a degree or diploma in any university or other institution. This thesis, to the best of my knowledge, contains no material previously published or written by another person, except where due acknowledgment is made in the text.

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All research conducted was under valid animal ethics approvals. Relevant permits were obtained from the Department of Primary Industries, Parks, Water and Environment and the University of Tasmania Animal Ethics Committee (A0009763 and A0009685).

Michael Kenneth Todd

Ecology of the Tasmanian Masked Owl

Dedication: This thesis is dedicated to the marvelously mysterious Tasmanian Masked Owl. May they continue to haunt Tasmania's forests.



*“Once the sun disappears, along with the light,
She stretches her wings and sets off in flight,
And hunts far and wide well into the night,
Small native mammals her especial delight;
She’s endangered!”*

From “The Masked Owl”

-Philip R. Rush, *Australian Poems That Would Enchant an Echidna* (2007)

Acknowledgements

This research was conducted under permits from the Department of Primary Industries, Parks, Water and Environment, Australian Bird and Bat Banding Scheme and the University of Tasmania Animal Ethics Committee. It was funded in part by the Co-operative Research Centre for Forestry, Winifred Violet Scott Charitable Trust, Australian Geographic Society, Threatened Species Section- Biodiversity Conservation Branch- Department of Primary Industries, Parks, Water and the Environment, Australian Bird Study Association, the Stuart Leslie Award (BirdLife Australia- formerly known as Birds Australia) and the Forest Practices Authority.

Many people assisted with the project in a myriad of different ways. Firstly, I would like to thank my supervisors Sarah Munks, Alastair Richardson, Mark Hindell, Rod Kavanagh, Phil Bell, David Bowman and Iain Taylor. People who provided particular logistical support included Daniel Livingston, Shaun Thurstans, Trent Penman, Jason Wiersma, Chris Spencer, David Young, David Ratkowsky, Nick Mooney, David Ratkowsky, Nick Gust, Peter Davies, Rod Knight, Jo Lee, Phil Rush, Steve Stanton, Barry Rumbold, Wayne Kelly, Felicity Wilkinson and Richard Holmes.

I would also like to thank those that volunteered their time on the off chance that they might get to see an owl including in particular, Angela Gillone, Sue Drake, Peter Tonelli, Simon Plowright, Chris Coleborn, Bronwyn Luck, Sarah Tassell, Mike Bysouth, John and Shirley Tongue, and Ron and Jill Harris among others.

The following people assisted me in making the project work in many different ways; Amy Koch, Murray Lord, Craig Webb, Alan McBride, Peter Shute, Jeff Davies, Tim Bawden, Ed McNabb, David Milledge, Carl Clifford, Adelaide Marshall, Laurie Conole, Stewart Nicol, Virginia Andrews-Goff, Rohan Bilney, Priscilla Park, Linley Grant, Mel Hills, Ninna Millikin, Arthur Clarke, Vanessa Thompson, Martin Stone, Mark Wapstra, Andrew Bonnitcha, Heather Chauncy, Bill

Ecology of the Tasmanian Masked Owl

Brown, Mark Holdsworth, Matthew Webb, Genevieve Gates, Erin Flynn, Lisa Cawthen, Shannon Troy, Niall Doran, Mike Driessen, Kate Hamilton, Kit Williams, Barrie Wells, Julia and Frank at Seaview Farm, David and Robyn at Millybrook, Mike at Paradise Cottage, Carolyn at Crayfish Creek Caravan Park, Colin and Marje at Taraki Cottages, Mary Kille, Anne Watson, Barry Gallagher, Rodrigo Hamede, Kevin Redd, Tim Reid, Shelly Lachish, Belinda Yaxley, Heidi Auman and Helen Stephens.

I thank my family in New South Wales as well as in Tasmania for supporting and encouraging me. In particular, Bev for hours of babysitting, Bron for supporting me through thick and thin and Henry and Lucy for giving me the inspiration I needed to persevere. Finally, I have to acknowledge my father Ernest for teaching me the importance of persistence (or was that stubbornness), and instilled in me the value of having an enquiring mind.





Abstract

Rare species are often those most in need of conservation measures and yet they are often the least well known and most difficult subjects for scientific research. The methods frequently applied when researching species ecology are often not feasible with rare species.

This study investigates the ways in which habitat influences the ecology and distribution of a rare, threatened nocturnal bird, the Tasmanian Masked Owl (*Tyto novaehollandiae castanops*) using mostly indirect methods. The results provide insight into the value of indirect methods in determining habitat surrogates that may be used in conservation planning for rare and threatened species. Diet of owls in different habitats was determined using analysis of regurgitated pellets and a synthesis of previously published data. It was found that while the owl has a wide range of potential prey species, owls focus on particular prey species in different areas. Introduced species, particularly rodents, made up a large proportion of the diet at most sites. Sites that had little native forest contained low percentages of native species in the diet.

Calling behaviour was explored using recordings of owls obtained during call playback surveys and via automatic recording devices set at roost sites. The screech call of the Tasmanian Masked Owl was found to be deeper and to reach higher frequencies than the Australian Masked Owl (*T. n. novaehollandiae*). Calls were shown to have the potential to discriminate between age, sex and potentially individuals.

The occurrence of the owl throughout its potential range in forested areas of Tasmania was investigated using call playback surveys. Occupancy probability modeling (presence-absence data) was used to calculate the detectability of the Tasmanian Masked Owl in call playback surveys and to define habitat and

landscape features that best predict owl presence. Wind (negative) and air temperature (positive) were found to have the most influence on Tasmanian Masked Owl detectability, while low elevation, mature dry eucalypt forest was determined to be the best predictor of occupancy. The best occupancy probability model was used to create habitat quality map. The habitat quality map was compared with maps created using presence only records and maximum entropy models. There was broad similarity in the maps although the habitat quality map was more detailed.

The occupancy probability methods will be of value for the study of habitat preferences of a wide range of cryptic, and/ or rare species. The survey methodology used would vary depending on the species of interest, but the statistical framework behind the models would remain applicable. The call analysis methods and the diet analysis methods are applicable to studies of other owl species.

By combining the results obtained using the indirect techniques with knowledge of owl ecology from the literature, possible causes of the estimated small population size for the Tasmanian Masked Owl were explored. A range of habitat factors can affect the Tasmanian Masked Owl, including nesting and roosting habitat, elevation and mature dry eucalypt forest. Prey availability (abundance and accessibility) is likely to be the ultimate factor responsible for the distribution and abundance of Tasmanian Masked Owls and it probably is reflected in the distribution of low elevation, mature dry eucalypt forest in Tasmania.

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Chapter 1 : Introduction

Ecology of rare species

In ecological communities most individuals come from only a few species which are deemed to be common, while most species are represented by relatively few individuals and are rare (Fisher *et al.* 1943; Preston 1948; Flather and Sieg 2007). Species are usually regarded as rare on the basis of being either low in abundance, having a restricted range, or both (Gaston 1997). Scale is also important, as species that are rare in one location may be common in another. The causes of rarity are either natural or anthropogenic in origin (Flather and Sieg 2007); natural rarity is an inherent biological characteristic of some species whereas anthropogenic rarity is caused by human activities that have resulted in a species becoming rare, independent of their biology. The two are not mutually exclusive, since natural rarity may predispose some species to be put under additional pressure by anthropogenic activities, either directly or indirectly.

One of the most intractable problems facing conservation biologists is the effective conservation of rare species. Almost by definition, rare species are often those most in need of conservation measures and yet for the same reason they are often the least well known and most difficult subjects for scientific research (Marcot and Molina 2007). Effective conservation planning requires an understanding of the processes that are responsible for limiting species' distribution, whether they are naturally occurring or anthropogenic (Harrison *et al.* 2008; Lindenmayer and Hunter 2010). Obtaining this understanding of rare species is inherently problematic.

This thesis deals with the ecology of a rare and threatened owl and illustrates ways to overcome the problems of gathering information for the effective conservation of rare species.

Owls of the world

The predatory raptors known as owls belong to the order Strigiformes. The approximately 205 species of owls belong to one of two families, the Strigidae (typical owls) and the Tytonidae (barn-owls) (del Hoyo et al. 1999; König et al. 2008; Wink et al. 2009). The Strigidae contains the world's largest owl (Eurasian Eagle Owl *Bubo bubo*), the smallest owl (Elf Owl *Micrathene whitneyi*) and one of the most studied owls, the Spotted Owl (*Strix occidentalis*) (del Hoyo et al. 1999). The Strigidae appears to have evolved more recently than the family Tytonidae with the earliest *Tyto* appearing in at least the Middle Miocene with the earliest Strigidae not appearing until the Lower Miocene (del Hoyo et al. 1999). Currently, the Tytonidae includes the *Tyto* genus (barn-owls) and the Phodilinae subfamily (bay-owls) (Wink et al. 2009). Taxonomy in the *Tyto* genus is often controversial but there are between 16-25 species in the family Tytonidae, of which more than half occur in Indonesia and Australia (del Hoyo et al. 1999; König et al. 2008). The *Tyto* owls typically possess a conspicuous facial ruff that forms a heart-shaped disc; an elongated and compressed bill; long legs with feathers on the posterior side of the tarsus pointing upwards; the inner toe and claw is equal in length to the middle toe, and the claw of the middle toe is pectinated, or serrated; the tenth outermost primary is as long as the ninth, and the tail is emarginated (del Hoyo et al. 1999).

The Barn Owl (*Tyto alba*) is one of the world's most widely distributed land birds occurring across Europe, Africa, Asia, Australia, North America and South America (Burton 1992). It is only absent from the most inhospitable desert regions and areas with extreme winters (Taylor 1994). It is a well-studied owl, mostly in Europe and North America, particularly in relation to its feeding ecology and its physiology. Most of the other species of *Tyto* owl are poorly known in comparison. The Barn Owl provides a useful comparison with other species of *Tyto*, however, most of the populations that have been studied occur in largely open man-made landscapes of Europe (Taylor 1994) and the U.S.A. (Lyman 2012), limiting their applicability to forest-dwelling *Tyto* owls in Australia.

Owl ecology

Owls are among the most well recognised of avian predators and exist on all continents excepting Antarctica. Many owl species are regarded as rare on the basis of low abundance across their range; they are usually nocturnal, hence rarely seen, and have behaviours that make them difficult birds to study. The way owls occupy and are influenced by their habitat has been widely studied because it is of critical importance in understanding the birds and their conservation. Some owls are migratory, only briefly maintaining small territories for breeding and covering large distances in their regular migrations (Brinker *et al.* 1997; Evans 1997). Some owls are nomadic, only occurring in parts of their range sporadically, usually as a consequence of local and short-lived peaks in food availability (Miller *et al.* 1975; Hutton and Brickhill 1985; Olsen and Doran 2002). Other owls are generally sedentary, maintaining territories throughout the year, regardless of whether breeding is taking place (Gerhardt *et al.* 1994; Blakesley *et al.* 2005). Differences between migratory and sedentary owls usually relate to food availability (Korpimäki 1992a; Rohner and Krebs 1998; Klok and de Roos 2007).

One of the consistent aspects of owl ecology is that “food-supply affects every aspect of demography, including age of first breeding, reproduction (proportion of pairs laying, hatching and fledging young, clutch and brood sizes), juvenile and adult survival, natal and breeding dispersal, and winter irruptions” (Newton 2002). Newton (2002) emphasises that food-supply is the primary limiting factor for the distribution and abundance of owls. Numerous species of owls have been shown to respond functionally to prey availability including the Tawny Owl *Strix aluco* (Southern 1970; Petty 1999), Short-eared Owl *Asio flammeus* (Korpimäki and Norrdahl 1991), Long-eared Owl *Asio otus* (Korpimäki and Norrdahl 1991; Sergio *et al.* 2008b), Spotted Owlet *Athene brama* (Pande *et al.* 2009), Great Horned Owl *Bubo virginianus* (Rohner 1996), Tengmalm’s Owl *Aegolius funereus* (Korpimäki 1992b), Eurasian Eagle Owl *Bubo bubo* (Penteriani *et al.* 2002), and Barn Owl *Tyto alba* (Taylor 1994), to name a few. The home range size of the world’s most closely

studied owl, the Spotted Owl *Strix occidentalis*, a mature forest specialist (Doak 1989; Moen and Gutiérrez 1997), is best predicted by the distribution and abundance of prey species (Zabel *et al.* 1995). A population of the Eurasian Eagle Owl in Spain was found to drop from 19 occupied territories (6 recorded breeding attempts) to 6 occupied territories (nil breeding attempts) after rabbit populations crashed to almost nil after a local outbreak of rabbit haemorrhagic disease (Martínez and Zuberogoitia 2001). Similarly, the effects of prey habitat quality on owl reproductive success has been shown in Barn Owls (de Bruijn 1994; Key 1995; Taylor 2002; Bond *et al.* 2004; Charter *et al.* 2009) as well as other owls (Korpimäki 1988; Korpimäki and Norrdahl 1991; Korpimäki 1992b).

Important aspects of owl feeding ecology other than simple food supplies include food availability (in contrast to abundance), owl foraging behaviour and prey behaviour. The availability of prey to birds is just as important as the abundance of that prey (Martinez *et al.* 2010). For example, owl prey that is more visually obvious (Kaufman 1974), or physically accessible (Derting and Cranford 1989), is more easily preyed upon by owls. Access to prey is important in the foraging habitat preferences of owls in Sweden (Aschwanden *et al.* 2005). Both Long-eared Owls and Barn Owls prefer to forage in open fields rather than in ecological compensation areas (ECAs): areas that have been set aside in agricultural areas for the purpose of improving regional biodiversity (Aschwanden *et al.* 2005; Arlettaz *et al.* 2010), despite the higher abundance of prey species within the ECAs (Aschwanden *et al.* 2007). The reason given for this was the inaccessibility of the prey within the dense vegetation of the ECAs.

Owls tend to have a particular foraging behaviour that either contributes to, or is a consequence of, the prey animals that they usually feed on. Some owls, usually those with long wings, hunt while in flight, by quartering over the ground from a low altitude, looking and listening for prey and diving down when prey is detected: examples include the Short-eared Owl (Vukovich and Ritchison 2008), the Eastern Grass Owl (*Tyto longimembris*) (Estbergs *et al.* 1978) and occasionally the Barn

Owl (Taylor 1994). However, most owls use the perch hunting technique, where the owl sits and waits from a suitable perch until prey is located (Andersson *et al.* 2009), examples include Tengmalm's Owl (Bye *et al.* 1992) and the Hawk Owl (*Surnia ulula*) (Sonerud 1997). Owls that use the hunting in flight technique are generally hunting in open habitats while perch hunters require perches, usually provided by trees, stumps or fenceposts. Owls that hunt mostly ground-dwelling prey such as the Australian Masked Owl (*Tyto novaehollandiae*) (Kavanagh 2002a) require access to the prey on the ground whereas owls that hunt arboreal prey such as the Powerful Owl (*Ninox strenua*) (Kavanagh 2002a; Cooke *et al.* 2006) are relieved of this requirement.

The behaviour of prey can also affect the success of owl foraging. There have been numerous studies on the effect of the behaviour of small mammals on their susceptibility to predation by the Barn Owl (Brown *et al.* 1988; Kotler *et al.* 1991; Shiffman and Eilam 2004; Stangl *et al.* 2005; Fux and Ailam 2009; Taylor 2009; Berger-Tal and Kotler 2010). Some species are more likely to avoid predation than others; this has been studied in detail with Barn Owls and their prey, mostly in experimentally controlled captive situations (Kaufman 1974; Longland and Price 1991; Edut and Eilam 2003; Shahaf and Eilam 2004).

A number of studies have found that Barn Owls are more likely to prey preferentially upon mammals of particular age and sex as a result of prey behavioural differences (Dickman *et al.* 1991; Taylor 2009). For example, prey species have been shown to be able to adjust their foraging behaviour in relation to perceived predatory risk (Brown *et al.* 1988). In response to the presence of owls, small mammals restricted their foraging to microhabitats with protection, even though that meant leaving resource patches that were richer in seed sources (Brown *et al.* 1988; Kotler *et al.* 1991). Kangaroo rats of the genus *Dipodomys* have been found to be under-represented in the diet of Barn Owls where they occur in North America, possibly due to their owl-avoidance behaviour (Stangl *et al.* 2005).

The availability of nesting sites can be a factor limiting owl populations below that which food-supply would permit (Newton 1994; Newton 1998). This has been shown to be the case in populations of owls where the erection of artificial nest sites resulted in significant increases in owl density, abundance and breeding success in species including the Barn Owl (Johnson 1994; Petty *et al.* 1994; Marti 1997; Meyrom *et al.* 2009). However, in situations where food supply is apparently low, the provision of nest boxes is ineffective in increasing abundance and breeding success (Moller 1994; Radley and Bednarz 2005). In addition, nest boxes erected in situations where natural nest sites are freely available experience limited take-up by owls (Southern 1970; Mossop 1997; Solheim *et al.* 2009), suggesting that in these situations it is food supply that is limiting owl numbers, not the availability of nesting habitat.

Research techniques in owl ecology

The direct methods most often applied to bird ecology (e.g., radio-telemetry, line transect surveys, observational techniques) are sometimes not feasible with rare species, usually because of difficulties in locating the species (resulting in small sample sizes). Indirect techniques (e.g., call playback surveys, regurgitated pellet analysis) are often the only option to obtain the ecological information most critical for the development of effective conservation measures. The need for cost-effective methods of researching species conservation and ecology is prompting an increase in interest in indirect techniques (Chamberlain *et al.* 2004; Drechsler *et al.* 2007; Franco *et al.* 2007; Cantarello and Newton 2008). Indirect techniques can be cost-effective, less intrusive, and can still provide valuable ecological information that can inform the conservation process (Benshemesh and Emison 1996; MacKenzie *et al.* 2004; Nekaris *et al.* 2008; Bilney *et al.* 2010; Boyer *et al.* 2010).

The documentation of owl diet via the examination of regurgitated pellets of indigestible prey parts has become a staple of owl research (Townsend 1926; Errington 1930; Dodson and Wexlar 1979; Trejo and Lambertucci 2009). The discovery that owls have a relatively high pH in their digestive juices and are unable

to digest bone, fur or feathers has proven valuable in the study of owl diet (Errington 1930; Craighead and Craighead 1956; Smith and Richmond 1972; Raczynski and Ruprecht 1974; Andrews 1990). Identification of the species in the pellets is usually regarded as a good indicator of owl prey (Banks 1965; Vernon 1972; Morton 1975b; Kusmer 1986; Yom-Tov and Wool 1997; Debus and Rose 2004). Vertebrate remains are particularly well preserved but insect remains are also found, although more difficult to identify to type (Clulow *et al.* 2011). There is a possibility that the remains of amphibians may be under-represented in *Tyto* pellets (Wilson *et al.* 1986), however, *Tyto* owls are generally regarded as mammal feeding specialists (del Hoyo *et al.* 1999), so it is unlikely to be a problem except in situations where mammal prey becomes rare. The method avoids the logistical difficulties of determining what secretive nocturnal birds such as owls are preying on by observation (Todd 2006). One limitation of the pellet method is that a single prey item (especially large ones) may be represented in more than one pellet (Craighead and Craighead 1956; Yom-Tov and Wool 1997). Rosenberg and Cooper (1990) recommended that the sampling unit should be a collection of pellets rather than individual pellets for this reason.

The use of the call playback method has proven valuable for the study of many animals that are either cryptic, rare or occupy large territories (Miller and Miller 1951; Foster 1965). It involves the playing of pre-recorded vocalizations (or occasionally vocal imitations) of the target animal through a speaker system to encourage a detectable response from the target animal (Levy *et al.* 1966; Silvy and Robel 1967; Dow 1970). Call playback has been used successfully for large mammals (Kiffner *et al.* 2008; Thorn *et al.* 2010) and birds including rails (Tomlinson and Todd 1973; Repking and Ohmart 1977; Giese *et al.* 1980; Richmond *et al.* 2010), frogmouths (Beruldsen 1997; Smith and Hamley 2009), owlet-nightjars (Doucette 2010), nightjars (Kavanagh and Peake 1993a), and owls (Siminski 1976; Gould 1977; Gerhardt 1991; Martinez *et al.* 2002; Navarro *et al.* 2005; Kissling *et al.* 2010). The call playback technique has revolutionised the study of nocturnal birds and is particularly useful for rare species that are difficult to

find by any other method. In Australia, call playback has become the standard technique for detecting owls (Milledge *et al.* 1991; Kavanagh and Peake 1993b; Debus 2001; Loyn *et al.* 2001a; McIntyre and Henry 2002; Parker *et al.* 2007).

While the use of call playback has greatly improved the rate of detection of owl species there is still a statistical problem stemming from the often low rate of detection. Most surveys fail to detect owls, resulting in what has been termed zero-inflated data (Wintle *et al.* 2005b). Even within surveyed locations, it is common for the species to be present but go undetected. This has prompted the investigation of species occurrence from a different perspective, that of the probability of occupancy of a site. The methodology is designed to permit reliable inferences about occupancy that deal adequately with detection probabilities less than one (MacKenzie *et al.* 2002; MacKenzie *et al.* 2003a; Wintle *et al.* 2004).

Quality of habitat for owls is in part a function of food-supply (and associated foraging issues) and nesting habitat but it is easier to predict and map owl habitat if it can be done on a broad scale based on vegetation characteristics, rather than directly measuring prey abundance, and searching for nesting sites. The measurement and prediction of habitat quality on a broad scale using radio telemetry data has been attempted for a number of owl species including the Spotted Owl (Forsman *et al.* 1977; Franklin *et al.* 2000) and the Barred Owl (Mazur *et al.* 1998). In Australia attempts to describe and map habitat quality for owls has generally been based on call playback survey results and opportunistic site records applied to GIS layers (Kavanagh and Peake 1993a; NSW National Parks and Wildlife Service 1994; Kavanagh *et al.* 1995; Loyn *et al.* 2001a; Loyn *et al.* 2002; Soderquist *et al.* 2002; Taylor *et al.* 2002; Wintle *et al.* 2005a). Potential nesting habitat quality has been predicted from habitat found around existing nests extrapolated to larger areas in Australia (Swindle *et al.* 1999; Isaac *et al.* 2008). Satellite imagery has been used to predict and map habitat quality for the Barn Owl in Belgium (Andries *et al.* 1994). All of these methods can be useful and

informative but they are all dependent on the quality and quantity of the information available.

The nocturnal behaviour of owls and the low density at which they often occur has made the study of their distribution and abundance more difficult than it is for most birds. Because of this, many of the standard direct techniques for studying distribution and abundance such as line-transect surveys and point counts (Anderson and Ohmart 1981; Pyke and Recher 1985) are ineffective for owls. The habitat used by owls, including in particular the territory size of territorial species, has been a prominent area of research over the last 30 years. The fitting of radio transmitters to owls has been the most used direct technique to monitor territory size, habitat use and movements, particularly with the Spotted Owl (Guetterman *et al.* 1991; Call *et al.* 1992; Forsman *et al.* 2005). The technique also enabled researchers to discover where the owls roosted and nested (Herter *et al.* 2002; Hamer *et al.* 2007). It is nevertheless, an expensive, labour-intensive and intrusive technique (Petty *et al.* 2004), prohibitively so for many studies of rare and threatened owls notwithstanding the quality of the data obtained.

Australian Masked Owl (*Tyto novaehollandiae*)

The Australian Masked Owl (*Tyto novaehollandiae*) is one of the largest and the second-most widespread of the barn-owls from the *Tyto* genus. It occurs sparsely across northern and eastern Australia, with a population occurring in south-west Western Australia (Barrett *et al.* 2003). The Australian Masked Owl has been a subject of targeted surveys in Western Australia (Liddelow *et al.* 2002), Victoria (Milledge *et al.* 1993; Loyn *et al.* 2001a; McIntyre and Henry 2002), New South Wales (Kavanagh and Peake 1993b; Debus 1995; Debus 2001; Parker *et al.* 2007) and Tasmania (Bell *et al.* 1996). Apart from Tasmania, where it is the only large forest owl, it is typically the least reported of all the Australian owl species (Peake *et al.* 1993; Debus and Rose 1994) and is poorly known. Many of the commonly held beliefs about the species are based on anecdotal observations, or extrapolations from other *Tyto* spp. (Schodde and Mason 1980; Debus 1993b; Hollands 2008).

While it is most often reported from the forested south-east of Australia (Blakers *et al.* 1984; Barrett *et al.* 2003), the Australian Masked Owl once occurred and possibly still does occur well inland, including a population that lives in caves on the Nullarbor Plain of Western Australia (Hyem 1932; Debus 1993a). It has been a source of intrigue that this apparently adaptable species with such a wide distribution apparently remains rare across its range. It is listed as vulnerable, endangered or near threatened in all the States that it occurs in except for Western Australia.

Studies on the Australian mainland have suggested that the Australian Masked Owl is most numerous in open forest and woodland, particularly in areas where the vegetation includes a mosaic of dense and sparse ground cover (Davey 1993; Debus 1993b; Peake *et al.* 1993; Debus and Rose 1994). Systematic surveys (based on presence and absence data) conducted in north-east New South Wales found that high probability areas of occurrence for the Australian Masked Owl were in drier forests and low probability areas were in mesic forests (NSW National Parks and Wildlife Service 1994). With the addition of incidental data and analysed as a presence only dataset, a model was constructed that reinforced the preference for drier forest types but highlighted a preference for wet forest components over extensive tracts of dry forest. The model identified a preference for less topographically rugged sites and forest interiors distant from cleared land and fragmented landscapes (NSW National Parks and Wildlife Service 1994).

The identified preference for forest interiors was seemingly in contrast to the abundance of incidental records that come from road kills and road-injured birds in semi-cleared and cleared areas (Peake *et al.* 1993; Debus and Rose 1994). As of 1994, 20% of all the records of the species in NSW were of road kills or road injuries, suggesting that Masked Owls may make use of the edge effect created by roads through wooded habitats (Debus and Rose 1994). However, as pointed out by Debus and Rose (1994), roads are the most intensively sampled habitat and the apparent preference for edges and cleared land could be a misleading artifact.

There is a growing body of knowledge associating the Australian Masked Owl with extensively forested areas. In south-east NSW, virtually all observation records were associated with extensively forested areas or occurred within one kilometre of the boundary of such areas (Kavanagh and Stanton 2002). A number of studies in south-east NSW have also found the Australian Masked Owl more often in unlogged forest, or in forests which had been subjected to only light selective logging, than in re-growth (Kavanagh and Peake 1993a; Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995). However, a study from northern NSW in mostly re-growth forests of an assortment of different silvicultures, detected the Australian Masked Owl more often immediately after logging than before, suggesting that even the cleared habitat was more likely to be occupied than the older re-growth forest (Cann *et al.* 2002).

Tasmanian Masked Owl (*Tyto novaehollandiae castanops*)

The Tasmanian Masked Owl is generally regarded as a rare species because it has a low overall abundance (Bell *et al.* 1996), large territory size (Young 2006), and is rarely observed (Barrett *et al.* 2003), despite its wide distribution in Tasmania. It is usually regarded as the largest of the world's barn owls, i.e. members of the genus *Tyto* (König *et al.* 2008), although it is comparable in size with the Sooty Owl *Tyto tenebricosa* (Mooney 1993; Bilney 2009). It has variously been regarded as a distinct species (König *et al.* 2008), or as a subspecies of the Australian Masked Owl (*Tyto novaehollandiae*) (Christidis and Boles 2008). The most recent study has suggested that the Tasmanian Masked Owl is best regarded as a subspecies of the Australian Masked Owl (Hogan *et al.* 2012).

Tasmanian Masked Owls are typically larger and heavier than mainland Australian Masked Owls and occur more often as a dark plumage morph (Higgins 1999c). They have no large forest owl competitors in Tasmania, unlike the mainland Australian Masked Owls. Research has shown that the Tasmanian Masked Owl preys upon larger mammals more often than on the mainland (Mooney 1993; Kavanagh 2002a). The smaller Barn Owl does occur occasionally in Tasmania as a

vagrant (Thomas 1979; Blakers *et al.* 1984) with a number of specimens occurring in museum collections (Todd, M.K., pers. obs.). However, there have probably been some misidentifications of *Tyto* owls in Tasmania. The Tasmanian Masked Owl has been incorrectly reported to only occur in dark and dark-intermediate colour phases (Higgins 1999c), when in fact it occurs in all colour phases including white making it superficially similar to the Barn Owl. For example, a deceased owl collected in 1910 was described as a strange form of Barn Owl (Hall 1910), but from the description the owl was likely a white morph Tasmanian Masked Owl. However, it should be noted that there is one unconfirmed record of Barn Owl nesting in a barn in Tasmania in the 1940s (Elliott 1999).

The Tasmanian Masked Owl is listed as endangered under the Tasmanian *Threatened Species Protection Act 1995*, vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* and as endangered in the 2010 Action Plan for Australian Birds (Garnett *et al.* 2011a). The breeding population has been estimated at between 200 and 665 pairs (Bell and Mooney 1997; Bell and Mooney 2002). Much of its core distribution overlaps with areas subject to production forestry (Bell and Mooney 2002) but little is known of the effects of different land use activities on the owl. Only 6% of the predicted distribution of the Tasmanian Masked Owl lay within dedicated reserves in 2002 (Bell and Mooney 2002). The owl is not adequately conserved within the reserve system and so its conservation relies on the ways in which other land use types are managed.

There has only been one systematic distributional survey for the Tasmanian Masked Owl, carried out in the winter months of 1996 (Bell *et al.* 1996). Apart from this survey, there have been several studies of the owl's diet (Green 1982; Green and Rainbird 1985; Geering 1990; Mooney 1992; Mooney 1993; Young 2006), its breeding habits (Sharland 1947; Fleay 1949; Hill 1955; Green 1982; Mooney 1997) and numerous anecdotal observations (Fletcher 1909; Fletcher 1918; Dove 1938; Skemp 1955; Green 1965; Mollison 1999). Most of these studies were based on small samples and limited observations. Two female Tasmanian Masked Owls were

captured and fitted with radio-transmitters in 2006, providing the first estimates of Tasmanian Masked Owl home range size, i.e. 1991 hectares and 1896 hectares (Young 2006).

The most detailed review so far of the ecology of the Tasmanian Masked Owl stated that there was a “dearth of information on the distribution, population status and habitat requirements of the Masked Owl ... in Tasmania” (Bell *et al.* 1996). Bell *et al.* (1996) identified some of the possible environmental constraints to the distribution of Tasmanian Masked Owls. They suggested that the preferred habitat of the Tasmanian Masked Owl lay in lowlands (<600 m a.s.l.) with a high mean annual temperature and low mean annual rainfall. The distribution of records reflected the distribution of dry sclerophyll forest, woodland and cleared land in Tasmania and was in accord with stochastic distribution models of the nominate subspecies in northeast New South Wales (NSW National Parks and Wildlife Service 1994).

Given the level of forest clearance (forestry, agriculture, urban subdivisions) within what is apparently the Tasmanian Masked Owl’s preferred habitat, its low representation in the reserve system, and that it remains the least well known of the Australian *Tyto* spp. there is a strong incentive for the studies reported here.

Thesis aim and objectives

The overarching aim of this thesis is to investigate the influence that habitat has on the distribution and ecology of a rare and threatened nocturnal bird, the Tasmanian Masked Owl, in forested landscapes. In particular, it explores the following questions relating to survey, habitat use and foraging ecology, at a broad scale, of this little studied owl. Where noted, the occurrence of other nocturnal birds is also reported upon. Some of the questions asked include:

Does the diet of Tasmanian Masked Owls vary according to location?

What is the calling behaviour of the Tasmanian Masked Owl and how might this influence survey results?

How do geographic and environmental variables influence detection probability, and site occupancy, of Masked Owls and two other species of Tasmania's nocturnal birds? What is the distribution of optimum habitat for the Tasmanian masked owl and other nocturnal bird species?

In this way it tests previous assumptions about factors that influence Masked Owl occurrence and habitat, in particular the importance of prey accessibility and availability. The study largely uses indirect techniques to do this due to ethical constraints placed on the project.

Ethical constraints

The thesis does not attempt to address the question of whether the availability of suitable nesting hollows limits population size. Early in the process, there was an intention to use GPS datalogger technology or radio telemetry to follow owls and locate nest sites, roost sites and preferred feeding habitat. Unfortunately, due to a combination of equipment failure and difficulties in obtaining animal ethics approvals (described below) this methodology had to be abandoned and alternative questions were posed.

The standard method for attaching tracking devices to owls throughout Australia is via lightweight harnesses, sometimes with a weak link that will eventually break allowing the harness to fall free after many months. The method has been used successfully in the study of Powerful Owls (*Ninox strenua*) (Kavanagh 1997), Sooty Owls (*Tyto tenebricosa*) (Kavanagh and Jackson 1997; Bilney *et al.* 2011), Barking Owls (*Ninox connivens*) (Kavanagh and Stanton 2009), Australian Masked Owls (*Tyto novaehollandiae*) (Kavanagh and Murray 1996; Kavanagh 1997; Kavanagh *et al.* 2008b) and Tiwi Island Masked Owls (*T. n. melvillensis*) (Smith, J. pers. comm.). Harness and transmitter combinations used on Australian owls have ranged

from 1.4% to approximately 5% of owl body weight. In Tasmania, David Young attached harnesses to two Tasmanian Masked Owls for his Honours research at UTAS in 2006. These harnesses had a Sirtrack “weak link” which was designed to break in the event of a harnessed animal becoming tangled in vegetation, but not to decay and break over time; this was not the understanding of those involved in the research and the UTAS Animal Ethics Committee. As a result of the harnesses not breaking, the UTAS Animal Ethics Committee developed a negative opinion about the use of harnesses on owls, despite the fact that there was no indication that the tracked owls had come to any harm.

The UTAS Animal Ethics Committee had concerns about the use of harnesses in this current project (2007 and 2008) but after some time and discussions permission was granted for their use in 2009. After raising the necessary funds, GPS dataloggers were purchased from the only company that claimed to be able to manufacture loggers at a small enough size to be acceptable to the UTAS Animal Ethics Committee (<3% of body weight). Unfortunately they proved to be faulty and had to be returned to the manufacturer at the cost of a significant amount of time. In the meantime, two Tasmanian Masked Owls were captured and fitted with standard VHF radio transmitters. One of these devices failed within one week of fitting. After the transmitter failure, the owl was not sighted again for over 6 months, but then appeared to be well; the transmitter and harness were not visible. The second owl was released with harness and was tracked for approximately 6 weeks until the owl was found dead with the transmitter and harness still attached. The harness showed signs of weakness at the site of the weak link but it had not yet come free. There was evidence of starvation, but when the owl was examined by the UTAS Animal Welfare Officer he concluded that the cause of death was inconclusive; animal ethics approval was subsequently withdrawn. Due to budget and time constraints by this stage (2 years into the project), it was decided to concentrate on other methods of studying masked owls in order to be able to produce a body of work suitable for a PhD in the time remaining. Methods were devised to explore the above questions relating to habitat use and foraging

ecology, at a broad scale, of this little studied owl. This was always intended to be the emphasis of this work and the intention of the thesis.

Thesis structure

Chapter 2 analyses the composition of the diet of the Tasmanian Masked Owl at a range of locations and attempts to relate any differences in terms of the environmental characteristics of the sites. The hypothesis that Tasmanian Masked Owls focus their dietary attention on particular prey species at each location, while having a diverse dietary range at the Tasmania-wide scale, is tested.

The calling behaviour of the Australian Masked Owl is poorly known and there are relatively few recordings of the species. Chapter 3 describes quantitatively and qualitatively the calls of the Tasmanian subspecies of the Australian Masked Owl and tests a number of hypotheses including that a number of environmental variables have a negative effect on Tasmanian Masked Owl calling rate.

The influence of geographic and environmental variables on the detection probability, and site occupancy, of Masked Owls and two other species of Tasmania's nocturnal birds is examined in Chapter 4. Using occupancy probability theory, occupancy models are created to explain the distribution of the three species taking into account the number of surveys at each site and the weather at the time of the survey. The potential utility of these habitat models for conservation planning is discussed. Several hypotheses are tested in relation to this including that the Tasmanian Masked Owl is more common at low altitudes, in dry eucalypt forest with an abundance of tree hollows and in forest that is in close proximity to forest edges.

Models, based on systematically collected data that describe the habitat preferences of the owl are then used to map the occurrence of optimum habitat for the species and these maps are compared with maps created by less rigorous datasets (Chapter

5). As Chapters 2-5 are written in the format of publications for scientific journals there is a small amount of repetition of background material in some sections between the chapters.

The final chapter (Chapter 6) discusses the findings of the research in relation to the overall objective of the thesis and places it in a context from which it can inform and provide direction to future research on the Tasmanian Masked Owl, the Australian Masked Owl and other cryptic, rare species that provide challenges to researchers and land managers.

Chapter 2 : Variation in the diet of the Tasmanian Masked Owl

Authors: Michael K. Todd, Chris Spencer and Phil Bell

Abstract

Knowledge of food requirements has been demonstrated to be critical to the conservation management of many owl species. Previous studies have shown that, in general, a diverse range of prey forms the diet of the Australian Masked Owl (*Tyto novaehollandiae*). However, anecdotal evidence suggests that individuals may select for specific prey items at particular locations. This study quantified the diet of the Tasmanian Masked Owl (*T. n. castanops*) at 17 sites in eastern Tasmania, through the examination of regurgitated pellets. Mammals dominated the diet at all but one of the sites, with introduced rodents (mostly introduced black rat (*Rattus rattus*) and house mouse (*Mus musculus*)) prominent in the diet at all sites. Bandicoots (mostly the eastern barred bandicoot *Perameles gunnii*) were an important food item in diet collections south of Hobart. There was a wider range of larger-sized mammals in the diet of the Tasmanian Masked Owl than is usually found in the diet of the mainland Australian Masked Owl. There was no clear relationship between diet and the environmental characteristics of the site, possibly because of the heterogeneous nature of most of the sites, but the results of this study support the idea that there is a focus on particular food sources at a particular locality. The prey species most common in the diet appears to vary across Tasmania and also between individuals. It may be that prey partitioning between the sexes is responsible for some of this variation. Because different owls focus on different prey, maintaining the presence and abundance of the species in an area may hinge

upon maintaining a range of different types of habitat for prey animals of varying sizes.

Introduction

Prey distribution and abundance is one of the main factors influencing the ecology of all raptors, including owls. Population densities of raptors can be limited by the availability of prey and this in turn can affect breeding success directly and indirectly (Newton 1979; Peery 2000; Aumann 2001). Food selection and availability has been demonstrated to be important to many owl species (Smith *et al.* 1999; Sunde *et al.* 2001; Penteriani *et al.* 2002). For example, food supply (and habitat related to food supply) has been shown to affect owl density and breeding performance in many studies (Korpimäki and Norrdahl 1991; Korpimäki 1992a; Korpimäki 1992b; Penteriani *et al.* 2002; Salvati *et al.* 2002; Bond *et al.* 2004; Klok and de Roos 2007; Sergio *et al.* 2008b), although not all (Meek *et al.* 2009; Frey *et al.* 2011). Home range size has also been linked to owl breeding performance (Sunde *et al.* 2001). Knowledge of the food requirements of a species is important to understanding its ecology and habitat requirements, and the study of diet is a necessary component of this. The conservation and management of a species requires that all aspects critical to a species survival are taken into account.

Published information on the diet of the Australian Masked Owl (*Tyto novaehollandiae*) is mostly sparse or restricted to studies of particular pairs (Debus 1993b; Kavanagh 1996; Kavanagh 2002a; Todd 2006). There has been a general consistency in the diet of the Masked Owl on the Australian mainland, with small ground-dwelling and scansorial mammals being important in the diet. Kavanagh (1996) examined the diet of a breeding pair of Australian Masked Owls on the south coast of New South Wales. This pair fed mostly on small native ground-dwelling or scansorial mammals from the genera *Rattus* and *Antechinus*. Near Newcastle, a female Australian Masked Owl was reported to feed mostly on the introduced black rat (Kavanagh and Murray 1996). A breeding pair from Lake Macquarie were found

to prey upon mostly bush rats (*Rattus fuscipes*), brown antechinus (*Antechinus stuartii*) and house mouse (*Mus musculus*) (Todd 2006). A nest tree of the Australian Masked Owl from Victoria was reported to contain mostly remains of rabbit and house mouse (McNabb *et al.* 2003). More recently, an analysis of the prey of two male Australian Masked Owls from northern New South Wales found house mouse and bush rat to be the two most commonly consumed prey species (Kavanagh *et al.* 2008a). Introduced species are sometimes important in the diet (Kavanagh and Murray 1996) but not always (Kavanagh 1996). The influence of environment on diet has not been investigated but it has been suggested that the Australian Masked Owl might require open understorey forest to be able to capture its ground-dwelling prey (Debus 1993b; Peake *et al.* 1993).

More detail has been published on the diet of Tasmanian Masked Owls (Green 1982; Green and Rainbird 1985; Mooney 1992; Mooney 1993). However, previous studies of the diet of the Tasmanian Masked Owl have either focused on a collection of pellets from one owl at one locality (Green and Rainbird 1985; Geering 1990; Young 2006) or they have combined pellet collections from across Tasmania (Mooney 1992; Mooney 1993).

Most studies of Tasmanian Masked Owl diet have found introduced rodents to be major components (Green 1982; Geering 1990; Mooney 1993; Young 2006; Milledge *et al.* 2010) with rabbits (Green 1982; Mooney 1992; Mollison 1999), bandicoots (Young 2006) and birds (Green and Rainbird 1985) also occasionally being important. In general these studies found a diverse range of prey; however particular prey species always dominate the diet of Tasmanian Masked Owls in particular areas. The most obvious difference between the Tasmanian Masked Owl and the mainland subspecies is the greater abundance in the diet of large and medium sized mammals.

The Tasmanian Masked Owl is the only large forest owl to breed in Tasmania, resulting in it having no close avian competition, unlike the Australian Masked Owl on mainland Australia where throughout its range there is at least one other large forest owl species present. The only other resident species of owl, the small Tasmanian subspecies of the Southern Boobook (*Ninox novaeseelandiae leucopsis*), is about one fifth the size of the Tasmanian Masked Owl (Higgins 1999c) and largely insectivorous (Green *et al.* 1986). The Barn Owl (*Tyto alba*) occurs as a vagrant in Tasmania but there has been one unconfirmed breeding report for the species (Elliott 1999). Although the diet of the Barn Owl often consists of small mammals (Baker-Gabb 1984; Heywood and Pavey 2002), its rarity or usual absence from Tasmania means it would provide little more than temporary, local competition for the Tasmanian Masked Owl.

The Tasmanian Masked Owl is a rare species because of a combination of low overall abundance (Bell *et al.* 1996), large territory size (Young 2006), and being rarely observed (Barrett *et al.* 2003), despite its wide distribution in Tasmania. It is usually regarded as the largest of the world's barn owls (*Tyto*) (König *et al.* 2008), although it is comparable in size to the female Sooty Owl *Tyto tenebricosa* (Mooney 1992). It is listed as endangered under the Tasmanian *Threatened Species Protection Act 1995*, vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999* and as endangered in the Action Plan for Australian Birds (Garnett *et al.* 2011a). Previous estimates of population size have included 200-400 breeding pairs (Bell and Mooney 2002) and 1300 mature individuals (Garnett *et al.* 2011a). Much of its core distribution overlaps with areas subject to production forestry (Bell and Mooney 2002) and yet little is known of the effects of different land use activities on the owl.

The diet of owls has most often been studied by the analysis of their pellets, which are made up of the regurgitated indigestible remains of their prey. This method of studying diet can be used for most raptors but is especially suitable for owls because

of their tendency to swallow prey whole or in large portions, notably including the head of their prey (Duke *et al.* 1975). *Tyto* owls have a relatively high stomach pH (Smith and Richmond 1972) and are only capable of limited digestion of bones (Cummings *et al.* 1976) giving further advantage to pellet-based studies. For example, it has been found that that 98% of the tibiae found in Barn Owl pellets in one study, were complete (Andrews 1990). The contents of pellets can be identified to species level by comparison of the remains with known reference specimens, particularly crania, jawbones, teeth and thighbones. The use of pellets to determine diet has been found to be accurate with little loss of information due to bone damage in digestion in Barn Owls (Raczynski and Ruprecht 1974; Dodson and Wexlar 1979; Taylor 2009).

In this study, the diet of the Tasmanian Masked Owl at particular localities was compared by analysing regurgitated pellets. The aim was to describe the composition of the diet at each location and evaluate any differences in terms of the environmental characteristics of the sites. The hypothesis, that although the Tasmanian Masked Owl eats a diverse range of prey at the Tasmania-wide scale, at a particular locality they usually focus on particular species, was tested.

Methods

Two-hundred and eighty-two regurgitated pellets and loose material from broken down pellets were collected at known roost sites of Tasmanian Masked Owl at eight locations in eastern Tasmania (Figure 2.1, Table 2.1). All pellet collections were made at sites where Masked Owls had been previously observed. Sites at Howden, Allens Rivulet, Sandford, Sandy Bay and Taroona were tree roosts, the sites at Glen Huon and Bagdad were cave roosts and the site at Bishopsbourne was a roost in a barn. In addition to these sites, the published results from sites at Crabtree, Mountain River (Young 2006), Pateena (Green 1982) and Triabunna (Green and

Rainbird 1985) were added to the total analysed data set. These four pellet collection sites were tree roosts, with the Pateena site being a nest site. Further unpublished additional datasets were included, involving sites at Liffey (C. Spencer), Broadmarsh (N. Mooney), Longford (N. Mooney), Waverley (N. Brothers, per N. Mooney) and Granton (N. Brothers, per N. Mooney). All of these unpublished additional sites were cave roosts except for Longford, which was a number of tree roosts. In total 503 individual pellets or assorted pellet remain collections were analysed from 17 sites.

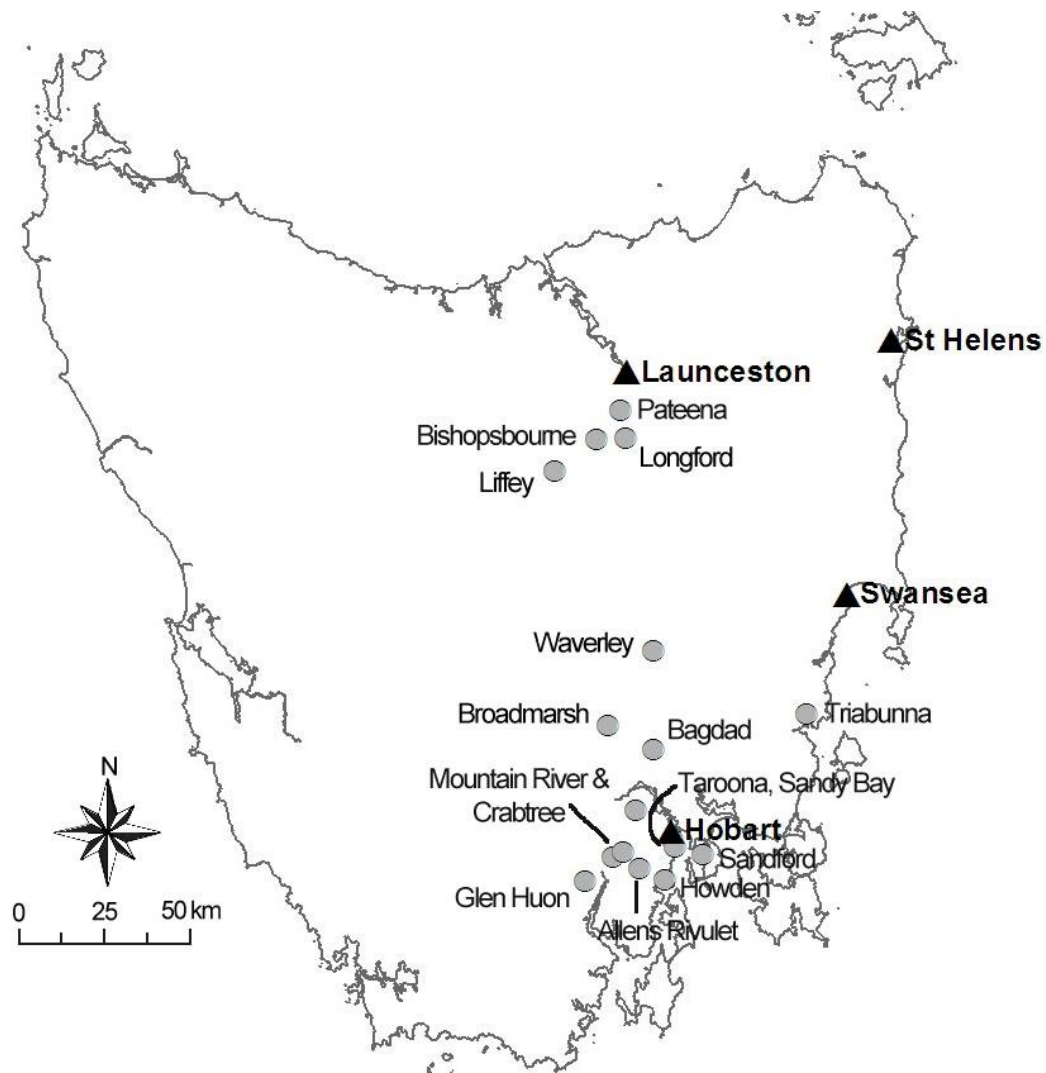


Figure 2.1- Location of sites (grey dots) where diet was analysed.

Table 2.1- Details of the locations where regurgitated Tasmanian Masked Owl pellets were collected. Habitat details are for a 2 km radius circle around the pellet collection point, extracted from the TASVEG mapping of Tasmania's vegetation (Harris and Kitchener 2005). Note that % native forest includes % dry eucalypt forest and % wet eucalypt forest. ¹ First published herein, ² Geering (1990), ³ Young (2006), ⁴ Green (1982), ⁵ Green and Rainbird (1985), ⁶ unpublished data (C. Spencer), ⁷ unpublished data (N. Mooney), ⁸ unpublished data (N. Brothers, per N. Mooney).

Site	Collection Dates	No. of Owls	Sex	% Agricultural	% Urban	% Native Forest	% Dry Eucalypt Forest	% Wet Eucalypt Forest
Howden ¹	Jul 2007, May 2008, Jun-Aug 2008 (all months inclusive), Apr 2009, Oct 2009, Jan 2010	?	U	17.8	1.6	33.7	33.4	0.0
Allens Rivulet ¹	Nov 2009 – Jun 2010 (all months inclusive),	1	F	43.7	1.2	50.9	47.3	1.8
Glen Huon ¹	Mar 2006, Jun 2010	1	F	37.5	2.5	39.9	15.5	20.3
Bagdad ¹	Jun 2010, Dec 2010	1	M	0.0	1.1	93.0	91.5	0.8
Sandford ¹	Mar 2006	?	U	33.1	0.0	52.1	51.9	0.0

Site	Collection Dates	No. of Owls	Sex	% Agricultural	% Urban	% Native Forest	% Dry Eucalypt Forest	% Wet Eucalypt Forest
Bishopsbourne ¹	Jun 2006	1	U	91.8	0.1	8.1	8.1	0.0
Sandy Bay ¹	Jun 2006	1	U	0.2	50.0	19.8	17.6	1.2
Taroona ^{1,2}	Oct 1982, Feb- Oct 2007	1	U	0.2	27.8	51.7	48.9	1.2
Crabtree ³	Jun 2006	1	F	65.7	1.4	27.0	21.6	5.4
Mountain River ³	Jun 2006	1	F	42.0	0.0	53.1	26.0	26.2
Pateena ⁴	Jan 1982	?	U	85.0	0.0	4.6	4.4	0.0
Triabunna ⁵	Nov 1980	1	U	0.70	0.20	97.5	97.5	0.00
Liffey ⁶	Jan 1987- May 1988	1-2	pair	74.12	0.00	23.08	4.85	16.92
Broadmarsh ⁷	Oct 1986, Aug 1988	?	U	60.81	0.00	38.84	37.95	0.00
Longford ⁷	May 1988	?	U	64.78	0.00	23.77	23.69	0.00
Waverley ⁸	Sep 1987	?	U	90.07	0.00	6.79	6.79	0.00
Granton ⁸	Feb 1980, Sep 1987	?	U	36.56	0.00	37.66	37.48	0.00

Pellets considered to have come from Tasmanian Masked Owls were examined and bones and other body parts were identified to species level where possible by comparison with known reference specimens and assorted published references (Green 1983; Triggs 1996). Material was then counted; counts represent the minimum known number of individuals, usually based on the number of left and right mandibles, crania and other identifiable bones.

To give an assessment of the biomass of prey that the owls were consuming, an estimate of the weights of prey items was used. Weights of prey species were estimated from weight ranges and means given in a number of different publications (Green 1967; Green 1968; Green 1972; Marchant and Higgins 1993; Munks 1995; Menkhorst and Knight 2001; Higgins *et al.* 2006; Van Dyck and Strahan 2008). Juvenile mammals were assumed to average 50% of adult weight. Where possible, weights of Tasmanian populations were used. Animals regarded as being large included rabbit, Tasmanian Pademelon, To account for the sizable variation in weights between individuals a standardization procedure was conducted on the weights following Southern (1954) and McDowell and Medlin (2009). A standard prey unit was taken to be twenty grams of prey (Southern 1954; McDowell and Medlin 2009) and the biomass of prey species was rated in terms of prey units. The values used are listed in Appendix 2.1.

Data analysis

To assist in comparisons between sites a diversity index (Shannon's Diversity Index) was calculated for each site, using the minimum known number of individuals scored for each pellet.

Multi-dimensional scaling ordination (MDS) was used to explore diet variation in terms of abundance of prey items between sites using Primer 6.1.13 (Clarke and Gorley 2005). The abundance data were standardized and a square root transformation was applied to the data to reduce the influence of rare items before

the ordination was conducted. The habitat data examined were collected from a two kilometre radius circle around the pellet collection points, obtained from the TASVEG vegetation mapping of Tasmania (Harris and Kitchener 2005).

Results

Diet composition

Across all the sites combined the Tasmanian Masked Owl had a diverse diet (Shannon's Diversity Index 2.45) consisting of 37 vertebrate species and three invertebrate species. At particular sites, however, the diversity of prey was much reduced (average Shannon's Diversity Index 1.64) with a couple of prey types usually dominating the diet (Table 2.2).

Mammals dominated all but one of the diet collections by abundance and by biomass, measured in prey units (Table 2.3). They usually made up over 90% of the identified items, with a maximum of 100% at Glen Huon, Mountain River, Sandford and Liffey. The only collections where they made up less than 90% of the diet were at Sandy Bay (85%), Taroona (77.9%), Triabunna (48.3%) and Waverley (86.4%), where birds made up the remainder. However, at these sites mammals usually still made up most of the diet by biomass (Sandy Bay 95.6%, Taroona 95.1%, Triabunna 85.2% and Waverley 67.7%). The Triabunna collection (Green and Rainbird 1985) was the only one where birds were prominent in the diet (42.9%). Most of the birds in this collection (94.3%) were the introduced Common Starling (*Sturnus vulgaris*) (Table 2.2).

Larger species dominated the diet samples according to biomass while being less numerous than smaller items. Species usually responsible for this were rabbit and macropods including Tasmanian pademelon (*Thylogale billiardierii*). For example at Allens Rivulet, the Tasmanian pademelon made up 9.4% of the diet by abundance but 35.6% by biomass (Table 2.2 and Table 2.3). Tasmanian pademelon in the

samples were usually juvenile although note that Young (2006) found one adult macropod skull in a pellet.

Where pellets were collected from near nests, both sexes may have contributed pellets to the collection (e.g. Green 1982). The pellets analysed by Young (2006) from Crabtree and Mountain River were known to be from female owls, since both individuals had been captured and measured. In the current study, pellets from Allens Rivulet and Glen Huon were probably females on the basis of the observed body size and foot size of the owls. The pellets collected at Bagdad were from a probable male owl identified on the basis of its pale plumage colour and small foot size.

Introduced species made up a large proportion of the diet at most sites (Figure 2.2). Common introduced species in the diet included black rat, house mouse and rabbit. The most common native species in the diet depended largely on the location. At sites south of Hobart, the eastern barred bandicoot was usually the most common, while in collections north of Hobart, native species were rare in the diet (Figure 2.2). Most prey were ground-dwelling but there were some interesting exceptions where possums were relatively prominent in the diet including Sandford (common ringtail possum (*Pseudocheirus peregrinus*), 27.6% of prey items), Liffey (common ringtail possum, 22.2% of prey items) and at Bagdad (common ringtail possum, little pygmy-possum (*Cercartetus lepidus*) and sugar glider (*Petaurus breviceps*), together 14.9%) (Table 2.2 and Table 2.3). In terms of abundance in pellet samples, rodents were usually prominent, ranging from a minimum of 7.4% of the diet at Liffey, to a maximum of 95.2% at Bishopsbourne (Figure 2.3). In terms of biomass consumed, rodents either ranked very high, if there were few larger animals in the sample, or quite low if there were many larger animals in the sample. For example, at Glen Huon, rodents made up 46.5% of the diet by abundance but only 12.6% of the diet by biomass, because of the abundance of the larger eastern barred bandicoot in the diet at Glen Huon (Table 2.3).

The most common rodent in the diet was usually the introduced black rat and occasionally the introduced house mouse. Black rat occurred in all but one collection, house mouse occurred in all but two collections while the brown rat (*Rattus norvegicus*) occurred in only three collections. Native rodents were usually not present in the collections and were never dominant (Table 2.4).

Relationship between diet and landscape/environment

The relationship between the area of native forest existing near the collection point and the proportion of native species in the diet was unclear. Sites that had little native forest (Triabunna 10.0%, Bishopsbourne 8.1%, and Pateena 4.6%) and were dominated by agricultural land usually contained low percentages of native species in the diet (Triabunna 14.8%, Bishopsbourne 0% and Pateena 10.9%). However, the only site with greater than 80% native forest (Bagdad 92.9%) also contained a low percentage of native species in the diet, which was against the general trend. The introduced black rat dominated the collections from here. The sites with the highest proportion of native species in the diet (all south of Hobart), consisted of between 26-53% native forest (Figure 2.4). The forest at most of the collection sites was almost entirely dry eucalypt forest with the exception of Liffey (17% wet eucalypt forest), Glen Huon (20%) and Mountain River (26%). The birds' diets at these sites were similar to those at the other nearby sites that were mostly dry eucalypt forest.

Where native species were dominant in the diet it was the eastern barred bandicoot that was the major diet species. Bandicoots (mostly eastern barred bandicoot) were the major prey at Howden (34.4%), Allens Rivulet (55.5%), Glen Huon (43.7%), Crabtree (34.0%) and were the second most abundant prey at Mountain River (23.5%) (Figure 2.3). An MDS (non-metric multi-dimensional scaling) comparison between the sites showed that there were distinct similarities between some of the sites, mostly determined by the proportional abundance of bandicoots in the owls'

diet. The sites south of Hobart were all quite similar to one another and the proportion of bandicoots in the owls' diet was high (Figure 2.5).

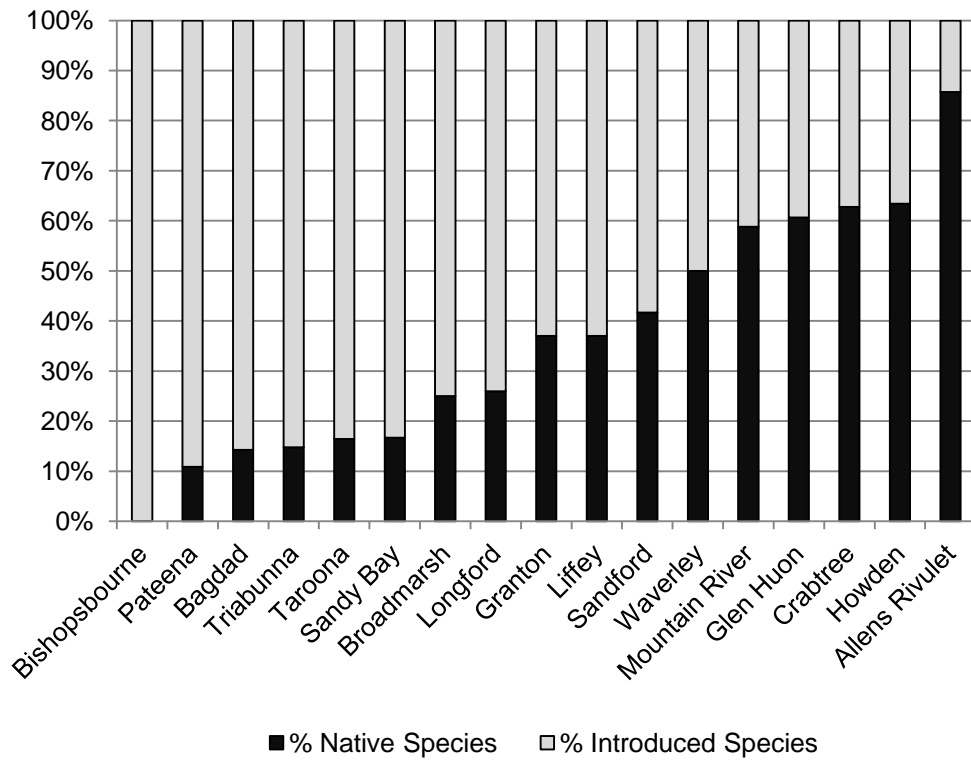


Figure 2.2- The percentage of the diet of the Tasmanian Masked Owl made up native and introduced species.

Table 2.2- Prey in collections of pellets, of the Tasmanian Masked Owl . Numbers refer to minimum number of individuals (MNI).

Source: 1 First published herein, 2 Geering (1990), 3 Young (2006), 4 Green (1982), 5 Green and Rainbird (1985), ⁶ unpublished data (C. Spencer), ⁷ unpublished data (N. Mooney), ⁸ unpublished data (N. Brothers, per N. Mooney). (i) introduced species.

Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
spotted-tail quoll (<i>Dasyurus maculatus</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
eastern quoll (<i>Dasyurus viverrinus</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tasmanian devil (<i>Sarcophilus harrisi</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dusky antechinus (<i>Antechinus swainsonii</i>)	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
swamp antechinus (<i>Antechinus minimus</i>)	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
southern brown	5	1	2	1	0	0	0	0	0	2	0	0	0	0	0	0	24	35

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Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopsbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
bandicoot (<i>Isoodon obesulus</i>)																		
eastern barred bandicoot (<i>Perameles gunnii</i>)	16	70	29	17	4	0	1	0	0	0	0	5	2	2	11	0	1	158
common brushtail possum (<i>Trichosurus vulpecula</i>)	0	0	0	1	0	0	1	0	2	0	0	1	0	0	1	0	0	6
eastern pygmy-possum (<i>Cercartetus nanus</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
little pygmy-possum (<i>Cercartetus lepidus</i>)	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6
sugar glider (<i>Petaurus breviceps</i>)	0	0	1	2	2	24	2	0	0	6	0	2	2	0	2	0	6	49
common ringtail possum (<i>Pseudocheirus</i>)	1	1	4	0	0	3	5	0	2	0	0	1	6	4	7	0	25	59

Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopsbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
<i>peregrinus</i>)																		
Tasmanian bettong (<i>Bettongia gaimardi</i>)	2	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0	0	6
long-nosed potoroo (<i>Potorous tridactylus</i>)	0	0	0	0	0	0	0	0	2	0	0	1	0	0	4	0	7	14
Tasmanian pademelon (<i>Thylogale billardierii</i>)	2	12	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	18
Bennett's wallaby (<i>Macropus rufogriseus</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
long-tailed mouse (<i>Pseudomys higginsii</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	6	0	7
water rat (<i>Hydromys chrysogaster</i>)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
house mouse (<i>Mus musculus</i>) (i)	8	1	10	0	3	90	1	187	6	55	0	4	0	1	20	7	29	422

Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopsbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
New Holland mouse (<i>Pseudomys novaehollandiae</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
broad-toothed rat (<i>Mastacomys fuscus</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
swamp rat (<i>Rattus lutreolus</i>)	0	0	0	7	1	0	0	0	0	2	0	1	0	0	0	0	0	11
black rat (<i>Rattus rattus</i>) (i)	5	6	14	12	2	84	3	3	17	26	10	38	0	18	47	4	38	327
brown rat (<i>Rattus norvegicus</i>) (i)	0	2	0	0	2	1	0	0	0	0	0	0	2	1	0	0	0	8
rat species (<i>Rattus</i> sp.)	2	12	9	0	0	3	1	8	0	0	2	0	0	0	0	0	59	96
rabbit (<i>Oryctolagus cuniculus</i>) (i)	2	4	0	4	0	0	10	0	23	20	0	14	15	7	22	0	42	163
brown hare (<i>Lepus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopsbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
<i>capensis</i>) (i)																		
feral cat (<i>Felis catus</i>) (i)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
little forest bat (<i>Vespadelus vulturnus</i>)	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
southern forest bat (<i>Vespadelus regulus</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Gould's wattled bat (<i>Chalinolobus gouldii</i>)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
microchiropteran bat sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
unidentified large mammal	17	12	0	2	0	0	4	0	0	0	0	0	0	0	0	0	0	35
unidentified small mammal	0	5	1	0	0	7	0	2	0	3	5	0	0	0	0	0	0	23
unidentified bird (Aves sp.)	1	1	0	0	0	8	0	0	0	0	1	19	0	1	0	0	5	36

Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopscourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
Common Blackbird (<i>Turdus merula</i>) (i)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Grey Fantail (<i>Rhipidura fuliginosa</i>)	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2
Common Starling (<i>Sturnus vulgaris</i>) (i)	0	0	0	2	0	0	0	8	1	100	0	0	0	0	4	0	0	115
House Sparrow (<i>Passer domesticus</i>) (i)	0	0	0	0	0	2	0	0	2	1	0	0	0	0	0	0	0	5
Brown Quail (<i>Coturnix ypsilophora</i>)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Satin Flycatcher (<i>Myiagra cyanoleuca</i>)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Collared Sparrowhawk (<i>Accipiter cirrhocephalus</i>)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Tawny Frogmouth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1

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Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopsbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
<i>(Podargus strigoides)</i>																		
Masked Lapwing <i>(Vanellus miles)</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	4
Eastern Rosella <i>(Platycercus eximius)</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Tasmanian Native-hen <i>(Gallinula mortierii)</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Australian Magpie <i>(Gymnorhina tibicen)</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
moths (Lepidoptera)	0	0	0	0	0	1	0	0	0	20	0	0	0	0	0	0	0	21
bug sp. (Pentatomidae)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Banksia longicorn (beetle) <i>(Paroplites australis)</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
TOTAL	61	128	71	53	17	235	29	208	55	240	20	86	0	0	0	0	0	1203

Species	Howden ¹	Allens Rivulet ¹	Glen Huon ¹	Crabtree ³	Mountain River ³	Bagdad ¹	Sandford ¹	Bishopshbourne ¹	Pateena ⁴	Triabunna ⁵	Sandy Bay ¹	Taroona ^{1,2}	Liffey ⁶	Broadmarsh ⁷	Longford ⁷	Waverley ⁸	Granton ⁸	TOTAL
MAMMALS	60	126	71	50	17	93	29	200	52	116	17	67	0	0	0	0	0	898
BIRDS	1	2	0	3	0	8	0	8	3	103	3	19	0	0	0	0	0	150
REPTILES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FROGS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INSECTS	0	0	0	0	0	1	0	0	0	21	0	0	0	0	0	0	0	22
Shannon's Diversity Index	1.97	1.63	1.67	2.01	1.99	1.61	1.94	0.45	1.52	1.72	1.37	1.59	1.24	1.65	1.96	1.61	2.00	2.45

Table 2.3- Percentage of diet of Tasmanian Masked Owl pellet collections in different parts of Tasmania. MNI refers to minimum number of individuals identified in samples. %N refers to percentage by number in the total collection and % PU refers to percentage by prey unit (20 grams) in the total collection.

Region		Dasyurids	Bandicoots	Possums	Macropods	Rodents	Rabbit	Other mammals	Bats	Birds	Insects	Total
South of Hobart	mni	2	170	44	29	222	52	37	0	11	0	567
	% N	0.35	29.98	7.76	5.11	39.15	9.17	6.53	0.00	1.94	0.00	
	%PU	0.07	38.38	5.36	27.58	10.87	12.24	5.37	0.00	0.12	0.00	
Midlands	mni	2	2	37	1	216	7	7	6	14	2	294
	% N	0.68	0.68	12.59	0.34	73.47	2.38	2.38	2.04	4.76	0.68	
	%PU	0.31	2.82	6.12	2.36	58.55	15.75	2.88	0.19	11.01	0.00	
North	mni	1	13	23	7	290	60	3	0	20	0	417
	% N	0.24	3.12	5.52	1.68	69.54	14.39	0.72	0.00	4.80	0.00	
	%PU	0.77	5.91	11.68	4.18	31.36	41.18	2.00	0.00	2.92	0.00	
Hobart	mni	0	5	4	1	55	14	5	0	22	0	106

Region		Dasyurids	Bandicoots	Possums	Macropods	Rodents	Rabbit	Other mammals	Bats	Birds	Insects	Total
	% N	0.00	4.72	3.77	0.94	51.89	13.21	4.72	0.00	20.75	0.00	
	%PU	0.00	8.29	4.44	0.92	51.46	18.04	13.32	0.00	3.42	0.00	
East Coast	mni	0	3	14	1	90	30	7	0	103	21	269
	% N	0.00	1.12	5.20	0.37	33.46	11.15	2.60	0.00	38.29	7.81	
	%PU	0.00	3.85	16.04	2.03	11.92	52.73	5.61	0.00	7.79	0.00	

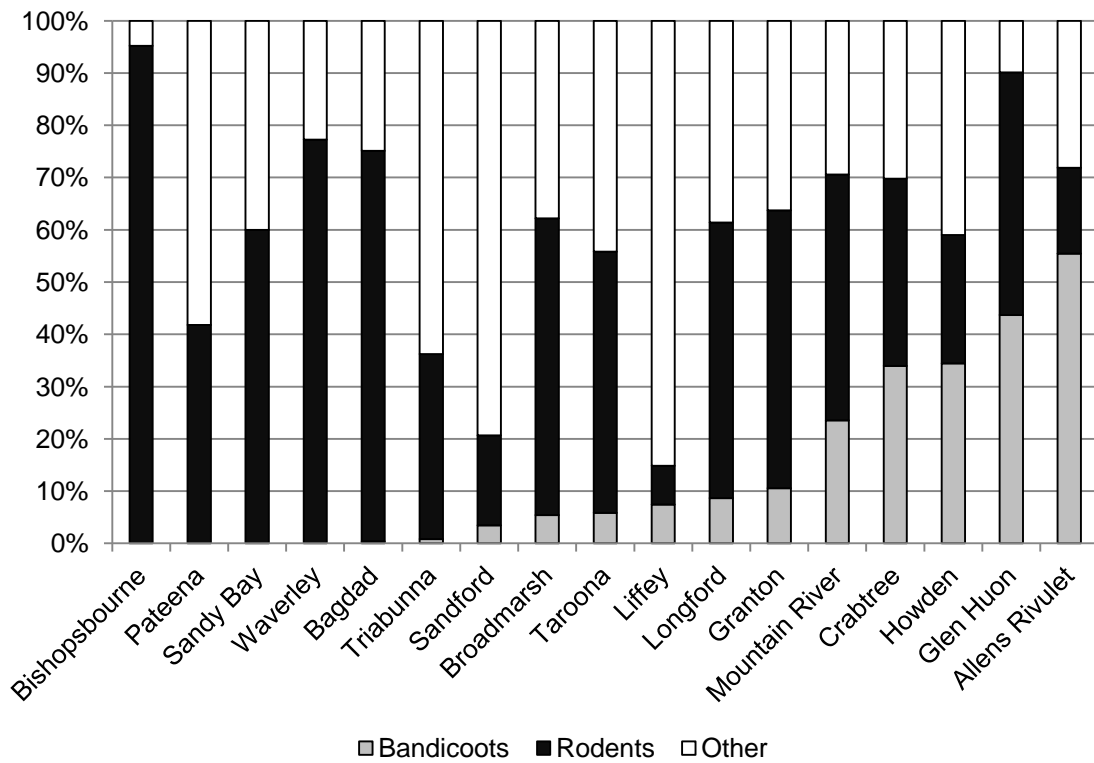


Figure 2.3- The percentage of the diet of the Tasmanian Masked Owl made up by bandicoots and rodents.

Table 2.4- Proportion of different rodent species identified in diet. Percentage in brackets is the percentage of total diet at that site that consisted of rodents. Based on MNI (Minimum Number of Individuals) identified. (i) introduced species.

	black rat (<i>Rattus rattus</i>) (i)	brown rat (<i>Rattus norvegicus</i>) (i)	swamp rat (<i>Rattus lutreolus</i>)	long-tailed mouse (<i>Pseudomys higginsii</i>)	house mouse (<i>Mus musculus</i>) (i)	water rat (<i>Hydromys chrysogaster</i>)	unidentified rodent
Howden (24.6%)	33.3	0.0	0.0	0.0	53.3	0.0	13.3
Allens Rivulet (16.4%)	28.6	9.5	0.0	0.0	4.8	0.0	57.1
Glen Huon (42.4%)	42.4	0.0	0.0	0.0	30.3	0.0	27.3
Crabtree (35.8%)	63.2	0.0	36.8	0.0	0.0	0.0	0.0
Mountain River (47.1%)	25.0	25.0	12.5	0.0	37.5	0.0	0.0
Bagdad (74.7%)	47.2	0.6	0.0	0.0	50.0	0.0	2.2
Sandford (17.2%)	60.0	0.0	0.0	0.0	20.0	0.0	20.0
Bishopsbourne (95.2%)	1.5	0.0	0.0	0.0	94.4	0.0	4.0
Pateena (41.8%)	73.9	0.0	0.0	0.0	26.1	0.0	0.0
Triabunna (35.4%)	30.6	0.0	2.4	0.0	64.7	2.4	0.0
Sandy Bay (60%)	83.3	0.0	0.0	0.0	0.0	0.0	16.7
Taroona (50%)	88.4	0.0	2.3	0.0	9.3	0.0	0.0
Liffey (7.4%)	0.0	100	0.0	0.0	0.0	0.0	0.0
Broadmarsh (56.8%)	85.7	4.8	0.0	4.8	4.8	0.0	0.0
Longford (52.8%)	70.1	0.0	0.0	0.0	29.9	0.0	0.0
Waverley (72.3%)	23.5	0.0	0.0	35.3	41.2	0.0	0.0
Granton (53.2%)	30.2	0.0	0.0	0.0	23.0	0.0	46.8

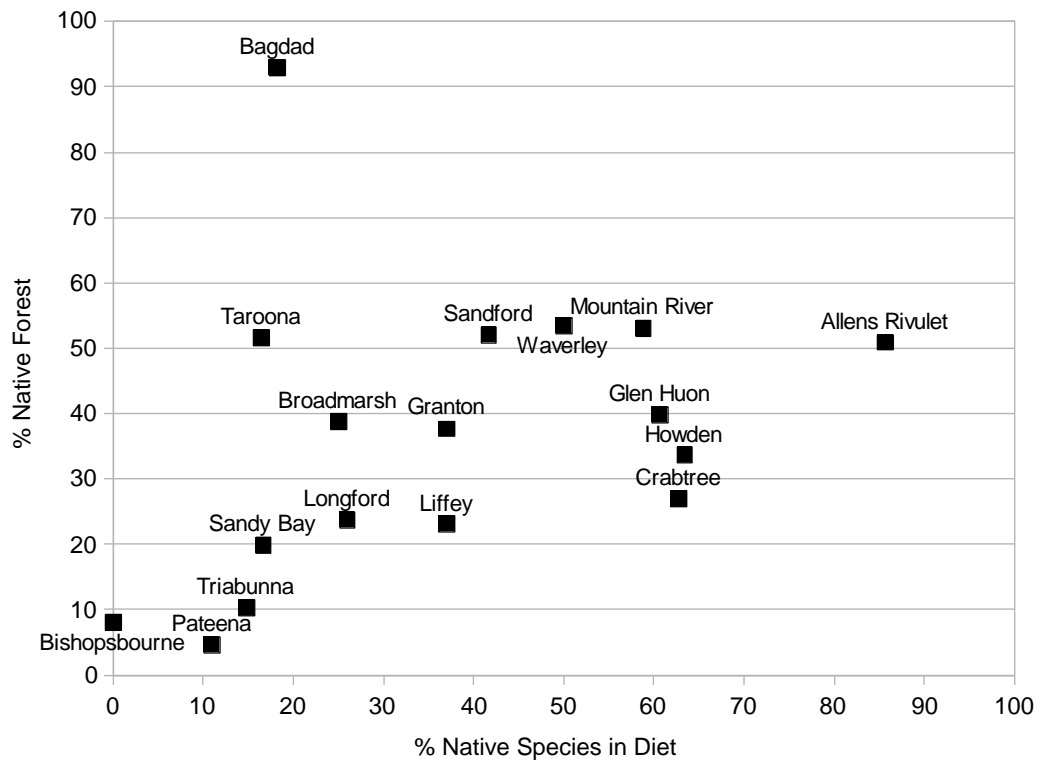


Figure 2.4- Percentage of native species in the diet of Tasmanian Masked Owl, against percentage of native forest in a 2 km. radius circle around the collection point. Diet estimated by abundance of items in pellets.

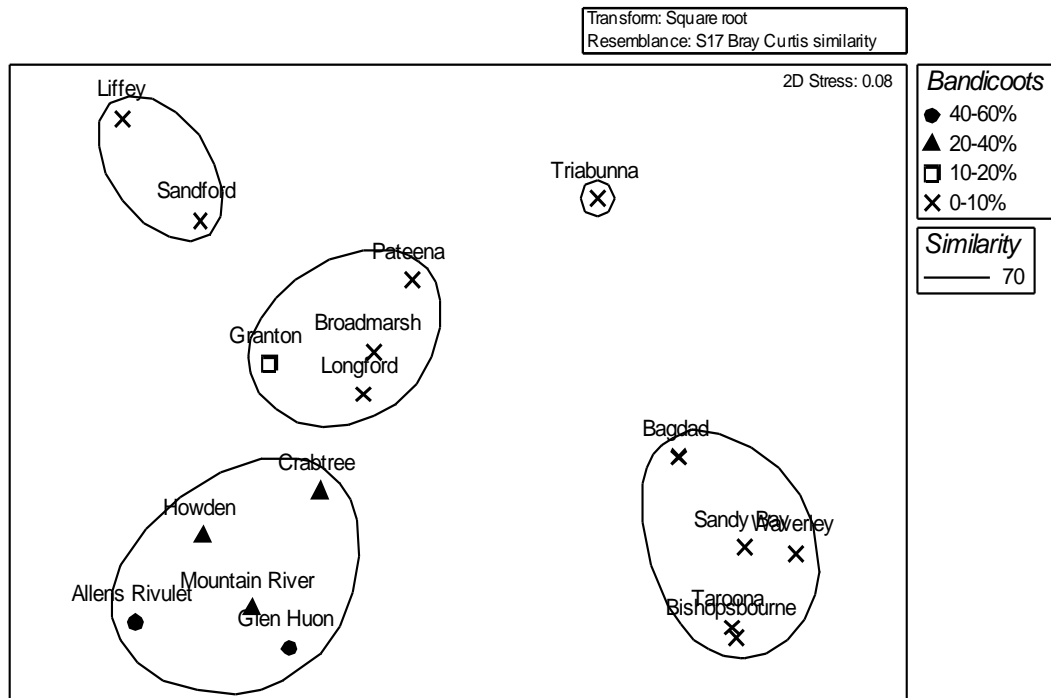


Figure 2.5- Multi-dimensional scaling ordination of the diet of Tasmanian Masked Owls (in terms of abundance) and the percentage of total diet consisting of bandicoot species.

Discussion

Although the diet of the Tasmanian Masked Owl at the broad scale is highly diverse (Mooney 1992), the results of this study indicate that individuals take specific prey items at particular locations. A focus on particular food sources at a particular locality is a common behaviour of raptors in general, and has been shown many times in owls of different genera, including *Tyto* (Lundie-Jenkins 1993; Taylor 1994; Kavanagh 2002a; Debus *et al.* 2004; Wiley 2010). However, there is no evidence to suggest that owls would discriminate between native species and introduced species so long as the target prey was comparable.

The dietary diversity of the Australian Masked Owl in different locations in New South Wales has been found to be low, as in this study of the Tasmanian Masked Owl. In south-east NSW, the diet of the Australian Masked Owl was found to have a Shannon's diversity index of 1.52 and on Central Coast NSW it had an index of 0.84, based on data tables within Kavanagh (1997). Dietary diversity is vulnerable to the effects of scale. When looked at on a population scale it may appear high (Mooney 1993), but when looked at on the scale of particular owls it will appear low.

This study has shown that particular species within a family are more likely to occur in the diet of the Tasmanian Masked Owl than others. For example, the eastern barred bandicoot was far more likely to occur in the diet than the southern brown bandicoot. The relationship between prey species diversity, prey availability and diet is relevant to all vertebrate predators including the Tasmanian Masked Owl. *Tyto* owls are sometimes described as "opportunistic generalists" in their feeding behaviour (Bunn *et al.* 1982; Mikkola 1983), but in reality individual owls concentrate their feeding on particular prey species, Taylor (1994) citing numerous examples of this from studies across the world. At a particular locality there may only be a select number of prey species that are abundant enough to provide a regular diet for owls by virtue of their size, behaviour and micro-habitat preferences. There have been numerous studies on the effect of small mammal behaviour on their availability to predation by the Barn Owl (Brown *et al.* 1988; Kotler *et al.* 1991; Shifferman and Eilam 2004; Stangl *et al.* 2005; Fux and Ailam 2009; Taylor 2009). Prey species that are of a less than perfect size or have behaviours that make them inaccessible tend to be only rarely taken and contribute little to the overall diet. In the case of the Tasmanian Masked Owl diet, the southern brown bandicoot is probably taken less commonly than the eastern barred bandicoot because of microhabitat preferences of the bandicoots (Hird and Hammer 1995; Reading *et al.* 1996).

Tyto owls throughout the world are predominantly predators of mammals (Goodman and Thorstrom 1998; Charter *et al.* 2009; Debus *et al.* 2010; Schulz and Magarey 2010; Wiley 2010) including the mainland subspecies of the Australian Masked Owl in both disturbed (Kavanagh and Murray 1996) and relatively undisturbed areas (Kavanagh 1996; Todd 2006). The only existing pre-European evidence of Tasmanian Masked Owl diet suggests that mammals were the main prey (Mooney 1993; Garvey 1999).

The Tasmanian Masked Owl was shown in this study to be principally a predator of mammals. The diet of the Australian Masked Owl across its range has been shown to be dominated by mammals with birds usually a distant second in importance (Mooney 1993; Kavanagh 1996; Kavanagh 2002a; Todd 2006; Kavanagh *et al.* 2008a). This is usually the case whether considered in terms of biomass or in terms of abundance. A rare exception is the collection from Triabunna where the Common Starling was the most abundant species in the diet (Green and Rainbird 1985), and also a report from near the Derwent River where the Common Starling was reported to be very common in pellets collected from caves in the 1950s (Mollison 1999). Rodents are often the most common item in the diet and have been shown to be prominent in the diet of Australian Masked Owls in New South Wales (Kavanagh 2002a; Todd 2006; Kavanagh *et al.* 2008b) and Tasmania (Green and Rainbird 1985; Mooney 1992). In some studies native rats (usually bush rat) have been the rodent most consumed (Kavanagh 1996; Todd 2006; Kavanagh *et al.* 2008a) while in others introduced species (particularly black rat) have been the rodent most consumed (Kavanagh and Murray 1996; Milledge *et al.* 2010).

In Tasmania, introduced rodents dominate the rodent component of pellet collections (Green and Rainbird 1985; Geering 1990; Young 2006). This study has confirmed the general importance of introduced rodents to the Tasmanian Masked Owl. The bush rat, which has been shown to be important to the Australian Masked Owl in parts of NSW, does not occur in Tasmania, thus is not available to the

Tasmanian Masked Owl although the swamp rat is widespread and often common (Hocking and Driessen 2000). The introduced black rat is probably the rodent most similar to the bush rat, in terms of size and behaviour, in the dry forests of Tasmania, and so may be filling the trophic niche in the diet of the Tasmanian Masked Owl. The detailed distribution of introduced rodents in Tasmania is unknown, but most of the pellet collections analysed in this study were from sites within range of disturbance and hence probably an available source of introduced prey. A high priority for future research should be the acquisition of samples from remote areas- a not inconsiderable task nevertheless. It is an unfortunate reality that most owl pellets are collected from places where people are most likely to find them. Without tracking of individual owls and subsequent location of nest and regular roost sites it will be difficult to obtain this quality of pellet collection.

There is a paucity of information on relative abundance of small mammals around Tasmania. Most published information on Tasmanian small mammals is either local (Taylor and Comfort 1993) or is broad state-wide distribution (Rounsevell *et al.* 1991). Specialist studies on some species including the swamp rat (Monamy 1995a; Monamy 1996; Driessen 1998), long-tailed rat (Stoddart and Challis 1993; Monamy 1995b; Driessen 1998), New Holland mouse (Pye 1991; Lazenby 1999) are useful in understanding the ecology of some of the species. There have been some studies looking at forestry impacts (Flynn *et al.* 2011; Stephens *et al.* 2011). However, most of the species studied have been those that seem to occur very rarely in Tasmanian Masked Owl diet, in some cases, especially with the New Holland mouse, partly because the species itself is rare and restricted in range. What does seem clear is that many of the species prefer habitats with dense understorey which presumably makes them more difficult for Masked Owls to catch. Essentially, there is little information on the relative abundance of introduced small mammals (in particular black rat and house mouse) in Tasmania. This emphasises the value of the indirect approach to assessing small mammal presence via regurgitated pellets. A local trapping exercise at favoured Masked Owl feeding sites (determined by accurate GPS datalogging)

would be informative. Microhabitats frequented by owls for hunting could be trapped and compared with microhabitats where hunting was apparently not taking place. This would be a potentially valuable avenue for future research.

There may be a lower abundance of small mammals in dry forest habitats than on the mainland. Certainly there are fewer common native species- two of the most common, the bush rat and the brown antechinus, being absent in Tasmania. Both of these species are prominent in the diet of Masked Owls in natural habitats on the mainland (Todd 2006; Kavanagh *et al.* 2008a). The absence of these species could explain why the black rat is more widespread in Tasmania than on the mainland. It is unknown whether the introduced black rat simply occupied a vacant niche in Tasmania or whether it forced its way in to the Tasmanian small mammal fauna at the expense of native species.

The presence of larger animals in the diet (rabbit, bettong, pademelon etc.) of the Tasmanian Masked Owl is potentially important due to the greater energy return provided by the extra biomass. It is probable that the Tasmanian Masked Owl is capable of killing prey by suffocation caused by compression of the thorax by their powerful feet (Mooney 1992; Csermely and Gaibani 1998; Einoder and Richardson 2007). The common buzzard (*Buteo buteo*) has been found to be able to exert a force of approximately 8 kg cm^{-2} , enough to cause death to mice via suffocation. The common buzzard is comparable in size to the male Tasmanian Masked Owl (Csermely and Gaibani 1998; Higgins 1999c), but is only 60% of the size of the female Tasmanian Masked Owl and has considerably smaller feet (Mooney 1992). It is likely that the female Tasmanian Masked Owl has sufficient power to kill all but the largest prey by thoracic compression.

A sizable proportion of the diet has been shown to be made up of prey larger than rodents (rabbit) in one study on the mainland (McNabb *et al.* 2003). In Tasmania, larger prey has been shown to be important in the diet of owls at a number of sites,

including rabbit (Hill 1955; Green 1982; Mooney 1993)(Hill 1955; Green 1982; Mooney 1993), Tasmanian pademelon and eastern barred bandicoot (Young 2006). In the current study, all three of these species were important at one site or another.

However, it is not known what proportion of large prey is actually consumed. Smaller animals, certainly rats, are consumed entirely, as evidenced by observations and the large number of bones and body parts found in regurgitated pellets (M.K.T. pers. obs.). The only published observation of a wild Tasmanian Masked Owl feeding on freshly killed large prey was from the 1950's (Mollison 1999). The Tasmanian Masked Owl was the major predator on rabbits in fenced enclosures in a study by the CSIRO in the Tasmanian Midlands between 1954 and 1959. "They stood on the rabbit and ate from the neck and back of the skull, and were never seen to open the body cavity or peel the skin..." (Mollison 1999). It is probable that the Tasmanian Masked Owl leaves a proportion of their large prey behind, so any measure of biomass based on the entire weight of animals could be misleading.

Male masked owls are usually considerably smaller than females (Mooney 1993; Higgins 1999c) and all studies to date indicate that they take smaller prey than females (Mooney 1992; Todd 2006). This means that females have a wider range of potential prey species available to them than males, which could have implications for breeding masked owls. For a period of approximately six weeks the female owl remains almost completely in the nest while there are eggs and nestlings present, the male provisioning the female (Fleay 1949; Hill 1955), the nestlings and himself. The dilemma for the female of whether to brood the young or begin hunting herself has been examined in the Barn Owl in Canada (Durant *et al.* 2004). The reinitiating of hunting by the female was found to occur at about the same time as the male food provisioning was no longer matching nestling food requirements. In 2006, a nest tree containing an adult female, an egg and a nestling Tasmanian Masked Owl was felled near Railton in northern Tasmania. The carcasses of house mouse and black rat were found in the nest cavity, almost certainly the product of predation by the

male of the breeding pair (DPIPWE 2006). An abundant source of small to medium sized prey that the male is capable of catching is probably required for masked owl breeding success.

The effect of sexual differences in prey selection should be taken into account in assessing diet studies. The sex of the owl responsible for depositing pellets is sometimes not known or not recorded (Green and Rainbird 1985). Where the sex of the Tasmanian Masked Owl has been noted as female, large prey has generally been identified in the pellet collections (Mooney 1993; Young 2006). The relative abundance of Tasmanian pademelon and eastern barred bandicoot in the collections from Crabtree, Mountain River (Young 2006), Allens Rivulet and Glen Huon (this study) fits with the hypothesis of the larger female owls taking larger prey. Mooney (1992) used the gut contents of known sex museum specimens to compare diet between the sexes and found that females were more likely to take larger prey.

The only near-certain male owl from which pellets were collected was the owl from Bagdad, which preyed upon mostly small prey, predominately rodents. Small arboreal mammals including sugar glider, juvenile common ringtail possum, little pygmy-possum and microchiropteran bats also occurred in the diet of this owl. Arboreal animals are typically rare in the diet of the mainland Australian Masked Owl, where other large forest owls tend to exploit this prey resource (Kavanagh 2002a).

It would be interesting to know whether the diet of the Tasmanian Masked Owl from areas dominated by wet eucalypt forest differs greatly from those residents in dry eucalypt forest. The effect of elevation on Tasmanian Masked Owl diet would also be of interest. Unfortunately, the low abundance of Tasmanian Masked Owl at higher elevations and within wet forests (M.K.T. pers. obs.) and the likely lower persistence of pellets make collections in these areas difficult.

A seasonal analysis of Tasmanian Masked Owl diet in the future would also be of interest if and when such a collection becomes available. At the time of writing, insufficient collections exist for this type of analysis. Many of the pellets collected in this study may have been up to years old and could not be assigned to a season. The date of collection does not necessarily relate to season of production as a pellet can last on the ground for many months in the open and for years when protected in a dry situation such as a cave or building. Only a small percentage of pellets were collected fresh and could be assigned to a season. It was not possible to return to a pellet collection site and collect regular samples as the owls did not use regular roost sites continuously. There were long periods of absence between owl occupation at roost sites. It is probable that the breeding of the Tasmanian Masked Owl will be found to coincide with the time of year when there are an abundance of juvenile mammals available, particularly where they feed upon eastern barred bandicoots.

The abundance of the eastern barred bandicoot in the diet of the Tasmanian Masked Owl at sites south of Hobart has not been reported previously. The eastern barred bandicoot has been shown to occur in high numbers in the Huon Valley (Mallick *et al.* 1998) near the Glen Huon pellet collection site. The bandicoot previously occurred in good numbers near the Bagdad pellet collection site (Mallick *et al.* 1997) but is now locally extinct (Mallick, pers. comm.). Eastern barred bandicoots may be a common component of the diet of females where available, possibly because of their habitat preferences and/ or behaviour. Male Masked Owls however, may be more likely to concentrate predation on rodents and small possums (gliders, pygmy-possums), even when bandicoots are present. However, prey selection is probably more complicated than simple abundance and availability of prey animals given that juvenile bandicoots are not much larger than rodents.

The eastern barred bandicoot is virtually functionally extinct on the mainland (Reading *et al.* 1996) and has declined through large parts of Tasmania, particularly

through the midlands (Robinson *et al.* 1991). The presence of the bandicoot in the 1990's was found to be associated with high quality agricultural land with deep soils and high rainfall (Driessen *et al.* 1996). Its preferred habitat contains open grassy areas for foraging and available ground cover for protection from predators. It has been suggested that previously unsuitable, heavily forested areas in parts of the south-east, north-east and north-west have been opened up by clearing for agriculture creating new areas of potential habitat. Its original habitat would probably have been grassland and grassy woodland through the Tasmanian midlands, where the eastern barred bandicoot was rare and patchily distributed (Mallick *et al.* 1997) in the 1990s and is now believed to be virtually extinct (Mallick, pers. comm.). If the range of the eastern barred bandicoot has changed in the south-east of the state over the last couple of hundred years, it is possible that historic collections of Tasmanian Masked Owl pellets from pre-European times might be able to demonstrate this.

Owl pellet deposits have been shown to survive for hundreds of years when protected within caves (Andrews 1990; Kusmer 1990). It would be of interest to compare recent pellet deposits with historic deposits in south-east Tasmania. Owl pellets have been used in this way to determine ecological change over long time periods in other parts of the world (Avery 1991; Bilney *et al.* 2010; Boyer *et al.* 2010). A comparative study would also shed light on which rodent species were important to the Tasmanian Masked Owl in the absence of the introduced rodents that currently dominate the rodent component of the diet.

Appendix 2.1- Weights of prey species and calculated prey units.

Scientific Name	Common Name	Reference	weight	prey units
<i>Antechinus swainsonii</i>	Dusky Antechinus	(Green 1972)	53	2.65
<i>Antechinus minimus</i>	Swamp Antechinus	(Green 1972)	67.75	3.3875
<i>Sminthopsis leucopus</i>	White-footed Dunnart	(Green 1972)	28	1.4
<i>Isoodon obesulus</i>	Southern Brown Bandicoot	(Van Dyck and Strahan 2008)	755	37.75
<i>Perameles gunnii</i>	Eastern Barred Bandicoot	(Van Dyck and Strahan 2008)	990	49.5
<i>Trichosurus vulpecula</i>	Common Brushtail Possum	(Van Dyck and Strahan 2008)	4000	200
<i>Cercartetus lepidus</i>	Little Pygmy-Possum	(Van Dyck and Strahan 2008)	8	0.4
<i>Cercartetus nanus</i>	Eastern Pygmy-Possum	(Van Dyck and Strahan 2008)	24	1.2
<i>Petaurus breviceps</i>	Sugar Glider	(Van Dyck and Strahan 2008)	127.5	6.375
<i>Pseudocheirus peregrinus</i>	Common Ringtail Possum	(Munks 1995)	995	49.75
<i>Bettongia gaimardi</i>	Tasmanian Bettong	(Menkhorst and Knight 2001)	1660	83
<i>Potorous tridactylus</i>	Long-nosed Potoroo	(Menkhorst and Knight 2001)	1100	55
<i>Thylogale billardierii</i>	Tasmanian Pademelon	(Menkhorst and Knight 2001)	5450	272.5

<i>Hydromys chrysogaster</i>	Water Rat	(Van Dyck and Strahan 2008)	680.5	34.025
<i>Mus musculus</i>	House Mouse	(Van Dyck and Strahan 2008)	20	1
<i>Pseudomys novaehollandiae</i>	New Holland Mouse	(Van Dyck and Strahan 2008)	23	1.15
<i>Mastacomys fuscus</i>	Broad-toothed Rat	(Green 1968)	122	6.1
<i>Rattus lutreolus velutinus</i>	Swamp Rat	(Green 1967)	105	5.25
<i>Rattus rattus</i>	Black Rat	(Van Dyck and Strahan 2008)	280	14
<i>Rattus norvegicus</i>	Brown Rat	(Van Dyck and Strahan 2008)	320	16
<i>Rattus sp.</i>	Rat species		300	15
<i>Oryctolagus cuniculus</i>	Rabbit	(Van Dyck and Strahan 2008)	1580	79
<i>Lepus capensis</i>	Brown Hare	(Van Dyck and Strahan 2008)	3350	167.5
<i>Vespadelus vulturnus</i>	Little Forest Bat	(Van Dyck and Strahan 2008)	4.05	0.2025
<i>Pseudomys higginsi</i>	Long-tailed Mouse	(Green 1968)	67	3.35
<i>Aves sp.</i>	Bird species		50	2.5
<i>Turdus merula</i>	Common Blackbird	(Higgins <i>et al.</i> 2006)	86	4.3
Unidentified large mammal			500	25
unidentified small mammal			250	12.5

<i>Grey Fantail</i>		(Higgins <i>et al.</i> 2006)	8.6	0.43
<i>Sturnus vulgaris</i>	Common Starling	(Higgins <i>et al.</i> 2006)	80.75	4.0375
<i>Passer domesticus</i>	House Sparrow	(Higgins <i>et al.</i> 2006)	27	1.35
<i>Coturnix ypsilophora</i>	Brown Quail	(Marchant and Higgins 1993)	115.5	5.775
<i>Myiagra cyanoleuca</i>	Satin Flycatcher	(Higgins <i>et al.</i> 2006)	17.8	0.89
<i>Swift Moth (Hepialoidae)</i>	Swift Moth (Hepialoidae)		1	0.05
<i>Bug (Pentatomoidae)</i>	Bug (Pentatomoidae)		0.05	0.0025
<i>Accipiter cirrhocephalus</i>	Collared Sparrowhawk	(Marchant and Higgins 1993)	172	8.6
<i>Paroplites australis</i>	Beetle- Banksia longicorn		0.05	0.0025
<i>Microchiropteran species</i>	Bat unident.		5	0.25

Chapter 3 : Calling behaviour of the Tasmanian Masked Owl

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Abstract

An understanding of the calling behaviour of nocturnal birds is critically important for their detection. The Australian Masked Owl is most commonly located by call playback surveys that prompt calling responses by resident owls, yet Masked Owl calling behaviour remains poorly understood. We present a detailed analysis of the calling behaviour of the Tasmanian subspecies of the Australian Masked Owl (*Tyto novaehollandiae castanops*) with a number of goals, to (1) describe the vocal repertoire of the species, using spectrograms, (2) examine differences in relation to plumage colour morph, sex, age and individual variation to consider the prospects for identifying individual birds, and, (3) examine environmental and temporal effects on calling behaviour. Three types of calls were identified - screech, continuous screech and chatter calls. The Tasmanian Masked Owl was found to produce a deeper (lower frequency) screech than mainland Masked Owls. Adult and immature Masked Owls produced different screech calls, while paired male and female Masked Owls produced different chatter calls to each other. Comparison of the chatter calls between individuals suggested that these types of calls may be used to identify individual owls via this non-invasive call playback survey technique.

Introduction

The vocalisations of birds are central to an understanding of bird behaviour and communication (Catchpole and Slater 2008), as well as to the effectiveness of bird surveys. The calling behaviour of nocturnal birds, such as owls, is particularly important since individuals spend a considerable period of time not visible to each

other, or to researchers. This is not only because they are active at night but also because they often have large territories and are mostly solitary (Burton 1992). Survey techniques for cryptic and rare bird species have made use of calls, either through listening for them or via the playback of calls to attract the target species (Johnson *et al.* 1981; Marion *et al.* 1981; Kavanagh and Peake 1993b; Stern *et al.* 1993; Prescott *et al.* 2002). The use of the call playback technique to locate nocturnal birds has revolutionised the study of such species (Kavanagh and Peake 1993a; Parker *et al.* 2007; Doucette 2010; Kissling *et al.* 2010) and it has become one of the standard techniques for locating owls.

The Tasmanian Masked Owl is a rare species because of a combination of low overall abundance (Bell *et al.* 1996), large territory size (Young 2006) and being rarely observed (Barrett *et al.* 2003), despite its wide distribution in Tasmania. It is usually regarded as the largest of the world's barn owls (*Tyto*) (König *et al.* 2008), although it is comparable in size to the female Sooty Owl (Mooney 1992). It is listed as endangered under the Tasmanian *Threatened Species Protection Act 1995*, vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999* and as endangered in the Action Plan for Australian Birds (Garnett *et al.* 2011a). Previous estimates of population size have included 200-400 breeding pairs (Bell and Mooney 2002) and 1300 mature individuals (Garnett *et al.* 2011a). Much of its core distribution overlaps with areas subject to production forestry (Bell and Mooney 2002) and research into its distribution, behaviour and ecology will help in understanding its conservation requirements. Call playback has become a standard census technique for the species (Kavanagh and Bamkin 1995; Bell *et al.* 1996; Debus 2001; Loyn *et al.* 2001a; Cann *et al.* 2002; Liddelow *et al.* 2002; McIntyre and Henry 2002; Parker *et al.* 2007). The calls of subspecies of the Australian Masked Owl have yet to be described quantitatively, in part because the Masked Owl is usually the rarest of the owls wherever it occurs in Australia, according to surveys for it (Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995; Kavanagh and

Stanton 1998; Debus 2001; Liddel *et al.* 2002). Combined with its rarity the Australian Masked Owl is generally silent, usually only calling on a few occasions a night (Kavanagh and Murray 1996). Debus (1995) and Kavanagh (1997) examined the frequency of calling of large forest owls, including the Australian Masked Owl, and both reported only rarely detecting the Australian Masked Owl from its call without having first prompted it using call playback. Spectrograms of the species have only been published three times; a single screech call from an owl in NSW together with a chatter call from a captive bird at Featherdale Wildlife Park, Sydney in 1990 (Kavanagh 1997) as well as a screech call from a captive female owl from Healesville Sanctuary, Victoria by Ed McNabb in 1988 (Higgins 1999c).

The most common call described for the Masked Owl is the *screech*, often described as a deeper (lower frequency) and louder version of the rasping hiss of the Barn Owl (Debus 1990; Debus 1995; Hollands 2008). The second most commonly noted call of the Masked Owl is the *chatter*, sometimes described as a *cackle*. The *screech* and *chatter* calls are produced by both sexes, with an extended form of the *chatter* thought to be used as a courtship call, given by males flying in circles high above tree canopy near the nest tree (Higgins 1999c). Other calls described in Higgins (1999) and Hollands (2008) are probably related to communication between a pair and/or offspring in close proximity.

The effects of environmental variables on owl calling behaviour have been studied but remain inconclusive. Wind and rain have often been found to have a negative influence on detectability and calling behaviour of owls (Morrell *et al.* 1991; Kavanagh and Peake 1993b; Debus 1995). Higher ambient air temperatures have been found to have a positive effect in some studies (Clark and Anderson 1997) but not all, with some studies reporting no effect (Kavanagh and Peake 1993b; Rocha and Rangel-Salazar 2001). Similarly, moonlight has had a positive effect with some owls (Morrell *et al.* 1991; Clark and Anderson 1997) and no effect with others (Clark and Anderson 1997; Braga and Motta Jr. 2009). In Australia, the Powerful

Owl (*Ninox strenua*), Sooty Owl (*Tyto tenebricosa*) and Australian Masked Owl have all been found to be unaffected by moon light (Debus 1995; Kavanagh 1997) during call playback surveys. However, the smaller Southern Boobook (*Ninox novaeseelandiae*) has been shown to be negatively affected by moon visibility by some researchers (Kavanagh and Peake 1993b) and unaffected by others (Debus 1997).

Little effect of season on owl calling or response to playback has been noted in Australian large forest owls (Kavanagh and Peake 1993b; Debus 1995; Kavanagh 1997). Kavanagh (1997) heard the Powerful Owl (*Ninox strenua*) slightly more often in winter-early spring in north-eastern New South Wales, and the Australian Masked Owl was heard more often during late spring-summer in south-eastern New South Wales. Debus (1995) found that large forest owls could be induced to call in virtually all months of the year, only the intensity of calling varied. Most records of breeding in the Tasmanian Masked Owl have been from spring to early summer (Mooney 1997); this could conceivably increase calling rate, signaling the start of breeding.

The use of calls to identify gender in nocturnal birds has been demonstrated in a number of species including the Marbled Frogmouth (*Podargus ocellatus*) (Smith and Jones 1997), Powerful Owl, Sooty Owl (Kavanagh 1997) and Barred Owl (*Strix varia*) (Odom and Mennill 2010), but not yet in the Australian Masked Owl. Differences in the Australian Masked Owl according to gender have been suspected based partly on body size and call frequency (R. Kavanagh, pers. comm.). The male of the Australian Masked Owl has been reported to produce an extended and continuous version of the chatter call during his courtship display (Kavanagh 1997). Australian Masked Owls can occur in a range of different colour morphs from dark to pale. Pale morphs are usually male, possibly always male (Hollands 2008). In the Australian Masked Owl dark morphs are more common in southern Australia, particularly so in Tasmania (Skemp 1955; Higgins 1999c). The relationship between

Masked Owl colour morph and gender could provide insight into gender differences, abundance and demography and thus the behavioural significance of the calls.

The use of calls to identify individual owls has been demonstrated in a number of owl species, especially in the genus *Strix* from the Northern Hemisphere (Galeotti and Pavan 1991; Appleby and Redpath 1997b; Hill and Lill 1998; Freeman 2000; Delport *et al.* 2002; Tripp and Otter 2006; Grava *et al.* 2008; Rognan *et al.* 2009). The calls of the African Wood Owl (*Strix woodfordi*) have been shown to be individually consistent and identifiable over decades (Delport *et al.* 2002). To date, individual distinctiveness of calls has not been shown in owls of the genus *Tyto*. Individual identification of Australian Masked Owls would have significant potential for non-intrusive monitoring of longevity, breeding and foraging ecology. In this study we examine the calling behaviour of the Tasmanian Masked Owl as part of a broader study of the distribution, abundance and habitat preferences of the Australian Masked Owl in Tasmania. Apart from describing the calls of the Tasmanian Masked Owl, the hypotheses that we will test include:

- the Tasmanian Masked Owl has measurably different calls to the mainland Australian Masked Owl.
- environmental variables, including in particular wind and air temperature can influence Tasmanian Masked Owl calling behaviour.
- Tasmanian Masked Owl calling rate increases in winter.
- Tasmanian Masked Owls can be aged and sexed by its calls.
- There is a relationship between colour morph of owl and calls given (related to relationship between sex and calls given).
- call analysis could be used to identify individual owls.

Methods

One thousand and eighty-four call playback surveys of the Tasmanian Masked Owl were conducted between 2007 and 2009 at 341 sites across Tasmania (Figure 3.1). Most of these sites were selected as part of a broader study into the distribution, abundance and habitat preferences of Masked Owls in Tasmania. Methodology followed similar studies on large forest owls in other parts of Australia (Debus 1995; Kavanagh and Bamkin 1995; Bell *et al.* 1996), except that only calls of the Tasmanian Masked Owl were broadcast. Playback of screech calls from mainland Australian Masked Owls was used initially to attract Tasmanian Masked Owls. The calls of Tasmanian Masked Owls obtained during these initial surveys were then used in subsequent surveys to attract further Tasmanian Masked Owls. The call playback procedure at each site involved five minutes of listening time, five minutes of broadcast of screech and chatter calls, followed by five minutes of listening and spotlighting around the vicinity of the playback.

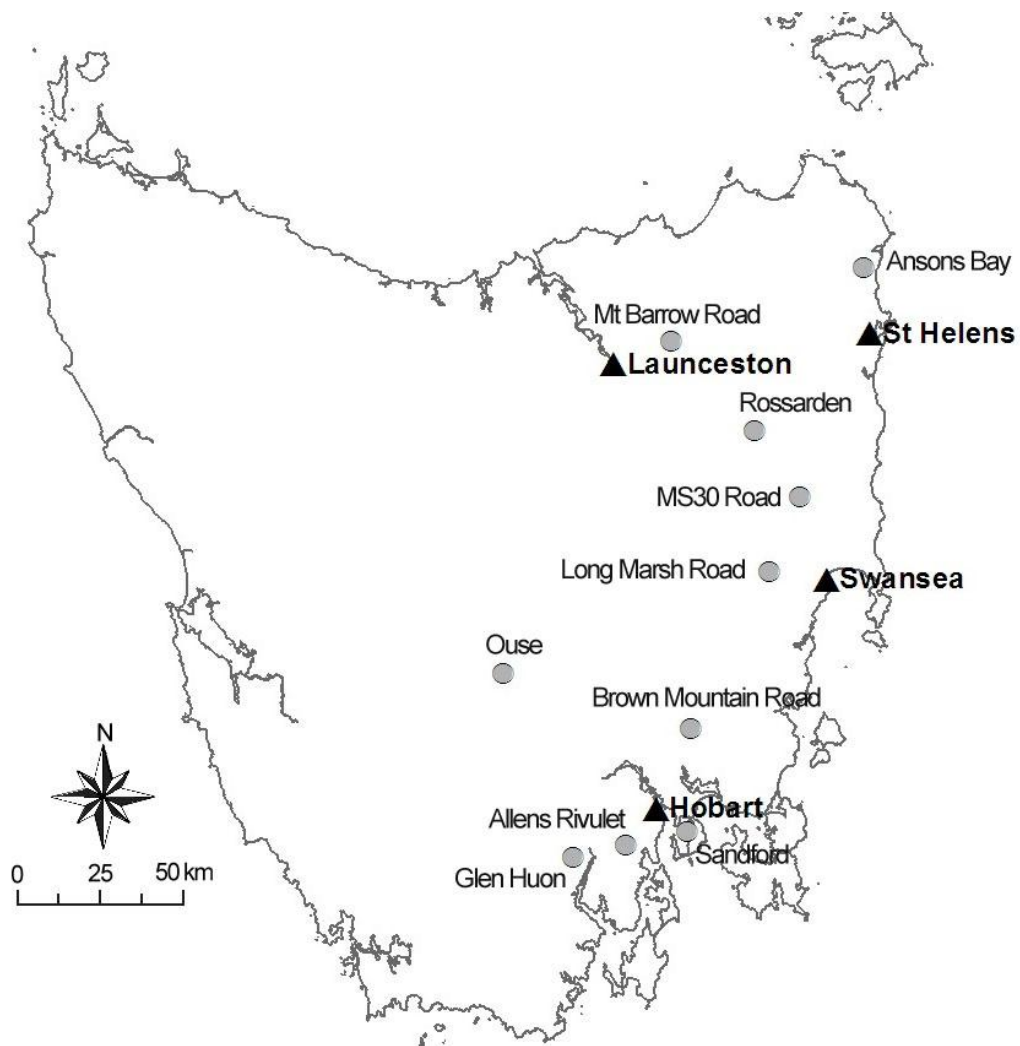


Figure 3.1- Locations where Tasmanian Masked Owls were audio recorded.

At the start of each survey the following data were recorded:

- Time of survey. Minutes post sunset was calculated later using the R statistical package (version 2.11.1, library *maptools*, function *crepuscle*).
- Wind speed, using a modified Beaufort scale. Categories were still, light breeze (only small upper branches moving), moderate wind (branches moving), strong wind.
- Precipitation. Categories were nil, drizzle, rain, heavy rain.
- Ambient air temperature. Subjective assessment of temperature in the categories cold, cool, mild, warm or hot.
- Cloud cover. Estimated percentage cloud cover.
- Moon phase. Categories were no moon visible, quarter moon (either waning or waxing), half moon, three-quarter moon, full moon.
- Nightlight. Categories were very dark (no moon, 100% cloud), dark (quarter moon or heavy cloud), moderately bright (detail visible, only light cloud, moon visible), bright (full moon or near full moon, no cloud).

Twelve further Masked Owl responses (nine of single owls, three of two owls), collected during a systematic forest owl survey conducted in 1996 (Bell *et al.* 1996) were also used in this current study. The methodology between the two surveys was identical. These additional data were only included in the analysis of the types of calls that were heard, and whether owls were heard or seen after detection was made.

Most owls attracted to the call playback called in response, giving the opportunity to record more calls of the species. Whenever possible, the calls were recorded using an Edirol R-09 recorder (Roland Inc., Japan) with a Sennheiser ME67 shotgun microphone and a K6 powering module. All recordings were wave files recorded at 44.1 kHz and 24 bits. Only calls that were without distortion from having the

recording level set too high or low were included in the analysis, this was determined by visual assessment in spectrograms. On some occasions it was possible to photograph the owls making the calls, assisting the identification of individual birds and in identifying sex and age. It has been reported that individual Masked Owls can be readily identified from photographs because of the variation in feather details and physical appearance between individuals (Hollands 2008). Photographs were taken with a Canon digital SLR camera with a Canon 100-400mm/f5.6 or 500mm/ f4 lens fitted, often with a Canon 1.4x teleconverter and SB580EX flash with fitted flash extender. Among the recordings obtained were recordings of probable breeding pairs of Masked Owls at Ansons Bay and on the MS30 road, north-west of Swansea (Figure 3.1).

In addition to the collection of calls made during the call playback surveys, calls were collected during winter and spring 2010 at known roosting sites at dusk and dawn at Allens Rivulet and Glen Huon in southern Tasmania (Figure 3.1) using an automatic audio-recording device (the Song Meter SM2 Digital Field Recorder produced by Wildlife Acoustics, www.wildlifeacoustics.com). All recordings were wave files recorded at 44.1 kHz and 16 bits. The device was set to record before dusk and continue for up to 2 hours after sunset, and then to record again before dawn and over sunrise.

All the recordings were analysed, converted to spectrograms and measured using Raven Pro 1.3 (Charif *et al.* 2008). Only calls that were recorded at an energy level of greater than fifty decibels were used to eliminate distant calls that were recorded only partially or at low levels. A second peak frequency (harmonic) was visible in spectrograms of screech calls. To measure this, selection boundaries were altered to eliminate the first peak frequency and then Raven Pro was used to select the peak frequency within the selection. Chatter calls were generally produced as part of a call sequence. Each call sequence consisted of a number of chatter calls separated

by at least three seconds of silence. The variables used to quantify calls are listed in Table 3.1.

Table 3.1- Variables used in quantitative assessment of calls made by the Tasmanian Masked Owl. *Only measured for screech calls. ** Only measured for chatter calls.

Measure	Description
Duration	Chatter calls: duration of call sequence measured in seconds. Screech calls: duration of screech call in seconds.
High frequency	The highest frequency in hertz (Hz) in the call sequence (chatter calls) or the screech.
Low frequency	The lowest frequency in hertz (Hz) in the call sequence (chatter calls) or the screech.
Centre or median frequency	The frequency that divides the selection into two frequency intervals of equal energy.
IQR bandwidth	Inter-quartile range bandwidth. The difference between the first and third quartile frequencies. The first quartile frequency divides the selection into the frequency interval containing the lowest 25% of the energy and third quartile includes 75% of the energy in the selection. The computation of the first quartile is similar to that of Median Frequency, except that the summed energy has to exceed 25% of the total energy instead of 50%. The computation of the third quartile is also similar to that of Median Frequency, except that the summed energy has to exceed 75% of the total energy instead of 50%.
IQR time	Inter-quartile range time. The difference between the first and third quartile times in seconds.
Peak frequency	The frequency at which the maximum power occurs within the selection, measured in hertz (Hz).
Second peak	To measure this, selection boundaries were altered to eliminate

(harmonic) frequency *	the first peak frequency and then Raven Pro was used to select the peak frequency within the selection.
Chatters per call sequence **	The number of chatter calls in the call sequence.
Chatters per second **	The number of chatter calls divided by the duration of the call sequence in seconds.
Longest chatter **	The duration in seconds of the longest chatter in the call sequence.
Average chatter length **	The average duration in seconds of chatters in the call sequence.

Data analysis

Chi square and t tests were used to examine potential differences between the calls of different aged and gender Tasmanian Masked Owls wherever appropriate. Multi-dimensional scaling ordination (MDS) and analysis of similarity (ANOSIM) were used to explore variation between calls using Primer 6.1.13 (Clarke and Gorley 2005). Data were checked for high correlations between variables before the MDS ordination was conducted, and variables were dropped to ensure that no highly correlated variables were included. Where necessary, a log (x+1) transformation was applied to the data to improve normality. A linear discrimination analysis using the R statistical package (library *maptools*, function *crepuscle*) was conducted on the chatter calls to investigate individual call differences (www.r-project.org).

Results

The playback of Tasmanian Masked Owl calls had a significant effect on the detection of calling Tasmanian Masked Owls. The majority of detections occurred during, or after, call playback (96.4%). Tasmanian Masked Owls were most often noted during the five minutes of call playback (78.3%). On only three occasions (3.6%) were owls detected during the five minutes of listening time before call playback. The difference between the detection rate before playback and the detection rate after playback had finished was significant ($\chi^2=7.78$, $p<0.01$, $df=1$ (Figure 3.2).

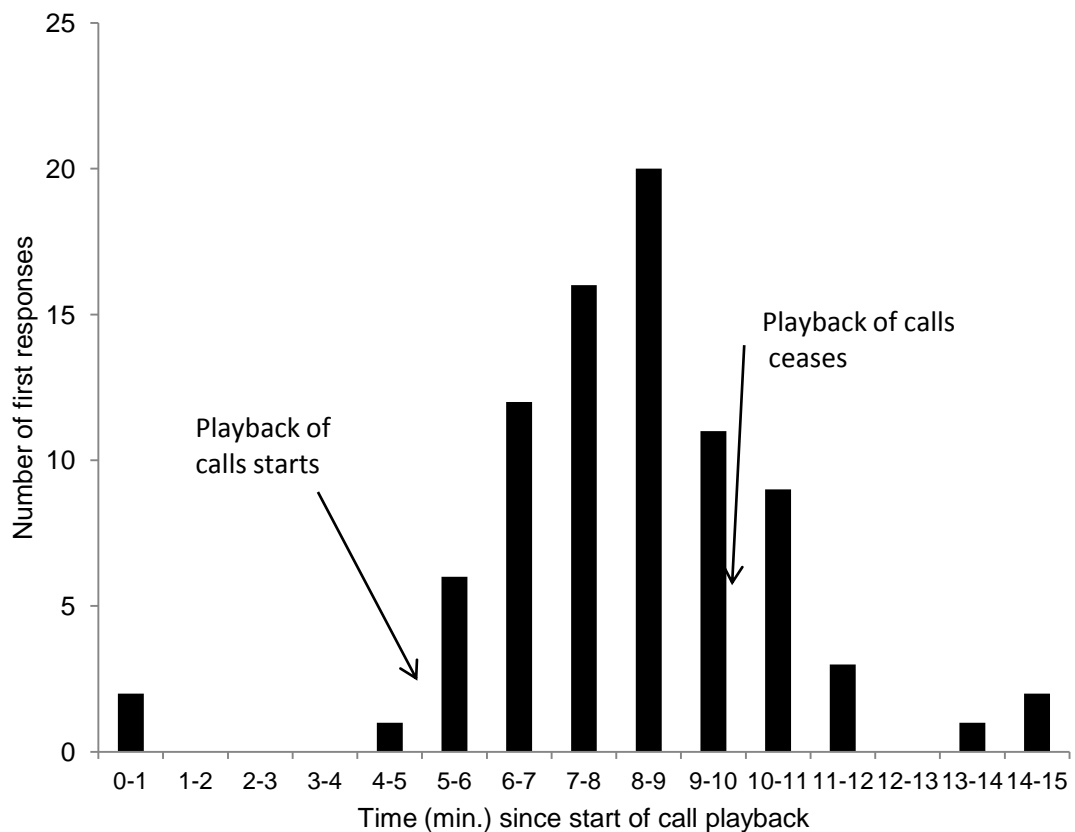


Figure 3.2- Minutes into call playback survey that Masked Owls were first detected. Each survey was 15 minutes in length, made up of 5 minutes of listening, 5 minutes of call playback, and 5 minutes of spotlighting and listening.

Description of calls

Screech calls

One-hundred and twenty-seven screech calls were recorded and analysed from six locations during the broad survey and via automatic audio recording devices at two locations (Allens Rivulet and Glen Huon, Figure 3.1). The automatic audio recording device also recorded screeches made by owls at their roost sites. Forty-five individual Tasmanian Masked Owls were photographed at a sufficient quality to detect a certain amount of down in the plumage.

The majority of calls were probably made by adult owls as no down was visible in photographs. Typically each screech would be separated by long periods of silence. Individuals at Sandford, Ouse and Brown Mountain (Figure 3.1) differed in that they gave a long series of many screeches for up to 45 minutes, hereafter described as the continuous screech call. The owls at these three locations were immature, as indicated by the presence of wisps of down on their plumage visible in carefully examined photographs. The recording of the Ouse continuous-screeching owl differed slightly between August 2008 and November 2008 (feather details in photographs confirmed that the owl recorded in August 2008 was the same individual photographed in November 2008). The second recording made of this owl's call was intermediate between the initial continuous-screech recording and that of adult owls. Continuously screeching owls gave shorter duration screeches at a higher peak frequency and higher centre frequency to owls without visible down plumage (Table 3.2). Many of the auditory differences between the calls can be seen in a spectrogram (Figure 3.3).

Adult owls had a series of peak frequencies within their screech which was not evident in the screech calls of immatures. A second peak frequency (harmonic) was measured when it was visible in the spectrogram (average for all adults 4698.8 ± 274.0 Hz) (Table 3.2). The duration of adult screech calls (1.60 ± 0.31 sec.) was significantly longer than those of immatures (1.08 ± 0.18 seconds) ($t = 10.77$, $df = 49$,

$P < 0.01$). The immature owls were usually higher in maximum frequency and always higher in peak frequency (3005.1 ± 425.1 Hz, $t=30.67$, $df=49$, $P < 0.01$) and median frequency (3212.7 ± 328.8 Hz, $t=45.39$, $df=49$, $P < 0.01$) than the adults (1764.02 ± 103.3 Hz and 1784.2 ± 82.5 Hz respectively). The inter-quartile bandwidth of immature screeches (1118.2 ± 349.6) was far greater than adult screeches (275.6 ± 115.4 Hz) (Table 3.2). The multi-dimensional scaling ordination confirmed the differences between adult and immature screech calls (Figure 3.4).

The screech calls reached approximate maximum frequency at 20,000 Hz (immatures) and 17,000 Hz (adults) which is higher than that of recordings for the mainland Australian Masked Owl at approximately 7,000 Hz (Kavanagh 1997) and, in another study, approximately 6,500 Hz for the screech call (Higgins 1999c; McNabb 2005).

Table 3.2- Comparison of attributes of the screech calls of adult and immature Tasmanian Masked Owls. Sample sizes of calls analysed in brackets. ** denotes significance at the $p=0.01$ level.

Measurement	Adult	Immature	Significance
Call duration (seconds)	1.60 ± 0.31 (50)	1.08 ± 0.18 (127)	$t=10.77$, $df=49$, $P < 0.01$ **
High frequency (Hz)	15387.1 ± 3886.5 (10)	17826.6 ± 1589.9 (127)	$t=1.97$, $df=9$, $P > 0.05$
IQR bandwidth (Hz)	275.6 ± 115.4 (50)	1118.2 ± 349.6 (127)	$t=24.04$, $df=49$, $P < 0.01$ **
Peak frequency (Hz)	1764.02 ± 103.3 (50)	3005.1 ± 425.1 (127)	$t=30.67$, $df=49$, $P < 0.01$ **
Median frequency (Hz)	1784.2 ± 82.5 (50)	3212.7 ± 328.8 (127)	$t=45.39$, $df=49$, $P < 0.01$ **
Second peak frequency (Hz)	4698.8 ± 274.0 (47)	Not present	Not tested

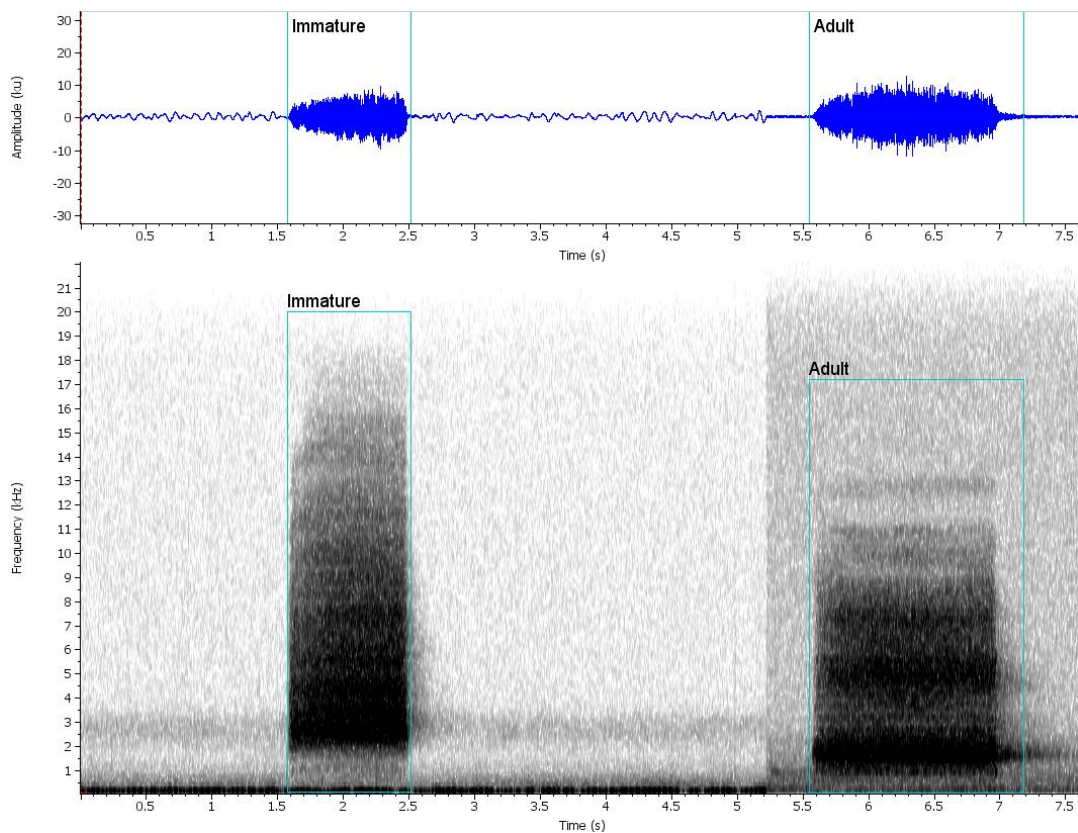


Figure 3.3- Typical examples of the screech calls of the Tasmanian Masked Owl presented as a spectrogram. The immature owl on the left is from Brown Mountain Road in November 2010 and the adult on the right is from Mt Barrow Road in September 2008.

Chatter calls

Chatter songs were recorded 15 times in response to playback and once with the automatic recorder at Glen Huon (Figure 3.1), but the latter recording was too poor to use in the analysis. Both male and female owls of territorial pairs were observed and recorded making chatter calls to each other, confirming that both sexes are capable of this type of call.

In order to compare these complicated calls, the calls were cut into call sequences which were made up of a series of chatter calls. These call sequences lasted for up

to 26 sec. (median 6 sec.) with many call sequences occurring over a period of many minutes. Each call sequence was separated from the next call sequence by more than three seconds and each call sequence was made up of a series of chatter calls (average 6 chatters per call sequence). The number of notes was calculated for one male and was an average of 7.8 notes per chatter, or 11.2 notes per sec. The two most common and easily identifiable notes were the 'chitter' and the 'chuckle'. The chitter is a single note of very short duration (approximately 0.03 sec.). The chuckle is slightly longer (approximately 0.05 sec.) and consists of a series of arrowhead-shaped notes concurrently delivered at different frequencies (Figure 3.5).

The overall sound of these notes is similar to a human chuckle. Most chatters were made up of a series of chitters and/or chuckles. Chatter calls varied substantially both within and between individuals. The chatter calls reached approximate maximum frequencies of up to 15,000 Hz, which is higher than that of the recording for the mainland Australian Masked Owl at approximately 9,000 Hz (Kavanagh 1997).

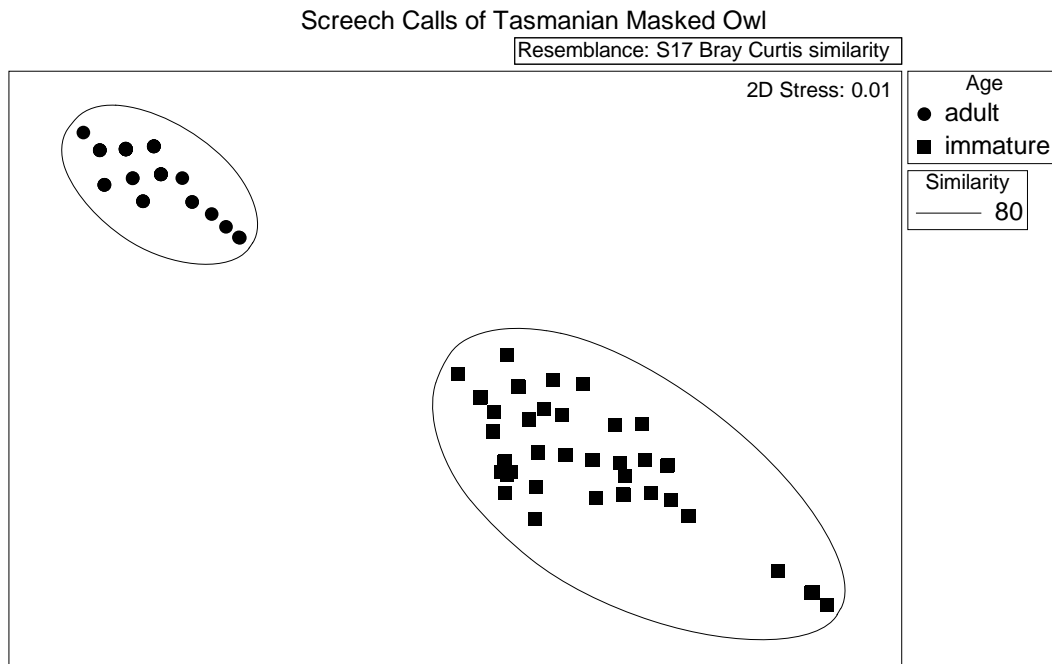


Figure 3.4- Multi-dimensional scaling ordination chart of the screech calls of adult and immature Tasmanian Masked Owls, based on call duration, peak frequency and median frequency.

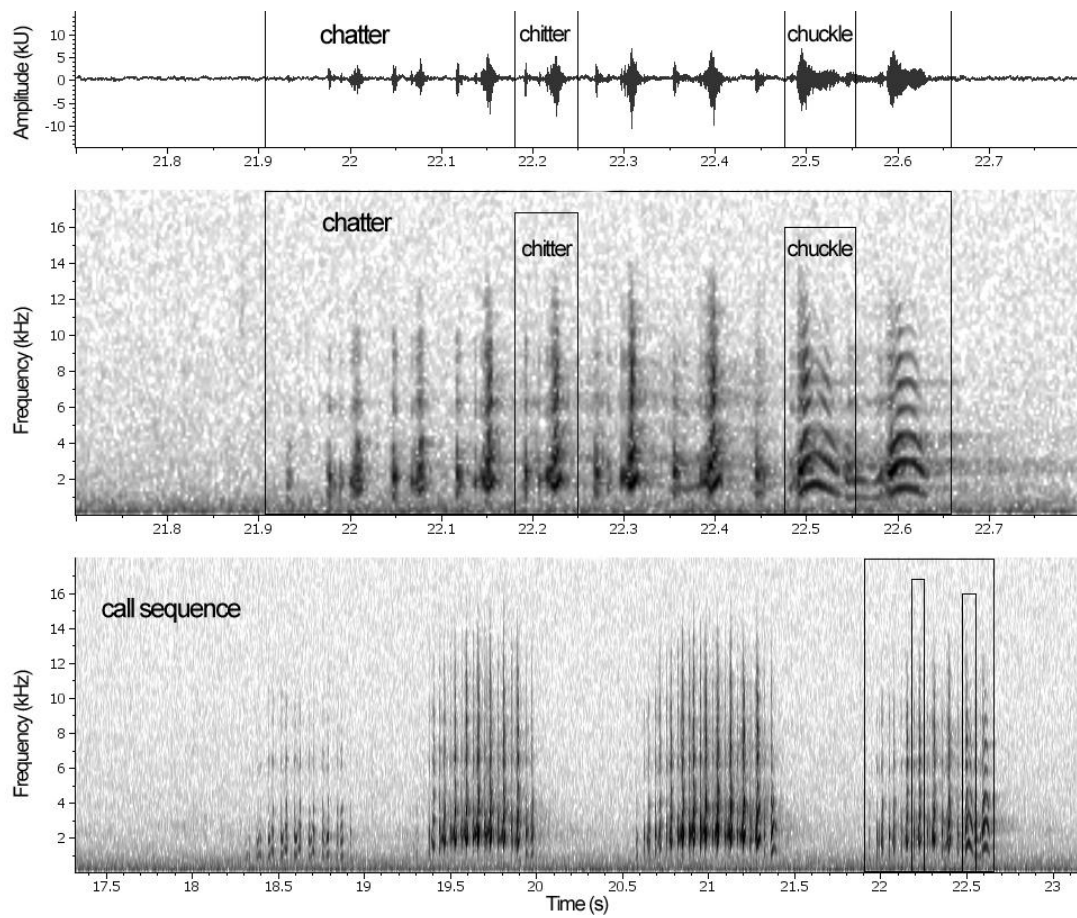


Figure 3.5- Typical spectrogram of a chatter call sequence of a Tasmanian Masked Owl. The call sequence (approximately 4.4 sec. duration) is made up of 4 chatters. The chatter (0.7 sec. duration) that is shown in detail is made up of 9 notes including 7 chitters and 4 chuckles.

Environmental and temporal effects on calling behaviour

Wind had a significant negative effect on the number of responses and hence detectability of Tasmanian Masked Owls ($\chi^2=12.63$, $p<0.01$, $df=2$). Tasmanian Masked Owls were significantly more likely to be heard calling, and hence detected, during calm conditions (11.7% survey success) (Table 3.3). Even a light breeze had a significant negative effect on the detectability of Masked Owls (5.6% survey success).

Precipitation probably has a negative effect on response by the owls, and hence detectability, but the small number of surveys conducted during rainy conditions prevented statistical testing. From 38 surveys that were conducted in rain (all drizzle), only one yielded a Tasmanian Masked Owl (2.6%). Ambient air temperature had a minor positive effect on the response rate of the owls, and hence detectability, but this was not statistically significant ($\chi^2=3.52$, $p>0.05$, $df=2$). Mild and warm temperatures (11.5% survey success) were more favourable conditions for detecting Masked Owls than cool and cold conditions (6.6% and 8.0% survey success respectively) (Table 3.4).

Responses of Tasmanian Masked Owls were allocated to 2 hour periods starting at sunset. There was no significant difference in detection of Tasmanian Masked Owls between different time periods of the night ($\chi^2=2.36$, $df=3$) (Appendix 3.2). None of the other environmental variables had detectable effects on responses by Tasmanian Masked Owls.

Tasmanian Masked Owls were detected slightly more often in winter (10.5% versus ~ 6-8% in other seasons) ($\chi^2=7.80$, $p=0.73$, $df=11$). In summer, Masked Owls were more likely to be heard producing the chatter call than the screech call (11 chatters, 5 screeches), whereas in winter, Masked Owls were more likely to be heard producing the screech call, than the chatter call (25 screeches, 18 chatters) ($\chi^2<0.0001$, $p=26.2$, $df=7$) (Table 3.5).

Table 3.3- Effect of wind strength on the detection of Tasmanian Masked Owls during surveys. Numbers in brackets are the expected number of detections if wind had no effect.

Wind	Not Detected	Masked Owl Detected	Total Surveys
Calm	423	57 (40)	480
Light Breeze	335	20 (30)	355
Moderate to Strong Breeze	214	12 (19)	226
Total	972	89	1061

Table 3.4- Effect of air temperature on detection of Tasmanian Masked Owls. Numbers in brackets are the expected number of detections if air temperature had no effect. Note that this was not statistically significant.

Air Temperature	Not Detected	Masked Owl Detected	Total Surveys
Cold	382 (376)	27 (33)	409
Cool	369 (369)	32 (32)	401
Mild-Warm	146 (152)	19 (13)	165
Total	897	78	975

Table 3.5- Number of Masked Owls and their calling behaviour when first detected for each season. Note: includes 12 records from Bell *et al.* (1996).

Season	Silent	Screech	Chatter	Continuous screech	Total
Summer	2	5	11	0	18
Autumn	3	8	10	2	23
Winter	3	25	18	2	48
Spring	2	8	7	1	18
Total	10	46	46	5	107

Sex differences

In two recording sessions both a male and a female owl were present and chattering (Table 3.6). The recording from MS30 road on the 23/4/2009 consisted of the continuous chatter (courtship call) of a male owl while circling above the forest canopy and female chatter calls in response while perched. The recording from Ansons Bay on 1/10/2008 consisted of a long series of separate chatters from a male with a short series of chatters from a female in response.

Within both recordings of pairs, females produced more notes with a lower peak frequency than the males. In addition, the female of the MS30 pair had a lower inter-quartile range bandwidth and median frequency (Table 3.6). The MDS ordination for the MS30 pair (Figure 3.6) strongly suggested that the male and female calls were distinctly different within pairs. The male also had a narrower range for call attributes than the female which were quite variable. The Ansons Bay pair failed to yield a clear MDS ordination plot.

Table 3.6- Differences in chatter calls between males and females at two locations.
Sample sizes for calls analysed are in brackets.

Ansons Bay	Male	Female	Significance
Notes per second	11.23 ± 1.87 (117)	14.9 ± 3.10 (9)	t=3.51, df=8, P<0.01 **
Chatter duration (sec.)	0.70 ± 0.19 (117)	0.56 ± 0.32 (9)	t=1.27, df=8, P>0.05
IQR bandwidth (Hz)	1292.7 ± 603.4 (117)	1167.6 ± 576.4 (9)	t=0.63, df=8, P>0.05
Peak frequency (Hz)	2302.8 ± 697.8 (117)	2009.8 ± 121.8 (9)	t=3.84, df=8, P<0.01 **
Median frequency (Hz)	2179.1 ± 514.5 (117)	2239.5 ± 192.6 (9)	t=0.75, df=8, P>0.05
MS30 Road	Male	Female	Significance
Notes per second	10.47 ± 0.83 (55)	11.80 ± 1.15 (57)	t=7.04, df=54, P<0.01 **
Chatter duration (sec.)	0.55 ± 0.08 (55)	0.57 ± 0.25 (57)	t=0.48, df=54, P>0.05
IQR bandwidth (Hz)	1027.3 ± 301.9 (55)	701.1 ± 303.4 (57)	t=5.70, df=54, P<0.01 **
Peak frequency (Hz)	2339.7 ± 562.3 (55)	2040.0 ± 357.8 (57)	t=3.35, df=54, P<0.01 **
Median frequency (Hz)	2411.7 ± 178.5 (55)	2055.1 ± 258.1 (57)	t=8.53, df=54, P<0.01 **

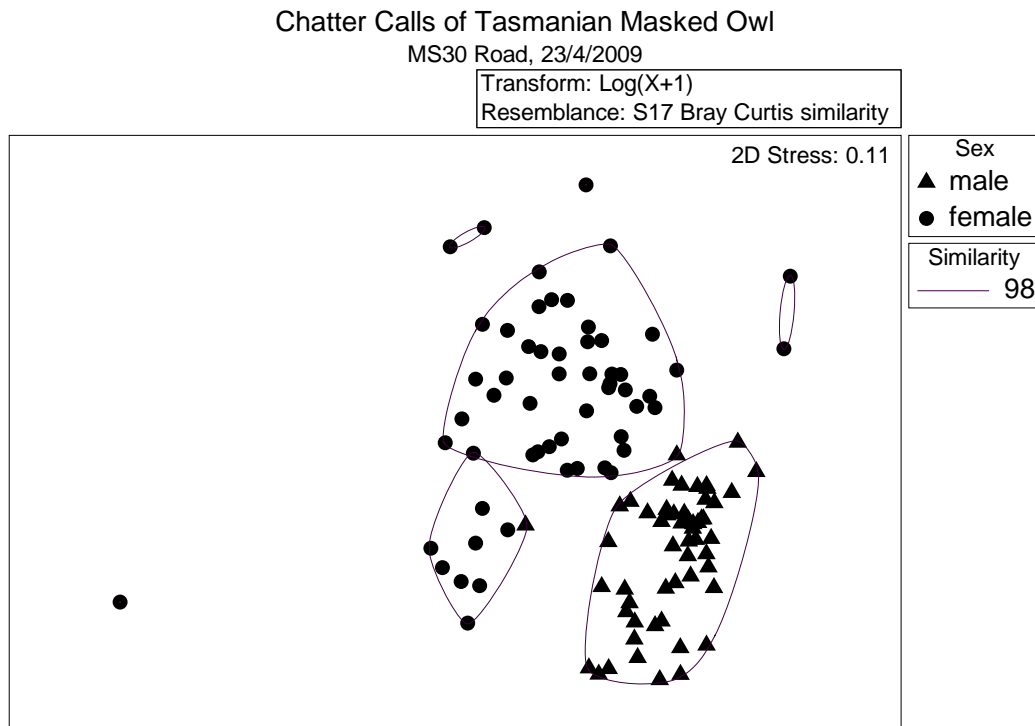


Figure 3.6- Multi-dimensional scaling ordination plot of the chatter calls of a pair of Tasmanian Masked Owls recorded on MS30 Road, 23/4/2009, based on the call attributes of low frequency, high frequency, call duration, peak frequency, median frequency, IQR bandwidth and notes per second.

The variables that distinguished male from female within the two pairs were less effective at identifying the sex of single owls recorded at other locations in Tasmania. A probable female Masked Owl (on the basis of its large size) was recorded chattering at Browns Creek Road on the 9/4/2009. An owl recorded chattering at Bashan Road on 20/11/2008 was probably a male on the basis of its small size and pale morph colour determined from photographs. Neither of these owls fitted the pattern expected for sex based on the call attributes measured, with the exception of peak frequency and median frequency.

Call types and colour morphs

One hundred and seven Tasmanian Masked Owl playback survey responses were examined, including 12 responses from Bell *et al.* (1996). Most Tasmanian Masked Owls were detected aurally (89.7%), whether it was from a distance (44.8%), while in flight (16.8%) or while perched (28.0%). Only 9.3% of Tasmanian Masked Owls seen during a survey remained quiet throughout the observation period. When calls were heard, screeches (43%) were as likely to be heard as chatter calls (43%). 4.7% of calls were continuous screech calls of immature birds.

There was no clear relationship between the colour morph of Tasmanian Masked Owls observed and the type of call that the owl was first heard to give (Appendix 3.3). Both screech calls and chatter calls were given by all colour morphs. Owls that called from a distance, and were thus not seen, were more likely than expected to be producing the screech call ($\chi^2=7.8$, $p<0.05$, $df=3$). Unobserved and silent owls were removed from the analysis together with the few owls that made continuous screeches because these screeches may be related to age rather than colour morph.

A two factor χ^2 test confirmed that the chatter call was more likely to be heard in response to playback than would be expected ($\chi^2=11.11$, $p<0.01$, $df=2$). The relative abundance of the three colour morphs in the population may influence analysis of calls and colour morphs. The dark morph was considerably more common (58.6%) than the intermediate morph (24.1%) or pale morph (17.2%) ($\chi^2=29.4$, $p<0.01$, $df=2$). Thus, even if male owls were more likely to produce a chatter call than a screech call and more likely than females to be a white morph then the fact that any owl is more likely to be a dark morph dilutes this effect. To test this, the analysis was repeated for each colour morph and none was more likely than expected to produce either a screech or chatter call. There was no relationship between colour morph and increased likelihood of production of screech calls ($\chi^2=0.95$, $p=0.62$, $df=2$) or chatter calls ($\chi^2=0.35$, $p=0.83$, $df=2$).

Individual variation

An analysis of similarity (ANOSIM) of the chatter call sequences for all recordings showed individuals varied ($R = 0.298$, $p < 0.1\%$). A linear discrimination analysis of individuals with >10 chatter call sequences successfully separated 74.6% of individuals. Screech calls appeared not to vary between individuals, although the screeches given by an individual did seem to be variable which could have confounded results.

Discussion

Description of calls

Vocalisations are critically important for communication in owls. This aspect of the behaviour of the Australian Masked Owl has been particularly difficult to describe due to the bird's apparent rarity, as well as its unpredictable breeding season and associated calling behaviour (Kavanagh and Murray 1996; Kavanagh 1997). This study is the first to describe the calls of the Tasmanian subspecies of the Australian Masked Owl and to describe the response of Tasmanian Masked Owls to call playback.

The screech and chatter calls produced by the Tasmanian Masked Owl reached approximate maximum frequencies up to 20,000 Hz and 15,000 Hz, respectively, both of which were higher than that of recordings for the mainland Australian Masked Owl at approximately 7,000 Hz and 9,000 Hz for the screech and chatter calls, respectively (Kavanagh 1997) and, in another study, approximately 6,500 Hz for the screech call (Higgins 1999c; McNabb 2005). A study on the calling behaviour of the Barn Owl in Germany identified many different types of calls, including some nestling calls that reached as high as 16,000 Hz (Bühler and Eppele 1980), but adult screech calls were limited to around 12,000 Hz. A spectrogram of a Barn Owl screech from Queensland shows a maximum frequency of 8,000 Hz (Higgins 1999b).

It is unusual for birds to produce calls of these high frequencies. The high frequency hearing cut-off of a passerine bird on average is 9,700 Hz, and 11,100 Hz for a non-passerine bird that is not an owl (Dooling 1992). There were clear differences between the single screech calls given by Tasmanian Masked Owls that were adult and those given continually by juvenile owls. Adult owl screeches were lower in minimum frequency, lower in peak frequency and longer in duration. These differences are clearly obvious to the human ear as well as being visual on a spectrogram. The continuous screech call is probably a type of begging call directed towards the parents.

Tyto owls do have a highly developed hearing ability which they use to locate their prey even in complete darkness (Payne 1971; Knudsen and Konishi 1979; Coles and Guppy 1988). Studies have shown that the Barn Owl has excellent absolute sensitivity throughout a wide range of frequencies (Dyson *et al.* 1998). In contrast to most owls, the Barn Owl also appears to be more sensitive at high frequencies. An average high frequency cut-off of 13,800 Hz has been observed for European Barn Owl *T.a. guttata* (Dyson *et al.* 1998) and 12,900 Hz for the North American Barn Owl *T. a. pratincola* (Konishi 1973). The significance of these high frequencies is unclear.

The peak frequency (frequency at which maximum power occurs, as opposed to the maximum frequency) in the screeches of adult Tasmanian Masked Owls was on average 1,764 Hz, much lower than the maximum frequencies of the calls. This is considerably lower than the approximately 1,800-3,000 Hz reported by Kavanagh (1997) and the approximately 1,800-2,500 Hz reported by (Kavanagh 1997; Higgins 1999c; McNabb 2005). This may be a result of the larger body size of the Tasmanian Masked Owl. That the Tasmanian Masked Owl produces a deeper screech than mainland Masked Owls has been suggested previously, albeit not measured (Hollands 2008). There is a negative correlation between the high

frequency of the Tawny Owl (*Strix aluco*) calls and body weight (Appleby and Redpath 1997a) and this is possibly a widespread feature of owl calls.

Tasmanian Masked Owl calls cover a wide range of frequencies simultaneously, similar to the calls of the Sooty Owl whose “trilling” calls straddle all frequencies in the range 1,000-14,000 Hz (Kavanagh 1997). This is a characteristic of all owls from the genus *Tyto* regardless of whether they occur in closed habitats like the Sooty Owl (Debus 1995) and Minahassa Masked Owl *Tyto inexpectata* (Mauro and Drijvers 1998), or in open habitats like the Barn Owl (Bühler and Epple 1980) and Grass Owl *Tyto capensis* (Erasmus 1992). It is possible that the function of the frequency range of *Tyto* owl calls is unrelated to habitat. Nevertheless, the calls of many birds have been shown to have frequencies that cut above or below ambient noise thus making them audible over greater distances. It has been suggested that communication in bird species whose calls occur with narrow bandwidths and low frequencies should be an advantage in habitats with complex vegetation structures (e.g. tall, dense forests which would otherwise absorb and muffle sounds). Conversely, high frequency calls and broad bandwidths, high-frequency modulations (trills and chatters), and short elements and inter-elements may be expected in more open habitats (Morton 1975a; Boncoraglio and Saino 2007). Ambient noise would not be a problem for the Tasmanian Masked Owl as the most vocal birds in Tasmania are diurnal. However, the range of frequencies produced by the Tasmanian Masked Owl would make them presumably effective in a wide range of forest types at great distances.

Frequency of calling

The calls of the Tasmanian Masked Owl were crucial to detecting their presence during the call playback surveys. It was rare for owls to be detected and remain silent, but there is also a strong likelihood that, occasionally, owls do not call at all and thus would not be detected during a survey (Wintle *et al.* 2005b). In this current study, 10.3% of the detected owls were completely silent suggesting that most of the

owls that were silent would still be detected visually. The silhouette of flying owls was often noticed, especially in moonlight. The owls would usually perch on obvious branches making them easily detectable using a spotlight. In a study in northern New South Wales, the Australian Masked Owl was never detected approaching playback silently but responded to playback by screeching only (50%), chattering only (27%) or screeching and chattering (23%) (Debus 1995). Surveys in NSW (Kavanagh 1997), found that call playback increased the likelihood of detecting the Australian Masked Owl compared to passively listening.

The frequency of calling by Tasmanian Masked Owls was increased by call playback, thus enabling the collection of more calls than would have been possible otherwise. The use of automatic song recorders at known roost sites demonstrated how infrequently the Masked Owl usually calls, even when the recorders are set to record near sunset when they are believed to call most often (Debus 1995; Kavanagh 1997). Studies of other species of owl have shown that spontaneous owl calling is more frequent within a couple of hours of sunset in the case of the Spotted Owl (Ganey 1990), the Ural Owl (*Strix uralensis*) (Lundberg 1980) and the Long-eared Owl (*Asio otus*) (Bull *et al.* 1989). The song recorder recorded mainly screeches from Tasmanian Masked Owls at their roost sites. This may be the normally given call by the species when unprompted by call playback. Call playback may evoke an aggressive response, increasing the likelihood of chatter calls being given, especially by males.

The increased likelihood of detection of Tasmanian Masked Owls using call playback was clearly demonstrated by the increase in responses that occurred during or just after the call playback as opposed to before the call playback. However, the time of night at which the call playback survey took place had no effect on the likelihood of Tasmanian Masked Owl detection. Time of night has previously been found not to have a significant effect on Australian Masked Owl responses to call

playback in New South Wales (Kavanagh 1997). This is an important result relevant to researchers planning future call playback surveys.

Environmental effects

Studies have found that wind and rain can have a negative influence on detectability and calling behaviour of owls (Morrell *et al.* 1991; Kavanagh and Peake 1993b; Debus 1995). Wind was found to have a significant negative effect on the detection of Tasmanian Masked Owls in this study, while air temperature had a positive effect on Tasmanian Masked Owl detection. It is generally unclear, however, whether the wind and rain actually affect calling behaviour or simply the ability of observers to detect owl calls.

Moonlight had no effect on the calling response of Tasmanian Masked Owls in this study, as has been found in some other studies of owls calling behaviour using the call playback technique (Clark and Anderson 1997; Braga and Motta Jr. 2009).

However, some caution should be applied when interpreting this result because of the possible call-stimulating effect of the call playback method. Most studies of owl calling behaviour have been affected by this same problem to some extent. Studies where calling behaviour and moonlight have been examined without using call playback are relatively rare. Owls that have been studied this way include the African Wood-Owl (*Strix woodfordi*) (Seavy 2004) and the Eagle Owl (*Bubo bubo*) (Penteriani *et al.* 2010) both of which called more often on moonlit nights.

However, the Mexican Spotted Owl (*Strix occidentalis lucida*) was found to call more often on dark nights (Ganey 1990). In Australia, no relationship between calling behaviour and moon phase or visibility was found in the Southern Boobook (Olsen *et al.* 2002).

The only study in Australia to have looked at calling behaviour of radio-tagged individual owls was on the unrelated Southern Boobook (*Ninox novaeseelandiae*) (Olsen *et al.* 2002). Southern Boobooks were found to call during wind and rain

(unlike studies that used call playback); however the reduced ability of researchers to hear Southern Boobook calls at distance during rain and wind reduced their likelihood of detection. This raises the possibility that the methods used could influence the conclusions that are reached and hence the need to reduce false negative results when surveying for owls by repeating surveys on several occasions (Wintle *et al.* 2005b).

Seasonal differences

The lack of significant seasonal variation in the response of the Tasmanian Masked Owl to call playback was consistent with other studies (Debus 1995; Kavanagh 1997). There was a minor difference in the type of call first detected, in different seasons; a higher proportion of screech calls in winter and chatter calls in summer. This may be because calls vary in relation to breeding behaviour in the Tasmanian Masked Owl, which has been reported to breed mostly in October (Mooney 1997), although note breeding records outside these months have been recorded in the last ten years (DPIPWE 2006) and a 2011 successful nesting at Middleton in May (pers. obs.). The frequency of spontaneous calling (without call playback) in the Australian Masked Owl has been reported to differ though, with a lack of calling outside the breeding season between September and December, and a flush of calling in the early stages of the breeding season between February and July, in Newcastle, New South Wales (Kavanagh and Murray 1996). When nesting was believed to have actually begun the calling rate declined again (Kavanagh and Murray 1996). In the current study, the slightly increased vocal activity in winter could be a result of Tasmanian Masked Owls defending territories from intruding owls prior to the onset of breeding. Once breeding has begun, Australian Masked Owls generally become less vocal and may not respond as vigorously to call playback (Kavanagh 1996). The only study to date on Tasmanian Masked Owl breeding found more nesting occurred in spring (Mooney 1997). More research is required to clarify the cause of variations in call type according to season.

Sex differences

There was no relationship between calls detected and colour morph. There is a commonly held assumption that females are usually darker in colour than males and screech more often than males, but this study was unable to confirm it. While there were differences between the calls of males and females within pairs, it was not shown that these differences could be extrapolated to other individuals to define sex. Many more recordings of known sex individuals are needed to define the differences between sexes.

Individual variation

The screech calls of adult Tasmanian Masked Owls were quite consistent, with similar characteristics of duration and frequency between individuals. This result needs to be further tested with other owls and with larger sample sizes, but screech calls might not be ideal for identifying individual owls. The difference between adult and immature Masked Owls was distinct.

The individual difference in chatter calls is the first evidence of individuality in vocal signals in Masked Owls, or indeed any *Tyto* species, though consistent individuality has been suggested in many birds (Saunders and Wooller 1988). The consistency of calls produced by an individual has useful management applications, particularly in population monitoring (Policht *et al.* 2009). If individual owls can be recognized from their calls then their calls can be used to assess the territory occupation by individuals, rather than accept the uncertainty of whether or not detected Masked Owls are non-territorial floaters (Rohner 1997a). Many species of bird, including owls, have been shown to be individually identifiable by the territorial calls of males (Terry *et al.* 2005). Tawny Owls respond differently to the calls of non-neighbour Tawny Owls than to neighbour Tawny Owls (Galeotti and Pavan 1993). Whether this variation in response to calls of individual owls occurs in the Tasmanian Masked Owl is unknown but would seem possible.

A more extensive series of recordings of individual owls would help to determine whether there is consistent variation that can be used to identify individuals. This would have considerable benefit for monitoring the presence and survival of Masked Owls and has potential for monitoring behaviour and ecology of Masked Owls. Controlled playback experiments to known radio-tagged individuals of particular call recordings might be useful in clarifying the function of the calls and the behavioural context in which they are used. Also, it is still not known whether the owls responding to playback are always the resident territory holding adults or whether sometimes non-breeding “floaters” also respond in this way, at least on occasions (Rohner 1997b).

Automatic recording devices

There is considerable scope for further research on *Tyto* owl calls, and in particular Masked Owl calls. For example, the automatic audio-recording device technique could record continually over entire nights to investigate whether unelicited calling is occurring throughout the night. There are limitations to this, in that the owl may be well clear of the recording range of the microphones for most of the night. This approach would not determine whether the owl was silent and present, but it could determine whether the owl was present and vocal. Fewer calls were recorded from owls returning to roost before dawn, perhaps because the owl returns to the roost far earlier than dawn. Recording all night may detect this.

The frequency of calling by Tasmanian Masked Owls was increased by call playback, thus enabling the collection of more calls than would have been possible otherwise. The use of automatic song recorders at known roost sites demonstrated how infrequently the Masked Owl usually calls, even when the recorders are set to record near sunset when they are believed to call most often (Debus 1995; Kavanagh 1997). Studies of other species of owl have shown that spontaneous owl calling is more frequent within a couple of hours of sunset in the case of the Spotted

Owl (Ganey 1990), the Ural Owl (*Strix uralensis*) (Lundberg 1980) and the Long-eared Owl (*Asio otus*) (Bull *et al.* 1989). The song recorder recorded mainly screeches from Tasmanian Masked Owls at their roost sites. This may be the normally given call by the species when unprompted by call playback. Call playback may evoke an aggressive response, increasing the likelihood of chatter calls being given, especially by males.

Conclusions

Of the hypotheses that were raised, some can be tentatively accepted. On the evidence available, the Tasmanian Masked Owl produces calls of lower peak frequency to the Australian Masked Owl on the mainland. Both screech and chatter calls reach higher frequencies than previously recorded in the Australian Masked Owl. Most environmental variables had no effect on Tasmanian Masked Owl calling except for wind (negative effect) and air temperature (positive effect); thus this hypothesis can be accepted. The effect of season on calling frequency was not proven and so this hypothesis is rejected, noting though the effect that call playback probably has on calling frequency. It would be useful to assess Masked Owl calling by the use of automatic recording devices to eliminate the stimulatory effect that call playback has on calling. The possibility that the Tasmanian Masked Owl can be sexed by its calls remains, but it was not conclusively proven in this study. The hypothesis that Tasmanian Masked Owl calls can be identified to individual level is tentatively accepted. More recordings of known individuals to measure individual variation would be useful in this regard.

Appendix 3.1- Calling behaviour of Tasmanian Masked Owls attracted to call playback.

Behaviour or call type	Number heard or seen
Silent	10
Screech	40
Chatter	40
Screech followed by chatter	6
Chatter followed by screech	6
Continuous screech	5

Appendix 3.2- Number of surveys in which Tasmanian Masked Owls were detected in relation to time (minutes) after sunset. Figures in brackets are the expected values if there was no effect of time after sunset.

Minutes post sunset	Not detected	Masked Owl detected	Total surveys
0-120	378 (371)	25 (32)	403
120-240	357 (359)	33 (31)	390
240-360	184 (187)	19 (16)	203
360-480	58 (60)	7 (5)	65
480-600	7 (6)	0 (1)	7
600-720	3 (3)	0 (0)	3
Total	987	84	1071

Appendix 3.3- Number of each colour morph of Tasmanian Masked Owls observed during surveys and the calls by which they were first identified.

Colour morph	Silent	Screech	Chatter	Continuous screech	Total
Dark	4	9	18	3	34
Intermediate	2	2	10	0	14
Pale	1	2	7	0	10
Unknown	3	27	11	2	49
Total	10	46	46	5	107

Appendix 3.4- Attributes of recorded screech calls of Tasmanian Masked Owl. Values are means \pm standard deviation.

Location and Dates	Allens Rivulet, June-July 2010	Glen Huon, Jul-Aug 2010	Lake Leake, Jun-Sep 2008	Mt Barrow Rd, Sep 2008	Rossarden, Jul 2008	Ouse, Aug 2008	Ouse, Nov 2008	Sandford, Mar 2008	Brown Mountain Rd, Nov 2010
Calls Analysed	13	27	8	1	1	24	19	58	26
Low Frequency (Hz)	1173.4 \pm 83.7	895.4 \pm 269.4	841.4 \pm 224.1	441.8	728.6	329.5 \pm 123.6	542.5 \pm 396.8	1541.7 \pm 157.4	1095.0 \pm 349.9
High Frequency (Hz)	-	-	16112.2 \pm 3992.7	13776.2	11197.6	18230.6 \pm 1260.3	17182.4 \pm 1991.1	17926 \pm 1436.3	19107 \pm 943.6
Call Duration (s)	1.4 \pm 0.1	1.5 \pm 0.1	2.0 \pm 0.3	2.089	2.643	1.1 \pm 0.1	1.4 \pm 0.1	1.2 \pm 0.2	0.9 \pm 0.1
Energy	78.7 \pm	82.4 \pm	94.7 \pm	94.6	100.3	96.45 \pm 3.6	95.8 \pm 3.9	98.3 \pm 2.9	91.1 \pm 3.3

Location and Dates	Brown Mountain Rd, Nov 2010	Sandford, Mar 2008	Ouse, Nov 2008	Ouse, Aug 2008	Rossarden, Jul 2008	Mt Barrow Rd, Sep 2008	Lake Leake, Jun-Sep 2008	Glen Huon, Jul-Aug 2010	Allens Rivulet, June-July 2010
(dB)							8.0	10.6	5.2
Peak Frequency (Hz)	3001.4 ± 293.0	2928.5 ± 372.1	3264.0 ± 670.8	2989.5 ± 361.9	1722.7	1722.7	1744.2 ± 60.9	1776.9 ± 129.0	1755.8 ± 66.2
Centre Frequency (Hz)	3246.5 ± 204.9	3109.7 ± 186.5	3436.2 ± 690.2	3247.9 ± 130.4	1722.7	1722.7	1808.8 ± 92.0	1789.7 ± 93.5	1765.7 ± 45
2nd Peak Frequency (harmonic) (Hz)	not present	not present	not present	not present	4478.9	4823.4	4586.6 ± 290.3	4793.6 ± 270.1	4565.0 ± 211.0

Chapter 4 : The effect of environmental variables on detection probability and site occupancy of Tasmanian nocturnal birds, particularly the Tasmanian Masked Owl *Tyto novaehollandiae castanops*

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Abstract

The habitat requirements of nocturnal birds in Tasmania are poorly known yet needed to implement appropriate conservation strategies, particularly for the threatened Tasmanian Masked Owl (*Tyto novaehollandiae castanops*). This study presents the results of the first intensive systematic survey of the Tasmanian Masked Owl, Southern Boobook (*Ninox novaeseelandiae*) and the Australian Owlet-nightjar (*Aegotheles cristatus*) in Tasmania: the data are used to describe and model habitat preferences. Using occupancy probability theory, occupancy models were created that explain the spatial distribution of the three species after accounting for the most influential environmental conditions affecting survey results. The most important factors affecting the detectability of the Tasmanian Masked Owl were wind (negative) and air temperature (positive). The detectability of the Southern Boobook was affected by wind (negative), rain (negative), temperature (positive) and nightlight (negative). The detectability of the Australian Owlet-nightjar was affected by wind (negative) and temperature (positive). Elevation (negative), mature eucalypt forest (positive) and dry eucalypt forest (positive) contributed most to the best models for the Tasmanian Masked Owl. The best models for the Southern Boobook included the attributes mean minimum temperature in the coldest month (positive) and total length of roads (negative) and

wet eucalypt forest (positive). The best models for the Australian Owlet-nightjar included the attributes dry eucalypt forest and woodland (positive) and open country (negative). Reasons for the importance of the site-landscape attributes to the Tasmanian Masked Owl models were explored and could include the availability of tree hollows or physiology, but most likely are caused by prey availability. The apparent preference for areas with mature eucalypt forest has management implications for Tasmanian Masked Owl conservation.

Introduction

Knowledge of the habitat occupied by nocturnal forest birds is important for the development of appropriate conservation strategies. However, for many species factors influencing their distribution and habitat preference remain poorly known. Studies have demonstrated a close relationship between old-growth forest and some species of forest owl in Europe (Laaksonen *et al.* 2004), North America (Bart and Forsman 1992; Dugger *et al.* 2005) and in south-eastern Australia (Milledge *et al.* 1991; Kavanagh and Bamkin 1995; Kavanagh 2002b). It is possible that the Tasmanian Masked Owl plays an important role in Tasmanian forest ecosystems. In the Italian Alps, the Eurasian Eagle Owl has been found to exert a top-down influence on their ecosystems and reflect biodiversity levels (Sergio *et al.* 2004). Kavanagh (1991) and Milledge (2004) have both suggested that large forest owls in Australia could be used as an indicator of forest biodiversity and habitat quality.

Recent research has revealed that there can be widespread cascading effects from the loss of apex predators, such as large owls, from ecosystems (Estes *et al.* 2011). While there is still an “incomplete and distorted picture of the influences of apex consumers”, Estes *et al.* (2011) conclude that there is a demonstrable threat to biodiversity posed by disruptions to trophic cascades brought about by the loss of predators. This view is in contrast to the views of some researchers who take the view that many apex predators are little more than passengers and that it is other

species and functions that are responsible for the maintenance of ecosystems (Cabeza *et al.* 2008). This also feeds into the arguments around whether apex predators can be used as surrogates for biodiversity (Sergio *et al.* 2005; Sergio *et al.* 2006; Sergio *et al.* 2008a). Recent work (Lewinsohn and Cagnolo 2012) has drawn attention to the importance of individual species to overall community conservation because of their roles in ecosystems. Also worth noting are studies that have looked at the stability of ecosystems in relation to predators (Gross *et al.* 2009). Gross *et al.* (2009) showed that the stability of food webs, or ecosystems, is enhanced when predators feed on multiple prey species and/ or species at an intermediate trophic level are fed upon by multiple species of predator. When the Tasmanian Masked Owl is considered in this light, its ecosystem could be seen to be unstable. The Tasmanian Masked Owl feeds mainly on a small number of species and there are a limited range of predators to feed on intermediate trophic level species in Tasmanian forest ecosystems.

The influence of forest structure on the abundance of Australian forest owls has been demonstrated in studies of owls in forests modified through logging. A study in Victoria found that the large forest owls (Powerful Owl *Ninox strenua* and Sooty Owl *Tyto tenebricosa*) were more common in old-growth forest (165 and 250+ year old forest) than in re-growth forest (50-80 year old forest) (Milledge *et al.* 1991). Similarly, a number of studies in south-east NSW have also found the Australian Masked Owl (*Tyto novaehollandiae*) more often in unlogged forest or in forests which had been subjected to only light selective logging than in re-growth (Kavanagh and Peake 1993a; Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995). However, a study in re-growth forests in northern NSW detected the Australian Masked Owl more often immediately after logging than before, suggesting that the cleared habitat was preferred to re-growth (Cann *et al.* 2002). Changes to the structure of forests as a result of logging have the potential to affect the distribution and abundance of nocturnal forest birds, either directly through the removal or alteration of habitat and/or indirectly through the effects on the abundance of their

prey (Doak 1989; Bell *et al.* 1996; Duncan 1997; Meiman *et al.* 2003).

The call playback technique (Foster 1965; Levy *et al.* 1966; Kissling *et al.* 2010), has proven to be particularly useful for rare species that are difficult to find by any other method. In Australia, call playback has become a standard technique for detecting owls (Milledge *et al.* 1991; Kavanagh and Peake 1993b; Milledge *et al.* 1993; Debus 2000; Loyn *et al.* 2001b; McIntyre and Henry 2002; Parker *et al.* 2007). While the use of call playback has greatly improved the rate of detection of owl species, there is still a statistical problem stemming from the low rate of detection. Most surveys fail to detect owls, resulting in zero-inflated data (Wintle *et al.* 2005b). The reality is that it is common for species to go undetected, even though the surveyed location may be occupied at least some of the time. Methods using logistic regression have been found to yield biased results when applied to presence-absence data in which there are false absences even at low frequencies (Tyre *et al.* 2003; Gu and Swihart 2004). This has prompted the investigation of species occurrence from a different perspective, that of the probability of occupancy of a site. The methodology is designed to permit inferences about occupancy that deal adequately with detection probabilities of less than one (MacKenzie *et al.* 2002; MacKenzie *et al.* 2003a; Wintle *et al.* 2004).

Five nocturnal bird species are found in Tasmania – the Tasmanian Masked Owl (*Tyto novaehollandiae castanops*), the Southern Boobook (*Ninox novaeseelandiae leucopsis*), the Tawny Frogmouth (*Podargus strigoides*), the Australian Owlet-nightjar (*Aegotheles cristatus tasmanicus*) and the Barn Owl (*Tyto alba*). The Tasmanian Masked Owl is the only large forest owl known to regularly breed in Tasmania, unlike mainland Australia where there are another five (or six, depending on taxonomy) large forest owl species present (Christidis and Boles 2008; Hollands 2008). The small Tasmanian subspecies of the Southern Boobook, the other owl resident in Tasmania, is about one-fifth the size of the Tasmanian Masked Owl

(Higgins 1999c) and largely insectivorous (Green *et al.* 1986). The Barn Owl occurs as a vagrant in Tasmania though there has been one unconfirmed breeding report for the species (Elliott 1999). Its rarity or usual absence from Tasmania means it would provide little more than temporary, local competition for the Tasmanian Masked Owl. The Tawny Frogmouth is particularly difficult to survey as it is often silent and does not respond to playback of calls of the larger owls. The Australian Owlet-nightjar and the Southern Boobook call more regularly and can be detected more readily using listening techniques.

There have been few detailed studies of Tasmania's nocturnal birds. Like all the other large forest owls in Australia, the Tasmanian Masked Owl requires large tree hollows for nesting and to a lesser extent for roosting (Hollands 2008). The only study of Tasmanian Masked Owl nests found that the birds require cavities in large old-growth eucalypt trees with dimensions between 95-191 cm in diameter and these are likely to be over 165 years of age (Mooney 1997). Research on tree hollows in Tasmania has indicated that such cavities are rare in the Tasmanian forest landscape (Koch 2007; Koch *et al.* 2008a). Koch (2007) notes however, that the Tasmanian Masked Owl has larger territories than other hollow-dwelling fauna, such that fewer hollows would be required per hectare than for a smaller species such as the Australian Owlet-nightjar, which uses hollows for roosting and nesting, and has relatively small territories (Brigham *et al.* 1998; Doucette 2010).

The Tasmanian Masked Owl has a low overall abundance (Bell *et al.* 1996), large territory size (Young 2006), and is rarely observed (Barrett *et al.* 2003), despite its wide distribution in Tasmania. It is often regarded as the largest of the world's barn owls (*Tyto*) (König *et al.* 2008), although it is comparable in size to the female Sooty Owl (Mooney 1992; Bilney 2009). It is listed as endangered under the Tasmanian *Threatened Species Protection Act 1995*, vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999* and as endangered in the Action Plan for Australian Birds (Garnett *et al.* 2011a). Previous estimates of population

size have included 200-400 breeding pairs (Bell and Mooney 2002) and 1300 mature individuals (Garnett *et al.* 2011a). Much of its core distribution overlaps with areas subject to production forestry activities in Tasmania (Bell and Mooney 2002), and, therefore more detailed research into its ecology is needed. Research on the Masked Owl (both Australian and Tasmanian subspecies), however, has been hampered by the general rarity of the species resulting in small sample sizes and usually inconclusive results. In various surveys for the Australian Masked Owl in NSW it has been found to be rare (Davey 1993; Debus 1995; Debus 2001; Parker *et al.* 2007).

The only systematic surveys to have been conducted on Tasmania's nocturnal birds were carried out in 1995 (Bell *et al.* 1996). They reported the results of call playback surveys conducted at 86 sites for the Tasmanian Masked Owl and the Southern Boobook (Bell *et al.* 1996). They found that elevation was negatively correlated with the detection of the boobook but not so for the Tasmanian Masked Owl. They also found that distance to forest edge was negatively correlated with records of the Masked Owl, although the sample sizes were very small. Bell *et al.* (1996) made the point that the incidental database of Tasmanian Masked Owl records is highly biased towards forest edges and cleared land and would be unlikely to provide support for a preference for forest interiors, even if it existed. However, they also mentioned the frequent use of cleared land and pasture by Tasmanian Masked Owls and a probable preference for a mosaic of forest and non-forest habitats within its home range. They concluded that our "knowledge of owls dwelling in forest interiors will remain poor until an intensive systematic survey is undertaken and the data used to describe and model habitat preferences" (Bell *et al.* 1996).

In this study the influence of geographic and environmental variables on detection probability and site occupancy of three of Tasmania's nocturnal birds in forested landscapes was examined but with a focus on the Tasmanian Masked Owl. In

particular, differences in elevation, forest type, forest disturbance and distance to forest edge were examined to see if they were reflected in the occurrence of the three target species in largely forested ecosystems. Using occupancy probability theory, occupancy models were created to explain the distribution of the three species present taking into account the number of surveys at each site and the weather at the time of the survey. The potential utility of these habitat models for conservation planning are discussed.

Methods

Site selection

Available digital data were used to select the sites in Arc GIS. In order to determine the occurrence of each species at different elevations and in different vegetation types, sites were randomly generated and then tested to see if they met the criteria elevation, vegetation type and distance to road (for logistical reasons). This was continued until a list of over 300 potential sites were generated. Of these, 211 were found to be accessible on the ground and were selected as survey sites (Figure 4.1). The sites were classified as either high altitude (> 450 m. a.s.l.) or low altitude (< 450 m. a.s.l.). Four hundred and fifty metres was chosen as the approximate altitudinal boundary below which *E. obliqua* forests become more common and above which *E. delegatensis* forests are more common. Vegetation communities dominated by these two species are the most common in Tasmania (Harris and Kitchener 2005).

High altitude sites were located in the Central Highlands, in the Ben Lomond region and also in south-east Tasmania. Low altitude sites were spread across the state. The two most common and widespread vegetation types in dry forest and wet forest in Tasmania were selected from Harris and Kitchener (2005). Together these four vegetation types make up over 75% of Tasmania's native forest. The forest types selected and their mapping unit code (Harris and Kitchener 2005) were:

- *Eucalyptus delegatensis* dry forest and woodland (DDE), usually >450 m. elevation.
- *E. delegatensis* wet forest (undifferentiated) (WDU), usually >450 m. elevation.
- *E. obliqua* dry forest (DOB), usually <450 m. elevation.
- *E. obliqua* wet forest (undifferentiated) (WOU), usually <450 m. elevation.

This division resulted in an approximately even allotment of sites between low elevation dry forest (52 sites), low elevation wet forest (57 sites), high elevation dry forest (61 sites) and high elevation wet forest (41 sites). All sites selected were at least two kilometres distant from each other and were accessible via road or vehicle track and were in areas of contiguous forest.

Survey method

The main survey sites were each surveyed on four occasions between 2007 and 2009. Surveys at each site were approximately three months apart and each survey was conducted in a different season (spring/summer/autumn/winter). Rainy and/or windy nights were generally avoided on the assumption that these conditions might negatively impact on survey results (Kavanagh *et al.* 1995).

All surveys were carried out between dusk and dawn with 93% of surveys conducted within six hours of dusk. Time of survey was not distributed evenly through the night for logistical reasons. Weather and road conditions affected how many sites could be surveyed in a night. In total, 1071 surveys were conducted in which the time of survey was noted, resulting in 267.75 hours of survey time. This includes surveys outside of the 211 main survey sites.

Survey methodology followed similar studies on large forest owls in other parts of Australia (Kavanagh and Peake 1993b; Debus 1995; Bell *et al.* 1996) except that only calls of the Tasmanian Masked Owl were broadcast. These calls were collected using playback of screech calls from the mainland Australian Masked Owl. These owls were in turn recorded using an Edirol R-09 24 Bit Wave/ MP3 digital audio recording device with a Sennheiser ME67 shotgun microphone and a K6 powering module. All recordings were made in wave format at 44.1 kHz. The calls played in the surveys included both screech calls and chatter calls and had silent periods interspersed to more closely resemble natural Masked Owl calling behaviour and to aid in detecting calling owls.

Each survey involved three basic components. Firstly, five minutes of quiet listening was conducted, in order to detect spontaneous calling of night birds. Secondly, five minutes of pre-recorded Tasmanian Masked Owl calls interspersed with short periods of silence were broadcast via a megaphone connected to an MP3 player. Finally, five minutes of further quiet listening and spotlighting around the vicinity was conducted. Calls of the Southern Boobook and the Australian Owlet-nightjar were not broadcast, but calls and sightings of these species were noted.

Environmental variables

The following categorical environmental variables, thought to have the potential to influence the detection of the birds using the listening-call playback method, were recorded for each site at the start of each survey:

- Time of survey.
- Wind speed- using a modified Beaufort scale. Categories were: still, light breeze (only small upper branches moving), moderate wind (branches moving), strong wind.
- Precipitation: nil, drizzle, rain, heavy rain.
- Cloud cover: estimated percentage cloud cover.

- Ambient air temperature: subjective assessment of temperature in the categories cold, cool, mild, warm or hot.
- Moon phase: no moon visible, quarter moon (either waning or waxing), half moon, three-quarter moon, full moon.
- Nightlight: very dark (no moon, 100% cloud), dark (quarter moon or heavy cloud), moderately bright (detail visible, only light cloud, moon visible), bright (full moon or near full moon, no cloud).

Data on site and landscape variables thought to have the potential to influence the occurrence of the nocturnal bird species are listed in Table 4.1. These data were extracted within 500 m, 1000 m, 2000 m and 4000 m radius circles around each of the 211 survey sites from relevant GIS databases held by the Forest Practices Authority and Forestry Tasmania. Data were collected at different radii from each survey location to cater for uncertainty about what area was relevant to the target species that may occupy the site.

The scale at which data is collected is likely to be particularly important in determining the habitat of the Tasmanian Masked Owl. Given that the Tasmanian Masked Owl probably has territory sizes of around 2000 ha (Young 2006), the 500 metre radius would be much smaller than an owl's territory but it is likely that this area would be part of a responding owl's territory. For example, a foraging owl may hear calls broadcast from 900 metres from its current position. It may then fly to the source of the calls and respond vocally, and be consequently detected at the survey site. While the original location of the detected owl is not known, there is a high probability that a 500 metre radius circle (78.5 hectares) surrounding the survey point, is part of the detected owl's territory. Given that a resident Tasmanian Masked Owl is likely to have a territory of at least four square kilometres (1600 ha), the 500 m radius circle may represent a 5% sample of the owl's territory. A radius

circle of 1000 metres (314.1 ha) represents a 20% sample of the hypothetical territory size.

Data analysis

The first step taken was to consider the effect of the weather and environmental variables on the species detectability, using the software *Presence* (Hines 2006) . Models incorporating the survey results and the environmental data were created. The best models were selected on the basis of Akaike Information Criteria (AIC) (Burnham and Andersen 2002). Models that involved covariates with low standard errors were selected over those with high standard errors.

The site variable data (Table 4.1) were then standardized in *Microsoft Excel* to eliminate any inconsistencies between the scale of measurement of variables using their mean and standard deviation. The formula for this standardization was:

$$Z = \frac{x - \mu}{\sigma}$$

Where μ =mean and σ = standard deviation.

The standardized data were then analysed using *Presence* (Hines 2006) to determine the probability of occupancy of each of the selected species. Models incorporating the survey results and the environmental and habitat data were created in all potential combinations. The best models were selected on the basis of Akaike Information Criteria (AIC) (Burnham and Andersen 2002). With the best fit model, the estimate and the standard error of the covariates were also presented. Models that involved covariates with low standard errors were selected over those with high standard errors.

Table 4.1- Site, landscape and disturbance history variables collected for each site.

Variable	Description
Wet eucalypt	Area (m ²) within each radius that was classified as 'wet

forest and woodland	eucalypt forest and woodland' using the TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Dry eucalypt forest and woodland	Area (m ²) within each radius that was classified as 'dry eucalypt forest and woodland' using the TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Open country	Area (m ²) of open country within each radius. This included <i>cleared land, agricultural land, urban land, exotic vegetation</i> and <i>native grassland</i> derived from TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Vegetation diversity	Diversity of broad vegetation types within each radius, calculated using the Shannon-Wiener index of diversity.
Distance to open country	Distance (m) to closest open country, as defined above.
Number of streams	Number of streams within each radius. DPIW, Tasmap data, 2010.
Maximum stream order	Maximum stream order within each radius. DPIW, Tasmap data, 2010.
Elevation	Metres above sea level as estimated using spline interpolation from Tasmanian 10 m contour data DPIW, Tasmap data, 2010. There was a high positive correlation with average annual rainfall and minimum temperature of the coldest month (obtained from the Bureau of Meteorology)..
Geology	1:250,000 digital map of Tasmanian geology (Mineral Resources Tasmania). In particular basalt geology (as an indicator of high fertility areas) and sandstone geology (as an indicator of poor fertility areas) were investigated. Sandstone geology was also chosen because of the habit of the

	Tasmanian Masked Owl using sandstone caves for roosting (Mooney 1992).
Topographic roughness index	An index was used that provided a quantitative measure of topographic heterogeneity (Riley <i>et al.</i> 1999). In ArcGIS, a model was created that calculates the sum change in elevation between a grid cell and its eight neighbor grid cells. 50 metre grid cells were used.
Plantation	Area (m ²) within each radius that is classified as <i>plantation</i> . From Structural Group data from Forestry Tasmania GIS spatial data ¹ (Stone 1998; Forestry Tasmania 2007a; Forestry Tasmania 2007b; Forestry Tasmania 2007c).
Re-growth	Area (m ²) within each radius that is classified as <i>re-growth</i> . From Structural Group data from Forestry Tasmania GIS spatial data ¹ (Stone 1998; Forestry Tasmania 2007a; Forestry Tasmania 2007b; Forestry Tasmania 2007c). Areas were classified as re-growth from aerial photograph interpretation. Actual age not known (Stone 1998).
Regeneration	Area (m ²) within each radius that is classified as <i>regeneration</i> , either after harvesting or fire. From Structural Group data from Forestry Tasmania GIS spatial data ¹ (Stone 1998; Forestry Tasmania 2007a; Forestry Tasmania 2007b; Forestry Tasmania 2007c). Regeneration is of a known age, as a result of a past forestry operation as opposed to <i>re-growth</i> (Stone 1998).
Mature eucalypt forest	Area (m ²) within each radius that is classified as <i>mature</i> , from growth stage data from Forestry Tasmania GIS spatial data (Stone 1998; Forestry Tasmania 2007a; Forestry Tasmania

	2007b; Forestry Tasmania 2007c). This can have some re-growth within but is dominated by mature trees.
High potential hollow abundance	Area (m ²) within each radius that is classified as <i>high potential hollow abundance</i> . From mapping that used aerial photographs to remotely assess potential tree hollow availability (Koch and Baker 2011). The predicted potential hollow abundance takes into account mature forest and the density (using crown canopy as the best representation available for tree density). To be in the <i>high hollow</i> category, crown cover needs to be >70% (Koch and Baker 2011).
High OR medium potential hollow abundance	Area (m ²) within each radius that is classified as <i>high or medium potential hollow abundance</i> . Details as for high potential hollow abundance. Medium potential hollow abundance is 40-70% crown cover. The two categories combined is 40-100% crown over.
Length of road	Total length of road (m) within each radius, estimated using 'the List 2008' Transport layer as maintained by the Department of Infrastructure Energy and Resources Tasmania and Forestry Tasmania's Roads Transport Layer Class 1 - 4, 2010.
Distance to nearest reserve	Distance (m.) from survey point to the nearest nature reserve, national park or forest reserve. Reserves as listed in the CAR Reserves layer, Tasmanian Reserve Estate.

¹ As described in Stone (1998), the structural group data is not completely accurate due to the patchy nature of native forest and how aerial photographic interpretation (PI typing) is derived. However, this method generates the best estimate of age for the area in question based on physical attributes. This is done through three dimensional interpretation of aerial photographs of the forest, in relatively homogenous 3 ha portions. Each of these portions is assigned to the aforementioned age class that

dominates the area, though it may include small portions of other age classes. The structural group data is less accurate for private land since most of it was created in 1979-1980. There is a risk that private land areas mapped as mature in 1980 have in fact, been harvested since. The majority of survey sites, however, were on public land. The sites that were potentially incorrectly coded in this way were checked either in person or by examination of aerial photographs from Google Earth (2010) and confirmed as mature.

The apparent effect of elevation, broad vegetation type, maturity of forest and area of open country were examined independently using chi square tests for the Tasmanian Masked Owl as these habitat variables have been previously suggested as factors affecting Tasmanian Masked Owl presence (Bell *et al.* 1996). Simple proportions were investigated to bring forward any apparent relationships with presence or absence. Broad vegetation type and elevation were examined for the Southern Boobook and the Australian Owlet-nightjar. The seasonal nature of Southern Boobook detection was also investigated.

Results

Distribution of detections of nocturnal birds

From 844 surveys (four visits to each of 211 sites), there were 89 detections of Tasmanian Masked Owls, 128 detections of Southern Boobooks, and 55 detections of Australian Owlet-nightjar. Of the 211 surveyed sites, 51 (24.2%) had Tasmanian Masked Owls (Figure 4.1), 93 (44.0%) had Southern Boobooks (Figure 4.2) and 46 (21.8%) had Australian Owlet-nightjars (Figure 4.3). There was no relationship evident between time of survey and the detection of Tasmanian Masked Owls (Table 4.2).

Models using all combinations of the environmental variables were trialed for each species. Each variable was tested individually and then other variables were added

until every possible combination had been tested. The likelihood of detection of the Tasmanian Masked Owl was most affected by wind (negative effect) and ambient air temperature (positive effect). The most effective model included both of these variables (Table 4.3).

The likelihood of detection of the Southern Boobook was affected by wind (negative effect), ambient air temperature (positive effect), precipitation (negative effect) and nightlight (positive effect) (Table 4.4). The likelihood of detection of the Australian Owlet-nightjar was affected by wind (negative effect) and ambient air temperature (positive effect) (Table 4.5).

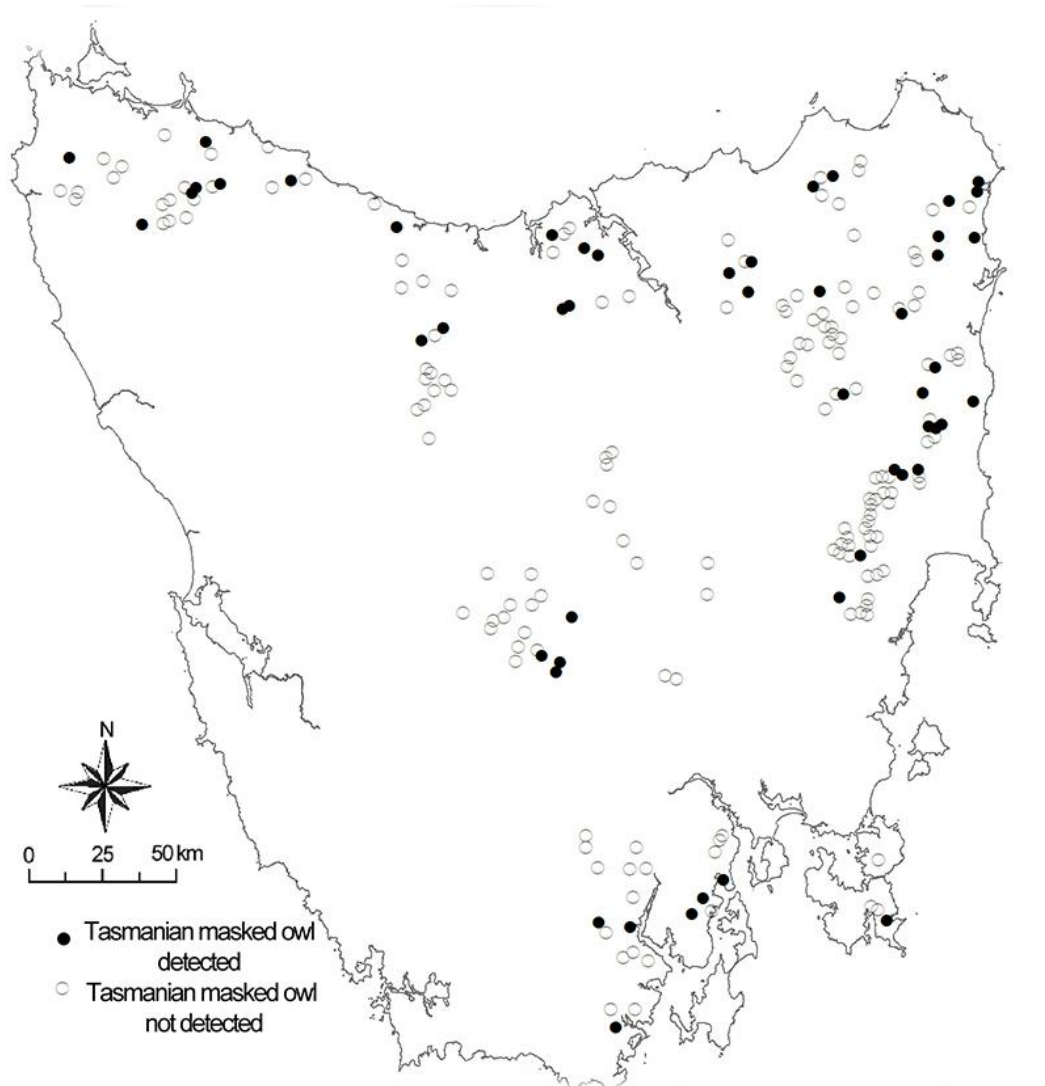


Figure 4.1- Location of survey sites. Sites where the Tasmanian Masked Owl was found to be present are marked with a complete circle.

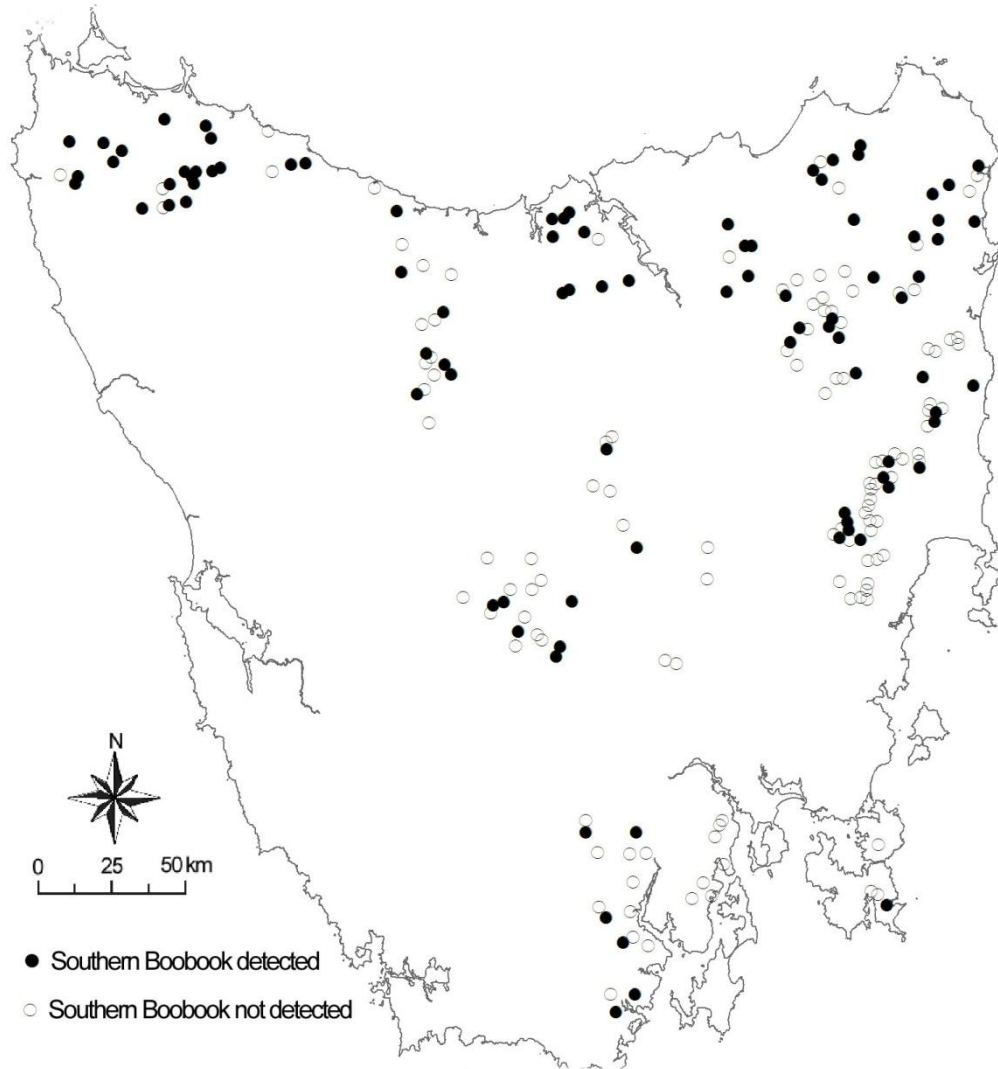


Figure 4.2- Location of survey sites. Sites where the Southern Boobook was found to be present are marked with a complete circle.

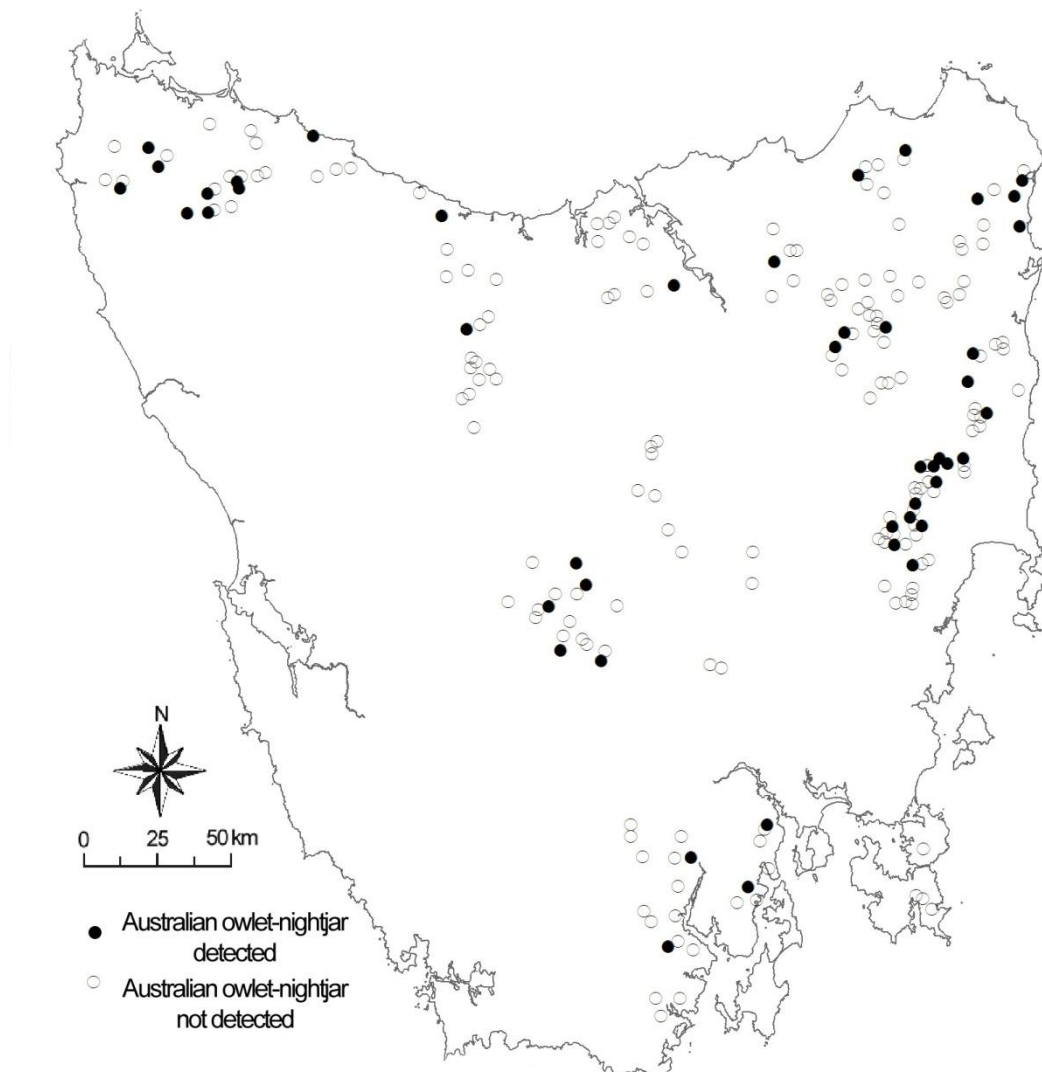


Figure 4.3- Location of survey sites. Sites where the Australian Owlet-nightjar was found to be present are marked with a complete circle.

Table 4.2- Time survey started and whether Tasmanian Masked Owl (TMO) was noted (expected number in brackets).

Minutes Post Sunset	TMO absent	TMO- present	Total Surveys
0-120	378 (371)	25 (32)	403
120-240	357 (359)	33 (31)	390
240-360	184 (187)	19 (16)	203
360-480	58 (60)	7 (5)	65
480-600	7 (6)	0 (1)	7
600-720	3 (3)	0 (0)	3
Total	987	84	1071

Table 4.3- Best fit models using only weather variables describing Tasmanian Masked Owl occupancy.

Model	AIC	deltaAIC	AIC wgt	no.Par.	-2*LogLikelihood
psi(.),p(temp,wind)	438.16	0	0.855	4	430.16
psi(.),p(temp)	442.39	4.23	0.1031	3	436.39
psi(.),p(wind)	444.38	6.22	0.0381	3	438.38
psi(.),p(.)	451.37	13.21	0.0012	2	447.37
psi(.),p(nightlight)	452.54	14.38	0.0006	3	446.54
psi(.),p(moon)	452.63	14.47	0.0006	3	446.63
psi(.),p(precip)	453.32	15.16	0.0004	3	447.32
psi(.),p(cloud)	453.37	15.21	0.0004	3	447.37
psi(.),p(moon,nightlight)	454.34	16.18	0.0003	4	446.34
psi(.),p(cloud,precip)	455.32	17.16	0.0002	4	447.32

Table 4.4- Best fit models using only weather variables describing Southern Boobook occupancy.

Model	AIC	deltaAIC	AIC wgt	no.Par.	-2*LogLikelihood
psi(.),p(wind,precip,temp,nightlight)	658.12	0	0.6626	6	646.12
psi(.),p(wind,temp,nightlight)	661.15	3.03	0.1456	5	651.15
psi(.),p(wind,precip,temp)	661.56	3.44	0.1186	5	651.56
psi(.),p(wind,precip)	664.33	6.21	0.0297	4	656.33
psi(.),p(wind,temp)	664.95	6.83	0.0218	4	656.95
psi(.),p(wind,nightlight)	665.57	7.45	0.016	4	657.57
psi(.),p(wind)	667.65	9.53	0.0056	3	661.65
psi(.),p(precip,temp)	701.73	43.61	0	4	693.73
psi(.),p(temp)	707.54	49.42	0	3	701.54
psi(.),p(precip)	710.57	52.45	0	3	704.57
psi(.),p(nightlight)	714.98	56.86	0	3	708.98
psi(.),p(.)	716.31	58.19	0	2	712.31
psi(.),p(cloud)	716.88	58.76	0	3	710.88

psi(.),p(moon)	717.27	59.15	0	3	711.27
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Table 4.5- Best fit models using only weather variables describing Australian Owlet-nightjar occupancy. ¹ Note that although the model psi(.),p(wind,cloud) has the highest AIC, the variable cloud has a high standard error and thus renders the model less reliable than psi(.),p(wind) or psi(.),p(wind,temp).

Model	AIC	deltaAIC	AIC wgt	no.Par.	-2*LogLikelihood
psi(.),p(wind,cloud) ¹	391.1	0	0.3965	4	383.1
psi(.),p(wind)	391.3	0.2	0.3587	3	385.3
psi(.),p(wind,temp)	392.07	0.97	0.2441	4	384.07
psi(.),p(temp)	406.11	15.01	0.0002	3	400.11
psi(.),p(.)	407.27	16.17	0.0001	2	403.27
psi(.),p(cloud)	407.48	16.38	0.0001	3	401.48
psi(.),p(moon)	407.5	16.4	0.0001	3	401.5
psi(.),p(nightlight)	407.56	16.46	0.0001	3	401.56
psi(.),p(precip)	409.22	18.12	0	3	403.22

Relationship between the likelihood of detection and survey variables

Elevation and broad vegetation type effects

Visual examination of the results revealed that there was a clear difference between sites below and above 575 metres elevation, rather than the arbitrary 450 metres that was chosen for site selection. As a result of this, the elevation 575 metres was used to compare and assess the results. Elevation and broad vegetation type (dry or wet eucalypt forest) were assessed using chi square tests of association. The Tasmanian Masked Owl was more likely to be detected at sites with greater than 50% dry eucalypt forest and at elevations less than 575 m. a.s.l. ($\chi^2=22.78$, 1 d.f., $P<0.0001$) (Table 4.6). At sites with greater than 80% dry eucalypt forest at elevations below 575 m. a.s.l., 50% of sites were occupied by Tasmanian Masked Owls. Very few sites above 575 m. a.s.l. were occupied by Tasmanian Masked Owls, regardless of the proportion of dry eucalypt forest.

The Southern Boobook was more likely to be detected at sites with greater than 50% wet eucalypt forest at elevations less than 575 m. a.s.l. ($\chi^2=8.54$, 1 d.f., $P=0.014$) (Table 4.6). Sixty-five per cent of sites below 575 m. a.s.l. with <10% dry eucalypt forest were occupied by Southern Boobooks. Australian Owlet-nightjar site occupancy was greatest at sites below 575 m. a.s.l. and with greater than 50% dry eucalypt forest ($\chi^2=11.42^{**}$, 1 d.f., $P=0.003$) (Table 4.6).

Table 4.6- Elevation and dominant vegetation type of sites occupied by the three species. Values in brackets are the expected values if there is no effect.

Elevation	Forest type	Tasmanian Masked Owl	Southern Boobook	Australian Owlet-nightjar	Total sites
<575m	>50% Wet	21 (19)	43 (34)	14 (17)	77
<575m	>50% Dry	27 (14)	28 (26)	21 (13)	60
>575m	>50% Wet	2 (7)	10 (14)	2 (7)	31
>575m	>50% Dry	1 (10)	12 (19)	9 (9)	43
		$\chi^2=27.3^{**}$, 1 d.f., $P<0.0001$	$\chi^2=8.54^*$, 1 d.f., $P=0.014$	$\chi^2=11.42^{**}$, 1 d.f., $P=0.003$	

There was a distinct seasonal effect in the proportion of surveys where Southern Boobook was detected. Southern Boobook was detected far more often in the summer months with a maximum at low elevations (<575 m. a.s.l.) in January of 41% of surveys with Southern Boobook detection, and at high elevations (>575 m. a.s.l.) in October of 31%. Between May and August there were no detections of Southern Boobook at high elevations (>575 m. a.s.l.). At low elevations (<575 m. a.s.l.) there were low levels of detection of Southern Boobook between March and July, with no detections out of 54 surveys in July (Figure 4.4). This result was highly significant (1 d.f., $P=4.79 \times 10^{-18}$).

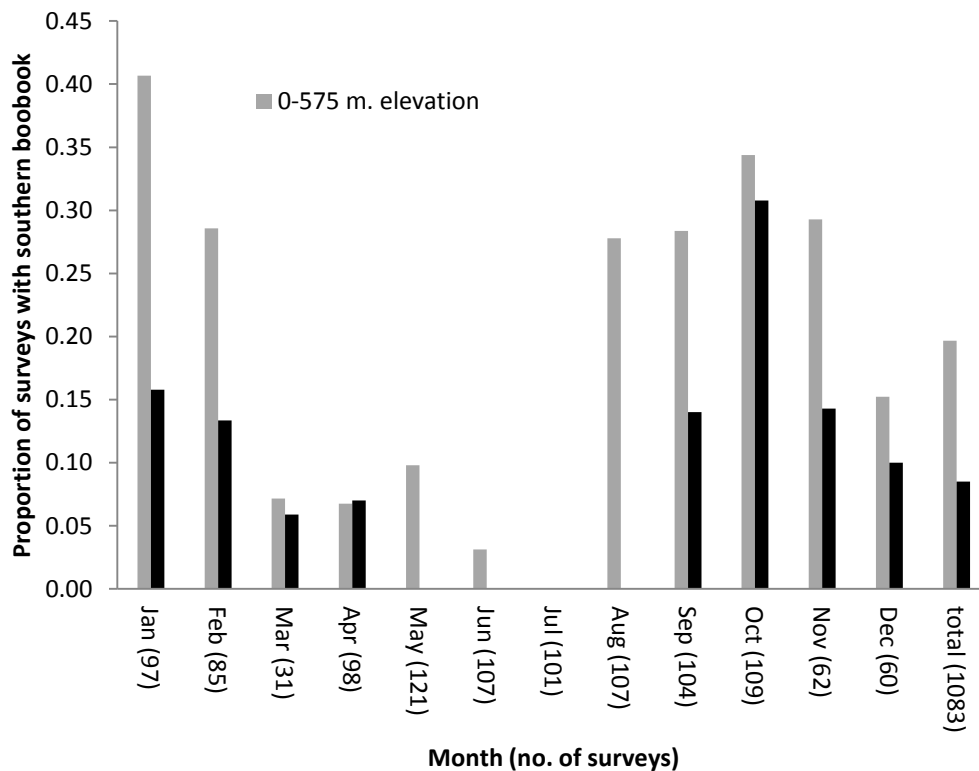


Figure 4.4- The proportion of surveys that detected Southern Boobook at high and low elevations at different times of the year.

Open country and the Tasmanian Masked Owl

The proportion of open country within the radius circle around the survey point had no effect on the likelihood of occupancy by the Tasmanian Masked Owl at 500 m scale ($\chi^2=1.14$, 2 d.f., $P=0.56$), 1000 m scale ($\chi^2=2.99$, 2 d.f., $P=0.22$), 2000 m scale ($\chi^2=3.12$, 2 d.f., $P=0.07$) or 4000 m scale ($\chi^2=1.85$, 2 d.f., $P=0.39$) (Table 4.7)

Table 4.7- The effect of open country (cleared land or native grassland) on the occupation of sites by the Tasmanian Masked Owl. The values in brackets are the expected number of occupied sites if open country has no effect. Only sites below 575 m. elevation included.

Scale		<10% open	10-30% open	30-80% open	Chi square test
500m	occupied sites	33 (30)	9 (9)	6 (9)	$\chi^2=1.14$, 2 d.f., P=0.56
	total sites	86	26	25	
1000m	occupied sites	32 (26)	9 (12)	7 (10)	$\chi^2=2.99$, 2 d.f., P=0.22
	total sites	77	36	29	
2000m	occupied sites	16 (17)	22 (17)	7 (11)	$\chi^2=3.12$, 2 d.f., P=0.21
	total sites	53	51	33	
4000m	occupied sites	13 (17)	18 (15)	14 (13)	$\chi^2=1.85$, 2 d.f., P=0.40
	total sites	57	49	42	

Mature forest and the Tasmanian Masked Owl

The proportion of mature forest around the survey point had a positive effect on the likelihood of a site being occupied by the Tasmanian Masked Owl at 500 m. scale ($\chi^2=11.70^{**}$, 2 d.f., $P<0.005$), 1000 m. scale ($\chi^2=6.30^*$, 2 d.f., $P<0.05$) and 2000 m. scale ($\chi^2=6.50^*$, 2 d.f., $P<0.05$). At 500 m and 1000 m scales, all sites with greater than 90% mature forest were found to be occupied by the Tasmanian Masked Owl. Sites with less than 50% mature forest had a generally reduced likelihood of Tasmanian Masked Owl occupation. The relationship was not present at the 4000 m scale, possibly because of the absence of sites with sufficiently high proportions of mature forest (Figure 4.5, Table 4.8).

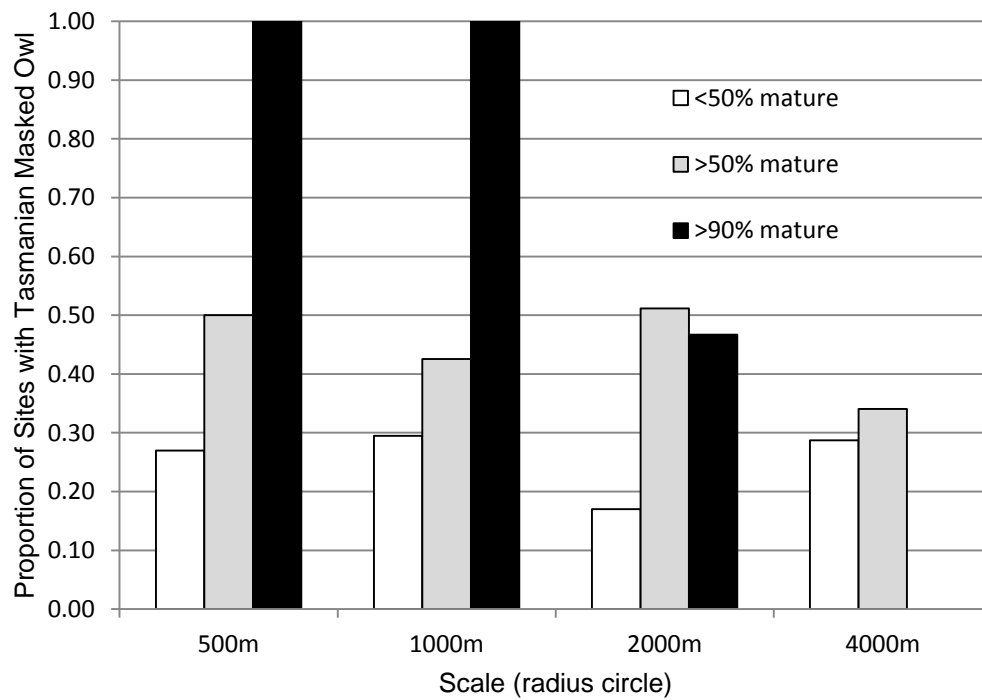


Figure 4.5- The relationship between mature forest and sites occupied by Tasmanian Masked Owls.

Table 4.8- The effect of mature forest on the occupation of sites by the Tasmanian Masked Owl. The numbers in brackets are the expected number of occupied sites if mature forest has no effect. Only sites below 575 m. elevation included.

Scale		<50% mature	>50% mature	>90% mature	Chi square test
500m	occupied sites	24 (34)	24 (18)	7 (3)	$\chi^2=11.70^{**}$, 2 d.f., P<0.005
	total sites	89	48	7	
1000m	occupied sites	28 (34)	20 (17)	4 (1)	$\chi^2=6.30^*$, 2 d.f., P<0.05
	total sites	95	47	4	
2000m	occupied sites	16 (17)	22 (17)	7 (11)	$\chi^2=6.50^*$, 2 d.f., P<0.05
	total sites	94	43	15	
4000m	occupied sites	29 (31)	16 (14)	.	$\chi^2=0.03$, 1 d.f., P=0.86
	total sites	101	47	.	

Because elevation seemed to have a strong influence on the likelihood of Tasmanian Masked Owl occurrence there is a risk that if the sites with a large amount of mature forest are unevenly distributed across the various elevation categories that there could be a skewed result. To investigate this, elevation was plotted against mature forest proportion (Figure 4.6). The plot showed clearly that there was an even distribution of different amounts of mature forest across the different elevation categories.

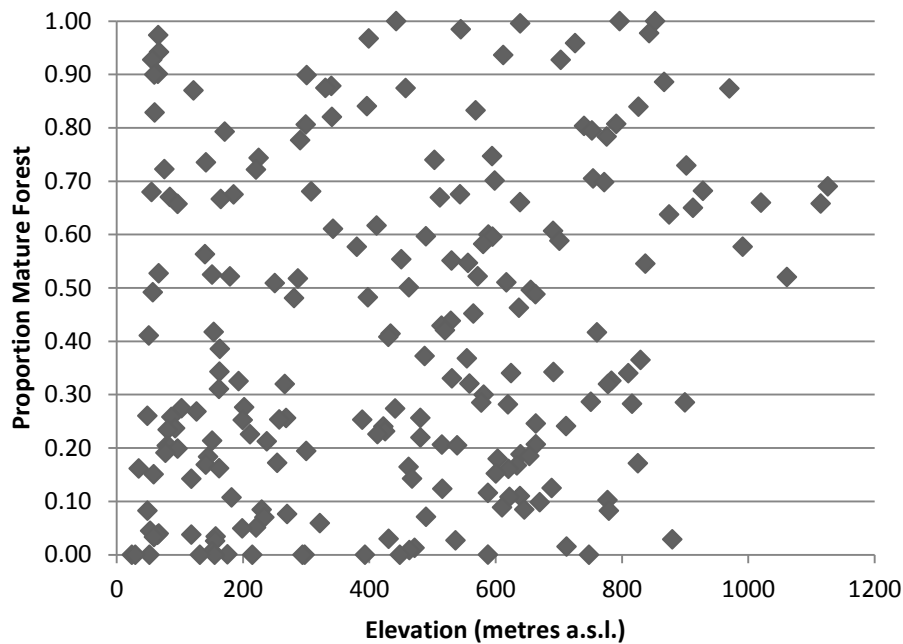


Figure 4.6- Distribution of mature forest proportion and elevation at sites at 500 m radius scale.

Relationship between probability of occupancy and environmental variables

Tasmanian Masked Owl

The relationship between the occupancy of sites by the Tasmanian Masked Owl and environmental variables was investigated using *Presence*. The models that best fit the data along with the covariate estimates and standard errors of the best fit model are presented in Tables 4.9 and 4.10. While certain variables were clearly contributing to most of the models, scale also had an effect. The smaller radius circles provided closer fitting models than the larger radius circles.

Elevation was the most important factor affecting the probability of Tasmanian Masked Owl occupancy, having a negative effect, and it appeared in all useful (delta AIC<5.0) models. The other important variables were area of mature forest

(positive effect) and area of dry eucalypt forest (positive effect) at 500 m and 1000 m scales. The closest fitting model at the 500 m scale (AIC 413.96) included elevation, mature eucalypt forest and dry eucalypt forest. The closest fitting model at the 1000 m scale (AIC 412.85) also included elevation, mature eucalypt forest and dry eucalypt forest. At the 2000 m scale, elevation and high potential hollow abundance were components (AIC 416.82) and at the 4000 m scale elevation and wet eucalypt forest (negative effect) were components (AIC 421.26). The closest fitting models derived from variables measured at the 500 m and 1000 m radius circles around the survey points provided the best fit to the data, with AIC's between 412.85 and 417.59.

Southern Boobook

The models that best fit the data along with the covariate estimates and standard errors of the best fit model are presented in Tables 4.11 and 4.12. Although elevation was an apparently significant factor when investigated independently, it was not an important contributor to models when compared to the minimum mean temperature in the coldest month of the year (min temperature) which was important in the best performing models at 500 m, 1000 m and 2000 m. Other variables that often occurred in the close fitting models included the area of wet eucalypt forest (positive effect) and the total length of roads within the radius (negative effect).

The closest fitting model at the 500 m scale (AIC 646.51) included minimum temperature (positive effect), length of roads (negative effect) and wet eucalypt forest (positive effect). The closest fitting model at the 1000 m scale (AIC 646.82) also included minimum temperature (positive effect), length of roads (negative effect) and wet eucalypt forest (positive effect). At the 2000 m scale, minimum temperature (positive effect), length of roads (negative effect) were components (AIC 645.48) and at the 4000 m scale average annual rainfall (positive effect) and topographic roughness (negative effect) were components (AIC 643.94).

Australian Owlet-nightjar

The models that best fit the data along with the covariate estimates and standard errors of the best fit model are presented in Tables 4.13 and 4.14. The most important variables affecting probability of detection in the best performing models were area of dry eucalypt forest (positive effect) and area of open country (negative effect). The 2000 m and 4000 m scales failed to provide any models that fitted the data for the owlet-nightjar. This was probably due to the clear inappropriateness of the scale, since owlet-nightjars have territories that are much smaller than this area (Doucette 2010). Although elevation was an apparently significant factor when investigated independently, it was not an important contributor to models.

The closest fitting model at the 500 m scale (AIC 377.9) included area of open country (negative effect) and dry eucalypt forest (positive effect). The closest fitting model at the 1000 m scale (AIC 380.59) also included plantation area (negative effect) and high potential for hollow abundance (positive effect).

Table 4.9- Best fit models of Tasmanian Masked Owl occupancy. Psi is the probability that a site is occupied by the target species, p is the probability of detecting the species, given that the species is present on a site.

500 metres- models	AIC	delta AIC	AIC wgt	Number of parameters	-2*log likelihood
psi (elevation, mature eucalypt forest, dry eucalypt forest), p(wind, temp)	413.96	0	0.4922	7	399.96
psi(elevation, mature eucalypt forest, dry eucalypt forest, mid-high hollow potential), p(wind,temp)	415.64	1.68	0.2125	8	399.64
psi(elevation, mature eucalypt forest), p(wind,temp)	415.94	1.98	0.1829	6	403.94
psi(elevation, mature eucalypt forest, mid-high hollow potential), p(wind,temp)	417.59	3.63	0.0801	7	403.59
1000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(elevation, mature eucalypt forest, dry eucalypt forest),p(wind,temp)	412.85	0	0.4825	7	398.85
psi(elevation, mature eucalypt forest),	414.83	1.98	0.1793	6	402.83

p(wind,temp)					
psi(elevation, mature eucalypt forest, dry eucalypt forest, high hollow potential),p(wind,temp)	414.84	1.99	0.1784	8	398.84
psi(elevation, high hollow potential, mature eucalypt forest), p(wind,temp)	415.48	2.63	0.1296	7	401.48
2000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(elevation, high hollow potential), p(wind,temp)	416.82	0	0.4665	6	404.82
psi(elevation, mid-high hollow potential), p(wind,temp)	417.4	0.58	0.3491	6	405.4
psi(elevation, mature eucalypt forest), p(wind,temp)	418.75	1.93	0.1777	6	406.75
4000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(elevation, wet eucalypt forest), p(wind,temp)	421.26	0	0.6758	6	409.26
psi(elevation, wet eucalypt forest, high hollow potential), p(wind,temp)	423.02	1.76	0.2803	7	409.02

Table 4.10- Estimate and standard error of the covariates in the best fit model for Tasmanian Masked Owl occupancy Psi is the probability that a site is occupied by the target species, p is the probability of detecting the species, given that the species is present on a site.

Logit $\psi = -0.13 - (1.38 * \text{elevation}) + (0.90 * \text{mature eucalypt forest}) + (0.59 * \text{dry eucalypt forest}) - 1.64 * (0.42 * \text{wind}) + (0.28 * \text{temperature})$	
Covariate	Estimate \pm standard error
Psi	-0.13 \pm 0.40
Elevation	-1.38 \pm 0.39
Mature eucalypt forest	+0.90 \pm 0.35
Dry eucalypt forest	+0.59 \pm 0.32
p1	-1.64 \pm 0.23
Wind	-0.42 \pm 0.16
Temperature	+0.28 \pm 0.15

Table 4.11- Best fit models of Southern Boobook occupancy. Psi is the probability that a site is occupied by the target species, p is the probability of detecting the species, given that the species is present on a site. Min temp= mean minimum temperature in the coldest month, precip=precipitation, temp=temperature.

500 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(min temp, roadlength, wet eucalypt forest), p(wind,precip,temp,nightlight)	646.51	0	0.3339	9	628.51
psi(min temp, roadlength), p(wind,precip,temp,nightlight)	647.08	0.57	0.2511	8	631.08
psi(min temp, wet eucalypt forest), p(wind,precip,temp,nightlight)	647.71	1.2	0.1833	8	631.71
psi(min temp), p(wind,precip,temp,nightlight)	648.72	2.21	0.1106	7	634.72
psi(elevation, roadlength), p(wind,precip,temp,nightlight)	649.53	3.02	0.0738	8	633.53
1000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(min temp, roadlength, wet eucalypt forest), p(wind,precip,nightlight,temp)	646.82	0	0.2792	9	628.82
psi(min temp, roadlength), p(wind,precip,nightlight,temp)	647.15	0.33	0.2368	8	631.15
psi(min temp, wet eucalypt forest), p(wind,precip,nightlight,temp)	648.3	1.48	0.1332	8	632.3

psi(min temp, roadlength, wet eucalypt forest, annual rainfall), p(wind,precip,nightlight,temp)	648.51	1.69	0.12	10	628.51
psi(min temp, annual rainfall), p(wind,precip,nightlight,temp)	648.71	1.89	0.1085	8	632.71
psi(min temp), p(wind,precip,nightlight,temp)	649.2	2.38	0.085	7	635.2
2000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(min temp, roadlength), p(wind,precip,temp,nightlight)	645.48	0	0.4758	8	629.48
psi(min temp, roadlength,annual rainfall), p(wind,precip,temp,nightlight)	645.78	0.3	0.4095	9	627.78
psi(min temp, annual rainfall), p(wind,precip,temp,nightlight)	649.53	4.05	0.0628	8	633.53
4000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(annual rainfall, topographic roughness), p(wind,precip,temp,nightlight)	643.94	0	0.8637	8	627.94

Table 4.12- Estimate and standard error of the covariates in the best fit model for Southern Boobook occupancy. Psi is the probability that a site is occupied by the target species, p is the probability of detecting the species, given that the species is present on a site.

Logit $\psi = -1.41 + (1.41 \cdot \text{average annual rainfall}) - (1.05 \cdot \text{topographic roughness}) - 1.60 (-0.75 \cdot \text{wind}) - (0.48 \cdot \text{precipitation}) + (0.29 \cdot \text{temperature}) + (0.23 \cdot \text{nightlight})$	
Covariate	Estimate \pm standard error
Psi	1.41 \pm 0.63
Average annual rainfall	+1.41 \pm 0.63
Topographic roughness	-1.05 \pm 0.40
p1	-1.60 \pm 0.17
Wind	-0.75 \pm 0.13
Temperature	+0.29 \pm 0.11
Precipitation	-0.48 \pm 0.27
Nightlight	+0.23 \pm 0.10

Table 4.13- Best fit models of Australian Owlet-nightjar occupancy. Psi is the probability that a site is occupied by the target species, p is the probability of detecting the species, given that the species is present on a site. temp=temperature.

500 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(open country, dry eucalypt forest), p(wind,temp)	377.9	0	0.3512	6	365.9
psi(open country, dry eucalypt forest), p(wind)	378.68	0.78	0.2378	5	368.68
psi(open country, dry eucalypt forest,plantations), p(wind,temp)	379.67	1.77	0.1449	7	365.67
psi(plantations, dry eucalypt forest), p(wind,temp)	380.72	2.82	0.0857	6	368.72
psi(plantations, dry eucalypt forest),p(wind)	381.1	3.2	0.0709	5	371.1
psi(open country), p(wind)	382.53	4.63	0.0347	4	374.53
psi(dry eucalypt forest), p(wind)	382.63	4.73	0.033	4	374.63
1000 metres- models	AIC	deltaAIC	AIC wgt	Number of parameters	-2*log likelihood
psi(plantations, high hollow potential), p(wind,temp)	380.59	0	0.1794	6	368.59

psi(dry eucalypt forest, open country), p(wind,temp)	380.94	0.35	0.1506	6	368.94
psi(plantations, high hollow potential, dry eucalypt forest), p(wind,temp)	380.96	0.37	0.1491	7	366.96
psi(dry eucalypt forest, plantations), p(wind,temp)	381.52	0.93	0.1127	6	369.52
psi(plantations, high hollow potential, open country), p(wind,temp)	381.72	1.13	0.1019	7	367.72
psi(dry eucalypt forest, high hollow potential), p(wind,temp)	381.87	1.28	0.0946	6	369.87
psi(plantations, dry eucalypt forest, high hollow potential, open country), p(wind,temp)	382.1	1.51	0.0843	8	366.1
psi(dry eucalypt forest), p(wind,temp)	382.54	1.95	0.0677	5	372.54
psi(high hollow potential), p(wind,temp)	384.49	3.9	0.0255	5	374.49
psi(plantations), p(wind,temp)	385.22	4.63	0.0177	5	375.22

Table 4.14- Estimate and standard error of the covariates in the best fit model for Australian Owlet-nightjar occupancy. Psi is the probability that a site is occupied by the target species, p is the probability of detecting the species, given that the species is present on a site.

Logit $\psi = -0.16 - (0.99 * \text{open country}) + (0.78 * \text{dry eucalypt forest}) - 2.10 (-0.72 * \text{wind}) + (0.26 * \text{temperature})$	
Covariate	Estimate (standard error)
psi	-0.16 \pm 0.51
Open country	-0.99 \pm 0.46
Dry eucalypt forest	+0.78 \pm 0.36
p1	-2.10 \pm 0.27
Wind	-0.72 \pm 0.18
Temperature	+0.26 \pm 0.16

Discussion

This study has provided a considerable clarification of the environmental attributes that affect the distribution of three species of nocturnal Tasmanian bird including the threatened Tasmanian Masked Owl. The statistical approach was particularly effective in dealing with the problem of zero-inflated binomial data with a high risk of false absences. Aside from relatively low species abundance, these characteristics of the data may be caused by the non-response of Tasmanian Masked Owls when they are present (either because of behavioural reasons or large territory size), or, in the case of the Southern Boobook and Australian Owlet-nightjar, because of reduced calling as playbacks were not conducted for these species. However, several assumptions were made (MacKenzie *et al.* 2006).

- Occupancy status at each site does not change over the survey season.
- The probability of occupancy is constant across sites, *or* differences in occupancy probability are modeled using temporal covariates (e.g., wind, rain).
- The probability of detection is constant across all sites and surveys, *or* is a function of site characteristics (e.g., dry eucalypt forest area, elevation).
- Detection of species at each location is independent.

Assumptions 2 and 3 are likely to be valid in this study as the survey covariates and site covariates used in the models were demonstrated to fit the data well.

Assumption 4 is also likely to be true as all the sites surveyed were at least 2 km distant from each other. This was based on expected territory size for the largest species (Tasmanian Masked Owl) and done to reduce the possibility of a positive response occurring from the same owl in adjacent sites. In reality, few of the sites were as close as 2 km to each other and there were no situations where an owl responded at adjacent sites.

Assumption 1 is the least certain. As there was approximately 12 months between the first survey at a site and the final survey, there is the possibility that occupancy status could have changed between the first and last surveys. Surveys were spread over a 12 month period to increase the chance of detecting each species at the time of year when it is most responsive to call playback (not well known, at least for the Tasmanian Masked Owl) and to provide a number of repeat visits (4) so that species detectability can be estimated. To ensure that surveys at a particular site were independent of each other, it was preferable to keep a reasonable time (i.e. 2-4 months) between each survey in case a playback survey influenced the likelihood of an individual owl responding again the next time. However, there are a number of factors that suggest that assumption 1 is still probably true, at least for the Tasmanian Masked Owl. Tasmanian Masked Owls are territorial (Young 2006) and so are unlikely to shift territory during the survey period unless there is a death. Large territorial owls tend to be relatively long-lived (Linkhart and Reynolds 2004). Given that territorial owls of a size smaller than the Tasmanian Masked Owl, such as the Barred Owl (*Strix varia*) in North America, have been recorded in the wild surviving for more than 18 years (Klimkiewicz 2002), the probability of survival of an individual Tasmanian Masked Owl over 12 months is likely to be high.

Tasmanian Masked Owl

Elevation was a significant factor in the probability of occupancy of sites by the Tasmanian Masked Owl. Higher elevation sites, above 575 metres, were significantly less likely to be occupied by the Tasmanian Masked Owl. A comparable study was conducted in north-east New South Wales by Kavanagh *et al.* (1995) in which the detection of the Australian Masked Owl was not found to be affected by elevations up to 1280 m. However, the highlands of Tasmania are more than 1300 km further south in latitude than the high altitude areas surveyed in the NSW study.

The overall diversity and abundance of many animal and plant taxa are lower in southern Australian highlands (Neave *et al.* 1996a; Neave *et al.* 1996b) and, in Tasmania, avian diversity is lower at high altitudes (Ratkowsky and Ratkowsky 1978; MacDonald 2001). On mainland south-east Australia, differences in the distribution of birds related to elevation were explained by the environmental attributes minimum temperature of the coldest month and mean precipitation of the driest quarter (Neave *et al.* 1996a). It is conceivable that these factors could either directly or indirectly affect prey species abundance of the Tasmanian Masked Owl. The diet of Spotted Owl (*Strix occidentalis*) in California has been found to vary depending on elevation and this has been linked to variations in Spotted Owl reproductive success (Verner *et al.* 1992; Smith *et al.* 1999).

One possible reason that needs to be considered for the reduced occupancy at high elevation is a physiological constraint that prevents them from occurring at higher altitudes. The *Tyto* genus is mostly tropical with the greatest species diversity occurring in the tropics, particularly Indonesia (del Hoyo *et al.* 1999), even the widespread Barn Owl is absent from areas with the coldest winters (Taylor 1994) although there are some populations in colder climates (Trejo and Lambertucci 2007). The Tasmanian Masked Owl is usually regarded as the largest and heaviest *Tyto* owl in the world (König *et al.* 2008); as increased body mass is often an adaptation to cold it is probably better adapted than other barn-owls (*Tyto* genus) to survive in cold climates. Owls generally have a lower basal metabolic rate than diurnal birds (Kirkwood 1979; Wijnandts 1983; Gessaman *et al.* 1991; Hohtola *et al.* 1994), this may assist them to survive in cold conditions. Bennett and Harvey (1987) believed this to be a response to the higher temperatures encountered during the day while the nocturnal birds are resting. Wind and low temperatures are probably the two most important factors in compromising the retention of body heat in the Barn Owl (McCafferty *et al.* 1998) with wetness increasing the impact of wind (McCafferty *et al.* 1997a). Roost sites that provide shelter from wind and rain would be advantageous to Tasmanian Masked Owls. The use of roost sites in

buildings and tree hollows has been found to contribute to considerable energy savings in Barn Owls in Scotland, particularly in winter months (McCafferty *et al.* 2001). As the Tasmanian Masked Owl has been found to roost during the day in dense foliage, possibly as often as they roost in tree hollows (Young 2006), this habit could be a constraining factor in the Tasmanian highlands. There may be a greater requirement for tree hollows by Tasmanian Masked Owls occurring in highland areas.

Mature eucalypt forest was prominent in all of the best fit models for the Tasmanian Masked Owl. The Tasmanian Masked Owl's requirement for mature eucalypt forest has been suggested by Bell *et al.* (1996) and Young (2006), and more generally for other forest owls (Kavanagh 1991; Scotts 1991; Loyn *et al.* 2001a; Kavanagh and Stanton 2002). A study in north-east New South Wales found that the Australian Masked Owl was more likely to be found on unlogged or selectively logged sites than on heavily logged sites (Kavanagh *et al.* 1995). However, a study that compared large areas of unlogged forest with large areas of logged/ unlogged mosaic forest in south-east New South Wales was inconclusive with regards to the effect of the logging on the Australian Masked Owl (Kavanagh and Bamkin 1995), possibly due to lower sample sizes.

Reasons for the association with mature eucalypt forest could be related to prey diversity/ abundance or to the availability of tree hollows for nesting and roosting. As a significantly larger bird than the Southern Boobook or the Australian Owlet-nightjar, the Australian Masked Owl has relatively demanding requirements for large tree hollows (Kavanagh 1997). Trees providing hollows for Tasmanian Masked Owls have been estimated to be usually greater than 150 years old in age and of diameter at breast height of approximately 100-150 cm (Mooney 1997; Koch *et al.* 2008b). Such trees are likely to be more abundant in areas of undisturbed mature forest (Koch and Baker 2011).

Mechanisms by which mature forest can affect the prey species of large forest owls depend very much on the habits of the species concerned. Studies on mainland Australia have shown that arboreal, tree-hollow-dwelling mammals such as possums and gliders are dependent on the retention of mature forest with abundant tree hollows (Lindenmayer *et al.* 1994; Gibbons and Lindenmayer 2000). The effect of logging disturbance on small mammals has been equivocal with one study finding no significant effects of logging on small ground mammals (Kavanagh and Webb 1998), while another found that the abundance of small, ground-dwelling mammals, in particular the bush rat (*Rattus fuscipes*), was affected by disturbance and the simplification of vegetation (loss of dense ground storey) years after logging (Catling *et al.* 2000). The diversity and abundance of ground-dwelling mammal fauna of forests in south-eastern New South Wales has been found to be closely linked to the complexity of the understorey (Catling and Burt 1995b).

Common species of small mammal in forests of eastern Australia, including the bush rat and the brown antechinus (*Antechinus stuartii*), are prominent components of the diet of the Australian Masked Owl on the Australian mainland (Kavanagh 1996; Todd 2006). In Tasmania, some small and medium-sized mammal species have been found to be more common in areas that have been disturbed through logging (Flynn *et al.* 2011) so the effects of logging on mammal abundance and diversity may not be a simple one.

The availability of open country, or at least forest edges, has been suggested as an environmental attribute that improves the likelihood of Australian Masked Owls (including the Tasmanian Masked Owl) being present in an area (Peake *et al.* 1993; Bell and Mooney 2002; Liddelow *et al.* 2002). Radio-tracking of individual Masked Owls in New South Wales (Kavanagh and Murray 1996), Victoria (McNabb *et al.* 2003) and two owls in Tasmania (Young 2006) has provided limited support for the idea that Masked Owls prefer to hunt at forest edges. McNabb *et al.* (2003) put forward three explanations for this apparent selection of edge habitats. The first was

that the Masked Owl was an “intrinsic edge-forager” and traditionally foraged along the interface between forest and sparser woodland. The second explanation implicated the presence of favoured prey species at the edge; in the case of the McNabb *et al.* (2003) study this was the rabbit. The third explanation was that their favoured forest habitats had been mostly cleared for agriculture and subsequently became fragmented, occurring mostly near farmland.

This study did not provide any support for the theory that areas with edge habitat were more likely to be occupied by the Tasmanian Masked Owl. The presence of open country (a measure of the availability of edges between forest/woodland and cleared land) had no effect on Tasmanian Masked Owl occupancy either positively or negatively. The vegetation diversity around sites also provided a measure of the available edge habitat between broad vegetation types, but this environmental attribute had no effect on Tasmanian Masked Owl occupancy.

All of the Masked Owls that have been radio-tracked, both on mainland Australia and in Tasmania (Kavanagh and Murray 1996; McNabb *et al.* 2003; Young 2006; Kavanagh *et al.* 2008b), have been in relatively fragmented forests with extensive areas of cleared land present. This artificial situation may have resulted in the perceived requirement for edge habitats, along with their apparent vulnerability to being hit by cars (Debus 1993b). It is possible that all three of the explanations provided by McNabb *et al.* (2003) are relevant to the Masked Owl. Most of the Masked Owls studied to date have been in fragmented habitat situations and may not be representative of Masked Owls across their range.

The results of this study suggest that while the Tasmanian Masked Owl does occur in fragmented forest and woodland areas and indeed could be more likely to be seen in these areas by chance, (or hit by cars), areas of contiguous forest are better habitat for the species. Thus areas of mature forest (of the right type) could be the critical habitat requirement rather than the availability of edge habitat. The other possibility

is that most areas surveyed in the current study have some edge habitat by virtue of past land clearance, logging activity, and the presence of roads, making the presence of edges ubiquitous and thus not a defining factor.

It was not feasible to include survey points in non-forest habitats; nevertheless this would be an interesting focus for future Tasmanian Masked Owl surveys. There was a limitation to how many sites would be required overall to obtain meaningful results and how many sites could be physically surveyed within the timeframe of just over a year. The repeat surveys of a site cannot be too far apart in time without violating assumptions of the detectability models. A future survey focusing on open habitats would reveal what proportion of the total Tasmanian Masked Owl population might occur outside of the forested areas.

The best performing models for the Tasmanian Masked Owl included dry eucalypt forest as an important environmental attribute. The Australian Masked Owl has previously been shown to occur more frequently in drier forests on mainland Australia (Debus 1993b; Peake *et al.* 1993; Kavanagh 1997). On the mainland, the Masked Owl often co-occurs with other large forest owls including the Powerful Owl, the Sooty Owl and the Barking Owl (*Ninox connivens*) (Hollands 2008) and experiences a certain amount of competition for habitat. Research has shown that the Australian large forest owls partition their habitat by habitat and also by diet, with the Australian Masked Owl being the only large forest owl to concentrate on drier forests and terrestrial prey (Kavanagh 2002a).

The Tasmanian Masked Owl is free from this competition and is presumably free to occupy wet eucalypt forests more than it would on mainland Australia. Certainly it does occasionally occur in wet eucalypt forests, as observed in this study, and indeed it has been recorded nesting in rainforest (Fleay 1949). However, the present study found that dry eucalypt forest had a positive effect on the likelihood of Tasmanian Masked Owls occupying a site and it seems likely that there is a

preference for dry eucalypt forest that is unrelated to competition. That wet eucalypt forest did not have a negative effect on the presence of Tasmanian Masked Owls (it simply had no effect according to most models) could indicate that wet eucalypt forest is still occupied but at a lower density to that in dry eucalypt forest. Most of the occurrences of Tasmanian Masked Owls in wet forest were at low elevations. It is not known whether there is a seasonal component to the occurrence of the owl in wet forests. The survey design does not allow for this type of analysis. Each survey (in any season) has a high probability of failure which is why 4 surveys were conducted at each site. The non-response of owls in a particular season at a particular site is meaningless. Direct tracking of individual owls fitted with tracking devices over the course of multiple seasons would be needed to investigate the possibility of seasonal habitat use.

It has been suggested that the Australian Masked Owl might require open understorey forest to be able to capture its ground-dwelling prey (Debus 1993b; Peake *et al.* 1993). The possibility has also been raised that the Australian Masked Owl may prefer to forage along ecotones. In particular, areas with a low, dense understorey which could provide refuge for small mammals, often near drainage lines, that are near areas of open understorey, where the mammals are occasionally exposed to owl predation (McCray and Kavanagh 2000). The current study did not support this theory, but given the survey design it did not refute it either.

Southern Boobook

The model best fitting the data for the Southern Boobook was one in which broad environmental features were more important than site specific features over the 4000 m. scale. High average annual rainfall and low topographic roughness (flat terrain) were the environmental attributes that featured in this model. It should be noted, however, that although parts of Tasmania with relatively high average annual rainfall were surveyed (the north-west, north and north-east), the areas of Tasmania with the highest average annual rainfall such as the south-west, were not included in

the surveys. Parts of Tasmania with relatively high average annual rainfall that were surveyed include the north-west, north and north-east. The area of wet eucalypt forest around the survey sites also featured as an important environmental attribute in two of the best performing models. Wet eucalypt forest and average annual rainfall are correlated with each other. At the 4000 m. scale, these environmental attributes would most likely be operating on populations of Southern Boobook rather than on individuals or pairs, as territory sizes for the Southern Boobook are likely to be much smaller than the 4000 m. radius around the survey points (Olsen and Bartos 1997).

The other best-fitting models all involved the environmental attribute mean minimum temperature in the coldest month of the year (hereafter called min temp). Min temp has an obvious association with elevation; however min temp was a better fit within the close-fitting models. Min temp has been found to be an important factor in defining bird distributions on mainland Australia. A study of the relationships between diurnal, terrestrial birds, vegetation and environmental attributes in south-east Australia found that differences in bird distribution associated with elevation were explained by min temp and also rainfall in the driest part of the year which in turn affected vegetation communities (Neave *et al.* 1996a).

As with the relationship between elevation and the Tasmanian Masked Owl, min temp could affect Southern Boobooks via physiology or diet. The Southern Boobook in Tasmania is mostly insectivorous (Green *et al.* 1986) and could conceivably be affected by reduced insect abundance in areas subject to low temperatures in winter (Doran *et al.* 2003).

The Southern Boobook differs from the other nocturnal species in this paper, in that some Tasmanian Southern Boobooks migrate to mainland Australia in winter (Mees 1964; Higgins 1999a). The proportion that avoid winter in this way is not known, but Mees documents a number of specimens of the Tasmanian subspecies, *N. n.*

leucopsis, in museum collections and a number of photographs of living and dead *N. n. leucopsis* on mainland Australia that have also been seen by the senior author, as well as documented sightings (Conole 1985). The low proportion of Southern Boobooks detected in this study in the winter months, particularly at high elevations, could be a result of this seasonal migration. Alternatively, it could be caused by a cessation of calling which would result in their non-detection given the survey methods that were used here. Southern Boobooks have a tightly defined breeding season (spring) (Hollands 2008), and calling outside of these months on the mainland is regarded as less common (Kavanagh, R.P., pers. comm.). Playback surveys for the Tasmanian Southern Boobook have detected the species at numerous sites in July and August 1996 (Bell *et al.* 1996). The lower proportion of detections in winter in the current study was probably a result of lower calling frequency, with seasonal migration contributing an unknown amount to the reduced detection rate.

The total length of roads within the circle surrounding the survey point was a significant environmental attribute in a number of the best performing models. A possible reason for this is a negative reaction of the Southern Boobook towards the disturbance caused by vehicle traffic. However, by virtue of the survey design, all sites had some roads running through them and it would be desirable to examine this relationship using sites with no roads to provide an adequate control.

Australian Owlet-nightjar

The closest fitting models to the data for the Australian Owlet-nightjar all included the environmental attributes open country (negative) and dry eucalypt forest (positive). The area of dry eucalypt forest around the survey points was a consistently significant contributor to the best-fitting models. While elevation appeared to be important when the results were examined initially, elevation failed to contribute to any of the close-fitting models, whereas open country and dry eucalypt forest dominated. The most comparable study to this one was one

conducted in north-east NSW (Kavanagh *et al.* 1995). This particular study found that Australian Owlet-nightjars were significantly more likely to be detected at low elevations and at sites recently heavily logged, however, most of the low elevation sites in this study were already heavily logged, hence the results were confounded to some extent (Kavanagh *et al.* 1995). The Tasmanian subspecies of the Australian Owlet-nightjar (*A. c. tasmanicus*), seems to be less common than the mainland subspecies, with lower detection rates than on mainland Australia (Kavanagh and Peake 1993a). It was the least often detected of the three nocturnal species studied.

The Tasmanian subspecies of the Australian Owlet-nightjar may be physiologically adapted to survive in a relatively cold environment. Energetic studies on the Australian Owlet-nightjar on mainland Australia have shown that they enter torpor while roosting in tree hollows during the day in winter (Brigham *et al.* 1998; Brigham *et al.* 2000). While in tree hollows they are relatively safe from predation and they can conserve energy during the day. The Australian Owlet-nightjar has also been found to increase its resting metabolic rate, probably by increasing plumage insulation, to cope with low winter temperatures (Doucette and Geiser 2008). The other nightbird to occur in Tasmania, the Tawny Frogmouth, has also been recorded to enter torpor in winter in New South Wales (Körtner *et al.* 2000) and presumably does so in Tasmania also. The Tawny Frogmouth was only rarely detected during the surveys. Any future surveys for the Tawny Frogmouth in Tasmania will need to use targeted call playback.

Future work

The influence of elevation and/or minimum temperatures in winter on the Tasmanian Masked Owl and the Southern Boobook requires further investigation. In particular, it would be informative to have more detail on the diversity and abundance of potential prey species in the environments sampled for the birds. This could be tested by sampling for prey species across an altitudinal gradient. In the case of the Tasmanian Masked Owl, small mammal trapping and infra red camera

traps could be used along altitudinal transects crossing the 575 metre elevation level (at which detection frequency of both species declines). It would be of interest to see whether there was a sudden decline in small mammal abundance and diversity at 575 metres or whether there was a gradual decline with increasing altitude. There may be a level of small mammal diversity and abundance at which Tasmanian Masked Owl occurrence becomes less likely. It would be reasonable to concentrate on rodents as a surrogate for Tasmanian Masked Owl prey given that rats and mice are usually an important item in the diet of Australian Masked Owls wherever they have been studied (Mooney 1992; Kavanagh 1996; Todd 2006; Young 2006). It has been suggested that a large part of the variation in forest mammal abundance could be caused by undescribed structural variation, whereas studies have focused on stratified sampling of broad climatic and terrain variables (Catling *et al.* 1998). In the case of the Southern Boobook and Australian Owlet-nightjar insects could be sampled on altitudinal transects instead of small mammals as both bird species appear mostly insectivorous in Tasmania (Green *et al.* 1986; Rose 1997; Brigham *et al.* 1999). It has been shown that mature eucalypt forest is a good indicator of the presence of Tasmanian Masked Owls. However, the question remains of how extensive these mature forest patches have to be to support viable Tasmanian Masked Owl populations. This would be a fruitful avenue for future research.

The physiological tolerance of the Tasmanian Masked Owl would be difficult to test directly without the invasive observation of the species in captivity at different elevations and climatic conditions. However, there are indirect methods that could be used that might contribute to answering this question. Temperature dataloggers (ibuttons) have been shown to be valuable in the study of animal usage of tree hollows (Cawthen *et al.* 2009; Moore *et al.* 2010). Temperature dataloggers placed in tree hollow roosts of the owls would give an indication of whether there is a particular temperature range that was preferred by the species. A comparison of birds at high and low altitude might show whether there is a dramatic difference in

temperature inside the insulated tree hollows at different elevations. If there were, this could indicate a potential limiting factor for the birds at higher altitudes.

Management implications

The availability of mature eucalypt forest has been shown to be strongly correlated with the likelihood of occupancy of a location by the Tasmanian Masked Owl. The current study involves many more detections than previous forest owl surveys in Tasmania or mainland Australia (also the number of visits to each location – four is much higher than other studies) giving more reliable information on the environmental attributes that affect the distribution and abundance of the threatened species. The positive association with mature eucalypt forest and the lack of any association with open country in this study suggests that continuous mature eucalypt forest may be more important than previously thought. This result has management implications for development activities that result in land clearing including forestry, clearing for agriculture and urban development.

Chapter 5 : Development of predictive habitat models for the conservation and management of the Tasmanian Masked Owl

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Abstract

Predictive habitat models have become a critically important means by which to demarcate areas and habitats that are a priority for species conservation. This study explores and compares different methods that may be used in the development of habitat models for rare species and their usefulness in conservation planning. Maps of predicted optimum habitat of the threatened Tasmanian Masked Owl were developed using two methods. The first used a robust habitat occupancy model that was based on systematic repeated surveys (Chapter 4). The second method involved maximum entropy modeling of Tasmanian Masked Owl distribution using existing database records. The dataset used for this method consists of non-systematically collected data that are prone to biases of survey effort. While the two maps were broadly similar in overall Tasmanian Masked Owl distribution the first method produced a more accurate and reliable distribution. A population size of approximately 366 breeding pairs was estimated using this map. A Bayesian belief network (BBN) was also created based on site-specific factors including prey availability (abundance and accessibility), roosting sites and nesting sites. This BBN, or one like it, could be used as a tool to assess the value of a particular site for the species. This study demonstrates the value of habitat occupancy models for the conservation of rare species like the Tasmanian Masked Owl and the need to be aware of the limitations of non-systematically collected data.

Introduction

Effective conservation planning is dependent on both adequate information on the location of species that are under threat and knowledge of the factors that are responsible for putting those species under threat. Unfortunately detailed information of this nature is often lacking especially for rare or little known species (Marcot and Molina 2007), the very species that are likely to be of conservation concern. Predictive habitat models have often been used to demarcate the important areas and habitats for species conservation. While detailed field research is the best means of understanding a species ecology and distribution, it is often time-consuming and expensive, particularly for species that are rare in the landscape. Models based on habitat surrogates, however, can contribute to our understanding of correlates and causes of declines or constraints on a species. Habitat modeling can be useful in the identification of particular vegetation types or habitat attributes that if lost or modified through land-use activities may pose a significant risk to the viability of populations of a species (Munks *et al.* 1996; Meggs *et al.* 2004). Such habitats can then be prioritized for conservation or restoration.

Habitat models have been used to describe the habitat and distribution of many organisms including plants (Lomba *et al.* 2010), fungi (Molina *et al.* 2011), insects (Meggs *et al.* 2004), crustaceans (Richardson *et al.* 2008), reptiles (Brown and Nicholls 1993), amphibians (Wassens *et al.* 2010), mammals (Spencer *et al.* 2011) and birds (Saab *et al.* 2011). One of the aims of many models, particularly coarse region-wide models is to produce maps so that the distribution of habitat of the target species can be represented visually. Maps representing areas of greater probability of occurrence of species of conservation concern are useful for land managers when assessing conservation priorities and in making land-use decisions. Models may also direct researchers to where knowledge gaps exist, and subsequently where future research would be best directed.

Certain qualifiers need to be considered when using habitat models to predict species distribution. The quality of the data used to create the models is an obvious constraint to

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the effectiveness of habitat models. In the case of rare or difficult to locate species, detectability is a critical issue. It is very difficult to create meaningful models describing the distribution of rare species if there is no way of incorporating detectability into the model. Models that can estimate presence or absence have a distinct advantage over those that lack information on true absence. The recent move towards modeling approaches that focus on occupancy and incorporate detectability has gone a long way towards accounting for this problem (MacKenzie *et al.* 2003b; Royle *et al.* 2005; MacKenzie 2006; Royle 2006).

A method that has been used successfully in North America has involved the creation of models for rare species at two different spatial scales (Marcot and Molina 2007), initially at an eco-regional scale, and then at a fine scale. The eco-regional scale models use broad topographic and climatic parameters in GIS analyses, by which habitat suitability can be mapped across large areas (Molina *et al.* 2006). Fine scale models using more detailed information and expert opinion can then be used in Bayesian belief network (BBN) models to describe habitat features that effect species presence. Because these finer scale variables have often not been mapped, alternatives to maps are needed to describe these models. The probabilities of occupancy of sites based on habitat quality can be calculated (Marcot 2006).

These two scales of models complement each other, the first predicting suitable areas at a regional scale, and the second enabling assessment of habitat quality using local features. Provided the original methods are accurate, this two-scale approach can reduce the need for potentially expensive field surveys for species in areas where the species is unlikely to occur. It also focuses management efforts in areas that are most likely to be important to a species. If financial resources are available it should be possible to meld two different scales of modeling to more accurately represent species distribution at a finer scale (Rastetter *et al.* 1992).

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Bayesian belief networks (BBNs) are a popular means of modeling species-habitat relationships and have been used in many fields of ecology (Raphael *et al.* 2001; Rowland *et al.* 2003; Stauffer *et al.* 2005; Mahmoud *et al.* 2009; Ticehurst *et al.* 2011). BBNs are useful for their flexibility and straightforward, explicit representation of data making them relatively easy for land managers to use. BBNs are basically a set of variables represented as a network of nodes that are linked by probabilities. The nodes represent variables that affect some outcome of interest (such as species presence), and the links represent how the variables interact with and affect each other. The inputs can be based on expert opinion and/ or real data. They can be easily updated as new information becomes available.

The Tasmanian Masked Owl has a low overall abundance (Bell *et al.* 1996), large territory size (Young 2006), and is rarely observed (Barrett *et al.* 2003), despite its wide distribution in Tasmania. It is usually regarded as the largest of the world's barn owls (König *et al.* 2008), all members of the genus *Tyto*. It is listed as endangered under the Tasmanian *Threatened Species Protection Act 1995*, vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999* and as endangered in the Action Plan for Australian Birds (Garnett *et al.* 2011a). Previous estimates of population size have included 200-400 breeding pairs (Bell and Mooney 2002) and 1300 mature individuals (Garnett *et al.* 2011a). Much of its core distribution overlaps with areas subject to production forestry (Bell and Mooney 2002) and yet little is known of the effects of different land use activities on the owl.

There has previously been only one systematic survey for the Tasmanian Masked Owl, carried out in the winter months of 1996 (Bell *et al.* 1996). Two Tasmanian Masked Owls were captured and fitted with radio transmitters in 2006, providing the first estimates of Tasmanian Masked Owl home range size- 1991 ha and 1896 ha (Young 2006).

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This study aims to use the results from a robust habitat occupancy model to map the potential prime habitat of the Tasmanian Masked Owl. This model implicated the importance of elevation, mature eucalypt forest and dry eucalypt forest on the probability of sites being occupied by the Tasmanian Masked Owl (Chapter 4). Other possible methods for analyzing the distribution and preferences of the owl are investigated and compared with the map based on the robust occupancy model, following the two-scale approach described above.

Fine scale factors may be responsible for whether a site is of critical importance for Tasmanian Masked Owls, for example, the presence of foraging habitat and breeding habitat in the local area. Their large territory size (Young 2006) means that there must be considerable areas of land that may meet the basic requirements of elevation, mature eucalypt forest and dry eucalypt forest but are not necessarily the critical areas for Tasmanian Masked Owl nesting, roosting or foraging. This level of detail is likely to be important but is difficult to predict due to lack of information. Site level details, such as nest site availability and food availability, are also likely to be required to make these types of fine scale judgments on the importance of sites to the owls. Bayesian belief networks are a useful tool used to conceptualize the importance of these site-specific variables (Raphael *et al.* 2001; Stauffer *et al.* 2005).

This study explores methods that may be used in the development of habitat models for rare and threatened species, like the Tasmanian Masked Owl, following the two-scale approach described by Marcot and Molina (2007), and their usefulness in conservation planning. A robust habitat occupancy model incorporating detectability (chapter 4), provides a basis for predicting the spatial distribution of habitats important to the Tasmanian Masked Owl. The primary aim of the present study is to create maps from the occupancy modeling using available GIS data to predict the likely occurrence of the owl across the landscape. Other available methods for analysing the distribution and habitat preferences of species were also investigated and compared with each other. These included landscape-scale *Maxent* maps (Phillips *et al.* 2006; Phillips and Dudik

2008) created from pre-existing presence-only datasets and a local-scale Bayesian belief network (Raphael *et al.* 2001).

Methods

From habitat occupancy model to predictive map

Call playback surveys were conducted on 4 occasions at each of 211 sites between 2007 and 2009. Details of how sites were selected and surveys conducted can be found in Chapter 4. Wet eucalypt forests and dry eucalypt forests at both high and low elevations were surveyed. Survey methodology followed similar studies on large forest owls in other parts of Australia (Kavanagh and Peake 1993b; Debus 1995; Bell *et al.* 1996) except that only calls of the Tasmanian Masked Owl were broadcast. Environmental variables thought to have the potential to influence the detection of owls were recorded for each site at the start of each survey, and these were used to calculate detectability. Data on site and landscape variables, at a 500 metre radius circle scale, thought to have the potential to influence the occurrence of the Tasmanian Masked Owl (Chapter 4) were extracted from relevant GIS databases held by the Forest Practices Authority and Forestry Tasmania.

Presence-absence modeling for the Tasmanian Masked Owl using the program *Presence* (MacKenzie *et al.* 2006) (Chapter 4) yielded occupancy models that were successful in predicting the presence of the Tasmanian Masked Owl. The model selected as the most effective in predicting Tasmanian Masked Owl occupancy included the variables elevation, mature eucalypt forest and dry eucalypt forest. To cater for the extreme effect that elevation had on Tasmanian Masked Owl occupancy above and below 575 metres a.s.l. (Chapter 4), the modeling procedure was repeated but elevation was used as a categorical variable, the two categories being above and below 575 metres a.s.l.

The model without the survey-specific detectability variables, which are not capable of being mapped, was then used in the creation of a predictive map. The covariate

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coefficients differed only slightly between the models with or without the detectability covariates included. While wind and temperature have a considerable effect on likelihood of detection of the Tasmanian Masked Owl in a survey, they have little influence on the covariate coefficients (Chapter 4).

The predictive map was created by coupling the chosen model with available GIS data (Figure 5.1) on these environmental variables. The State of Tasmania was divided into a grid of 866 metres square units using *ArcGIS*. The size grid of 886 metres is comparable to the 500 metre radius circles around the survey points. Each grid square was given a suitability value depending on its average elevation and the proportion of mature forest and dry eucalypt forest within it. The resulting values were then divided into categories each representing half a standard deviation.

The average territory size of the Tasmanian Masked Owl is probably around 2000 hectares based on those of a male Tasmanian Masked Owl radio-tracked on the Tasman Peninsula in 2009 (Appendix 5.1) and two female Tasmanian Masked Owls radio-tracked in the Huon Valley in 2006 (Young 2006). All three of these owls occupied partially cleared habitat. It is impossible to know how representative they are of owls in complete forest or in mostly cleared habitat. However, they are a reasonable starting point. The territories of paired male and female large forest owls usually overlap (Kavanagh 1997), so it is also reasonable to regard these estimates as the territory of a pair. It is acknowledged that actual territory sizes will vary depending on habitat quality, as has been found for other territorial forest owls on mainland Australia (Soderquist and Gibbons 2007; Kavanagh *et al.* 2008b; Kavanagh and Stanton 2009; Bilney *et al.* 2011; Olsen *et al.* 2011). The three Tasmanian Masked Owls that have been radio-tracked were all in what was mostly sub-optimal habitat (medium and low categories), based on the subsequent predictive habitat map. Nevertheless, 2000 hectares is a reasonable estimate of territory size, and as such was used to calculate the number of territories that could occur in Tasmania based on the different categories of habitat potential that were mapped.

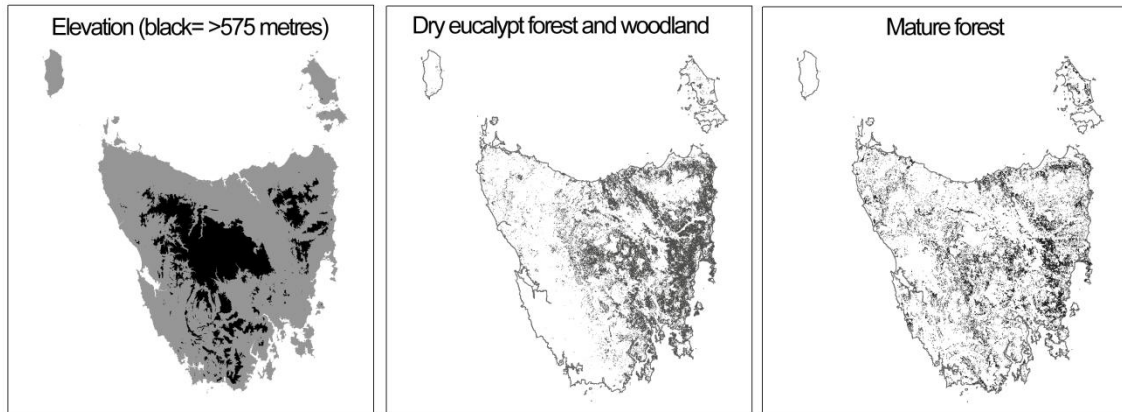


Figure 5.1- Base GIS data used to create the predictive map, based on the robust habitat occupancy model. Source data: Elevation contour data (DPIW, Tasmap data, 2010), dry eucalypt forest and woodland (TASVEG 2.0, DPIPWE 2009), mature forest (Forestry Tasmania 2010).

Evaluation of habitat occupancy model using presence-only data

To evaluate the results from the presence-absence modeling exercise a non-systematic test dataset was created from opportunistic surveys conducted during this study over the last four years, records from the biological records database maintained by the Department of Primary Industry, Parks, Wildlife and the Environment (Natural Values Atlas), the New Atlas of Australian Birds produced by BirdLife Australia (formerly known as Birds Australia) (Barrett *et al.* 2003), and from specimens in the Tasmanian Museum and Art Gallery. Location accuracy was established for each record; some records were of insufficient accuracy to be used at all. Other records were sufficiently accurate to be used to assess some geographic features but not others, such as vegetation type. This resulted in over 300 records that could be used as a presence dataset depending on their accuracy. Forty-six per cent of these records were post 1996 when Bell *et al.* (1996) conducted their assessment of Tasmanian Masked Owl records.

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The dominant vegetation, elevation and average annual rainfall within a 500 metre radius circle around the site of these records were examined to determine any obvious patterns. The vegetation data were obtained from TASVEG 2.0 (2009) (Harris and Kitchener 2005), elevation data (metres above sea level) were estimated using spline interpolation from Tasmanian 10 m contour data (DPIW, Tasmap data, 2010) and average annual rainfall was obtained from the Bureau of Meteorology. It was not possible to test the relationship between mature eucalypt forest and this dataset due to the Forestry Tasmania license agreement not covering the whole of the state.

The non-systematic dataset was used to produce maximum entropy ecological niche models using the program *Maxent* version 3.3.3a (Phillips *et al.* 2006). *Maxent* is a presence-only probability modeling software that uses environmental variables to determine the most likely theoretic niche for a species. *Maxent* creates a uniform layer of probability distribution based on the set of environmental variables; essentially a random background model. The species presence records are then compared to the background model to determine which environmental variables are most likely to be responsible for (or at least correlated with) the species distribution (Perry *et al.* 2011a).

Model accuracy is determined by comparing how distant the presence records are from the random background model as measured by the area under the receiver operator curve (AUC). An accurate model will have an AUC of near 1, while a model that is no better than random will have an AUC of around 0.5 (Phillips *et al.* 2006; Phillips and Dudik 2008). The environmental variables chosen for use in these maximum entropy models are listed in Table 5.1. Many of these environmental variables were discounted in the most parsimonious of the habitat occupancy models (Chapter 4) but it was thought worthwhile to trial them with this different dataset also. Only records that had accurate locations associated with them (within 500 metres) were used in the modeling. Most of the records were accurate to within 100 metres.

The models were tested using 25% of the records taken at random from the original dataset. A receiver operating characteristic (ROC) curve was plotted. The ROC curve plots percent correct predictions of species presence as a function of percent false predictions of species presence (Marcot 2006). A ROC curve in the upper left corner of the graph has best predictive power. The area under the curve is 1 when the model is free of errors, 0.5 along the diagonal when there are completely random errors, and <0.5 below the diagonal when the model produces more errors than correct predictions (Marcot 2006)

Development of a Bayesian belief network (BBN) to predict occurrence at the local scale

The objective of the BBN developed in this study was to provide an intuitive picture of what is likely to be affecting the importance of particular sites to the reproductive potential of the Tasmanian Masked Owl. In developing the BBN it was assumed that the site being evaluated was within the high or very high category of the predictive habitat map developed from the habitat occupancy model (i.e. an area below 575 metres elevation, with mature dry eucalypt forest present). The three basic variables selected to be included in the BBN were prey abundance and availability, roost site availability and nest site availability (Table 5.2). These were considered to be the basic resources required for breeding. The program *GeNIe*, version 2.0 (<http://genie.sis.pitt.edu>), was used to create the BBN.

To assist in the entry of data into a BBN a *proforma* was developed to assist the compilation of the relevant and important information. Using existing knowledge about the Tasmanian Masked Owl's diet (Chapter 2), habitat preferences (Chapter 4), roosting and nesting habitat (Mooney 1997), a *proforma* was created that could be used by land managers and owl habitat surveyors to rate the potential importance of local sites to owls, the risk of disturbance and the need for management action.

Chapter 5- Development of predictive habitat models

Table 5.1- Habitat variables used in the maximum entropy modeling of Tasmanian Masked Owl distribution.

Variable	Description
Wet eucalypt forest and woodland	Area (m ²) within 500 metre radius circle that was classified as 'wet eucalypt forest and woodland' using the TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Dry eucalypt forest and woodland	Area (m ²) within 500 metre radius circle that was classified as 'dry eucalypt forest and woodland' using the TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Non eucalypt forest and woodland	Area (m ²) within 500 metre radius circle that was classified as 'non eucalypt forest and woodland' using the TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Cleared land	Area (m ²) within 500 metre radius circle that was classified as 'Agricultural, urban or exotic' using the TASVEG 1.3 (2006) layer (Harris and Kitchener 2005).
Elevation	Metres above sea level as estimated using spline interpolation from Tasmanian 10 m contour data DPIW, Tasmapi data, 2010. There was a high positive correlation with average annual rainfall and minimum temperature of the coldest month (obtained from the Bureau of Meteorology).
Annual rainfall	Average annual rainfall (Bureau of Meteorology).
Minimum temperature	Mean minimum temperature of the coldest month (Bureau of Meteorology).
High potential hollow abundance	Area (m ²) within 500 metre radius circle that is classified as <i>high potential hollow abundance</i> . From mapping that used aerial photographs to remotely assess potential tree hollow availability (Koch 2011; Koch and Baker 2011). The predicted potential hollow abundance takes into account mature forest and the density (using crown canopy as the best representation available for tree density). To be in the <i>high hollow</i> category, crown cover needs to be >70% (Koch and Baker 2011).

Table 5.2- Local habitat features used in a Bayesian belief network to describe the importance of particular sites to the reproductive potential of the Tasmanian Masked Owl, and references to why and how they are important.

Local Habitat Features	References
Eucalypt forest with open understorey	Open understorey probably important in allowing access to the prey (Debus 1993b; Peake <i>et al.</i> 1993; McCray and Kavanagh 2000).
Small-sized mammals	Small mammals (particularly rodents) important to both sexes but particularly while male is provisioning nest (Mooney 1992; Kavanagh 1996; Kavanagh 2002a; DPIPWE 2006; Todd 2006; Kavanagh <i>et al.</i> 2008a). Also see Chapter 2.
Medium-sized mammals	Medium mammals important to the female in particular and provide optimal foraging advantages while the female is providing food for large young in the nest (Hill 1955; Mooney 1992; Todd 2006). Also see Chapter 2.
Roosting habitat	Dense mid-storey vegetation, large tree hollows and sandstone caves can all provide suitable roosting habitat, needed throughout the year by both sexes (Bell <i>et al.</i> 1996; Mooney 1997; Young 2006).
Nesting habitat	Large tree hollows needed for nesting (Bell <i>et al.</i> 1996; Kavanagh 1996; Mooney 1997; Young 2006).

Results

From habitat occupancy model to predictive map

The best fit models all differed from each other by less than two AIC values, indicating little difference between the models (Burnham and Andersen 2002). Given that dry eucalypt forest and woodland consistently had a positive effect on Tasmanian Masked Owl occupancy the model incorporating this variable was preferred for the map creation. Using elevation as a categorical variable rather than as a continuous variable increased the effect of elevation but it did not change the basic results which were that elevation, mature forest and dry eucalypt forest were indicators of the probability of Tasmanian Masked Owl occupancy of a site. The model without the detectability

variables had a lower AIC value as was to be expected. The models concerned are presented in Table 5.3 with the coefficients of the preferred model presented in Table 5.4.

Eight categories of a half standard deviation were created and these were further categorized as very high, high, medium, low and very low habitat potential for the purposes of mapping (Table 5.5). The lowest four standard deviation categories were combined into the category very low habitat potential to indicate the lower number of records in high elevation areas.

Predictive habitat map created from habitat occupancy model

The predictive habitat map based on the habitat occupancy model shows the distribution of the different categories of habitat in Tasmania. The most extensive areas of high and very high habitat potential occur in the central eastern and north-east areas of Tasmania (Figure 5.2 and Figure 5.3). When viewing these figures it is important to remember that owls can be and were recorded in less suitable sites as well as in more suitable sites. It is a question of probability of occurrence rather than presence/ absence.

Extensive areas of high potential habitat are lacking in the higher elevation areas around Ben Lomond in the north-east, a large swath through the central highlands and most of western Tasmania. Using 2000 hectares as an average Tasmanian Masked Owl territory size, there could be 62 territories in very high habitat potential areas and 426 territories in high habitat potential areas. This would equate to 488 breeding pairs of Tasmanian Masked Owls. However, not all these areas of high and very high habitat potential areas are contiguous to each other and so the actual number could be less. The other unknown is how many Tasmanian Masked Owl territories occur in the less suitable areas where Tasmanian Masked Owls still occur at a lower density. This includes high altitude areas, wet eucalypt forest and agricultural land with large paddock trees. Many of these territories could operate as population sinks (Pulliam 1988; Schaub *et al.* 2010), without producing sufficient offspring to replace the parents, but certainly some owls occur in these habitats. There will also be an unknown number of un-paired owls that may or

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may not have regular territories. Some of these birds will be immature owls from the previous breeding season. Because of these uncertainties it is impossible to arrive at an accurate estimate of population size but it is probably around 500 breeding pairs.

Table 5.3- Best fit models of Tasmanian Masked Owl occupancy at 500 metre radius scale using elevation as a categorical variable. Psi is the probability that a site is occupied by the target species; p is the probability of detecting the species, given that the species is present on a site. The model selected for mapping is indicated in bold.

Models incorporating detectability	AIC	delta AIC	AIC wgt	Number of parameters	-2*log likelihood
psi (elevation, mature forest), p (wind, temp)	365.72	0	0.2836	6	353.72
psi (elevation, mature forest, dry eucalypt forest and woodland), p (wind, temp)	366.36	0.64	0.2059	7	352.36
psi (elevation, mature forest, high hollow potential), p (wind, temp)	367.66	1.94	0.1075	7	353.66
psi (elevation, mature forest, medium-high hollow potential), p (wind,temp)	367.7	1.98	0.1054	7	353.7
psi (elevation, mature forest, dry eucalypt forest and woodland)	402.52				

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Table 5.4- Comparison between the best fit models with and without detectability. Estimate and standard error of the covariates in the best fit model for Tasmanian Masked Owl occupancy using elevation as a categorical variable.

Covariate estimates and standard error	Model with detectability	Model without detectability
Elevation	-3.38 ± 0.84	-3.52 ± 0.79
Mature forest	+0.66 ± 0.32	+0.72 ± 0.30
Dry eucalypt forest and woodland	+0.34 ± 0.31	+0.34 ± 0.28
Wind	-0.84 ± 0.28	-
Air temperature	+0.22 ± 0.21	-

Table 5.5- Description of habitat potential categories used in mapping the predicted Tasmanian Masked Owl distribution. * area of all very low categories combined.

Habitat potential category	Standard deviation range	Area (ha.)	2000 ha. units within category
Very low	-3.92 to -3.32		
Very low	-3.32 to -2.59		
Very low	-2.59 to -1.86		
Very low	-1.86 to -1.12	1498950*	749*
Low	-1.12 to -0.38	1310708	655
Medium	-0.38 to 0.35	3009910	1505
High	0.35 to 1.09	851407	426
Very high	1.09 to 1.20	124657	62

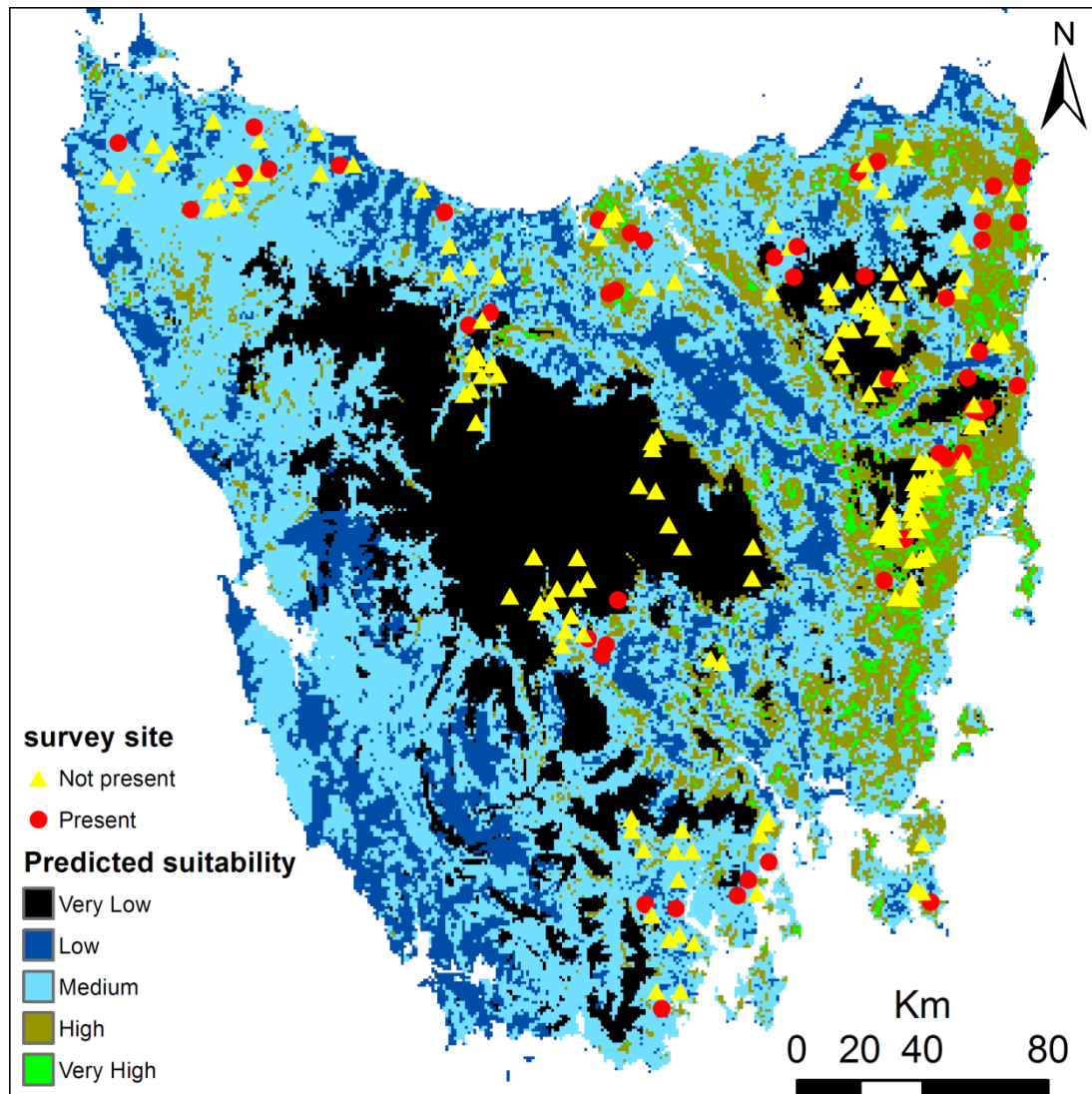


Figure 5.2- Predicted habitat quality map for the Tasmanian Masked Owl. Symbols represent sites where systematic surveys were conducted and Tasmanian Masked Owls were detected.

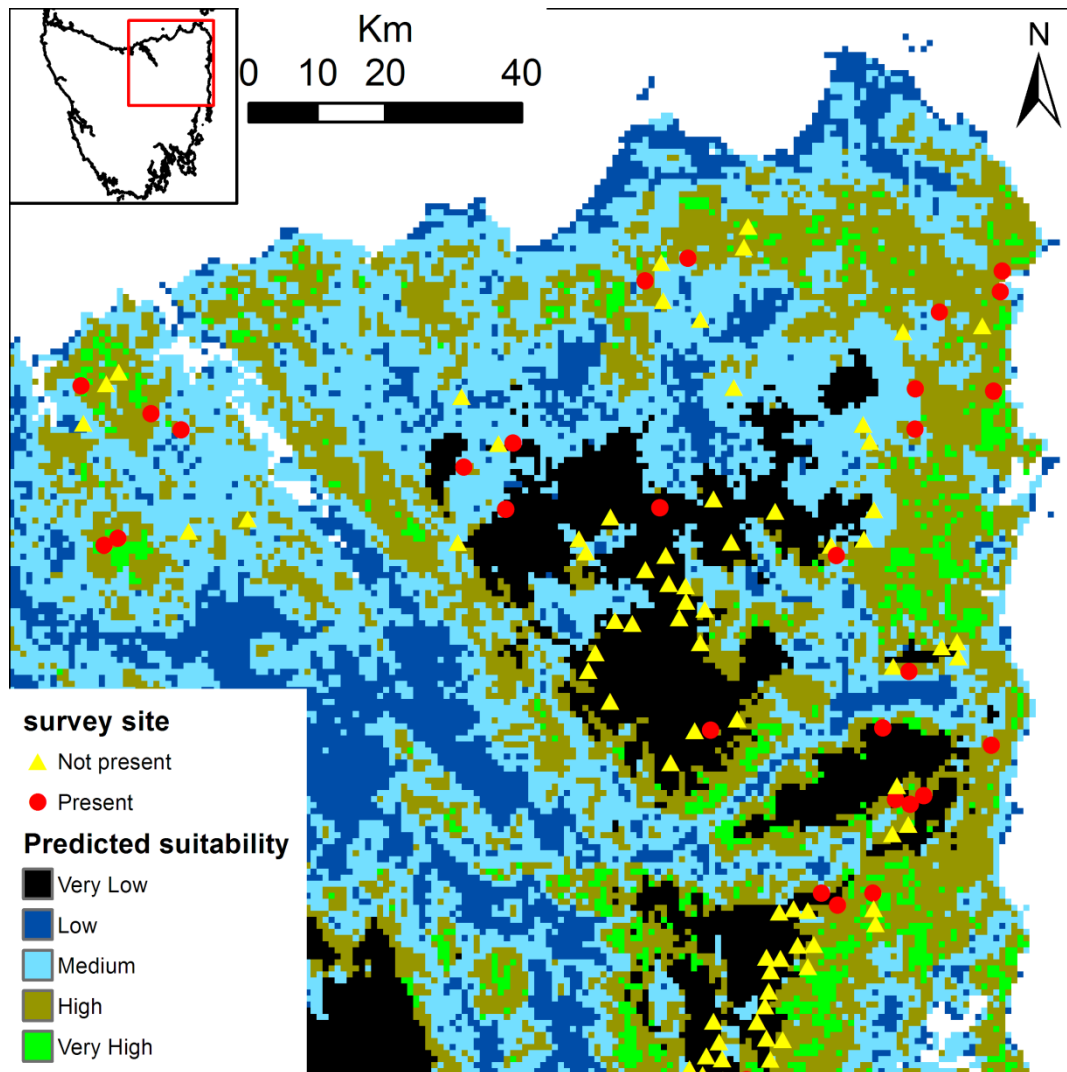


Figure 5.3- Predicted habitat quality map of north-east Tasmania, for the Tasmanian Masked Owl. Symbols represent sites where systematic surveys were conducted and Tasmanian Masked Owls were detected.

Evaluation of habitat occupancy model using presence-only data

Examination of some of the simple attributes of sites where the Tasmanian Masked Owl has been recorded revealed some trends and also some biases. One hundred and fifty-one records collected between the years 1996 and 2011 were accurate to within 100 metres, and were considered accurate enough for assessment in terms of surrounding vegetation type. The most common vegetation type at these recorded Tasmanian Masked Owl sites was *Agricultural, Urban and Exotic* (45.7% of sites had >50% of this vegetation type). The second most common vegetation type was *Dry Eucalypt Forest & Woodland* (25.2% of sites >50% of this vegetation type). The third most common vegetation type was *Wet Eucalypt Forest* (9.3% of sites had >50% of this vegetation type). All the other vegetation types that occurred at masked owl sites were usually minor in area compared to the above three vegetation types and were only very rarely dominant at a site (>50% of the site). The dominance of the *Agricultural, Urban and Exotic* and *Dry Eucalypt Forest & Woodland* categories is borne out by the fact that when the two categories were combined they were dominant (>50% of the site) at 123 of the 151 sites (Table 5.6).

The mean elevation at sites where the masked owl has been recorded was usually less than 400 metres a.s.l. (90.1% of sites). Only 4.0% of sites were greater than 600 metres a.s.l. (Table 5.7). The average annual rainfall at sites was generally low with 90.9% of sites occurring where there was an average annual rainfall of less than 1200 mm (Table 5.8). In summary, most of the records were from areas with low average annual rainfall, low elevation and were dominated by the TASVEG categories *Agricultural, Urban and Exotic* or *Dry Eucalypt Forest & Woodland*.

Table 5.6- Dominant vegetation community within a 500 metre radius circle around sites where Tasmanian Masked Owls have been recorded. Only records accurate to within 100 metres and recorded between 1996 and 2011 were used. Vegetation data are from TASVEG (Harris and Kitchener 2005).

Vegetation community	Dominant at site (>50% of circle)	Minor at site (<50% of circle)
Agricultural, urban and exotic vegetation	69	82
Dry eucalypt forest and woodland	38	113
Wet eucalypt forest and woodland	14	137
Non-eucalypt forest and woodland	0	151
Rainforest and related scrub	0	151
Scrub, heathland and coastal complexes	3	148
Highland treeless vegetation	0	151
Moorland, sedgeland, rushland and peatland	1	150
Saltmarsh and wetland	1	150
Native grassland	2	149
Other natural environments	1	150
Agricultural, urban and exotic vegetation AND Dry eucalypt forest and woodland combined	123	28

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Table 5.7- Mean elevation within a 500 metre radius circle around sites where the Tasmanian Masked Owl has been recorded. Only records accurate to within 500 metres were used.

Mean elevation range (m)	Number of Sites
0-100	114
100-200	66
200-300	35
300-400	12
400-500	8
500-600	7
600-700	6
700-800	2
800-900	1
1200-1300	1

Table 5.8- Average annual rainfall (mm) within a 500 metre radius circle around site where Tasmanian Masked Owl has been recorded. Only records accurate to within 500 metres were used. Note that there are fewer sites than in Table 5.7 due to missing rainfall data for some sites.

Average annual rainfall (mm)	Number of sites
400-600	33
600-800	74
800-1000	60
1000-1200	53
1200-1400	9
1400-1600	3
1600-1800	2
1800-2000	2
2200-2400	4
2400-2600	1

Maximum entropy models

The map of the maximum entropy model for the Tasmanian Masked Owl incorporating the seven environmental variables (average annual rainfall, elevation, mean minimum temperature in coldest month of year, high potential hollow abundance, cleared land (agricultural, urban and exotic), dry eucalypt forest and woodland, wet eucalypt forest and non-eucalypt forest), showed a distribution largely in the north and the east of Tasmania with concentrated areas in the central north and south-east (Figure 5.4).

The model was quite effective at predicting the distribution of Tasmanian Masked Owl records as shown by the AUC values on the receiver operating curve (Figure 5.5). The AUC values were 0.855 for the training data and 0.819 for the test data. They were well above the random prediction AUC of 0.5 (Figure 5.6). The jackknife test of variable importance for the maximum entropy model showed that three particular environmental variables were driving the model with the others contributing little (Figure 5.6). The environmental variable with highest gain when used in isolation was average annual rainfall, which therefore appeared to have the most useful information by itself. The environmental variable that decreased the gain the most when it was omitted was mintemp (mean minimum temperature in the coldest month), which therefore appeared to have the most information that was not present in the other variables (Figure 5.6). Elevation was the other most significant contributor.

Another model was produced using only the environmental variables average annual rainfall, mintemp and elevation. This produced a roughly similar map to the more complicated model (Figure 5.7), which was also effective at predicting the distribution of masked owl records as shown by the AUC values on the receiver operating curve (Figure 5.8). The AUC values were 0.837 for the training data and 0.822 for the test data well above the random prediction AUC of 0.5.

Twenty-five per cent of the records were randomly set aside for testing the model. This allows *Maxent* to do some simple statistical analysis. Much of the analysis used a

threshold to make a binary prediction, with suitable conditions predicted above the threshold and unsuitable below. A plot shows how testing and training omission and predicted area vary with the choice of cumulative threshold (Figure 5.9). The omission on test samples is a very good match to the predicted omission rate, the omission rate for test data drawn from the *Maxent* distribution itself. The predicted omission rate is a straight line, by definition of the cumulative output format. In situations where the test omission line lies well below the predicted omission line it is usually because the test and training data are not independent, for example if they derive from the same spatially auto correlated presence data (Phillips *et al.* 2006). The environmental variables average annual rainfall, elevation and mintemp were the best predictors of the distribution of Tasmanian Masked Owl records from the non-systematic dataset.

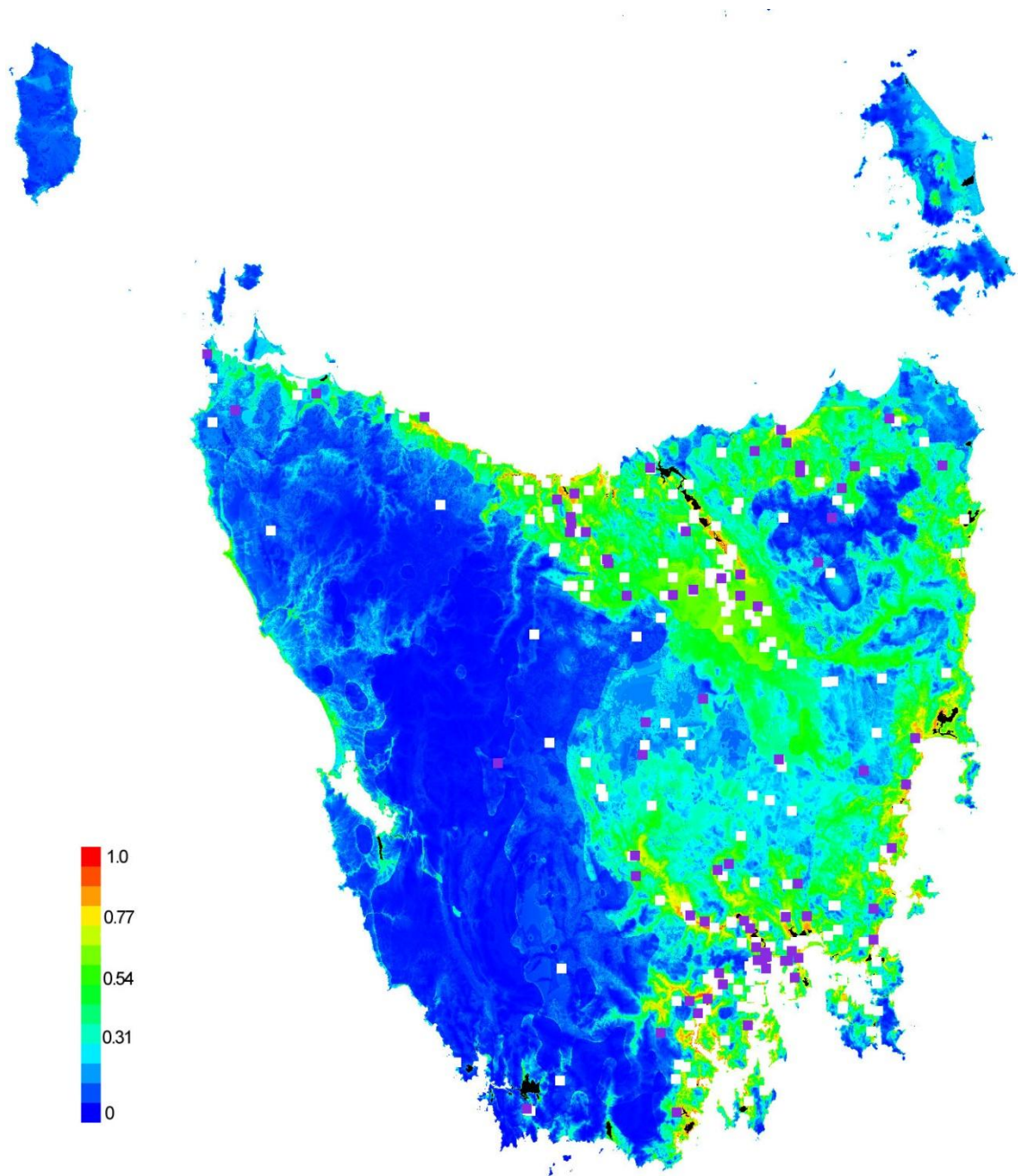


Figure 5.4- Representation of the Maxent model for the Tasmanian Masked Owl incorporating the environmental variables average annual rainfall, elevation, mean minimum temperature in coldest month of year, high potential hollow abundance, cleared land (agricultural, urban and exotic), dry eucalypt forest and woodland, wet eucalypt forest and non-eucalypt forest. Warmer colours show areas with better predicted conditions. White dots show the presence locations used for training, while violet dots show test locations. Map created by *Maxent*.

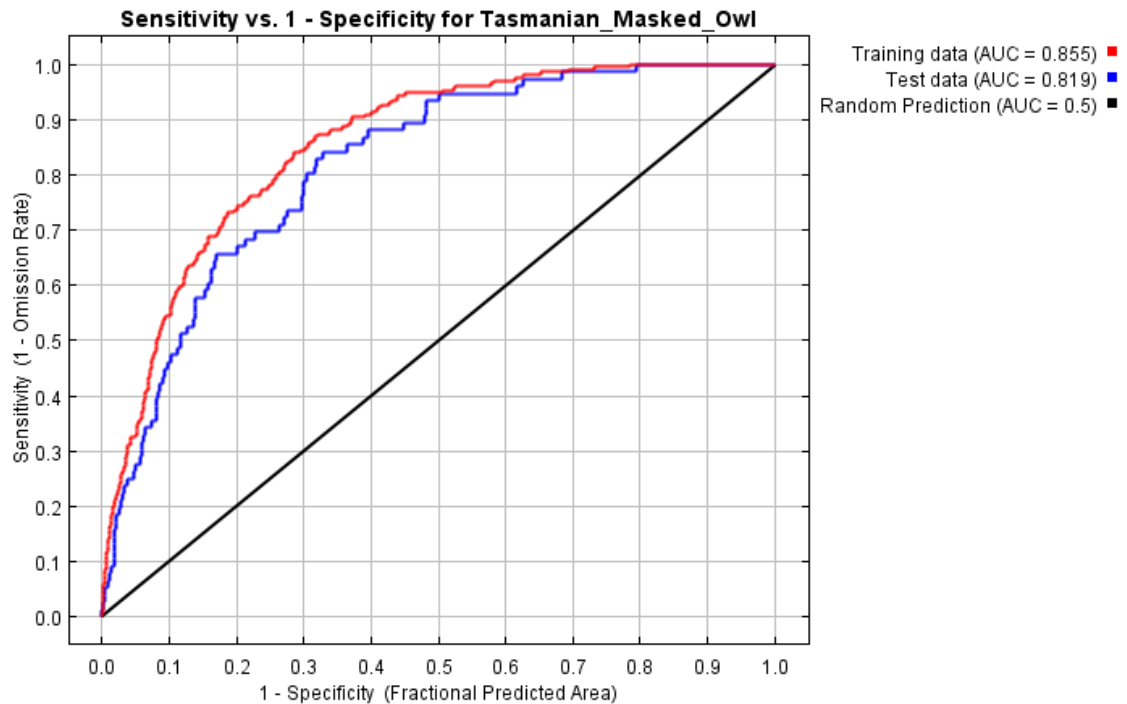


Figure 5.5- Receiver operating characteristic (ROC) curve for the maximum entropy model involving the environmental variables average annual rainfall, elevation, mean minimum temperature in coldest month of year, high potential hollow abundance, cleared land (agricultural, urban and exotic), dry eucalypt forest and woodland, wet eucalypt forest and non-eucalypt forest. AUC is shown to be much greater than 0.5.

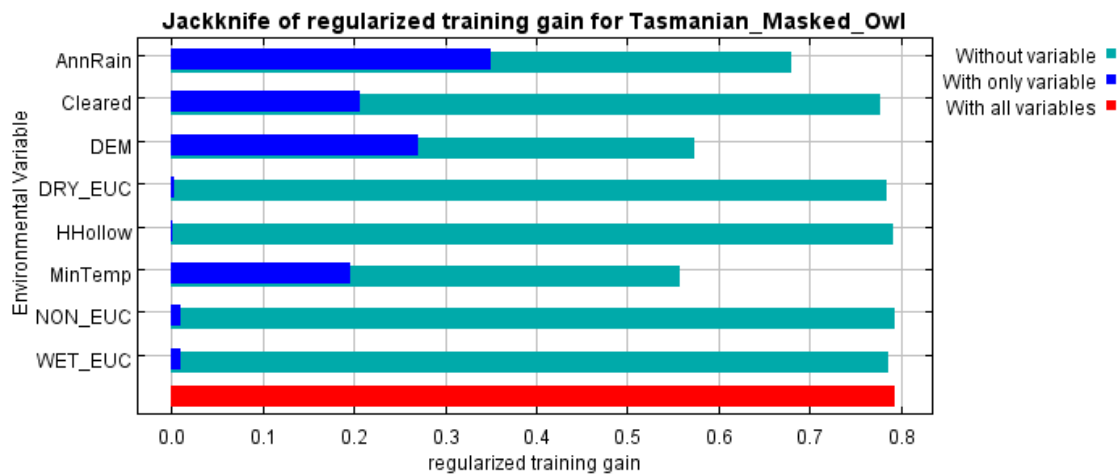


Figure 5.6- Jackknife test of variable importance for the maximum entropy model involving the environmental variables average annual rainfall (annrain), elevation (DEM), mean minimum temperature in coldest month of year (MinTemp), high potential hollow abundance (HHollow), cleared land (agricultural, urban and exotic), dry eucalypt forest and woodland (DRY_EUC), wet eucalypt forest (WET_EUC) and non-eucalypt forest (NON_EUC). The environmental variable with highest gain when used in isolation is average annual rainfall (AnnRain), which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is minimum temperature (MinTemp), which therefore appears to have the most information that is not present in the other variables.

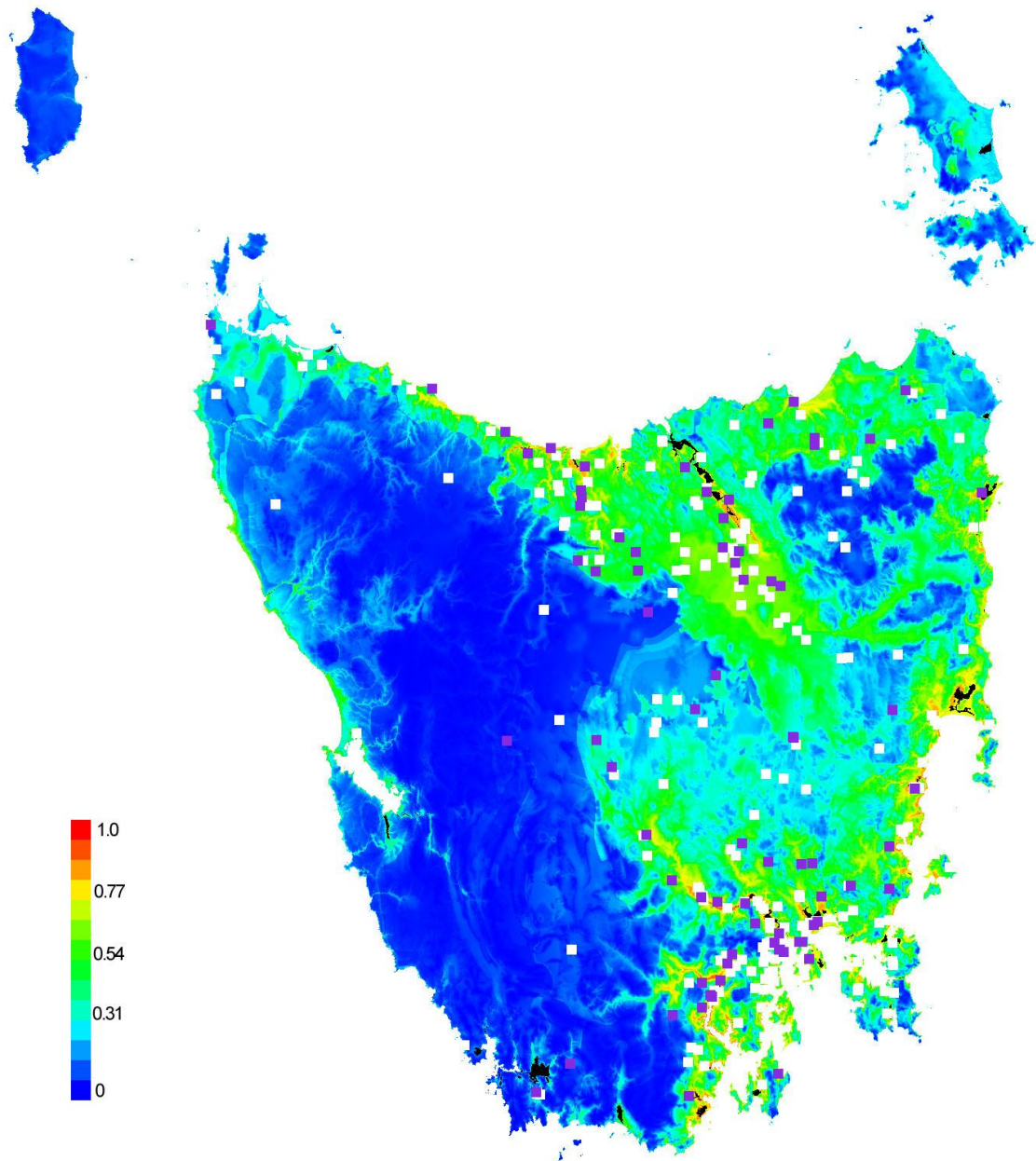


Figure 5.7- Representation of the Maxent model for the Tasmanian Masked Owl incorporating the environmental variables average annual rainfall, elevation, mean minimum temperature in coldest month of year. Warmer colours show areas with better predicted conditions. White dots show the presence locations used for training, while violet dots show test locations. Map created by Maxent.

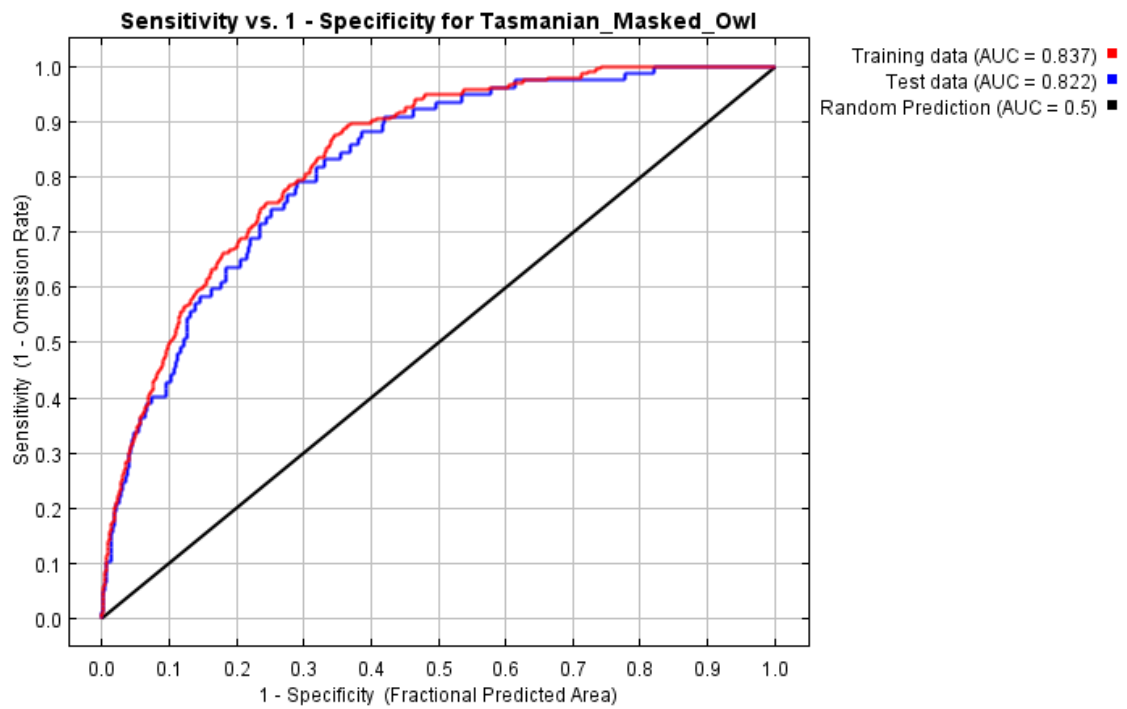


Figure 5.8- Receiver operating characteristic (ROC) curve for the maximum entropy model involving only the environmental variables average annual rainfall, elevation, mean minimum temperature in coldest month of year. AUC is shown to be much greater than 0.5.

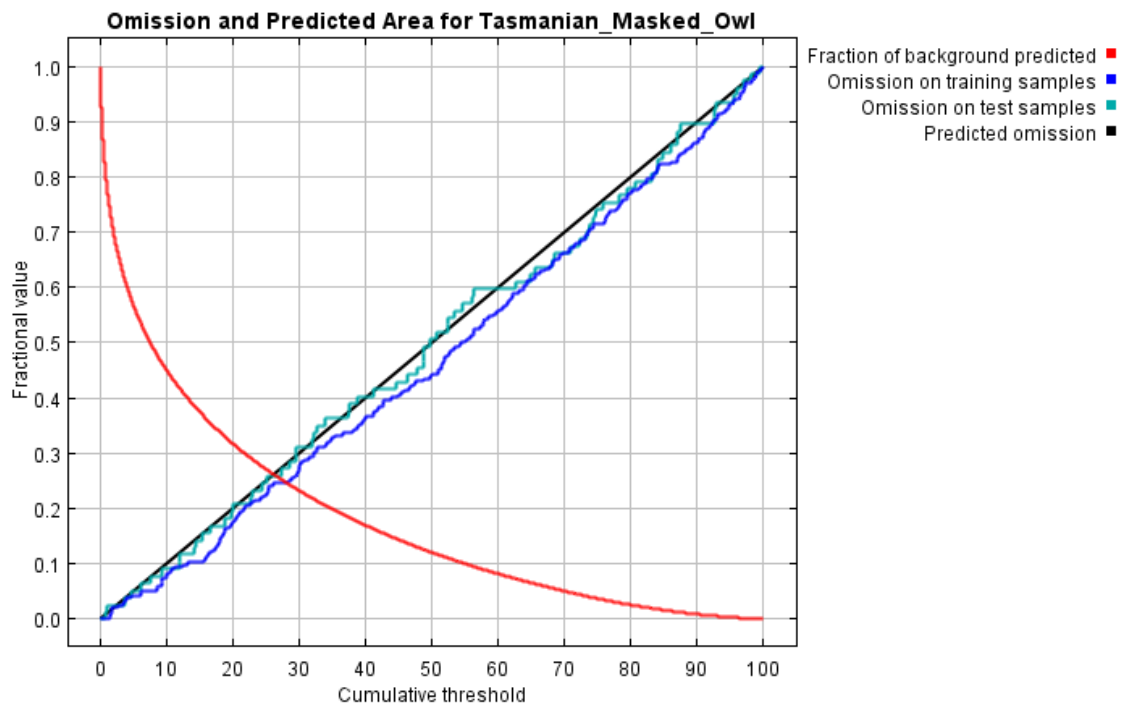


Figure 5.9- Omission rate and predicted area as a function of the cumulative threshold. The omission rate is calculated both on the training presence records, and on the test records. The omission rate is close to the predicted omission, because of the definition of the cumulative threshold. Maximum entropy model involving only the environmental variables average annual rainfall, elevation, mean minimum temperature in coldest month of year.

Bayesian belief network (BBN) to predict occurrence of the Tasmanian Masked Owl at the local scale

The BBN provides a simple representation of the expected probability, based on expert opinion, of Tasmanian Masked Owl occupancy of sites and the relative effect of different site-specific variables (Figure 5.10). The BBN, as used in this study, assumes that the site being tested is already within what would be mapped as high or very high potential habitat, i.e. an area below 575 m. elevation, with mature dry eucalypt forest

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present. This is an example of the two-tier approach (Molina and Marcot 2007), where the first tier is the predicted habitat potential map and the BBN is the second tier.

Nodes within the prey section of the BBN included small mammal abundance (*Rattus* spp., house mouse and other small mammals) and medium mammal abundance (bandicoots, rabbits, ringtail possum, other mammals). Obviously all these prey types would not be available at all important sites, but there probably has to be a certain abundance of prey within each of these categories. Small mammals are likely to be of greater importance than medium sized mammals as they are probably what the male is preying upon while the female is restricted to the nest during incubation and early nestling stages (Mooney 1993; DPIPWE 2006). The other factor is the availability of the prey (especially terrestrial mammals) to the owls; the absence of areas with open understorey could impede access to the prey. Other important nodes included were roost site availability (tree hollows, dense midstorey vegetation or sandstone caves) and nest site availability (living or dead trees with hollows). Without these resource requirements breeding would not be possible.

To assist in the entry of data into a BBN such as the one in Figure 5.12, a *proforma* can be used to assist the compilation of the relevant and important information (Table 5.9). A BBN such as this one could be used in situations where an on-site assessment needs to be made of the probability of a site being important to the Tasmanian Masked Owl. This could include forestry situations where potential logging coupes occur in high potential habitat, or in large development proposals.

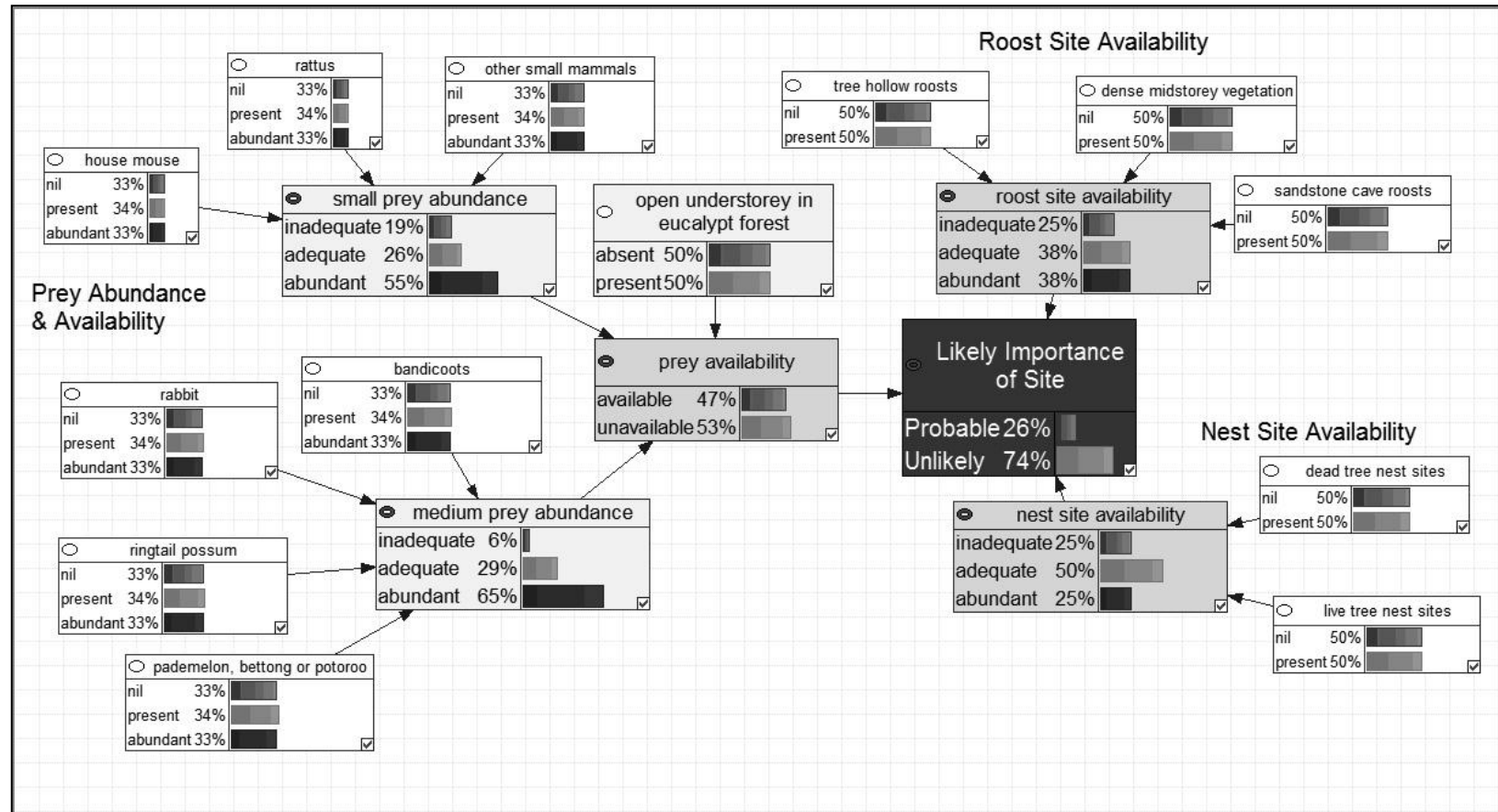


Figure 5.10- Bayesian Belief Network (BBN) for factors likely to affect whether a particular site is likely to be important to the Tasmanian Masked Owl. BBN created in the program GeNIe (version 2.0).

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Table 5.9- Example of proforma for scoring expected quality (most likely, 10; least likely, -10) of potential Tasmanian Masked Owl habitat in local areas mapped as very high and high predicted habitat potential for the Tasmanian Masked Owl. The numbers used here are simply an example of how habitat could be scored. The relative weight of the different variables is something that would need to be determined by either extensive research or consultation with experts in an expert panel type situation.

Habitat Features		Potential scores	Excellent habitat, eg. mature dry forest	Poor habitat, eg. re-growth forest	Good local habitat, eg. semi-cleared farmland
Foraging Habitat					
Eucalypt forest with open understorey?	complete	10			
	some	5	x		x
	none	0		x	
Small-sized mammals					
<i>Rattus</i> species	abundant	10	x		x
	present	5		x	
	absent	0			
House Mouse	abundant	10			
	present	5	x		x
	absent	0		x	
Other small mammal species	present	5	x		
	absent	0		x	x
No small mammals present		0			
Medium-sized mammals					
Bandicoots	abundant	10	x		
	present	5			
	absent	0			x

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Rabbit	abundant	10			x
	present	5			
	absent	0			
Ringtail Possum	abundant	10			
	present	5		x	
	absent	0	x		
Bettong, Pademelon or Potoroo	present	5	x		x
	absent	0			
No medium-sized mammals present		0			
Roosting Habitat					
Suitable tree hollows for roosting?	present	10	x		x
	absent	0			
Suitable dense midstorey vegetation for roosting?	present	5	x	x	
	absent	0			
Suitable sandstone caves for roosting?	present	5			
	absent	0			
No roosting habitat present		0			
Nesting Habitat					
Suitable tree hollows for nesting in living trees?		10			
Suitable tree hollows for nesting in dead trees?		10	x		x
No nesting habitat present		0			
Total score			65	15	75

Discussion

Habitat models are an extremely useful method of conceptualizing and visualizing the distribution of species and how they are affected by their environment. They are critically important for conservation management, especially for rare and difficult to detect species that may suffer from being under-recorded and/ or poorly understood. Nevertheless, there are many methods available for modeling, mapping and describing species distribution and species habitat requirements, and choosing the right modeling strategy is important. The importance of clarifying the objectives of models, and the spatial scale at which habitat models might apply is an important consideration when using habitat models in conservation decision-making.

The advances in the modeling of species occupancy and detectability have been especially important for rare and difficult to detect species. The incorporation of estimates of the detectability of target species into models can reduce the impact of false absences which result in type I errors. In the case of forest owl surveys, most surveys fail to detect owls resulting in zero-inflated data (Wintle *et al.* 2005b). Even within surveyed locations, it is common for species to be present but go undetected. Methods using logistic regression have been found to yield biased results when applied to presence-absence data in which there are false absences even at low frequencies (Tyre *et al.* 2003; Gu and Swihart 2004). This has prompted the investigation of species occurrence from a different perspective, that of the probability of occupancy of a site. The methodology is designed to permit inferences about occupancy that deal adequately with detection probabilities less than one (MacKenzie *et al.* 2002; MacKenzie *et al.* 2003a; Wintle *et al.* 2004).

In order to estimate detection probability repeated surveys are required and each survey should be independent, the aim being to reduce the likelihood of false negatives (ie. deciding that the species is not present when in fact it just went undetected). The number of sites should be maximised to ensure greater precision of the occupancy estimate, however this should not be at the expense of repeated surveys which are

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necessary to account for imperfect detection and resulting false absences (MacKenzie 2006; MacKenzie *et al.* 2006).

This study was able to utilize the results from occupancy modeling of the Tasmanian Masked Owl to create a map of optimum habitat that may assist in the management of this species. The robust occupancy modeling of habitat revealed that elevation, mature eucalypt forest and dry eucalypt forest are the main factors that affect Tasmanian Masked Owl distribution. The map showed how the range of the Tasmanian Masked Owl is defined especially by their virtual absence from high elevations, making large parts of Tasmania largely unavailable to the owl. In particular, the Central Highlands and highland areas in the north-east (around Ben Lomond), are sub-optimal (low and medium potential) habitat. Outside of this constraint, the best habitat for the species occurs wherever there are large areas of mature dry eucalypt forest. The best areas in Tasmania for these habitat features exist in the central north, north-east, east and south-east.

The use of habitat models to map predicted distribution of Australian Masked Owl habitat has been carried out in parts of NSW (NSW National Parks and Wildlife Service 1994; Kavanagh 1997; Kavanagh 2002b), however, these models were not based on robust occupancy modeling using multiple visits to sites. The model for southeast NSW (Kavanagh 1997; Kavanagh 2002b) was based on a limited dataset of 28 Masked Owl locations from 669 sites that were visited once each. However, the model is the only one to date to have been field-tested and revised, the result of which confirmed the negative effect of elevation and proximity to rainforest on the Australian Masked Owl in south-east NSW (Kavanagh 2002b). There has been a previous attempt to map predicted Tasmanian Masked Owl habitat based on habitat models (Bell and Mooney 2002). The Bell and Mooney (2002) predictive map was based on existing database records and was mostly determined by elevation, low average annual rainfall and high annual mean temperature. As a result it was broadly similar to the maximum entropy modeling maps presented here.

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The modeling and subsequent population size estimation is limited to the extent that surveys were only conducted in mostly forested habitats for logistical reasons. As a result of this, estimates of the number of Tasmanian Masked Owls occurring in agricultural areas are only an educated guess. Presence-absence surveys conducted in agricultural areas would enable a refining of the estimate used here.

Although the estimated population size is speculative it is based on a robust habitat occupancy model (MacKenzie *et al.* 2004; MacKenzie *et al.* 2006) and on the best available evidence on average territory size for the Tasmanian Masked Owl (Young 2006). The estimate of 366 breeding territories (732 breeding owls) is between previous estimates of population size of 1330 breeding owls (Bell *et al.* 1996; Bell and Mooney 1997) and 200-400 pairs (Bell and Mooney 2002). The estimate in Bell *et al.* (1996) was based on a territory size of 1000 ha, which was the best information available at the time. It also was based on known records rather than estimated optimum habitat. The estimate in the current study is more reliable because it is based on a robust survey methodology and modeling technique and a more accurate average territory size. While there is a degree of uncertainty about the estimate, it is likely that the population size of the Tasmanian Masked Owl is comparable with a previous estimate of 200-400 pairs (Bell and Mooney 2002).

The positive association of the owls with dry eucalypt forest is of conservation concern. The dry forests of Tasmania have been heavily cleared in the past, particularly through the midlands. Clearance of dry forests was still extensive and ongoing in the 1970s (Kirkpatrick and Dickinson 1982) and 1980s (Kirkpatrick 1991). Most of the land clearance in the 1970s and 1980s was in dry forest and woodland (Kirkpatrick 1991), probably prime habitat for the Tasmanian Masked Owl. Little of Tasmania's dry forest is in the protected World Heritage Areas (Balmer and Whinam 1991) and dry forest vegetation communities are generally poorly conserved in comparison to other forest types (Tasmanian and Australian Governments 2007). Compounding the problem is the continuing decline of large rural trees through the Midlands (Close and Davidson 2004). These large paddock trees are remnants of what would once have been prime

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Tasmanian Masked Owl habitat. Even as isolated paddock trees they still have considerable habitat value (Law *et al.* 2000; Gibbons and Boak 2002; Fischer *et al.* 2010) and are at least partly responsible for the continued presence of Tasmanian Masked Owls at low density in mostly cleared agricultural landscapes. Whether the owls can survive in these landscapes once the large paddock trees have disappeared is not known, but their loss will probably result in the loss of many remaining roost and nest trees given that these trees are often the largest and oldest trees remaining in the landscape. Tasmanian Masked Owls have been recorded roosting in man-made structures such as disused barns but they are unlikely to nest in such situations.

The importance of mature eucalypt forest to the Tasmanian Masked Owl is directly relevant to forest management. A large proportion of the remaining dry eucalypt forest in Tasmania is within areas subject to forestry activity, which has an obvious effect on forest maturity. The way in which forest is managed therefore, has implications for the maintenance of high potential Tasmanian Masked Owl habitat. What is not known with certainty is how much mature forest is important for a pair of Tasmanian Masked Owls. It is probable that the area of mature forest required is related to food abundance, food availability or possibly both. Mature forest obviously has an increased likelihood of providing the large tree hollows needed for roosting and nesting also. However, given the large territory size of the Tasmanian Masked Owl, only a portion of its territory would need to be mature forest for this reason alone.

The best test of a model is to compare predictions from the model with an independent, freshly collected and targeted data set to see whether the results hold true. This was not feasible for the current study but the presence- only, non systematic dataset was the best available for this purpose. The data from the presence-only, non-systematic dataset were supportive of the relationship between elevation and Tasmanian Masked Owl occurrence. The maximum entropy models of these data showed that it was average annual rainfall that was the most important factor in determining where the Tasmanian Masked Owl records lay, with more records occurring in drier areas of the State. Lower average annual rainfall approximately matches the distribution of dry eucalypt forest

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and woodland and is not a surprising result. However, most of the records occurred in areas dominated by the vegetation community *agricultural, urban and exotic* rather than in *dry eucalypt forest and woodland*. It is unlikely that this represents a preference for agricultural land, rather it is likely that it represents a bias in this type of non-systematically collected data (Ferrier 2002). Most of these records are from areas where people are most likely to encounter Tasmanian Masked Owls not necessarily where they are most likely to occur. Tasmanian Masked Owls are most often encountered by chance, often adjacent to roadsides where they are seen in car headlights, and they are often found as road kills. Obviously these types of encounters are more likely to occur where people spend more time. The majority of records are from the vicinities of Launceston and Hobart, the two major human population centres.

Maximum entropy modeling is suited to modeling the distribution of rare species as it is robust to small datasets. It is a presence only method, and thus can be used in analysing datasets that may be collected in a non-systematic way including large databases and museum records. It is being used increasingly for these reasons (Phillips *et al.* 2006; Phillips and Dudik 2008; Perry *et al.* 2011a; Perry *et al.* 2011b). The areas of high probability on the *Maxent* maps represent areas where the model predicts a high probability of Tasmanian Masked Owl presence on the basis of low elevation, relatively warm temperatures in the coldest part of the year and relatively low average annual rainfall. The model suggests that the areas of highest probability are in coastal and estuarine fringes. There is no evidence to suggest that Tasmanian Masked Owls are in a higher density in these areas and it is probably an anomalous result caused by a buffering effect of winter sea temperatures on air temperatures. The modeling is probably more accurate away from the coast.

Both of these methods proved to have value for predicting the optimum habitat of the Tasmanian Masked Owl across the state. There is no doubt that prey abundance/availability, roost site availability and nest site availability are the important resource needs that must be met for the Tasmanian Masked Owl to be able to breed successfully in a location. It is probable that Tasmanian Masked Owls occur in some areas where the

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nest site resource needs are not met, but if so they are by definition not breeding successfully. The existence of population sinks in owl populations has been confirmed elsewhere (Altwegg *et al.* 2003; Schaub *et al.* 2010).

The Bayesian belief network (BBN) produced an intuitive picture of how site-specific habitat features could be affecting Tasmanian Masked Owl habitat on a local basis. BBNs are relatively easy to build and can take advantage of experts' experience when empirical data might be sparse. The BBN presented in this study represented the opinion of one researcher, albeit based on results from robust habitat modeling, state-wide diet data and previously published research. Before a BBN like this is used to make actual management decisions, the methodology used should be refined, involving consensus input from more experts. BBNs that have been used to assist with management decisions elsewhere have usually been peer reviewed and involved a number of iterations. BBNs are useful tools for combining empirical data with expert judgment, and for helping to structure existing knowledge and to communicate with and advise land managers (Marcot 2006). It is preferable that the models be tested and updated with unbiased, known site data on the target species.

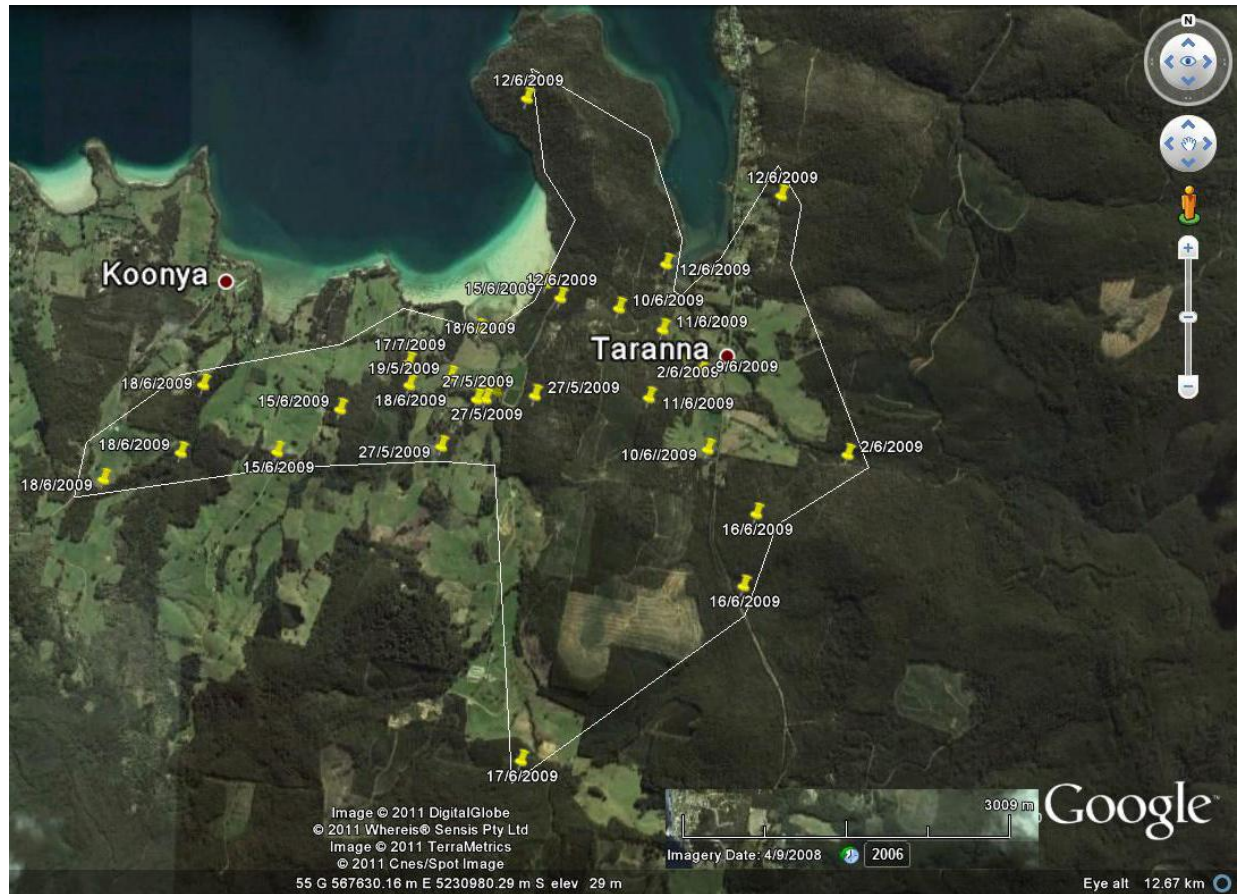
This research demonstrated that it is possible to use habitat occupancy models for rare, difficult to detect species, to create maps of potential habitat that will be able to be used for management purposes. By basing the predicted habitat potential map on data from robust presence-absence occupancy probability models, greater reliability can be placed in the results. The predicted habitat potential map was used to estimate the population size of the Tasmanian Masked Owl at approximately 366 breeding pairs. What remains uncertain is whether these high and very high potential areas support greater reproductive output than medium and low potential areas. Some of these medium and low potential areas could be operating as population sinks while high and very high potential areas could be acting as population sources. Extensive field testing would be required to test these results. The predicted habitat potential map has the potential to be used as a management tool in assessing the probability of Tasmanian Masked Owl occurrence in areas subject to forestry activities, particularly on a landscape scale. The

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combination of habitat occupancy modeling with Bayesian belief networks (the two-tier approach) should be particularly useful for management scenarios with threatened species.

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Appendix 5.1- Locations of radio-tracked male Tasmanian Masked Owl on the Tasman Peninsula between 19/5/2009 and 17/7/2009.



Chapter 6 : Discussion

Habitat has a profound influence on the distribution and ecology of the Tasmanian Masked Owl. Through the use of a range of mostly indirect methods this study confirmed some of the previous assumptions about factors that influence Masked Owl occurrence and habitat. In particular, the study pointed towards the likely importance of prey accessibility and availability in determining the occurrence of the owl. The results provided insight into the value of indirect methods in determining habitat surrogates that may be useful in conservation planning for rare and threatened species. These indirect techniques are less intrusive, more cost effective and less labour intensive than many traditional techniques (e.g. radio-telemetry) used to study owls.

Patterns in the diet of the Tasmanian Masked Owl were determined by analysing regurgitated pellets (Chapter 2). The work provided a baseline from which future research into the diet of the owl and the influence of dominant vegetation types can be investigated. The calling behaviour of the owls was explored by the use of call playback and by analysing recordings of the calls (Chapter 3). The screech calls were found to differ from the mainland Australian Masked Owl in reaching higher maximum frequencies and also lower minimum frequencies. Differences in calls were found between different adults and immature, sexes and individuals. The potential exists for identification of individuals based on their calls, and this has the potential to be a valuable non-intrusive means of monitoring site occupancy. By using the principles of occupancy modelling and call playback surveys, the preferred habitat of the owl was determined to be mature dry eucalypt forest and woodland occurring at low elevations in Tasmania (Chapter 4). This information was used to describe the distribution of high quality habitat for the species (Chapter 5). The result is an improvement in our understanding of the Tasmanian Masked Owl.

Tasmanian Masked Owl- rare species?

The Tasmanian Masked Owl is sparsely distributed across north-western, northern, north-eastern, eastern and south-eastern Tasmania (Chapter 4, Chapter 5) and probably consists of fewer than 500 pairs (Chapter 5). This estimate is similar to, albeit slightly greater than, estimates for two other threatened raptors in Tasmania, the Tasmanian Wedge-tailed Eagle (*Aquila audax fleayi*) and the Grey Goshawk (*Accipiter novaehollandiae*) (Mooney and Holdsworth 1988; Mooney and Holdsworth 1991; Brereton and Mooney 1994). Natural rarity in terms of overall population size may be a feature of Tasmanian raptors due simply to the limited geographic extent of the island. Teasing out the distinction between natural rarity and anthropogenic induced rarity can be complicated and is often not adequately considered when considering conservation status (Gaston 1997). The tangled issue of rarity, perceived threat of extinction and conservation status in lists remains a thorny one (Burgman 2002). For example, ROTAP (Rare or Threatened Australian Plant) lists are dominated by species of restricted range and/ or habitat rather than species with widespread but declining ranges, or that is rare throughout the landscape (McIntyre 1992). Species that are rare but have a wide distribution are more difficult to conserve via the traditional means of conserving only parts of the landscape (Franklin 1993). For many species it is not feasible for them to be adequately conserved solely within the reserve system and so their conservation relies on the ways in which other land use types are managed.

If the Tasmanian Masked Owl is a naturally rare species then it raises the question of how it managed to survive, at a low population size, over a time period of approximately 12,000 years since Tasmania has been separated from mainland Australia (Lambeck and Chappell 2001). Harrison *et al.* (2008) raised a number of potential hypotheses that could explain how naturally rare species could persist through evolutionary time. One of these was that naturally rare species have life history traits that confer extinction resistance (Kunin and Gaston 1993; McKinney 1997). McKinney (1997) reviewed the palaeontological literature and concluded that species that had a wide geographical range but were locally sparse (as in the Tasmanian Masked Owl) were relatively resistant to extinction. Another possibility is that the Tasmanian Masked

Owl has been more numerous in the past and has declined since European settlement. This could be due to a decline in range with the reduction in forest cover through the Midlands and in northern Tasmania, or through an increase in territory size resulting in a lower carrying capacity across the range, or possibly both. A potential cause of an increased territory size could be a reduction in prey availability. Evidence for a range decline is implied by the existence of former cliff roost sites where owls no longer occur (Mooney, N. pers. comm.) suggesting that they may have occurred at a higher density in the past (Garnett *et al.* 2011a).

Conservation of the Tasmanian Masked Owl will probably rely on how land is managed outside the conservation reserve system. Only 6% of the predicted distribution of the Tasmanian Masked Owl lay within dedicated reserves in 2002 (Bell and Mooney 2002), despite this distribution being greater in area than that mapped in the current study. The majority of the very high potential and high potential habitat lies in areas that are subject to forestry activity. Apart from high elevation dry eucalypt forests, many of the least conserved vegetation communities in Tasmania are dry eucalypt forests (Tasmanian and Australian Governments 2007). Although the conservation of the Tasmanian Masked Owl is often discussed in terms of the availability of nesting and roosting sites, the results of this study indicate that the availability (accessibility) of their prey is probably also a critical and sometimes overlooked factor. The relative importance of the availability of foraging habitat and nesting habitat may vary between areas and would be a valuable avenue for future research.

Tasmanian Masked Owl distribution and abundance

Low elevation sites (below 575 metres a.s.l.) were found to be much more likely to be occupied by Tasmanian Masked Owls than higher elevation sites, despite the presence of mature dry eucalypt forest (important to Tasmanian Masked Owls as shown in Chapter 4) in large areas across the Central Highlands. A number of non-exclusive reasons could explain the apparent rarity of the Tasmanian Masked Owl at high elevations. It could be purely physiological, related to tree hollow availability (potentially more important in colder climates for shelter reasons) or it could be related

to food availability. There is no evidence to suggest that suitable tree hollows would be less abundant in high elevation forests than they are at lower elevations. In fact, mature high elevation dry forests which presumably possess many tree hollows, are disproportionately represented in the reserve system in Tasmania (Tasmanian and Australian Governments 2007).

The Tasmanian Masked Owl may possess a low tolerance of cold conditions for physiological reasons. Some studies have suggested that owls in the family Tytonidae (in particular the Barn Owl), are less capable of surviving in cold conditions than owls from the family Strigidae because of their plumage (Johnson 1974) and lipid reserves (Piechocki 1960). Conversely, more recent studies have found that the Barn Owl's lipid reserves are similar to other owls (Massemin and Handrich 1997) and its plumage insulation comparable to other birds (McCafferty *et al.* 1997b; McCafferty *et al.* 1997a). Nevertheless Barn Owls have been reported to be one of the most sensitive of raptors to winter starvation in cold environments (Marti and Wagner 1985; de Bruijn 1994), a situation that is conceivable for the Tasmanian Masked Owl as well given that the genus *Tyto* is mostly tropical in distribution (del Hoyo *et al.* 1999). A study of the effect of cold on captive Barn Owls showed they used hypothermia in only a limited way, relying on energetically expensive regulatory thermogenesis when confronted with cold conditions (Thouzeau *et al.* 1999). Cold temperatures and low prey availability could make high elevation areas marginal habitat for the Tasmanian Masked Owl causing reduced reproductive success as has been noted in owls elsewhere (Thomas *et al.* 1990; Bart and Forsman 1992; Verner *et al.* 1992; LaHaye *et al.* 1997). Research on the abundance of Tasmanian Masked Owl prey at different elevations could be informative and help to elucidate the cause of the increased rarity of Tasmanian Masked Owls at high elevations.

Dry eucalypt forest is preferred by the Australian Masked Owl on mainland Australia (Peake *et al.* 1993; Debus and Rose 1994; NSW National Parks and Wildlife Service 1994; Kavanagh *et al.* 1995) and in Tasmania (Chapter 4). On mainland Australia this may be partly due to the presence of other large forest owl species in other vegetation

types, in particular the Sooty Owl in wet eucalypt forest and rainforest, and the Powerful Owl which occurs in dry eucalypt forest also but preys more often on arboreal mammals (Kavanagh 1997; Kavanagh 2002a). In Tasmania, however, there are no other large forest owls suggesting that the preference for drier forests could be related to a genuine preference for them, or their associated features.

Tree hollow abundance is one potential reason for the preference for mature dry eucalypt forest and needs to be considered. Studies have shown that the frequency of hollow-bearing trees can vary between different eucalypt forest types and between eucalypt species (Munks *et al.* 2007; Fox *et al.* 2009). However, Koch *et al.* (2008a) found no significant difference in tree hollow abundance between dry and wet *E. obliqua* forests in Tasmania. As Tasmanian Masked Owls have large territories of approximately 2000 hectares (Young 2006), if the basic requirements for tree hollows are met, it seems unlikely that extra tree hollows above that threshold would make an area better habitat. However, it is still not known how many tree hollows are required and used by a pair of owls in each territory. For example, mountain brushtail possums (*Trichosurus caninus*) in Victoria, have been shown to use many different tree hollows yet most of these hollows were only used rarely (Lindenmayer *et al.* 1996b). Another consideration is that the greater the number of potential hollows in an area, the greater the likelihood of one of these hollows being suitable (Lindenmayer *et al.* 1996a). The probability of an area supporting a nest site has been shown to increase with increasing density of potential nest hollows overall, in some parrots (Burbidge 1986; Webster 1988; Cameron 2006), however, the territorial behaviour of Tasmanian Masked Owls would limit the usefulness of overall hollow abundance as an indicator of nesting habitat.

While the abundance of tree hollows might not be critical to the Tasmanian Masked Owls in many areas, the quality of tree hollows could still be a factor in the preference for mature dry eucalypt forest. The quality of tree hollows, as opposed to their quantity, can significantly contribute to the reproductive success of hollow-nesting birds (Wesołowski *et al.* 2002; Wesołowski and Rowiński 2004; Berkunsky and Reboreda

2009; Politi *et al.* 2009), including owls (Severinghaus 2007). A preference for particular high quality hollows within the territory of a pair of Tasmanian Masked Owls could make those trees critical and more important than the abundance of hollows in general. With a species that has such a small population size, the requirements of individual pairs of owls should be considered, whenever possible, in any conservation strategy. The most important trees to pairs of breeding owls are an important part of this.

Mature eucalypt forest has a high density of large trees with hollows, suitable for both roosting and nesting purposes for large forest owls (Kavanagh 2002b). However, the variable *potential tree hollow abundance* failed to appear in the closest fitting models for the Tasmanian Masked Owl occurrence (Chapter 4). This suggests that tree hollow abundance per se may not be an indicator of Tasmanian Masked Owl occurrence. A high tree hollow abundance may be an added advantage of mature eucalypt forest but perhaps is not the defining factor itself.

Dry forest in Tasmania tends to support a greater abundance of small and medium sized mammals than wet forest in Tasmania (Flynn *et al.* 2011). Despite the fact that some native small mammals including the swamp rat, dusky antechinus and long-tailed rat commonly occur in wet eucalypt forest (Stephens *et al.* 2011) they are rarely preyed upon by Tasmanian Masked Owls. This combined with a tendency for mature dry forest to develop an open understorey could make dry forest more suitable for Tasmanian Masked Owls on the basis of prey abundance and prey availability. Open understorey will assist Masked Owls by providing a clear access to small and medium ground-dwelling prey. This habitat feature has been suggested as a possible requirement for Masked Owls (Debus 1993b; Kavanagh and Murray 1996; Kavanagh 1997; McCray and Kavanagh 2000).

Barn Owls in the British Isles choose particular sites for foraging on the basis of abundance and availability of preferred prey (Askew *et al.* 2007b; Askew *et al.* 2007a; Taylor 2009). Unlike the Tasmanian Masked Owl, British Isles Barn Owls often hunt in

the late afternoon allowing researchers the advantage of directly observing their behaviour (Taylor 2009). In England, an owl was observed hunting in particular fields that had a higher abundance of the preferred prey (the field vole *Microtus agrestis*) than fields that they did not hunt in. Also, because the actual sites of prey capture were observed, it was possible to show that the capture points had more field voles than control points in the same field (Askew *et al.* 2007b). In Scotland, Barn Owls were found to hunt almost exclusively along the edges of fields where field voles were most accessible (Taylor 1994; Taylor 2009). What this shows is that in the territory of an owl, there are particular areas that are most important for providing adequate and accessible prey that probably make up only a small proportion of the overall territory. There is no reason to believe that Tasmanian Masked Owls should be any less selective of foraging sites; sites with the best access to preferred prey are likely to be critically important.

Access to prey is important in the foraging habitat preferences of owls in Sweden (Aschwanden *et al.* 2005). Long-eared Owls and Barn Owls prefer to forage in open fields rather than in ecological compensation areas (ECAs): areas that have been set aside in agricultural areas for the purpose of improving regional biodiversity (Aschwanden *et al.* 2005; Arlettaz *et al.* 2010), despite the higher abundance of prey species within the ECAs (Aschwanden *et al.* 2007). The reason for this was the inaccessibility of the prey within the dense vegetation of the ECAs. The availability of fields nearby enabled the owls to benefit from greater prey abundance in the vicinity. It would be useful to investigate prey abundance at Tasmanian Masked Owl foraging points (given that these points are usually unknown), and compare these with areas where owls do not forage. This would provide an insight into the ways that prey abundance, behaviour and habitat preferences impact on the Tasmanian Masked Owl. Similarly, differences in these variables across the range of habitats in which the Tasmanian Masked Owl occurs would be informative. Discovering more about small mammal habitat preferences in Tasmania would help us to understand Tasmanian Masked Owl habitat preferences.

According to work by Newton (1979), a raptor the size of the Tasmanian Masked Owl should have an average territory size of 1-7 km², when in fact they probably have an average territory size of close to 20 km² (Young 2006). This suggests that there has been some restriction on the ability of the Tasmanian Masked Owl to reach maximum density. The limitation is unlikely to be reproductive, since in captivity, the Tasmanian Masked Owl can produce multiple consecutive clutches with no regard to season (Fleay 1949), when adequate food supplies are available (C. Spencer, pers. comm.).

It is worth considering the feral population on Lord Howe Island and the isolated Tiwi Island subspecies (*Tyto novaehollandiae melvillensis*) to see if they provide any further insight into owl density in Tasmania, as it also is an island, albeit a larger one. The population on Lord Howe Island is an unnatural situation, yet it could demonstrate what might be possible for island predators with virtually unlimited food supplies.

The Lord Howe population occurs at an extremely high density (Milledge *et al.* 2010; Milledge 2011). Territory sizes of two radio-tracked females were 230 hectares and 75 hectares with considerable overlap of territory boundaries. This population is apparently only limited by the level of tolerance in territory overlap between adjacent pairs. While the forest type on Lord Howe Island is atypical (subtropical rainforest), there are no mammalian predator competitors, large hollow-bearing trees are abundant and rodents (black rat and house mouse) and nesting seabirds provide an abundant food supply (Lord Howe Island Board 2009). The estimated population size of 20 pairs plus immature birds (Milledge *et al.* 2010) in an area of 16.56 km², far exceeds the 2000 hectare territory size previously mentioned for Tasmanian birds. This feral population was previously believed to have originated from Tasmania but is now believed to have been introduced from the mainland (Hogan *et al.* 2012).

The Tiwi Islands subspecies of the Australian Masked Owl appears to occur at a relatively high density given the frequency of its detection in surveys over the last ten years (Woinarski *et al.* 2003; Garnett *et al.* 2011b). Actual territory size information remains unavailable (Smith, J. pers. comm.). This *could* be regarded as the natural

situation for masked owls when they have no large owl competition and mostly intact forest cover. In this scenario, the density of masked owls in Tasmania would be lower than expected suggesting that potential numbers are being limited somehow. However, the comparison between the Tiwi Islands Masked Owl and the Tasmanian Masked Owl is probably tenuous. On the Tiwi Islands, not only are the masked owls free from competition from other large owls they are also free from competition with carnivorous mammals (Woinarski *et al.* 2003). In Tasmania a suite of carnivorous mammals are present including two species of quoll, the Tasmanian devil and historically, the thylacine, all of which would feed to some extent on terrestrial small and medium-sized mammals (Jones and Barmuta 1998; Jones and Stoddart 1998; Glen and Dickman 2006; Dawson *et al.* 2007). The Tiwi Islands also have a very different suite of small mammals present and apparently lack the introduced black rat and house mouse (Woinarski *et al.* 2003). And finally, Tasmania is significantly larger than the largest of the Tiwi Islands.

The territory size of Tasmanian Masked Owls could vary from that estimated here. Some owls would have smaller territories while others would have larger ones as is generally the case with all animals (Moorcroft 2008). This has been found with the Australian Masked Owls that have been radio-tracked on the mainland (Kavanagh and Murray 1996; McNabb *et al.* 2003; Kavanagh *et al.* 2008b). Two alternative arguments can be made in relation to territory size of Tasmanian Masked Owls.

- 1) Semi-cleared areas with greater access to rabbits and eastern barred bandicoots might be better owl habitat and so intact forest territories could be larger than the estimated 2000 hectares. In this scenario there would be fewer owls than has been predicted in this thesis, unless there is a large population of owls in the cleared areas compensating for the lower numbers in the forests.
- 2) Semi-cleared areas might be sub-optimal habitat (as suggested by the modeling) and so the 2000 hectare territory size would be an over-estimate. In this scenario there would be more owls in the forests than suggested in this thesis, as the

territory sizes would mostly be smaller. Alternatively, the best owl habitat, may have been cleared in the past and thus there would be lower numbers regardless.

Tasmanian Masked Owl conservation status

The Tasmanian Masked Owl is a rare species both in terms of its low population size and sparse, although widespread, distribution in Tasmania. Demography, ecology and genetics all interact to affect the persistence of small populations. There has been considerable debate on the question of how large populations need to be to ensure persistence and whether there is a critical population size that is consistent across taxa (Reed *et al.* 2003; Traill *et al.* 2007; Flather *et al.* 2011). Models using minimum viable population sizes (MVPs) have concluded that populations of around 5000, regardless of taxa life history, are necessary to ensure long-term persistence (Reed *et al.* 2003; Traill *et al.* 2007). However, others have argued that risk of extinction is affected by life history and environmental context, variables that are difficult to detect with noisy data (Flather *et al.* 2011) and that there can be no ‘magic number’. Despite the debate about the methods used, most seem to agree that species probably need to occur in multiple populations that total thousands rather than hundreds to persist in the long term (Soulé 1987; Thomas 1990; Sinclair *et al.* 2006; Traill *et al.* 2007; Flather *et al.* 2011). The low population size of the Tasmanian Masked Owl is a concern especially considering that they almost certainly occur as one population, because of their dispersal capabilities. Even if the population size of the Tasmanian Masked Owl before European settlement was twice the size that it is now, total population would have been in the low thousands for approximately 12,000 years, since Tasmania was last separated from mainland Australia (Lambeck and Chappell 2001). Environmental stochasticity, or year-to-year variation in environmental conditions (especially weather) is believed to be the most important source of variation in rate of population change (Sinclair *et al.* 2006). Its effect is often indirect via effects on food supply. It is probable that the Tasmanian Masked Owl has a population size of greater than 500 individuals, the effective population size at which genetic diversity was regarded as likely to remain stable by Franklin (1980). Nevertheless, populations of species that are restricted to islands have been found on average to have a lower genetic diversity than mainland populations

(Frankham 1997). Whether the Tasmanian Masked Owl has a low genetic diversity is unknown, although recent analysis of genetic variation in the Australian Masked Owl has suggested that the Tasmanian Masked Owl is only distinct from the Australian Masked Owl at a subspecific level (Hogan *et al.* 2012). In summary, the low population size of the Tasmanian Masked Owl reduces its likelihood of persistence into the long term and makes it vulnerable to changes in its environment probably via effects on its food supply.

Tree hollow availability is only likely to be a constraint on breeding Tasmanian Masked Owls in areas that have been mostly cleared, as in agricultural areas. Some of these areas may once have been high quality Tasmanian Masked Owl habitat, particularly where dry eucalypt forest and woodland occurred on fertile soils in the Midlands. The species preference for mature eucalypt forest (Chapter 4), further suggests that there may be less Tasmanian Masked Owls in the Midlands today, than there were before European clearing. It is unknown how many breeding pairs occur through agricultural areas such as the Midlands, and also whether these pairs regularly breed successfully. Populations of owls occurring in sub-optimal habitat in other parts of the world are often population sinks (Pulliam 1988; Bart and Forsman 1992; Altwegg *et al.* 2003; Schaub *et al.* 2010). There is also the question of how many of the Tasmanian Masked Owls in the total population are non-territorial floaters (Rohner 1997b; Rohner and Krebs 1998; Sunde 2008; Campioni *et al.* 2010). Presumably many immature owls leave their birth territories and are unable to find high quality territories. European Eagle Owl juveniles fitted with satellite tracking devices in Switzerland were found to disperse over distances up to 230 km from their birthplace. Settlement places of juvenile Eagle Owls were on average 46 km distant from their birthplace (Aebischer *et al.* 2010). Non-breeding Tasmanian Masked Owls may occur in agricultural areas and other habitats that might be low quality habitat. Habitats that are able to provide only enough food to support one or two Masked Owls per territory are obviously not sufficiently food-rich for successful breeding, which would need to be able to support two adults plus offspring.

Tasmanian Masked Owl habitat constraints

The density of Tasmanian Masked Owls in agricultural areas could be determined by reduced roosting/ nesting habitat (loss of large tree with hollows) or reduced food availability. The provision of nest boxes has proven successful in increasing Barn Owl densities (de Bruijn 1994; Johnson 1994; Radley and Bednarz 2005; Klein *et al.* 2007; Meyrom *et al.* 2009) and could be conducted in Tasmania in areas with a shortage of tree hollows but abundant potential prey; this could indicate whether tree hollows are a limiting factor in these habitats. Nest boxes have only been used to a limited extent on Australian Masked Owls (Thomson 2006) and would be most likely to be used by owls in areas with a shortage of natural tree hollows. Alternatively, the rehabilitation of remnants of forest and woodland (particularly in terms of understorey), could result in an increase in small and medium-sized mammal habitat (Mallick *et al.* 1997) and subsequently mammals (prey for owls) as has been found in Switzerland (Aschwanden *et al.* 2005; Aschwanden *et al.* 2007; Arlettaz *et al.* 2010). Either, or both, of these long term experiments could be illuminating.

Introduced species, in particular rodents (black rat and house mouse), were important in the diet of the Tasmanian Masked Owl at most of the sites studied (Chapter 2). Rodents are probably particularly important while the male is provisioning the female and young, while also feeding themselves (DPIPWE 2006). Native rodents were rare in the diet. The native eastern barred bandicoot was prominent in the diet wherever it was common, south of Hobart, but it has become rare over much of its former range (Driessen *et al.* 1996; Reading *et al.* 1996; Mallick *et al.* 1998) and thus not widely available to the Tasmanian Masked Owl. Information on the diet of the Tasmanian Masked Owl before European settlement would reveal which native species owls were feeding on before the arrival of non-native rodents and rabbits. The Tasmanian Masked Owl often roosts in sandstone caves (Sharland 1958; Mooney 1997) and sizable deposits of old owl pellet material can be collected from these sites, some of which are older than European settlement (Garvey 1999; Garvey 2006). Analysis of old owl pellet material from caves has proved invaluable in the assessment of pre-European mammal

faunas elsewhere (Smith 1977; Kusmer 1986; Avery 1991; Bilney *et al.* 2010; Boyer *et al.* 2010). A comparable study would be informative in Tasmania where the Tasmanian Masked Owl is the only large forest owl.

It is possible that there has been a major shift in the Tasmanian small mammal fauna. Native small mammals that are reasonably common like the swamp rat are rare in masked owl diet (also rare in the diet on the mainland) probably due to either behaviour and/ or habitat selection by the rat (Monamy 1995a). Common prey species on the SE mainland (bush rat and brown antechinus) are absent in Tasmania. The black rat has either moved into a vacant niche or it has pushed its way into the niche once occupied by other species. There is some tantalizing info from a small masked owl deposit from a Midlands sandstone cave where broad-toothed rat was the most common prey item (Mooney 1993). Significantly more cave pellet deposits need to be analysed to give a better picture of this.

In forestry situations, it is likely that mature forest has sufficient natural microhabitats of dense vegetation that would provide suitable protective habitat for rodents (Catling and Burt 1997; Catling *et al.* 1998). Areas of re-growth may provide ideal conditions for rodents but their dense nature would probably fail to allow access to prey for the Tasmanian Masked Owl. Even areas with a mostly mature forest canopy would probably fail to provide good foraging habitat for Tasmanian Masked Owls if there was a dense re-growth element in the understorey and mid storey. The thinning of re-growth could have a positive effect on the provision of Tasmanian Masked Owl habitat.

Studies on the effect of logging on mammals in Australia have shown that different species respond in different ways to the habitat disturbance (Lunney 1984; Lunney *et al.* 1987; Kavanagh and Webb 1998; Stephens *et al.* 2011). Populations of the bush rat (*Rattus fuscipes*) and the agile antechinus (*Antechinus agilis*) have been shown to collapse immediately after logging (Recher *et al.* 1980; Lunney and Ashby 1987; Lindenmayer *et al.* 2010), but recover to prior abundance levels within 3-8 years (Lunney and Ashby 1987; Kavanagh and Webb 1998). Both of these species have been

found to prefer dense understorey vegetation (Hall and Lee 1982; Robinson 1987; Catling and Burt 1995a). In contrast, the white-footed dunnart (*Sminthopsis leucopus*) has been shown to prefer open understorey and is probably negatively impacted upon by dense re-growth (Lunney and Ashby 1987; Lunney *et al.* 1989). It has been shown to occur more often soon after logging but then decline after vegetation recovery (Lunney and Ashby 1987; Kavanagh and Webb 1998). In Tasmania, a study in wet eucalypt forests found that the response of small mammals to clearfelling with retained areas (aggregated retention) differed between species with swamp rat (*Rattus lutreolus*) being negatively affected and long-tailed mouse (*Pseudomys higginsii*) showing no effect at all from logging (Stephens *et al.* 2011).

A study in the Central Highlands of Victoria found no difference in small mammal abundance between undisturbed forest and islands of forest that had been retained within clear fell coupes (Lindenmayer *et al.* 2010). The clear felled areas, however, had drastically reduced small mammal abundance immediately after harvest. Lindenmayer and colleagues concluded that the retained islands of intact forest provided refuge areas for small mammals despite their abundance being very low in surrounding clear felled areas. These islands probably operate as a source for small mammal re-colonisation of clear felled areas once they recover and also probably provide shelter for prey from predators.

The common factor is the importance of retaining mature habitat around (or within) harvested areas in production forest landscapes in order to facilitate the recolonisation of the area by mammals (Kavanagh and Webb 1998; Lindenmayer *et al.* 2010; Flynn *et al.* 2011). The retention of patches of intact forest within clear fell logging coupes probably reduces initial impacts of clear felling and may assist the recovery of small mammal populations. The Tasmanian Masked Owl operates at more of a landscape scale and so would be affected by the cumulative effects of many disturbances. It is probable that the Tasmanian Masked Owl prefers landscapes with a mosaic of different age structures, providing roosting habitat, nesting habitat, foraging habitat and prey habitat. It is probably negatively impacted upon by extensive areas of intensively

managed forest, hence its apparent increased occupancy of areas that have mature forest. What is not known is whether areas with a mosaic of different age forest (but including mature forest) are more or less likely to support Tasmanian Masked Owl than areas with entirely mature forest. Surveys for the species in high quality habitat within Tasmania's reserve system could answer this question providing they were conducted using the same methodology as in this study (Chapter 4).

Conclusion

Effective conservation measures for the Tasmanian Masked Owl should have the overall goal of at least maintaining the population size and preferably increasing it. To achieve this, different measures would be required in different parts of Tasmania and within different land uses. The goal on a local scale would be to ensure the availability of roosting habitat, nesting habitat and foraging habitat for the species. This thesis has contributed to a greater understanding of the Tasmanian Masked Owl and it has highlighted significant gaps in our knowledge that should be targeted to refine our understanding of the species, and large forest owl ecology in Australia overall.

Conserving the Tasmanian Masked Owl can be seen as part of a broader issue; the maintenance of ecological integrity in Tasmania's forests. Conserving sufficient areas of mature dry eucalypt forest and in particular a diverse and abundant small and medium-sized mammal fauna will have a positive impact on the survival of the Tasmanian Masked Owl in the landscape. This scenario that could be seen as an example of the keystone species concept at work (Simberloff 1998; Delibes-Mateos *et al.* 2007), i.e. the presence of important prey species being critical to the survival of predators that rely on them.

Apex predators like large owls, can be important to ecosystems- their loss causing widespread cascading effects (Estes *et al.* 2011). Estes *et al.* (2011) conclude that there is a demonstrable threat to biodiversity posed by disruptions to ecosystems brought about by the loss of predators. Large owls are dependent on the existence of adequate

habitat which in turn makes their presence an indicator of biodiversity (Sergio *et al.* 2005; Sergio *et al.* 2008a). The link between breeding density of the Eurasian Eagle Owl (a top predator), and its habitat (principally feeding habitat and food supply) (Penteriani *et al.* 2002), and its subsequent suitability as a biodiversity indicator (Sergio *et al.* 2004), is an excellent example of this.

Mature dry eucalypt forest at relatively low elevations has been found to support the greatest abundance of small and medium mammals (Flynn *et al.* 2011) and it also supports the highest probability of occupancy of the Tasmanian Masked Owl. The converse of this is that an area that is able to support a breeding territory of the Tasmanian Masked Owl must have a diverse and abundant small and medium mammal fauna, as per the umbrella species concept (Simberloff 1998). The utility of raptor territories as a surrogate for biodiversity has been suggested before (Milledge 2004; Sergio *et al.* 2005; Sergio *et al.* 2006), but remains controversial (Cabeza *et al.* 2008; Kéry *et al.* 2008; Roth and Weber 2008; Sergio *et al.* 2008c). Regardless, the complete conservation of ecosystems requires the conservation of all species within the ecosystem which by default includes the top predators and their prey.

By using an assortment of indirect techniques this work has contributed to a greater understanding of the ecology of a rare and threatened owl in Tasmania, the results of which could be applicable to the Australian Masked Owl across its range. The indirect methods proved to be useful and would be valuable in studies of other cryptic or rare fauna species. Prey availability (abundance and accessibility) is likely to be the ultimate factor responsible for the distribution and abundance of Tasmanian Masked Owls and it probably is reflected in the distribution of low elevation, mature dry eucalypt forest in Tasmania.

Chapter 7 : Bibliography

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