Territory size and diet throughout the year of the Wedge-tailed Eagle *Aquila audax* in the Perth region, Western Australia

Simon C. Cherriman

This dissertation is submitted in partial fulfilment of the requirements for the degree of Honours in the Bachelor of Science (Environmental Biology). It represents 80% of the formal course requirements for one academic year.

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Abstract

The wedge-tailed eagle *Aquila audax* is the largest and one of the better known birds of prey in Australia. After being blamed for lamb deaths in many parts of the country, the wedge-tailed eagle suffered a history of extensive persecution for over a century. Consequently, its diet has been studied in a variety of regions, but there is no published literature on its biology near Perth, Western Australia. Thirty-two nests belonging to five eagle pairs were discovered at five sites near Perth, one on the Swan Coastal Plain and four on the Darling Scarp. Two of the study sites, Karakamia and Paruna Wildlife Sanctuaries, are owned and managed by the Australian Wildlife Conservancy (AWC). Over a period of 36 months from 2004 to 2006, eagle behaviour at each site was monitored, and based on location records of wedge-tailed eagle sightings, territory size in this region averaged 35.6 km^2.

Diet was also studied over a three year period in the five territories. A collection of prey remains (n = 610), regurgitated pellets (n = 164), as well as some observations of fresh prey from nests, revealed 13 species of mammals, 20 birds and four reptiles taken as eagle prey. Rabbits *Oryctolagus cuniculus* and macropods (especially immature western grey kangaroos *Macropus fuliginosus*) were the main prey items, constituting 29.1 and 11.7% of total prey numbers, 30.1 and 30.6% of biomass taken (from prey remains), and 49.1 and 15.6% of total pellet mass, respectively. At Karakamia, where several threatened species of marsupial are common in an environment free from introduced mammals, eagles preyed mainly on native marsupials. Brush-tailed possums *Trichosurus vulpecula*, woylies *Bettongia penicillata*, tammar wallabies *Macropus eugenii* and quenda *Isoodon obesulus* contributed 27.4, 11.0, 8.4 and 5.1% of diet biomass, respectively, at Karakamia. In contrast, the diet of wedge-tailed eagles at Whiteman Park in a environment where mammal communities have been highly altered by man, consisted mostly of rabbits (63% by number, 73.8% of biomass). Birds, including Australian ravens *Corvus coronoides* (4.7% of biomass) and wood ducks *Chenonetta jubata* (2.5%) were also important as eagle prey in the Perth region and reptiles, particularly the bobtail skink *Tiliqua rugosa* (0.8%), were less frequently taken.

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Table of Contents

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List of Tables

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List of Figures

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List of Appendices

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1. Introduction

1.1. Background

The largest Australian bird of prey (raptor) and one of the largest members of its genus, the wedge-tailed eagle *Aquila audax* grows to almost one metre in length and has a wingspan of up to 2.5 m (Brooker 1996; Pizzey and Knight 1999). The sexes are similar in plumage but show reversed sexual size dimorphism, with females and males having body weights of 4.7 and 2.5 kilograms, respectively (Brooker 1996; Figure 1).

Plumage of wedge-tailed eagles becomes darker with age, ranging from the golden brown appearance of juveniles to the almost black (apart from the pale wing bar and chestnut nape) form of adults, normally reached at 6 - 7 years when breeding commences (Ridpath and Brooker 1986a). Monogamous pairs hold breeding territories containing several nests (Ridpath and Brooker 1987), defended aggressively from other eagles with conspicuous aerial displays (Brooker 1974). This is similar to that described for other large eagles (e.g. golden eagles *A. chrysaetos*, Dixon 1937; Collopy and Edwards 1989). Nests can reach sizes of 1.8 m wide x 2.9 m deep (Gaukrodger 1924), and are lined with fresh eucalypt sprigs during breeding (Hollands 2003; Olsen 2005). Commonly clutches are of two eggs, but in many cases only one offspring is reared to fledging (Cupper and Cupper 1981). After remaining with their parents during a post-fledging period of 3 - 4 months (Allott *et al.* 2006), immature eagles may travel 784 - 868 km from the natal area (Ridpath and Brooker 1986a; Marchant and Higgins 1993), and for some time occupy a wandering existence before finding mates and establishing breeding territories themselves (Leopold and Wolfe 1970).

Figure 1. Breeding pair of wedge-tailed eagles: larger female (left) and smaller male.

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Arguably one of the most persecuted raptors in the world, the wedge-tailed eagle was shot across Australia for the majority of the 1900s because of its alleged predation on lambs. Bounties on eagles were paid by state governments, and hundreds of thousands of birds were killed throughout a period of extensive persecution. In the ten years between 1950 and 1959 in Queensland and Western Australia, about 120 000 such bounties were paid (Beckman 1988). Subsequently many studies were conducted in various parts of the country on the ecology of this raptor, with emphasis on the proportion each species of prey animal comprises in their diet, in an effort to establish the true impact of eagles on lambs (see Marchant and Higgins 1993 for review; also Olsen 2005; Olsen *et al*. 2006; Debus *et al*. 2007). Wedge-tailed eagles eventually received protection throughout Australia in 1989 (Brooker 1996; Parker 2000). In Western Australia bounties ceased in 1967, but in 1980 the wedge-tailed eagle remained without protection (apart from in the Shire of Kojonup) and was still declared vermin in 17 shires (Brooker and Ridpath 1980). It is now protected as a native species under the *Wildlife Conservation Act 1950* (DEC 2007). Nonetheless, wedge-tailed eagles are still shot and poisoned illegally in some areas.

1.2. Territory Size

The territory size of raptors is thought to be influenced by the reliability of available food resources and amount of suitable nest sites in a certain area (Newton 1976). It is an important aspect of raptor ecology, especially in conjunction with diet information, as it gives further insight into the success of birds in differing habitat types. Several methods have been used to determine the territory/home range size for large eagles, particularly golden eagles in various parts of their range in the northern hemisphere. However, no Australian studies on wedge-tailed eagles have focused solely on territory size. Rather, most have investigated a combination of ecological aspects such as diet and nesting success (Leopold and Wolfe 1970; Brooker and Ridpath 1986a, 1986b, 1987; Robertson 1987; Sharp *et al*. 2001; Dennis 2006).

1.2.1. Territory Size Study Methods

In a study of golden eagles in San Diego, Dixon (1937) plotted the locations of 27 breeding pairs on a map. He then drew what were considered to be the boundaries of each territory, based on 36 years of experience in studying the eagles in the field. The area of each territory was calculated, ranging from 19 to 59 square miles (about 49 - 152 km^2), and averaging 36 square miles (92 km^2). While this method may have been accurate for that particular study, it relied on extensive behavioural studies of resident pairs and could result in considerable errors for other studies. Without plotting locations known to be visited by territorial eagles over a period of time (e.g. through radio-tracking), there remains a chance eagles could utilize habitat unknown to the observer.

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The ‘minimum area’ method of animal home range (Mohr 1947) involves calculating the area enclosed by imaginary lines connecting the outermost points visited by the individual animal(s). Collopy and Edwards (1989) employed this technique to quantify the boundaries and territory size of golden eagles nesting in south-western Idaho, the mean of which was determined as 3276 ha (approximately 33 km²). This method may produce an overestimate of territory size if boundaries are not well defined. However, the Idaho eagles had abutting territories, with once again researcher experience compensating for possible errors, and for the purpose of this study the figures obtained were deemed to be accurate (Collopy and Edwards 1989). They were also of the same magnitude as those of Dixon (1937).

Near Carnarvon on the dry west coast of Western Australia, mean territory size of wedge-tailed eagles was determined to be 50 km², and in the south-east of this state, it ranged from 32 - 103 km² (Ridpath and Brooker 1987). These figures were calculated by dividing the total study area by the number of territorial eagle pairs. In the Canberra area Leopold and Wolfe (1970) found wedge-tailed eagle territories averaged 31 km² using the same technique. Similarly, Phillips *et al.* (1990) used this approach and found golden eagle territories along the Montana-Wyoming border to range from 29 - 36 km². Once again years of experience allowed the researchers to become familiar with eagle pairs, and also reduced the chance of pairs going undetected in the study area. This method may be accurate in unfragmented habitat where vegetation clearing is minimal, however in severely altered landscapes it is probably over-simplified. In populated zones (such as the Perth metropolitan region), territory size may be overestimated, as eagles may not fully or only intermittently utilize patches of significantly altered land (e.g. residential areas and closed-canopy pine plantations; Olsen 2005).

Watson *et al.* (1992) investigated golden eagle nesting density in Scotland during 1982 - 1985. It ranged from 26.1 - 14.7 pairs per 1000 km², which equates to a territory size range of approximately 38 - 68 km², or an average of 51 km² per territorial pair. Watson *et al.* (1992) arrived at these figures by assessing the number of territorial pairs per unit of potential hunting ground (open country), thereby discounting habitats not conducive to eagle hunting such as closed canopy woodland, open water and farmland close to habitation. This method helps account for errors that could arise from considering the whole study area, which may contain unsuitable foraging habitat, and thus overestimate territory size (e.g. Ridpath and Brooker 1987).

At two study sites in western Scotland, Haworth *et al.* (2006) used a combination of recording daily positions of eagles triangulated by using radio-tracking equipment, and plotting actual eagle sightings on maps, to calculate a ‘ranging distance’ from the centre of the birds’ territory

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(as determined by the nest area). Based on this information, golden eagle territory size averaged approximately 30 km² (2955 ha, calculated from data in Haworth *et al*. 2006). As expected, range figures were smaller during the summer (breeding season) when eagle activity focussed primarily around an active nest site, and larger in winter (non-breeding), when demand from developing chicks was reduced and a broader area searched to satisfy feeding requirements of the adult eagles. The more restricted summer range was also thought to be a result of greater food availability, meaning birds did not have to travel as far to find food as in winter (Haworth *et al*. 2006).

Using radio-tracking and triangulation methods over an extended period, such as those discussed above, is perhaps one of the more accurate ways of quantifying eagle territory size. It is, however, a costly and time-consuming exercise, and the capture and application of radio-harnesses to wild eagles may disrupt natural behaviour and introduce biases. Another method which has been used successfully in the past is the 'nearest neighbour' method (Krebs 1999). Distances between the nearest neighbour (in the case of eagles, distances between active nests) are measured and the mean is calculated. Using this method, Sharp *et al*. (2001) found the mean distance between active wedge-tailed eagle nests in western New South Wales to range from 2.05 - 3.35 km, suggesting nesting densities of one pair per 3 - 9 km². However, it was emphasised that these results should not be taken as an indicator of territory size, as foraging distances varied with landforms and as a result territories were probably elliptical in shape.

In a study of wedge-tailed eagle territories on the Fleurieu Peninsula, South Australia, the nearest neighbour method was slightly modified in an alternate approach (Dennis 2006). Here, the average midpoint distance to three nearest neighbour active nest sites was used as a radius to calculate a theoretical circular territorial area which denoted likely 'ownership.' These calculations determined a range of 18.1 - 75.5 km², or an average eagle territory size of 34.3 km² (Dennis 2006). The territory sizes calculated appeared to be accurate for this study, and the large area surveyed (1540 km²) and high number of breeding pairs recorded (29) probably accounted for this. Also, the study zone consisted of a long, narrow peninsula bounded by ocean (small area relative to perimeter), therefore definite boundaries could be assigned to it (wedge-tailed eagles do not occupy open ocean), and there was a high degree of certainty that all breeding pairs were found. However, for study regions not bounded by open water, these methods may not be accurate as it would be difficult to assign definite boundaries, and error is increased if relatively few breeding pairs are considered.

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1.2.2. Territory Size Summary

In considering the variety of methods available, the technique used to quantify eagle territory size is dependent on the physical parameters of the individual study area. The resources available to the investigator and the objectives of the research should set standards as to how accurate these calculations must be. However, with all methods, familiarity with both the study region and the resident eagle pairs are useful in providing better grounds for accurate data collection on and validation of territory size.

1.3. Raptor Diet

1.3.1. Importance of Raptor Diet

Research into the individual aspects of any animal's life gives us valuable insight into its ecology as a whole, and this is especially relevant to birds of prey (Lewis *et al.* 2004). A raptor's physical characteristics are usually well suited to the ecosystem in which it belongs, and by studying diet, we can relate physical adaptations to behaviour relevant to hunting techniques (Olsen 1995). Diet information also reveals how well a species can cope with changing environmental conditions, its population density and distribution, and the success of its breeding in various environments. Furthermore, the degree humans influence the life of raptors can be evident through diet studies (e.g. exposure to harmful pollutants; Olsen 1995). Together these facts support the argument that studying diet is perhaps the most useful form of research on raptors for conservation and management purposes.

1.3.2. Breeding Diet

Like most creatures, raptors essentially have two stages in their life: they are either breeding or not breeding. Most raptor activity is centralised around a particular nest site during a period of time while breeding occurs (Olsen 1995). This is advantageous to researchers as a known nest location can be revisited over a season to gather information. Consequently, most raptor dietary studies have focused on the breeding season.

1.3.3. Non-breeding Diet

Non-breeding diet can theoretically be determined in a similar way to breeding diet, by collecting the remains of animals eaten and regurgitated pellets (see 'Diet Study Methods' in Section 1.4 below), given a perching area is known (Baker-Gabb and Pettigrew 1982). However, the behaviour of raptors in the non-breeding season can be very different from the breeding season, depending on the species (Olsen 1995). Wedge-tailed eagles can occupy very large territories (Ridpath and Brooker 1987), and travel extremely large distances (Ridpath and Brooker 1986a). Discovering roosts and perch trees within their territory is challenging without radio- or satellite-tracking of birds, making it a costly and time-consuming exercise. Even if

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some roosts and perches are discovered, wedge-tailed eagles have many more within their territory (N. Birks pers. comm.), and do not always use the same sites (unlike some owls; Valente 1981). Further problems, including scavenging and feeding behaviour (discussed below) still apply to the non-breeding season. Therefore, few studies focus on raptor non-breeding diet.

The only known study to include some analysis of 'summer food' for wedge-tailed eagles was conducted on the dry west coast of Western Australia (Brooker and Ridpath 1980). This data was in the form of pellets collected from below perch trees. These pellets contained the same types of prey species as determined by the prey remains and pellets from nests during breeding. Although eagles apparently reused the perch trees, the topography and vegetation within the study area facilitated easy location of the trees: this would not always be the case in other bio-regions of Australia, where topography and vegetation structure differ.

1.4. Diet Study Methods

Studies on raptor diets have been made across the globe for many species using a variety of methods, and can give qualitative (types of prey eaten) or quantitative (numbers of prey eaten) results (Marchant and Higgins 1993; Olsen 1995). A combination of both of these results gives the best information. A researcher armed with the knowledge of numbers of each type of prey eaten by a raptor over a particular time span has a very good ecological understanding of that species. Three common methods of diet study are direct observations, prey remains and pellets, as discussed below.

1.4.1. Direct Observations

In theory, making direct observations of raptor hunting could give the most accurate interpretation of food habits. However, raptors are generally cryptic animals, and it is often difficult to observe their behaviour in the field for extended periods (Collopy 1983a). One study on Australian kestrels *Falco cenchroides* in New South Wales did manage to quantify diet by using direct observations (Genelly 1978). Over 300 prey-capture events were observed and in most cases prey were able to be categorised (Genelly 1978). However, this study was conducted on a species which hunts by hovering over open farmland, making observations of birds easy, and despite intensive fieldwork, some data from a collection of pellets was still required to determine actual numbers of individual prey.

In most other cases, hunting away from nests is rarely observed, and as raptors are very alert creatures with sharp eyesight, watching their behaviour at nests undetected is difficult. Other studies have used hides or blinds at raptor nests to identify prey species delivered (e.g. Collopy

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1983b; Redpath *et al.* 2001). These provide more reliable data, although once again there is a requirement for high observation time (e.g. approximately 1950 hours, Collopy 1983b). More recently, video cameras have successfully been used obviating the need for an observer to remain in a hide for long periods (Takeuchi *et al.* 2006; Collins and Croft 2007; Silva and Croft 2007).

1.4.2. Prey Remains

During the nesting season, a large amount of prey is brought back to a raptor's nest as food for developing young, and the remains of this can be collected from beneath nests and identified with relative ease (Marchant and Higgins 1993; Olsen 1995). A common approach is to use prey remains to enumerate the minimum number of individual prey animals that these items constitute (e.g. Leopold and Wolfe 1970; Brooker and Ridpath 1980). This allows the researcher to determine the proportion of each type and number of prey taken in one nesting season, and in doing so provide both qualitative and quantitative data.

Feeding roosts not necessarily associated with nest sites have also been used as a source of raptor prey remains. African fish eagle *Haliaeetus vocifer* diet in Kenya was inspected based on skeletal material collected from beneath a roost that was used for successive years by several eagles, providing a reliable source of prey remains (Stewart *et al.* 1997). Similarly, Smith (1985) used remains from nests and roosts to determine the diet of the osprey *Pandion haliaetus* and white-bellied sea-eagle *H. leucogaster* on islands of the Great Barrier Reef. Both these studies quantified a variety of prey animals for the raptors concerned, although it was not specified whether they focused on breeding or non-breeding seasons.

Considering prey numbers alone determined by prey remains can misrepresent the importance of various prey species. For this reason, minimum prey numbers are often used to calculate total biomass consumed, by multiplying numbers by approximate weights of various prey species (e.g. Brooker and Ridpath 1980; Tjernberg 1981; Baker-Gabb 1984; Collopy 1983b; Aumann 1988; Olsen *et al.* 2006; Debus *et al.* 2007; Parker *et al.* 2007; Winkel 2007). It then becomes clearer if a raptor hunts preferentially for a particular weight range of prey, or a particular species regardless of its weight.

1.4.3. Pellets

A common technique used in determining diet is by analysing regurgitated pellets collected from nests and roost sites (e.g. Leopold and Wolfe 1970; Brooker and Ridpath 1980; Baker-Gabb 1984; Hull 1986; Debus and Rose 1999; Harder 2000; Davey and Pech 2004; Sharp *et al.* 2002a, 2002b; Olsen *et al.* 2006; Debus *et al.* 2007; Parker *et al.* 2007; Winkel 2007). Like

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many other birds, raptors regurgitate pellets that contain indigestible material consumed during feeding. Some raptors, particularly nocturnal species such as owls, have a favoured roost site, and pellets that accumulate under these can be collected (Valente 1981). Mammalian hair and fur in pellets can be microscopically analysed to determine the species to which it belongs (Brunner and Coman 1974; Triggs and Brunner 2002). Feathers and scales, which also occur in pellets, can often be identified to genus or sometimes species (Baker-Gabb 1984; Hull 1986), depending on the detail required in the study. Proportions of each type of hair, fur, feathers and scales in a pellet are then calculated, using either proportion of the total pellet volume (Dickman *et al.* 1991), mass (Parker *et al.* 2007), or percentage composition estimated by eye (Brooker and Ridpath 1980), to determine the relative abundance of various prey species in pellet material.

1.4.4. Assessment of Diet Study Methods

The broad range of raptor diet studies that exist have all used at least one of the three methods discussed above, or a combination of several. The results obtained for certain species have shown considerable variation, and it is useful to know which of the methods have given the most reliable results. Generally speaking, direct observational data is the most accurate, both qualitatively and quantitatively, provided sufficient time is spent in the field to account for all raptor prey delivered to nests. This requirement however, can make direct observations impractical. Prey remains are thought to overestimate larger prey quantitatively and underestimate smaller prey, which may be missed altogether, and the converse applies if pellets alone are used.

Studies that have used direct observations include that of Collopy (1983b), who observed no differences between the species composition (i.e. qualitative data) recorded at golden eagle nests in south-western Idaho when the prey remains collection method was compared to direct observations. However, a substantial underestimate of biomass (i.e. quantitative data) resulted from the prey remains data alone, and the observational data was necessary for a true account of actual numbers of prey delivered. This research recommended that further studies using prey remains also use systematic observations to increase the accuracy of their quantitative data.

In Scotland, Redpath *et al.* (2001) combined the direct observation technique with the use of prey remains and pellets collected from hen harrier *Circus cyaneus* nests, to compare the three methods of analysis. The raptors' nests were watched twice weekly from hides to record prey items delivered, and prey remains and pellets were also collected from beneath nests prior to each watch. As with other findings, it was concluded that prey remains over-represented larger prey and under-represented smaller prey. Combining data from remains and pellets did not

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eliminate biases from either technique, however the consideration of pellet material gave higher species diversity than the observational data alone. This was probably because the harriers fed on smaller prey, which were harder to identify directly.

Pellets gave the most accurate representation of diet of Bonelli's eagle *Hieraeetus fasciatus* in Spain, which was investigated using the three study methods in an assessment to see which method was most effective (Real 1996). This study showed that biases arose from using prey remains alone as indicators of food because smaller prey animals were eaten whole and thus underestimated. In addition, differences in the number of prey remains of different prey species were detected. More bones of pigeon *Columba* spp. were found than were rabbit bones, even though observations confirmed that these two species occurred at similar proportions in the eagles' diet. This difference was attributed to the adult eagles being inclined to remove larger prey items (i.e. rabbit bones) from the nest, and leave inconspicuous bones of smaller prey (i.e. pigeons).

Adult nest-cleaning behaviour is known to confound prey remain studies if larger prey items, which normally persist in nests for longer periods, are regularly removed (Tjernberg 1981; Real 1996). However, with golden eagles in Sweden, Tjernberg (1981) found the consistency of this behaviour to vary greatly between pairs. Furthermore, remains discarded on the ground either directly below or away from the nest are vulnerable to removal by scavengers such as foxes (Sharp *et al.* 2002a). Resistance to natural decay also varies with the size of remains, and unless collections are made regularly while a nest is in use, smaller, more fragile items are likely to be missed (McGahan 1967). All these problems make the reliability of obtaining an effective sample highly variable.

Glading *et al.* (1943) conducted a study to determine the reliability of raptor pellets as indicators of food habits. This research showed that the presence of a prey animal in a pellet is indicative that the raptor has consumed one item of that species. However, it was determined that while this assumption can be reasonably accurately applied to the pellets of owls (order Strigiformes), hawk (diurnal birds of prey: hawks, kites, harriers, vultures, eagles and falcons within the order Falconiformes) pellets, on the other hand, can be misleading and are unreliable indicators of prey quantities. This is because owls usually capture prey and swallow it whole, leading to the production of a pellet comprising the whole prey animal in regurgitated form (Valente 1981). Hawks, however, carefully dissect prey and eat selective portions of it (Glading *et al.* 1943). Thus, an eagle feeding on one large prey species may regurgitate pellets over several days containing material of that species, which would result in an overestimate of quantitative prey data obtained from these pellets (Sharp *et al.* 2002a). Despite this, many subsequent studies

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seem to have made a general assumption that Glading *et al*'s (1943) findings apply to all raptors, and still use pellet analysis to quantify the diet of birds from the order Falconiformes.

More recently, technology has allowed for errors in the direct observation method to be minimised with all the prey brought to a nest documented through video surveillance. Northern goshawk *Accipiter gentilis* diet was assessed using three methods at nests in south-east Alaska (Lewis *et al.* 2004). Observational data was gathered from video footage recorded each day at nests throughout the period of rearing young, as well as collections of remains and pellets. Combining the two indirect methods gave a similar account of diet to the video-recording method. However, directly recording prey delivered to the nest revealed more individuals and higher species diversity of prey than did the analysis of remains or pellets. This is contrary to the findings of Redpath *et al.* (2001), who recorded a higher prey species diversity from pellets than from observations alone, although the observational data in this case was made from hides not cameras, increasing the likelihood of some prey being missed.

Takeuchi *et al.* (2006) studied golden eagle diet at one nest over two breeding seasons using direct video-recording. This research concluded that the eagles predominantly selected Japanese hare *Lepus brachyurus* over other types of prey. Although the effectiveness of using the direct recording method was not assessed in this study, it appeared to account for virtually all prey items that were delivered to the nest, the majority of which were easily identified. Using video not only increases the effectiveness of study at a single nest, but it also allows the simultaneous surveillance of several nests (Silva and Croft 2007). Hence this technique is most useful if the research is focussed on studying diet of a particular raptor species over a broad area.

Despite the effectiveness of videographic methods, their use may be limited by the sensitivity of the birds under study. Breeding failures were thought to be researcher induced when eagles abandoned nests after camera installation during two separate studies in successive years in western New South Wales (Collins and Croft 2007; Silva and Croft 2007). In this way, not only did the diet study at those nests fail, but it also caused unnecessary reproductive failures, which are undesirable in any form of research.

Using observations, food remains and pellets at nests can also be unreliable because these methods assume all prey eaten during the breeding season is brought back to the nest (Parker 2000). Other potentially important prey items in the diet of eagles could be eaten away from nests and thus go undetected (McGahan 1967), especially as pellets may not always be cast at or near the nest site (N. Birks pers. comm.). A female little eagle *Hieraaetus morphnoides* was observed to return to the nest with a full crop, despite no food being delivered to the nest during

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a full day of observations, suggesting feeding away from the nest (Debus 1983). In addition, studying diet in the breeding season only may not give an accurate account of the food a raptor takes in its life as a whole, as this may change throughout the year (Olsen 1995; Parker 2000). There is speculation that wedge-tailed eagle diet during the year consists mainly of live prey in the breeding season (for adults and nestlings), and of carrion in the non-breeding season (Olsen 1995), however no studies have explored this hypothesis.

1.4.5. Diet Study Methods Summary

No method of diet study is without its shortfalls, and invariably the use of only one will produce an intrinsic bias. Employing a combination of various techniques will present a broad analysis of a raptor's diet, increase the qualitative sample size (Sharp *et al*. 2002a), and therefore give more insight into its food habits as a whole. Importantly, when collecting data on food habits of raptors, data from pellet analysis and that from prey remains should be presented separately to avoid biases and ensure findings are as accurate as possible (Sharp *et al.* 2002a).

1.5. Previous Research on Wedge-tailed Eagle Diet

The diet of many of Australia's 24 species of diurnal raptor has been studied in a variety of places since the early 1900s, but detail of findings varies between species and parts of Australia (e.g. Marchant and Higgins 1993; Baker-Gabb 1984; Aumann 2001). The wedge-tailed eagle, because of its history of persecution, has attracted special interest with regard to food habits, particularly from conservationists who are sceptical about accusations of eagles having an impact on lambs and the sheep industry. It is now probably one of the better studied Australian raptors with regard to its diet, however, most studies have occurred in eastern Australia.

1.5.1. Formal Studies

One of the first studies on wedge-tailed eagle diet was conducted in south-eastern Australia (Leopold and Wolfe 1970). This research demonstrated that collecting prey remains from nests during the breeding season gave an accurate description of the number and type of prey eaten. Freshly killed prey animals were counted at active nests every few days, and the proportion of total prey they comprised was found to be very similar to the proportion of remains collected from other nests in the same area. Mammals were shown to be the most favoured prey of wedge-tailed eagles, with European rabbit and hare *Lepus capensis* comprising 60% of their diet by number. The adaptability of eagles was also demonstrated, with the birds taking other prey in arid areas where lagomorphs were not as abundant: rabbits 31% of diet, kangaroos (26%), birds (15%), and lizards (18%). Despite these findings, however, biomass was not considered and prey size was not quantified.

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Wedge-tailed eagle diet in this region was subsequently reviewed by Fuentes *et al.* (2007) in 2002 and 2003 in a study which investigated eagle prey preferences four decades after Leopold and Wolfe (1970). This research found that there were significant changes in various prey categories. Compared to the findings of Leopold and Wolfe (1970), the eagles ate less rabbits (43.8% in 1964 *cf.* 16.9% in 2002 - 2003), hares (15.8 *cf.* 7.9%) and lambs (8.9 *cf.* 1.8%), and consequently consumed greater quantities of macropods (1.9 *cf.* 19.4%), parrots (3.5 *cf.* 10.9%) and other birds (4.6 *cf.* 17%; Fuentes *et al.* 2007).

Near Melbourne, the diet of wedge-tailed eagles was studied in open farmland surrounded by eucalypt forests, where prey remains and pellets were collected from eight nests (Hull 1986). In this area the eagles ate mostly rabbits, but interestingly ringtail possums *Pseudocheirus peregrinus* constituted a substantial proportion (20%) of prey (Hull 1986). From this study it is evident that, contrary to popular belief, eagles can occupy closed forest and successfully hunt animals found in this habitat type (Burnett *et al*. 1996; Fawkner 1991). Like Leopold and Wolfe (1970), Hull's (1986) study also presented diet as number of individual animals taken, but it combined the results of pellet analysis and prey remains, and did not consider biomass.

Robertson (1987) assessed eagle diet as well as reproductive success in New South Wales by collecting and identifying prey remains from nests, and investigating if rabbit numbers influenced breeding density and success. Once again, rabbits were the main prey, and although their density influenced the number of young eagles fledged per nest, there was an upper limit to the breeding density of eagles even in years of very high rabbit abundance. No pellets were considered, and as this study focused mainly on breeding success of the eagles in relation to food supply, information on diet composition is limited by the one technique of analysis used.

Harder (2000) discovered that eagles in eastern New South Wales ate 29 species of vertebrates, comprising 50% mammals, 27% birds and 23% reptiles by number. Subsequent studies in New South Wales have reached similar conclusions to this and other research. Sharp *et al*. (2002a, 2002b) found that eagles ate mainly rabbits where available (47.8% of diet), as well as reptiles (22.6%) and macropods (13.7%). However, following the introduction of the Rabbit Calicivirus Disease (RCD) to some of the study sites, the proportion of reptiles in eagle diet increased dramatically (up to 54% in some areas), a further indicator of the ability of wedge-tailed eagles to adapt their diet to include the most readily available prey. In a similar study very close to the same area, rabbits were the main prey again, but in contrast prey switching was not observed (Davey and Pech 2004). Rabbits were still being hunted despite other prey species being of higher abundance, indicating selective, species dependent feeding.

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In more recent times, a study of wedge-tailed eagles and white-bellied sea-eagles near Canberra investigated the dietary overlap between these two species (Olsen *et al*. 2006). This research showed that although similar in size and occupying the same general habitat, the two species generally ate mutually exclusive prey species. Wedge-tailed eagles again preferred mammals, especially juvenile eastern grey kangaroos *Macropus giganteus* and rabbits (22.2 and 12.6% of biomass, respectively) while sea-eagles ate mostly fish (54.1% of biomass) and sea birds (29.7%). Diet quantification methods combined the findings of previous research, and a more accurate account of prey numbers was given by: (1) using prey remains to determine minimum numbers; (2) using pellets to add to this minimum number data but not double-counting individual species and not assuming one pellet represented one prey item (*cf.* Glading *et al.* 1943); and (3) supplementing the minimum number data from prey remains and pellets with observations of prey deliveries or kills that were not identified by either of the first two methods. This approach was chosen to minimise sources of bias found in other studies (Collopy 1983b; Real 1996; Sharp *et al.* 2002a).

Using the same methods as Olsen *et al.* (2006), breeding diet in the New England region of New South Wales was studied in one year at two wedge-tailed eagle nests (Debus *et al.* 2007). After biomass calculations, which took into account wastage factors of different sized prey, rabbits were again determined to be the favoured prey (40% of biomass). Breeding biology, including adult behaviour at nests and observed hunting events, were also described. This research presented findings of the most recent formal study on wedge-tailed eagle diet and breeding biology to date.

1.5.2. University Projects

Four University Honours projects have been conducted to study wedge-tailed eagles in various locations in the eastern states of Australia. These have since been published as scientific journal papers (Collins and Croft 2007; Parker *et al.* 2007; Silva and Croft 2007; Winkel 2007). Prey remains and pellets were analysed separately by Winkel (1993) in a study conducted in north-west Queensland, where eagles appeared to show an overwhelming preference for mammals (up to 89% of biomass) compared to birds (10%) and reptiles (1%) in their feeding habits. Mammalian species taken included lamb (up to 21% of biomass), red kangaroo *Macropus rufus*, pig *Sus scrofa* and cat *Felis catus*, while non-mammalian species included Australian bustard *Ardeotis australis* and bearded dragon *Pogona vitticeps*.

Subsequent research by Silva (1998) and Parker (2000) have reported similar findings to other studies previously mentioned, with mammals again constituting the preferred diet. The study methods used by Parker (2000) also followed those of previous research, with prey remains and

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pellets both being considered with their findings presented separately. Parker (2000), who found macropods to dominate eagle diet, also suggested that eagles are selective predators, taking lambs despite variations in their relative abundance and travelling large distances to do so.

In a different approach to previous research, Silva and Croft (2007) and Collins and Croft (2007) used video-surveillance to monitor active eagle nests and record the behaviour of parent eagles at the nest, as well as the type of prey animals taken. This method generally proved easier than those previously employed to study diet, as most whole animals were sighted and identified as they were brought to the nest. However, Silva and Croft (2007) were unable to identify 32% of prey animals delivered. Also, the very invasive process of installing cameras at nests caused many hatching failures, and for conservation purposes, was not recommended in the future (Silva 1998).

1.5.3. Studies in Western Australia

In Western Australia, the first major study on wedge-tailed eagles examined diet, as well as nest sites and spacing, breeding in relation to food supply, age and movements (Brooker and Ridpath 1980; Ridpath and Brooker 1986a, 1986b, 1987). This research concluded that the eagles ate a wide range of food types, but where available preferred mammals greater than 500 g in mass, especially rabbit, but also brush-tailed possum *Trichosurus vulpecula*, kangaroo *Macropus* spp., fox *Vulpes vulpes* and cat. A variety of bird species, especially those weighing more than 100 g, were also taken, including those from orders Anseriformes (pacific black duck *Anas superciliosa* and wood duck *Chenonetta jubata*), Psittaciformes (galah *Cacatua roseicapilla* and ringneck parrot *Barnardius zonarius*) and Passeriformes (Australian raven *Corvus coronoides* and Australian magpie *Gymnorhina tibicen*), as well as emus *Dromaius novaehollandiae* (chicks were taken as live prey, adults as carrion) and some raptors (e.g. brown falcon *Falco berigora*).

A variety of methods were used by Brooker and Ridpath (1980) to determine eagle diet, including pellet and prey remain analyses, however these two methods were combined to determine overall prey proportions. Both number and biomass of prey items were considered, where biomass was calculated by multiplying the number of individuals by the average weight of that prey type. Differing results were obtained from each approach. For example, the proportion of mammals in prey remains was 53% by number, but 83.7% by biomass in one study area (Brooker and Ridpath 1980), indicating the importance of larger prey to eagles.

Endangered mammals and rabbits were found to comprise the diet of wedge-tailed eagles at Shark Bay, Western Australia in a study which compared two areas with differing mammal

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populations (Richards and Short 1998). On Bernier Island where rabbits are absent, threatened banded hare-wallabies *Lagostrophus fasciatus*, rufous hare-wallabies *Lagorchestes hirsutus*, and burrowing bettongs *Bettongia lesueur*, comprised 53%, 35.9% and 8.5% respectively of eagle diet. These proportions were very similar to the percentage of each species in the total mammal population, suggesting unselective feeding by wedge-tailed eagles. At Heirisson Prong on the mainland, where all three species of threatened mammal are extinct, eagles fed solely on rabbits, corresponding to the findings of Brooker and Ridpath (1980) and other studies. More recently in this area, a dietary switch was observed during an outbreak of RCD, and eagles at Heirisson Prong included pied cormorants *Phalacrocorax varius*, some reintroduced burrowing bettongs, and reptiles in their diet (J. Richards unpub. data). Pellets were not collected from eagle nests in either of these studies, and remains used to quantify diet were almost all skulls (Richards and Short 1998; J. Richards unpub. data). Apart from threatened mammals and rabbits, and a small quantity of fish remains, no other animals were found in the diet.

1.5.4. Other Diet Observations

Other reports of wedge-tailed eagle diet are from observations made as short notes and anecdotal sightings published in various journals and other Australian publications, and have not been part of formal studies on diet. These also include photographic studies which have listed various sightings of prey animals (Cupper and Cupper 1981; Hollands 2003). Most prey animals taken in these observations are consistent with the findings of research mentioned above, and further illustrate the adaptability of wedge-tailed eagles. For example, eight piglets were taken from a farm by a pair of eagles nesting nearby (Anon. 1944). Eagles sometimes hunt in pairs to kill small lambs (Cain 1936; Debus 1978), and work cooperatively in larger groups to bring down adult kangaroos (Geary 1932; McGilp 1936). Two adult eagles were witnessed feeding on a deer calf (Anon. 1995), which they were most likely to have hunted cooperatively. Threatened burrowing bettongs and hare-wallabies have been removed from a breeding enclosure at Dryandra Woodland, near Narrogin in Western Australia (Friend and Beecham 2004; Fulton 2006). At one nest in New South Wales, 120 rabbit carcasses were counted, and at another where rabbits were not abundant, galahs were the main food source, as well as foxes, hares, small kangaroos and goanna (Hobbs 1962). Emu chicks and a black bittern *Ixobrychus flavicollis* were observed to be hunted by wedge-tailed eagles by Burton and Morris (1993). Remains of birds including great cormorants *Phalacrocorax carbo*, spoonbill *Platalea* sp. and grey teal *Anas gibberifons* were found at a nest in central western New South Wales (Brooker 1983), and larger cockatoo species (yellow-tailed black-cockatoo *Calyptorhynchus funerus* and galah) have been taken in flight (Haby 1997). There are even reports of attacks on humans: seven wedge-tailed eagles dive-bombed a group of children who were not accompanied by any adults (Le Souef 1905).

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1.6. Study Aims and Objectives

Despite the extensive research base on wedge-tailed eagles in Australia, no research has been published in the present study area, which includes the Darling Scarp and Swan Coastal Plain of the Perth region. This is because few nests have previously been discovered (M. Brooker pers. comm.). Cherriman (2004) analysed the remains of prey from six eagle nests in this region and showed that wedge-tailed eagles consumed more birds in the Mediterranean zone than the arid zone (*cf*. Brooker and Ridpath 1980); this probably reflected prey availability at the time of the undergraduate university study, and limited study time span. An insufficient amount of data was obtained to conduct statistical analyses, and most findings presented were anecdotal. However, this project provided a grounding for further research, forming the basis of the present honours study which further examined the diet and investigated territory size and nest characteristics of wedge-tailed eagles.

The objectives of this project were to:

1) Estimate the territory size of the wedge-tailed eagle in the Perth region and compare it with that of eagles in other bioregions.

2) Assess the diet of the wedge-tailed eagle in the breeding season.

3) Assess the diet of the wedge-tailed eagle in the non-breeding season.

4) Compare the breeding and non-breeding diet of the wedge-tailed eagle in the Perth region.

5) Compare the diet of the wedge-tailed eagle in the Perth region to that of eagles in other bioregions.

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2. Study Area and Climate

The study was conducted in the Perth region in the south-west of Western Australia (Figure 2), and extended from Whiteman in the west, east to Chidlow, south to Kalamunda and north to Bullsbrook (Figure 3). The area consists of two major landforms, the Swan Coastal Plain and the Darling Scarp.

The Swan Coastal Plain is a narrow belt composed of aeolian, alluvial and colluvial sand deposits that extends from Jurien Bay (Latitude 30°06'S) in the north to Dunsborough (33°45'S) in the south (Gibson *et al.* 1994). It is bounded by the Indian Ocean to the west and the Darling Scarp to the east (Figure 2). Vegetation is highly diverse with 30 distinct communities recognised, including *Eucalyptus* and *Banksia* woodlands, as well as various shrublands and damplands (Gibson *et al.* 1994).

The Darling Scarp is a major geological feature that extends from Bullsbrook (Latitude 31°40'19"S) in the north to south of Dardanup (33°23'58"S) in the south (Markey 1997). It forms a boundary between the Darling Plateau to the east and the Swan Coastal Plain to the west (Figure 2). The escarpment occupies a narrow region of about one to three kilometres wide, rising above the Swan Coastal Plain to an altitude of about 250 m. This zone includes the area of transition from coastal sandplain with associated plant communities described above to jarrah forest on the lateritic soils of the Darling Range (Markey 1997).

The Perth region experiences a dry, Mediterranean climate, with seasonal rainfall occurring mostly in winter (Table 1). This is followed by a warm, dry summer of five to six months. Comparatively the Darling Scarp receives much higher annual rainfall than the adjacent Swan Coastal Plain (average 800 - 900 mm), due to an orographic effect with the sudden increase in altitude (Gentilli 1989). The annual precipitation commences at 800 - 1100 mm at the foothills on the western edge of the scarp and increases to over 1200 mm on the highest ground, with peaks of over 1300 mm at locations 10 - 12 km east of the Darling Scarp. There is an additional rainfall gradient in a north-south direction, with an increase from about 700 mm per annum north of Bullsbrook to nearly 1300 mm per annum at Dwellingup to the south (Gentilli 1989). Importantly, since the mid-1970s there has been a sustained 15 - 20% reduction in rainfall in the south-west of Western Australia encompassing much of the study area (Nicholls 2002), which has major on-going implications for maintenance of habitat and ecosystem function.

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TABLE 1

Temperature and rainfall figures for seven locations in the Perth region.

Source of data: [1]Bureau of Meteorology 2007; [2]AWC 2007a; [3]Davies 2007.

Location	Elevation (m above sea level)	Mean Max. Temp. (°C)	Mean Min. Temp. (°C)	Mean Rainfall (mm)
[1] Perth Metropolitan	25	24.4	12.6	758.9
[1] Perth Airport	15	24.4	12.1	783.5
[2] Paruna Wildlife Sanctuary	259	*	*	728.1
[2] Karakamia Wildlife Sanctuary	280	*	*	800.5
[3] Mt Helena	295	*	*	1213.7
[1] Kalamunda	210	22.6	12.0	1066.8
[1] Bickley	384	22.5	11.0	1106.3

* = not available

The nesting territories of wedge-tailed eagles documented in this study occurred in five main study areas (Figure 3): Whiteman Park, located on the Swan Coastal Plain; and Karakamia Wildlife Sanctuary, Paruna Wildlife Sanctuary, Gidgegannup (which includes John Forest National Park), and Helena Valley (which includes Mundaring and Kalamunda National Parks), all located on the Darling Scarp.

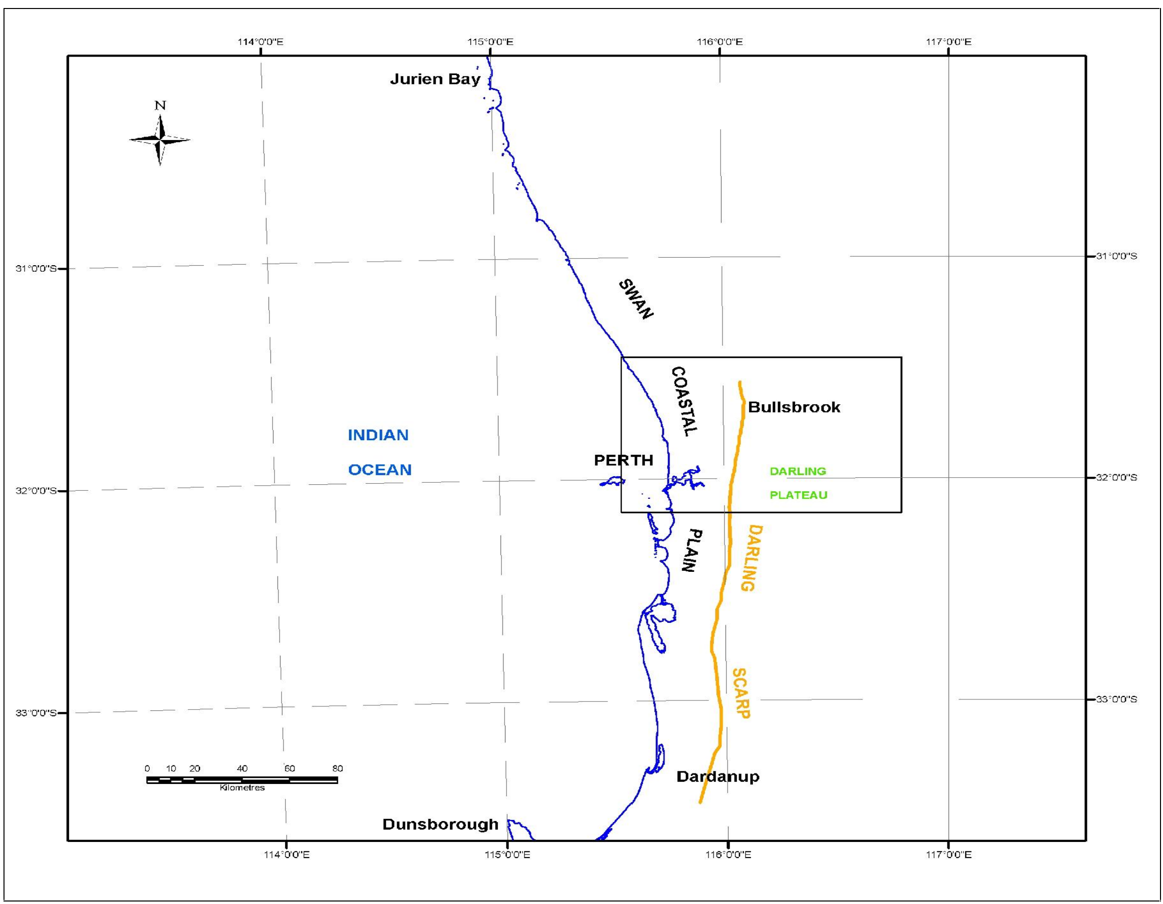

Figure 2. Location map showing the Perth region and related features.

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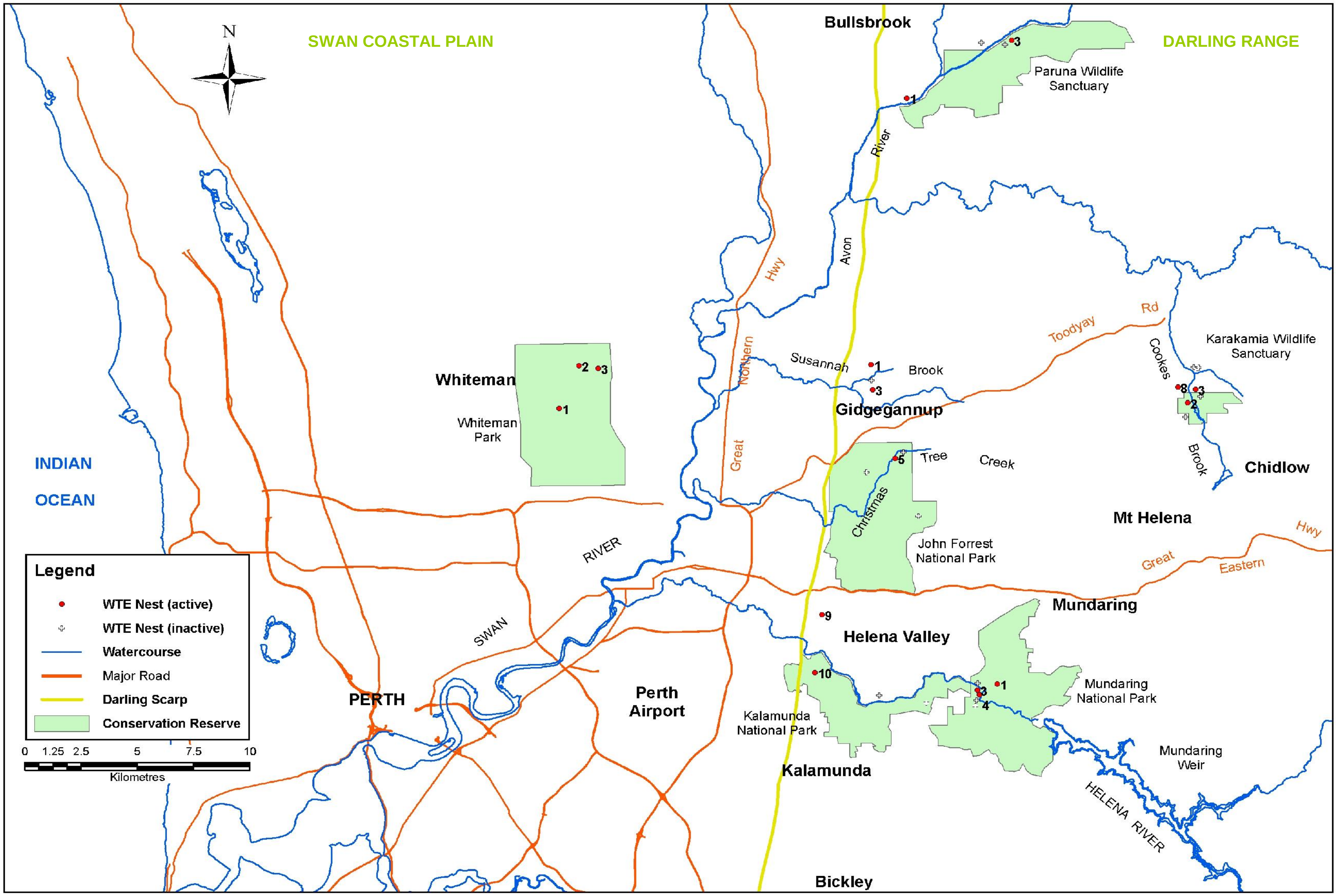

Figure 3. Wedge-tailed eagle (WTE) nests (active nests are numbered) and study sites in the Perth region.

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2.1. Whiteman Park

Situated approximately 20 km north of Perth on the Bassendean dune system, Whiteman Park (Figure 3) is one of the largest areas of extensive bushland in a relatively natural state on the Swan Coastal Plain (State of Western Australia 1997). The park is more than 4 300 ha in area, with about 2 000 ha forming part of the conservation area (State of Western Australia 2007). The land is managed by staff from the Department for Planning and Infrastructure (DPI), who undertake a variety of conservation initiatives. Every two to three months, 100 dried meat baits and 60 eggs containing 1080 poison (sodium monofluoroacetate) are dispersed in the conservation area to control fox numbers (J. Whyte pers. comm.).

The landscape has undulating sandy dunes, which support about 25 plant community types. These include occasional large jarrah *Eucalyptus marginata* and marri *Corymbia calophylla* trees among *Banksia* (*B. menziesii*, *B. attenuata* and *B. ilicifolia*) woodland and associated shrubs, and damplands of *Melaleuca* species and sedges (Whiteman Park 2003). Topographically, the undulating landscape is quite different to that of the other four study sites, however, occasional mature eucalypt trees on the dune crests provide the eagles with suitable nest sites. Three nests were located in the conservation area (Figure 3; Table 2). Nest 1 was relatively old and was used successfully in 1997 and 1999 (Brooker 2006). Since the beginning of this study, two new nests were constructed: Nest 2 (constructed 2004, used 2004 and 2005) was located north-east of Nest 1, and Nest 3 (constructed and used 2006) is directly east of Nest 2.

2.2. Karakamia Wildlife Sanctuary

Karakamia Wildlife Sanctuary is owned and managed by the Australian Wildlife Conservancy (AWC). AWC is an independent, non-profit organisation dedicated to the conservation of Australia's threatened wildlife and ecosystems. AWC acquires land to establish sanctuaries, implement practical on-ground conservation programs, conduct scientific research into key issues and undertake public education programs. Currently the organisation owns 16 sanctuaries covering 1 800 000 ha (AWC 2007b).

Karakamia was established in 1991 and consists of 260 ha of bushland in the Perth Hills (Figure 3). AWC in conjunction with the Western Australian Department of Environment and Conservation (DEC) reintroduced several species of native mammals to the sanctuary during the 1990s, which have become re-established in an environment in which they once were abundant. These include the woylie (brush-tailed bettong) *Bettongia penicillata*, quenda (southern brown bandicoot) *Isoodon*

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obesulus, tammar wallaby *Macropus eugenii*, western ring-tailed possum *Pseudocheirus occidentalis*, quokka *Setonix brachyurus* and numbat *Myrmecobius fasciatus* (Copley and Schmitz 1997). Feral animals including the European fox, cat and rabbit were eradicated before native mammal reintroductions took place, and have been prevented from re-colonising with a nine kilometre feral-proof fence, which encloses the sanctuary.

The vegetation consists of upland jarrah and marri woodland, wandoo *Eucalyptus wandoo* woodland, granite outcrop shrubland, and about eight other major plant communities described by Markey (1997). As well as remnant bushland, the sanctuary has some areas of open grassland and is surrounded mostly by cleared farmland for grazing stock (AWC 2007c). Cooke's Brook, the main drainage system, flows through a deep valley which is the favoured nesting area for wedge-tailed eagles. Eight nests are known from this valley system (Figure 3; Table 2), three of which were active during the course of this study.

2.3. Paruna Wildlife Sanctuary

Paruna Wildlife Sanctuary was established by AWC in 1998, creating a 2 000 ha wildlife corridor between Walyunga National Park to the south-west and Avon Valley National Park to the north-east (Figure 3). Paruna forms a southern border along the Avon River. This major watercourse and its associated valley system is deep and rugged, with vegetation generally dominated by upslope wandoo woodlands and various shrubs and heathland communities on the steep valley slopes (Markey 1997), and mixed jarrah and marri forest on the hilltops (AWC 2007c).

The sanctuary is home to several threatened mammal species that were initially reintroduced during the late 1990s, and whose populations have been supplemented with additional releases into the 2000s (AWC 2007c). These animals include the woylie, quenda, tammar wallaby and black-flanked rock-wallaby *Petrogale lateralis*. Other native mammals including the chuditch (western quoll) *Dasyurus geoffroii* have become re-established in the sanctuary by natural re-colonisation from adjacent National Parks following fox control. A 17 km vermin-proof fence extends along the southern boundary of Paruna, and stops most feral animals from entering the sanctuary from open farmland areas further south. Broad-scale fox control is carried out monthly by the distribution of dried meats containing 1080 poison, which helps minimise fox numbers. The rugged Avon Valley with its associated large (mostly wandoo) trees is ideal nesting habitat for wedge-tailed eagles. Four nests are known from this area (Figure 3; Table 2), with only two active during this study.

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2.4. Gidgegannup

This study site was located almost directly east of Whiteman Park at the edge of the Darling Scarp and consists of two valley systems divided by a major highway, Toodyay Road (Figure 3). Although not as rugged as the Avon Valley, these valleys contain vegetation very similar to that described in Section 2.3 ‘Paruna Wildlife Sanctuary’ above, with dominant wandoo trees and open heathland covering fairly steep terrain. Seven wedge-tailed eagle nests were located at this study site (Figure 3; Table 2). Three of these lay in one valley (which contains Susannah Brook) to the north of Toodyay Road and the other three were located in another valley (containing Christmas Tree Creek) just south of Toodyay Road in John Forrest National Park. One nest (Nest 7) was not directly near either of the smaller clusters. Only two of these nests were active during this study, one in each of the two smaller clusters of three. It is therefore possible that two separate eagle pairs may occupy this area. However, both smaller clusters have not been active simultaneously in any one year, and given the proximity of each cluster compared to distances between alternate nests of other pairs in this region, they have been assumed to belong to the same pair of eagles for the purpose of this study.

2.5. Helena Valley

The Helena Valley borders the Helena River, which extends from east of the Darling Range in a westerly direction to the Swan Coastal Plain (Figure 3). It lies directly south of the Gidgegannup site, and includes the conservation areas of Kalamunda and Mundaring National Parks. The valley is steep-sided, and vegetation here is very similar to that associated with the Avon Valley, and described for ‘Paruna Wildlife Sanctuary’ in Section 2.3 above. Ten wedge-tailed eagle nests are known from this valley system (Figure 3; Table 2). Six of these nests were clustered in a small area approximately 5 km east of the other four. Some of these nests are probably very old, and may have been built by a previous pair of eagles utilizing a different nest area within this valley, which have since died or moved away. As with the Gidgegannup site described above, two pairs of eagles may occur here, but again for the purpose of this study, no nests were active simultaneously in any one year, and thus are assumed to belong to the same pair.

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3. Methodology

3.1. Nest location and Characteristics

Wedge-tailed eagles have been studied in the Perth region since 1999 (Cherriman 2004; this study). Several pairs of adult birds often centralise their territory in rugged valleys (e.g. the Avon and Helena Valleys described above), running approximately west to east into the Darling Range at the foot of the Darling Scarp. With four exceptions, all nests were located by opportunistic surveys conducted by the author since 1999 in the territory of each breeding pair (Nests 1 and 2 at Whiteman Park were shown to the author by J. Wallace; Nest 1 at Karakamia by A. Dugand; Nest 10 at Helena Valley by M. Brooker). This involved walking through bush along the ridge of one side of a steep valley and periodically searching trees on the opposite side of the valley with binoculars. Nests were usually obvious, especially if they were built in wandoo trees, as the dark nest sticks contrasted with the pale bark of the nest tree. On discovery of a nest, its approximate height and dimensions were recorded. During June and July each year, known nests were checked for eagle activity, and other suitable areas within each territory were inspected for any newly built nests unknown to the observer. The nest was deemed active if it contained eggs, or if it was lined with fresh leaves, which usually indicate a prelude to laying (Olsen 2005).

3.2. Territory Size

The locations of wedge-tailed eagle nests were used to determine the core territorial area of each pair of wedge-tailed eagles. All nests located were grouped in small clusters, where the distance between nests in a cluster was relatively small compared to the distance between nests of alternate clusters (Ridpath and Brooker 1987; Robertson 1987). Usually one nest in a cluster was active during a breeding season, and it was assumed that each cluster of nests belonged to a separate breeding pair. The area in proximity to the nest cluster was the territory of the resident pair of eagles, and the same birds usually occupied the same territory each year (Kochert *et al.* 1999). When aerial displays were observed, these were always in the vicinity of a cluster of nests, and it was assumed that the resident pair was defending this area as a breeding territory (Brooker 1974). Land between clusters of nests was assumed to be the surrounding home range of a breeding pair which would have some overlap between neighbouring eagles.

Eagle territory size was determined by the 'minimum area' method (Mohr 1947) as used for golden eagles by Collopy and Edwards (1989). This involved finding the outermost points visited by individual eagles and calculating the area enclosed by imaginary lines connecting them. These

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locations were recorded through observation in the field within each territory and plotted on a 1:100 000 topographic map. It was thought that this method would provide the most accurate results for this study, as the researcher had become increasingly familiar with movements and behaviour of each pair of eagles. In addition, eagle territorial displays had been observed at the outermost locations from the associated pairs' active nest, and this supported the theory that these points were a reasonably accurate representation of the external boundaries of each territory (Collopy and Edwards 1989). Other methods previously used for large eagles were either too general (Dixon 1937), would have produced gross overestimates (Ridpath and Brooker 1987, Phillips *et al.* 1990), were over-complicated (Watson *et al.* 1992, Dennis 2006) or beyond the scope of this study (Haworth *et al.* 2006).

3.3. Breeding Diet

Three separate techniques were used to give the most accurate account possible of the diet of wedge-tailed eagles in the Perth region during the breeding season, which was considered to be from May to November. Diet was quantified by collecting prey remains, regurgitated pellets, and observing fresh prey taken to the nest when inspected for prey remains during breeding. To avoid any bias that may occur from using any one method simultaneously (Sharp *et al.* 2002a), the results of these techniques were presented separately (e.g. Parker *et al.* 2007).

3.3.1. Prey Remains

All visible remains of wedge-tailed eagle prey were collected from below nest sites known to be active throughout the study from 2004 to 2006. Nest sites included the nest tree, as well as nearby perch trees where prey is carried to and 'prepared' before being presented at the nest to incubating adults or developing nestlings. Nests were visited several times during each breeding season, usually only after eggs had hatched to prevent desertion of the eggs by incubating parent birds.

Prey remains were sorted and identified to genus, and if possible, to species, by comparison with specimens in a reference collection made from the same region as the study, and by using specimens from the Western Australian Museum. Data from prey remains were calculated using the methods of Leopold and Wolfe (1970) and Brooker and Ridpath (1980), whereby remains were used to determine the minimum number of individual prey animals consumed (Figure 4). Numbers were then converted to biomass using approximate weights of prey animals (Appendix 1), obtained by weighing a sample of the prey population or from the literature. A maximum of 5000 grams was used for larger animals based on the maximum weight an eagle can carry (Brooker and Ridpath

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1980). The average weight for each of the three prey categories (mammals, birds and reptiles) was used for an approximate weight of unidentified members of these categories, respectively. Sources of prey weights were, mammals: Gemmell and Nelson (2004); Strahan (2004); Willis and Collman (2006); Winkel (2007); L. Appelt (pers. comm.); birds: Serventy and Whittell (1976); Beutel *et al.* (1983); Johnstone and Storr (1998, 2004); Y. Sitko (pers. comm.); reptiles: B. Maryan (pers. comm.).

Although other studies have calculated actual weights of prey taken using growth curves (Richards and Short 1998; Olsen *et al.* 2006) and wastage factors (Baker-Gabb 1984; Parker *et al.* 2007), no attempt was made to do this in the present study. This was because: (1) prey remains did not reliably consist of a representative suite of bones required to calculate approximate weights; and (2) the figures that were used were considered to provide a reliable indicator of the relative importance of various prey species based on their weight, rather than relying on prey numbers alone.

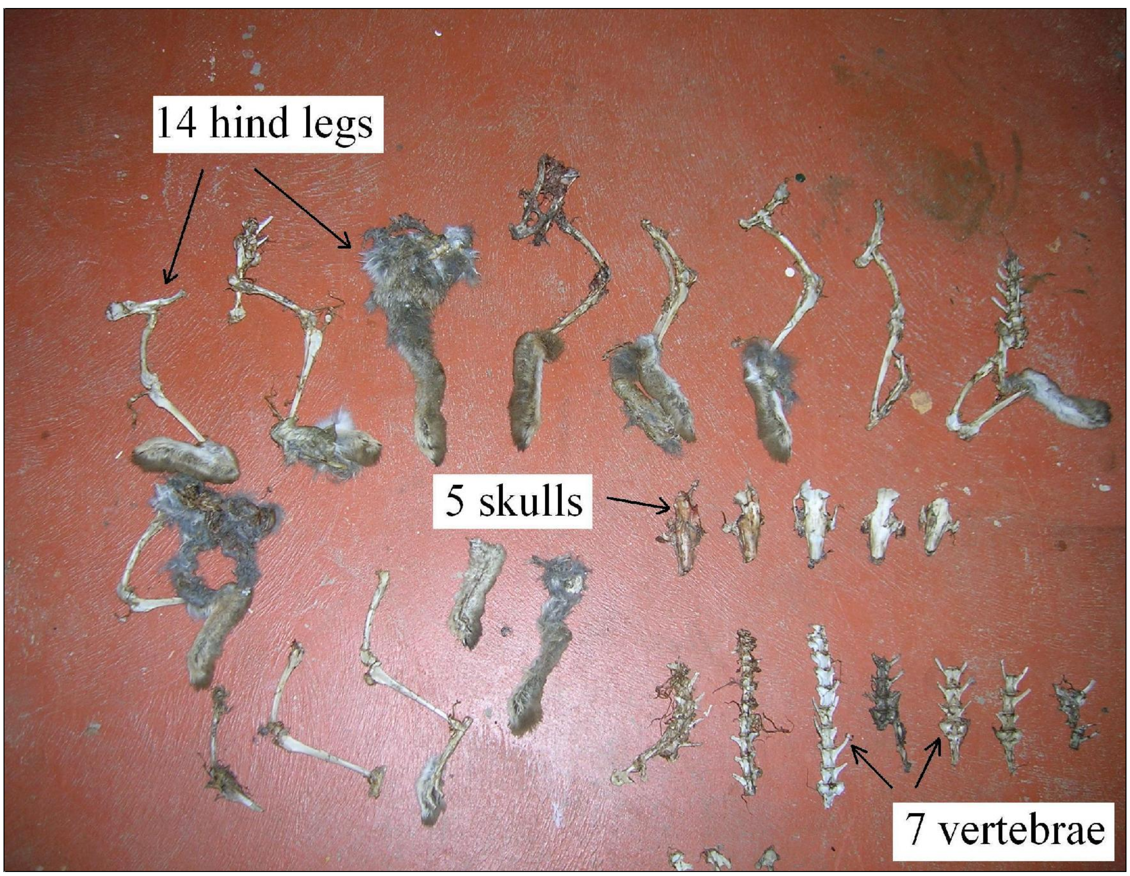

Figure 4. Procedure of calculating minimum numbers from prey remains: 26 fragments constituting a minimum number of seven rabbits *Oryctolagus cuniculus*.

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3.3.2. Pellets

Regurgitated pellets containing fur, feathers and other indigestible prey material were also collected from nest sites during the breeding season. After being air-dried for 24 hours, each pellet was weighed, teased apart with tweezers, and analysed on a plastic dissecting tray in the laboratory (Figure 5). Hair, fur, feathers and scales found within a pellet were separated and the percentage composition of each material was estimated. This was done by spreading the contents over a 20 x 20 cm grid (composed of 100 x 2 cm² squares) and counting the number of squares occupied by each type of material (Figure 6). Length of pellets was not recorded as many pellets were broken into fragments, and pellet length was not considered to be a useful parameter for this diet study.

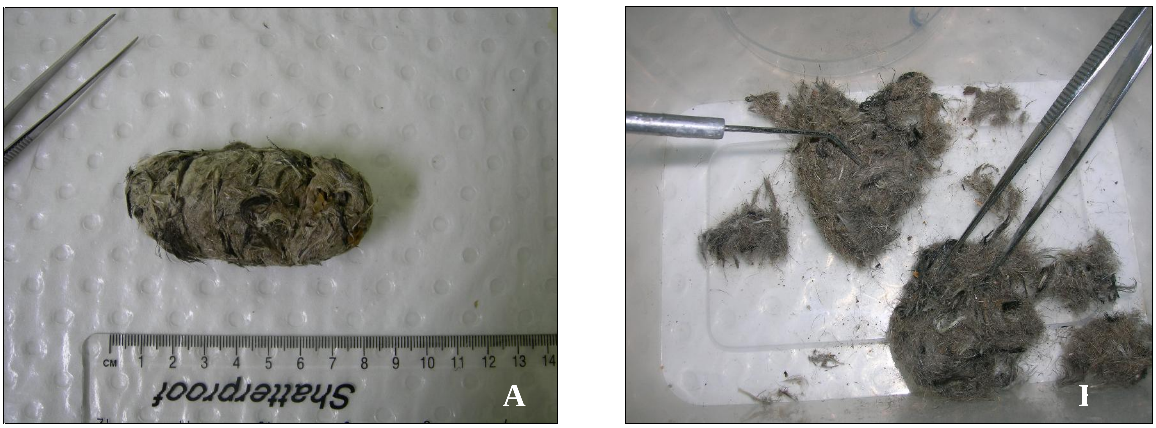

Figure 5. Procedure of analysing eagle pellets in the laboratory: intact pellet (A), being dissected (B).

Figure 6. Procedure of determining percentage composition of wedge-tailed eagle pellet. This pellet was comprised of 55% mammal (bottom) and 45% bird (top). Bone fragments and nails have been separated and are visible at top left.

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Material in pellets was then allocated to a particular prey category. Feathers were classified as belonging to 'bird' and occasionally were able to be identified to genus or species by comparing them with the reference collection; scales were classified as 'reptile,' with material being identified to genus or species where possible; hair and fur were classified as 'mammal' and identified to genus or species where possible using techniques discussed by Brunner and Coman (1974), and using reference photos from the Hair ID CD (Triggs and Brunner 2002). This involved observing whole mounts of mammal guard hairs under the microscope to analyse hair medulla patterns, which are diagnostic for different genera or species. Other material found in pellets, for example bone fragments, were identified as prey remains (above) and used to aid in identification of a prey category within a pellet. The number of categories in each pellet was then recorded.

Finally, the mass of prey categories in a pellet was calculated by assigning the percentage composition of that category in the pellet to the pellet's mass (Doncaster *et al.* 1990). Prey categories contained in eagle pellets were represented as: (1) the frequency of pellets in which a prey category occurred; and (2) the percentage mass of prey categories in pellets (Dickman *et al.* 1991). No attempt was made to quantify the number of individual prey animals represented in pellets (Glading *et al.* 1943). This method can produce biased results for raptors such as wedge-tailed eagles, whose prey may be over- or under-estimated depending on its size (Collopy 1983b; Real 1996; Dickman *et al.* 1991; Redpath *et al.* 2001; Sharp *et al.* 2002a).

3.3.3. Fresh Observations

Observations of fresh prey were made when the active nests were visited for collection of prey remains and pellets during the breeding season. Any fresh kills on the nest platform were recorded and identified to species using appropriate field guides: Menkhorst and Knight (2004) for mammals, Pizzey and Knight (1999) for birds and Bush *et al.* (1995) for reptiles.

3.3.4. Statistical Analyses

Chi-squared Goodness of Fit analyses were carried out on the prey remains and pellet data using SPSS for Windows Version 15.0. Raw frequencies were used for both prey remains and pellet data. Some prey species had expected values which were too low for valid analysis using Chi-squared tests, so the data for these were pooled into broader categories. Mammals were classified as genus or species where possible or as 'other mammal'; birds were grouped into five categories based on their Order: Anseriformes, Columbiformes, Psittaciformes, Passeriformes and 'other bird'; reptiles were grouped as one 'reptile' category. This was done for both prey remains and pellets to allow for

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comparison between the two diet study methods. Chi-squared tests were then performed separately on prey remains and pellet data to determine eagle preferences for prey categories across the whole Perth region, and on prey remain data only (unpooled, except for two introduced pigeons, see Appendix 3) for two of three prey animal classes (i.e. mammal and bird) to determine preferences for species within these classes. Pellet data was not included in the latter of these analyses because of difficulty in identifying all prey animals in pellets to the species level, and reptiles were excluded because of insufficient data. Chi-squared cross-tabulations were also performed on the three prey classes for both prey remain and pellet data to determine which of these each pair of eagles exhibited significant preference for at the five study sites.

3.4. Non-breeding Diet

In order to compare breeding with non-breeding diet, it was necessary to collect prey data during the non-breeding season (December to April). At the beginning of the study it was assumed that like some other raptors, for example Australian kestrels (Genelly 1978), wedge-tailed eagles use the same roost site each night and regurgitate a pellet, which contains material from food eaten that day. This is the case during the breeding season, where most eagle activity is centralised around the nest site (Olsen 2005).

Observations of eagles in the field were made to determine if any favoured roosts existed during the non-breeding season. At all study sites, records were kept of any eagle sightings, especially those of birds feeding on live prey or carrion. This was done with the help of staff from Karakamia, Whiteman Park and others who notified the author of any observations of wedge-tailed eagles during the non-breeding season. During the 2005 - 2006 non-breeding season at Whiteman Park, one of the smallest study sites, an attempt was made to locate roosting eagles at night, in the hope that pellets would be found. However, this was not successful and the method was not used at any of other sites (see '2006 Non-breeding Season' in Section 4.4.1).

Pellets containing fur, feathers and other indigestible prey material that were collected within the territory of wedge-tailed eagles during the non-breeding season were analysed using the same methods for 'Breeding Diet' in Section 3.3.2, as discussed above.

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4. Results

4.1. Nest location and Characteristics

Thirty-two nests belonging to five breeding pairs of wedge-tailed eagles were located and monitored within the five study sites to determine whether they were active during each breeding season. Details of nests from the five study sites are shown in Table 2, and the location of each active nest is shown in Figure 3. Nests dimensions averaged 1.3 m wide by 1.1 m deep, mean height above ground was 15.5 m, and each pair had an average of 6.4 nests. Breeding success for nests where the outcome was known is also shown in Table 2.

TABLE 2

Characteristics of wedge-tailed eagle nests in the Perth region.

Study Site	Nest Number	Tree Species	Nest Height (m)	Width x Depth of Nest (m)	Year Active	Young Fledged
Whiteman Park	1	*C. calophylla*	20	1.5 x 1.8	1997, 1999	u
	2	*E. marginata*	10	1.2 x 0.5	2004, 2005	1, 1
	3	*C. calophylla*	12	1.2 x 0.8	2006	2
Karakamia	*1	*C. calophylla*	12	u	u	-
	2	*E. marginata*	22	1.5 x 1.2	2005	1
	3	*E. wandoo*	10	1.2 x 0.6	2004	u
	*4	*C. calophylla*	15	1.3 x 1.5	u	-
	*5	*C. calophylla*	16	1.0 x 1.2	u	-
	*6	*E. marginata*	18	1.2 x 1.5	u	-
	*7	*C. calophylla*	19	u	u	-
	8	*C. calophylla*	20	1.2 x 1.8	2006	1
Gidgegannup	1	*E. wandoo*	10	u	2001	1
	*2	*E. wandoo*	12	1.5 x 0.5	u	-
	3	*E. wandoo*	12	1.2 x 0.4	2005	1
	*4	*E. wandoo*	18	1.5 x 1.6	u	-
	5	*E. wandoo*	15	1.5 x 0.5	2004	0
	*6	*E. wandoo*	10	u	u	-
	*7	*C. calophylla*	20	1.5 x 0.5	u	-
Paruna	1	*E. wandoo*	18	1.8 x 2.1	2001, 2002	1, u
	*2	*E. wandoo*	20	1.4 x 1.8	u	-
	3	*E. wandoo*	15	1.8 x 1.8	2006	1
	*4	*E. wandoo*	25	u	u	-
Helena Valley	1	*E. wandoo*	15	1.0 x 1.2	2003[1]	0
	*2	*E. wandoo*	18	u	u	-
	3	*C. calophylla*	10	1.2 x 0.5	2002[1]	0
	4	*E. marginata*	20	1.0 x 0.8	2004[1]	0
	*5	*E. wandoo*	18	1.0 x 1.5	u	-
	*6	*E. wandoo*	16	1.2 x 1.0	u	-
	*7	*C. calophylla*	20	1.0 x 1.2	u	-
	*8	*E. wandoo*	10	1.2 x 1.1	u	-
	9	*C. calophylla*	15	1.4 x 0.8	2005	1
	10	*C. calophylla*	4	0.9 x 0.4	2006	0
	mean	-	**15.5**	**1.3 x 1.1**	**-**	**0.92 #**
* = old nest	[1] = lined with leaves but no eggs laid					

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4.2. Territory Size

Territory size of wedge-tailed eagles in the Perth region averaged 35.6 km^2, ranging from 23.5 km^2 at Karakamia to 46.9 km^2 at Helena Valley (Table 3). Most territories were asymmetrical, and their boundaries were often determined by landforms (e.g. Collopy and Edwards 1989). This was especially relevant to the Helena Valley territory, which was elliptical in shape and followed the Helena River from the foot of the Darling Scarp *c.* 9 km east, with the approximate boundaries formed by the walls of the Helena Valley.

TABLE 3

Characteristics of wedge-tailed eagle territories in the Perth region.

Study site	Approximate size of territory (km^2)	Mean distance to external boundary from active nest[1] (km)	Number of nests in territory
Whiteman Park	29.4	4.2	3
Karakamia	23.5	3.3	8
Gidgegannup	42.4	5.1	7
Paruna	35.5	4.4	4
Helena Valley	46.9	5.2	10
mean	**35.6**	**4.4**	**6.4**

[1] calculated from records of locations visited by individual eagles

4.3. Breeding Diet

Wedge-tailed eagles took a broad range of prey species in the Perth region, with 37 vertebrate species (13 mammals, 20 birds and four reptiles) recorded (Appendix 1). Of these, six mammals and four birds were introduced species. At Karakamia, eagles preyed upon all species of threatened marsupial available. At Whiteman Park and Paruna where threatened species are also available, the eagles preyed on some of these species but appeared to utilize them to a lesser extent than the Karakamia eagles, however data at Paruna was limited by relatively small prey samples.

4.3.1. Prey Remains

A total of 247 prey animals were identified from 610 individual prey remains, collected from eagle nests at the five study sites during three breeding seasons in 2004, 2005 and 2006 (Table 4 for summary; Appendix 2 for complete dataset). Nine species of mammals, 19 birds and four reptiles were represented in this sample (Appendices 3 and 4). Figure 7 shows one collection of prey remains from Paruna. Chi-squared Goodness of Fit showed that among all prey categories, eagles in the Perth region had most significant preference for rabbits (29.1% by number, 30.1% of biomass), ‘songbirds’ (15.0%, 5.1%), ‘other macropods’ (11.7%, 30.6%) and ‘ducks, swans, geese’ (7.7%, 6.3%) in order of priority (Chi-squared test: χ^2 = 187.57, df = 11, P < 0.001; Table 4).

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Mammals were the most important prey class for breeding eagles, contributing 57.5% by number and 82.1% of biomass across the five sites, and being preyed upon significantly more than expected at Whiteman Park (χ^2 = 28.90, df = 8, P < 0.001; Table 4). Among mammals, eagles showed significant preference for rabbits and western grey kangaroos (χ^2 = 297.58, df = 9, P < 0.001; Appendix 3). At Whiteman Park in particular, rabbits comprised 63.0% by number (73.9% of biomass) of eagle diet (Table 4; Appendices 3 and 4). Other mammals taken in the Perth region included pig, cat, and quenda, and at Karakamia, brush-tailed possum, woylie, tammar and brush wallaby.

Birds were also important eagle food, consisting of 38.5% by number (17.2% of biomass) of diet across the five sites (Table 4, Appendices 3 and 4). This prey class was taken significantly more than expected at two of the study sites on the Darling Scarp (Gidgegannup and Helena Valley; χ^2 = 28.90, df = 8, P < 0.001; Table 4). Important species of avian prey were ravens (12.6% by number, 4.7% of biomass) and wood ducks (4.5%, 2.5%; χ^2 = 176.40, df = 18, P < 0.001; Appendix 3). Other species commonly taken included pacific black duck, galah, ringneck parrot (each 2.4% by number, and 1.8, 0.5 and 0.4% of biomass, respectively) and magpie (2.0%; 0.5%). Reptiles including the bobtail skink *Tiliqua rugosa* were less frequently taken (reptiles 4.0% of total diet by number, 0.8% of biomass), only being recorded at two of the five sites, Karakamia and Gidgegannup. Reptiles were, however, preyed upon significantly more than expected at Karakamia (χ^2 = 28.90, df = 8, P < 0.001; Table 4).

There was considerable variation in the reliability of collecting prey remains between sites and between years (Appendix 2). The collection of remains was further limited each year by the fact that breeding did not always occur in every eagle territory. At Whiteman Park and Karakamia, the resident wedge-tailed eagles bred each year of the study, hence these sites provided reliable data. However, at Gidgegannup, a breeding attempt failed in 2004, the male eagle was found dead at the nest during late 2005, and this is likely to have resulted in no breeding in 2006. The territory of the Paruna pair was visited in 2001 and 2002 (before this study commenced), but not again until 2006 and thus only one year of breeding data exists. The Helena Valley pair bred in 2005, but nesting attempts in 2004 and 2006 both failed, resulting in no data being obtained.

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TABLE 4

Minimum number of individuals and percentage of biomass as determined from remains of wedge-tailed eagle prey from five study sites in the Perth region.

Prey Species		Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total All Sites
MAMMALS:							
Quenda	*Isoodon obesulus*	1 (0.6)	9 (5.1)				10 (2.2)
Brush-tailed Possum	*Trichosurus vulpecula*		15 (27.4)			1 (12.9)	16 (11.6)
Woylie	*Bettongia penicillata*		12 (11.0)				12 (4.3)
Tammar Wallaby	*Macropus eugenii*		3 (8.4)		2 (23.7)		5 (5.6)
Western Brush Wallaby	*Macropus irma*		1 (1.8)				1 (0.7)
Western Grey Kangaroo	*Macropus fuliginosus*	4 (11.9)	9 (24.1)	4 (43.5)	4 (45.0)	2 (37.6)	23 (24.3)
Total Macropods		*4 (11.9)*	*25 (45.3)*	*4 (43.5)*	*6 (68.7)*	*2 (37.6)*	*29 (30.6)*
*Rabbit	*Oryctolagus cuniculus*	63 (73.9)	2 (2.1)	2 (8.6)	2 (8.9)	3 (22.3)	72 (30.1)
*Other Mammal			1 (3.1)	1 (9.0)	1 (12.1)		3 (3.2)
	Total Mammals:	**68 (86.3)**	**52 (82.9)**	**7 (61.2)**	**9 (89.6)**	**6 (72.8)**	**142 (82.1)**
BIRDS:							
Ducks, Swans, Geese	*Anseriformes*	6 (4.3)	8 (8.1)	3 (10.9)	1 (2.4)	1 (4.1)	19 (6.3)
Pigeons, Doves	*Columbiformes*	3 (0.8)	1 (0.2)			2 (2.5)	6 (0.5)
Parrots, Cockatoos	*Psittaciformes*	6 (1.7)	4 (0.7)	5 (4.9)	1 (2.0)	1 (1.0)	17 (1.6)
Songbirds	*Passeriformes*	14 (4.1)	12 (4.1)	7 (10.8)	2 (3.2)	2 (4.2)	37 (5.1)
Other Bird		3 (1.6)	5 (2.4)	4 (10.5)	1 (2.7)	3 (15.5)	16 (3.7)
	Total Birds:	**32 (13.7)**	**30 (15.5)**	**19 (37.2)**	**5 (10.4)**	**9 (27.2)**	**95 (17.2)**
REPTILES:							
	Total Reptiles:	**0**	**8 (1.5)**	**2 (1.7)**	**0**	**0**	**10 (0.8)**
	TOTAL:	**100 (100)**	**90 (100)**	**28 (100)**	**14 (100)**	**15 (100)**	**247 (100)**

* = introduced species

= eagles demonstrated most significant preference for prey category in the Perth region (from Chi-squared test: $\chi^2 = 187.57$, df = 11, $P < 0.001$)

= observed frequency for prey class significantly more than expected at study site (from Cross-tabulation test: $\chi^2 = 28.90$, df = 8, $P < 0.001$)

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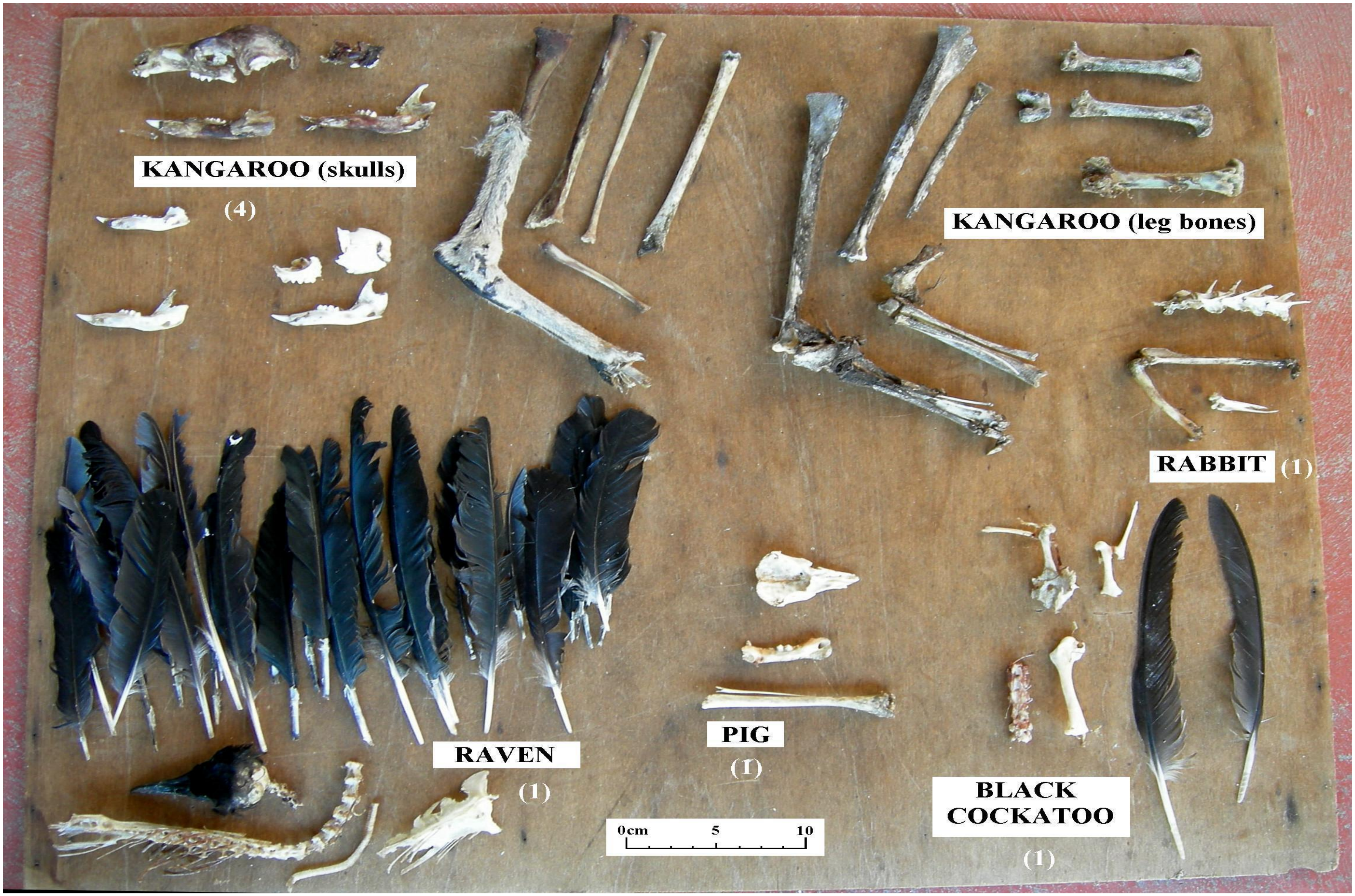

F … ers of individuals are shown in parentheses.

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4.3.2. Pellets

One-hundred and sixty-four pellets weighing a total of 1086 grams were collected during the breeding season from active nests at the five study sites. Pellets averaged 6.62 ± 3.50 grams in weight and contained a mean of 1.88 ± 0.85 species per pellet (Appendices 5 and 6). Table 5 shows the number of pellets containing various prey categories (category frequency), and the proportion of pellet mass (percentage mass) contributed by each category at the five study sites. Category frequency totals add up to more than 164 as the majority of pellets contained more than one prey species. Actual prey species and their proportions in pellets are shown in Appendix 5, and the guard hair whole-mounts of some mammal species are shown in Figure 8.

Cross-tabulation statistical tests showed that eagles had most significant preference for similar categories as determined for the prey remains data above (Table 4 *cf.* Table 5). Rabbits occurred in 93 pellets (49.1% of total pellet mass), 'other macropods' in 46 (15.6%), 'songbirds' in 32 (2.3%) and 'other birds' in 30 (4.2%), in order of priority (Chi-squared test: $\chi^2 = 256.16$, df = 11, $P < 0.001$; Table 5). Mammals overall occurred frequently in pellets (198 times), comprised 86.4% of total pellet mass, and were once again taken significantly more than expected at Whiteman Park ($\chi^2 = 18.11$, df = 8, $P < 0.05$; Table 5). Brush-tailed possum, quenda and woylie were commonly found in pellets at Karakamia (Appendix 5). European fox, sheep *Ovis aries* and goat *Capra hircus* were species detected in pellets that were not found in prey remains.

Birds were found in 97 pellets and comprised 12.9% of pellet mass, being taken significantly more than expected at Gidgegannup and Helena Valley ($\chi^2 = 18.11$, df = 8, $P < 0.05$), with ravens and wood ducks again being common prey species (Appendix 5). Reptiles occurred infrequently in pellets, with only one species (bobtail skink) being detected in 14 pellets, and comprising <1% of total pellet mass. Reptiles were also found more than expected in the Karakamia pellet sample ($\chi^2 = 18.11$, df = 8, $P < 0.05$).

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TABLE 5

Frequency of pellets containing prey categories and percentage mass of prey categories in pellets (n = 164) at five study sites in the Perth region.

Prey Species		Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total All Sites
MAMMALS:	Total Pellets Collected:	**(73)**	**(55)**	**(9)**	**(12)**	**(15)**	**(164)**
Quenda	*Isoodon obesulus*		16 (16.9)			8 (19.3)	24 (6.7)
Brush-tailed Possum	*Trichosurus vulpecula*		14 (17.2)			2 (19.1)	16 (6.8)
Woylie	*Bettongia penicillata*		8 (17.1)				8 (4.9)
Other Macropods	*Macropus* spp.	23 (14.9)	10 (13.9)	2 (32.6)	7 (19.0)	4 (12.1)	46 (15.6)
*Rabbit	*Oryctolagus cuniculus*	71 (81.7)	8 (10.2)	7 (41.5)	4 (40.3)	3 (10.7)	93 (49.1)
*Other Mammal			6 (6.2)	1 (2.1)	3 (13.1)	1 (5.0)	11 (3.2)
BIRDS:	Total Mammals:	**94 (96.6)**	**62 (81.3)**	**10 (76.1)**	**14 (72.4)**	**18 (66.1)**	**198 (86.4)**
Ducks, Swans & Geese	*Anseriformes*		8 (8.7)	2 (15.0)		1 (4.3)	11 (3.7)
Pigeons & Doves	*Collumbiiformes*		1 (0.6)				1 (0.2)
Parrots & Cockatoos	*Psittaciformes*	7 (1.0)	9 (2.1)	3 (5.7)	2 (12.6)	2 (2.1)	23 (2.5)
Songbirds	*Passeriformes*	10 (1.9)	10 (3.2)	1 (0.5)	4 (5.3)		32 (2.3)
Other Bird		11 (0.3)	10 (2.4)	3 (0.9)	5 (8.8)	8 (27.5)	30 (4.2)
REPTILES:	Total Birds:	**28 (3.2)**	**38 (17.1)**	**9 (22.1)**	**11 (26.8)**	**11 (33.9)**	**97 (12.9)**
	Total Reptiles:	**2 (0.2)**	**9 (1.5)**	**1 (1.8)**	**2 (0.8)**		**14 (0.7)**
	TOTAL:	**124 (100)**	**109 (100)**	**20 (100)**	**27 (100)**	**29 (100)**	**309 (100)**

* = introduced species

[blue] = eagles demonstrated most significant preference for prey category in the Perth region (from Chi-squared test: χ^2 = 256.16, df = 11, P < 0.001)

[yellow] = observed frequency for prey class significantly more than expected at study site (from Cross-tabulation test: χ^2 = 18.11, df = 8, P < 0.05)

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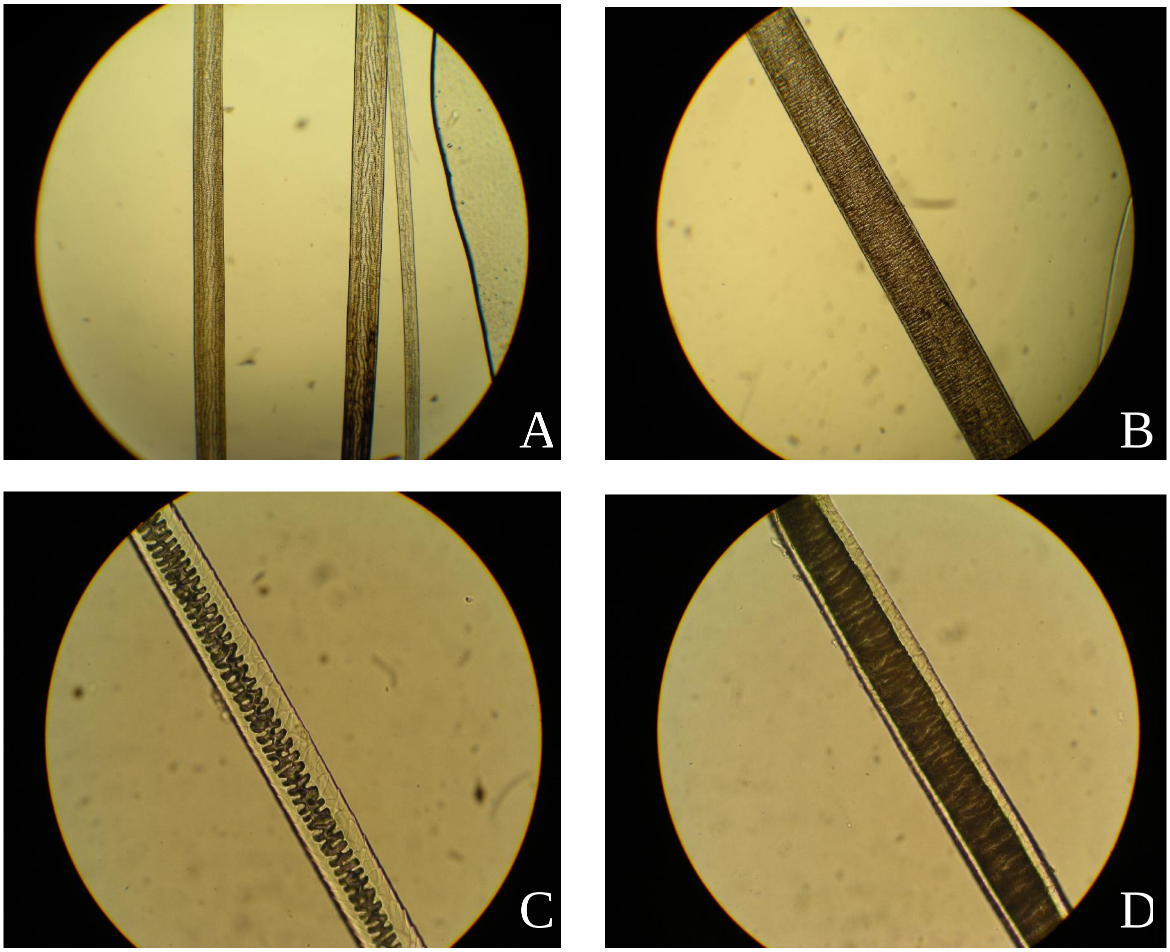

Figure 8. Whole mounts of mammal guard hairs showing diagnostic medulla patterns of rabbit *Oryctolagus cuniculus* (A) viewed at 10x magnification, quenda *Isoodon obesulus* (B), brush-tailed possum *Trichosurus vulpecula* (C) and fox *Vulpes vulpes* (D), viewed at 40x magnification, found in wedge-tailed eagle pellets at Whiteman Park (A), Karakamia Wildlife Sanctuary (B, C) and Helena Valley (D).

4.3.3. Fresh Observations

Thirteen vertebrates (six species of mammal, six birds and one reptile) were identified as fresh prey during visits to active nests in the breeding season (Table 6). Three of these species, chuditch (Figure 9), juvenile emu (Figure 10) and woylie, were not identified in the prey remains or pellets collected from the Paruna nest. All other prey species were recorded at each study site using at least one of the two other methods. Insufficient data were obtained using this method for statistical analyses. However, it is still evident from Table 6 that the proportions by number of each prey class (mammal, bird and reptile) reflect the results of the prey remains method: i.e. mammals comprised the highest percentage of diet by number (57.7% *cf.* 57.5%, Appendix 3), followed by birds (34.6% *cf.* 38.5%) and reptiles (7.7% *cf.* 4.0%).

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Figure 9. Carcass of chuditch *Dasyurus geoffroii* (foreground) on wedge-tailed eagle nest at Paruna Wildlife Sanctuary in 2006.

Figure 10. Carcasses of two juvenile emus *Dromaius novaehollandiae* (back) with eaglet aged ~3 weeks on wedge-tailed eagle nest at Paruna Wildlife Sanctuary in 2006.

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TABLE 6

Number of animal species and percentage number of totals observed as fresh prey at wedge-tailed eagle nests in the Perth region.

Prey Species		Whiteman Park	Karakamia	Gidgegannup	Paruna	Total All Sites
MAMMALS:		2005, 2006	2005, 2006	2004, 2005	2006	
*Chuditch	*Dasyurus geoffroii*				1	1 (3.8)
*Woylie	*Bettongia penicillata*				2	2 (7.7)
Tammar Wallaby	*Macropus eugenii*		1			1 (3.8)
Western Grey Kangaroo	*Macropus fuliginosus*			2	1	3 (11.5)
Pig	*Sus scrofa*				2	2 (7.7)
Rabbit	*Oryctolagus cuniculus*	6				6 (23.1)
	Total Mammals:	**6**	**1**	**2**	**6**	**15 (57.7)**
BIRDS:						
*Emu (juv.)	*Dromaius novaehollandiae*				2	2 (7.7)
Australian Wood Duck	*Chenonetta jubata*			1		1 (3.8)
Pacific Black Duck	*Anas superciliosa*	1				1 (3.8)
Galah	*Cacatua roseicapilla*	1				1 (3.8)
Australian Magpie	*Cracticus tibicen*	1				1 (3.8)
Australian Raven	*Corvus coronoides*	1	2			3 (11.5)
	Total Birds:	**4**	**2**	**1**	**2**	**9 (34.6)**
REPTILES:						
Bobtail Skink	*Tiliqua rugosa*			2		2 (7.7)
	Total Reptiles:	**0**	**0**	**2**	**0**	**2 (7.7)**
	TOTAL:	**10**	**3**	**5**	**8**	**26 (100)**
* = not identified in prey remains or pellets						

4.4. Non-breeding Diet

Despite extensive fieldwork in the territories of each study pair (n = 106 hours), only five wedge-tailed eagle pellets were collected in the non-breeding season (Appendix 6). Often the eagles were not sighted at all, and it appears that during the summer and autumn, the breeding pair and their offspring from the previous breeding season are highly nomadic within their territory. It seems that during this period eagles do not have a favoured roost tree, but will readily use granite outcrops for roosting (J. Dell pers. comm.). To gain further insight into eagle behaviour, wildlife photographer Nicholas Birks, who has spent more than 20 years observing and photographing wild eagles, was contacted in 2006.

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Birks (pers. comm.) noted that eagles may roost anywhere in their territory, including the middle of a paddock. He also commented that eagles do not always cast a pellet during the night – they may become active very early in the morning and cast just before they begin to hunt, which may be away from where they roost. Also, foxes include the roosts and perches of raptors in their daily routine of hunting/scavenging and Birks (pers. comm.) has often seen them collect and bury raptor castings. In all sites of the current study except for Karakamia, foxes are potential ‘thieves’ of eagle pellets. Paruna is frequently fox baited, as is Whiteman Park, however neither of these sites have an enclosed, feral-proof fence stopping foxes from passing through the area and taking pellets. Even so, pellets that may be dropped among the *Banksia*, jarrah, wandoo and marri woodlands of the present study sites are incredibly difficult, if not impossible to find opportunistically, given that no set roost exists.

Unfortunately the limited pellet data did not allow for statistical analyses or comparisons between breeding and non-breeding diet. However, analysis of the five pellets did reveal seven species of prey animal: quenda, rabbit, raven and ringneck parrot taken at Whiteman Park; and quenda, woylie, pacific black duck, raven and bobtail skink taken at Karakamia. These species were all detected in the breeding season (see Section 4.3 above).

The following observations made during the non-breeding season describe eagle behaviour during direct feeding, relating to possible feeding attempts, or indicating the location of possible perch/roost trees where pellets could be cast. All observations were made by the author unless otherwise specified. Data is presented for two non-breeding years, 2006 and 2007.

4.4.1. 2006 Non-breeding Season (December 2005 - April 2006)

Karakamia, 15th February 2006, ~ 0930 hours

Two adults and one immature wedge-tailed eagle were observed circling low (<50m) over the large lake at Karakamia. One adult then perched on a branch of a dead tree in bushland east of the lake while the others continued circling. The perched bird seemed to watch over the lake for several minutes before flying again, and all three eagles gained height while circling and disappeared from view. Approximately 100 coots *Fulica atra* were present on the surface of the lake at the time. The area under the dead tree was searched carefully but no pellets or prey remains were found.

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Seabourne Road, Parkerville, 15th February 2006

A neighbour in Seabourne Road, Parkerville, reported a wedge-tailed eagle taking a domestic chicken from her chicken pen (G. Gardner, pers. comm.). It is uncertain if this eagle was a resident from one of the territories in this study, and if so, which territory it occupied. This location lies *c.* 6 km north-east of the Helena Valley nesting territory, and 7 km south-east of the Gidgegannup nesting territory.

Dartnall Road, Parkerville, 16th February 2006, ~ 0800 hours

An adult wedge-tailed eagle was observed feeding on a fresh dead rabbit on Dartnall Road (N. Evans, pers. comm.), which is *c.* 500 m south-east of the location described above. Whether the eagle had killed the rabbit itself, or whether it was a road-kill victim, is unknown.

Karakamia, 25th February 2006

Two adults and an immature eagle were observed flying low over the hill above the nest active in 2005. Fresh eagle scats were visible on vegetation below the nest tree, suggesting use of this tree for roosting in the non-breeding season, and three fresh pellets were located.

Karakamia, 26th February 2006, ~ 1500 hours

An immature wedge-tailed eagle was observed perched on a freshly killed brush wallaby *Macropus irma* in the middle of open paddock (Figure 11). As the observer approached, the eagle flew low over the treetops and out of sight. The wallaby had been torn apart from the ventral side, partially eaten, and its viscera lay about one metre away. An hour later, as the observer watched with binoculars from *c.* 150 m away, an adult wedge-tailed eagle landed in a large jarrah tree and searched the paddock area close to the wallaby carcass. It perched for about half an hour then flew away in the direction it had approached from. No more eagles were observed until sunset several hours later. By 0930 hours the following morning the wallaby carcass had gone.

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Figure 11. Carcass of brush wallaby *Macropus irma* killed by wedge-tailed eagle during the non-breeding season at Karakamia Wildlife Sanctuary, 26th February 2007.

Over the following four - six weeks after the above observation, a further six dead brush wallabies were observed in the same open paddock. Most carcasses appeared quite old at the times of discovery, and none had obvious signs consistent with eagle kills and/or feeding. The most likely cause of death was starvation due to the extremely dry conditions over the summer. It is interesting to note that, if this interpretation is correct, eagles did not feed on carrion despite it being readily available.

Karakamia, 18th March 2006

Large tufts of tammar wallaby fur were discovered among vegetation in jarrah woodland *c.* 50 m east of the nest active in 2005. On closer inspection, a depression was visible, where it appeared the body of a wallaby had laid, and traces of wallaby scats and small flecks of blood were visible on leaves. This indicated that a wallaby had perhaps been predated by an eagle and was eventually carried off to be fed on at an alternate location.

Whiteman Park, 30th March 2006, 1600-2100 hours

During late afternoon, the conservation area of Whiteman Park was searched and five large dead trees located on top of sandhills close to the nest active in 2005 were located and recorded with a

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GPS. These trees were known to be used as perches by wedge-tailed eagles during the previous breeding season. Two eagles were seen soaring very high on thermals, circling above the *Banksia* woodland. Each of the five trees was revisited at night and searched with a spotlight to check for roosting eagles and pellets below trees. No eagles were observed perching and no pellets or prey remains were located.

Karakamia, 2nd April 2006, ~ 1945 hours (dusk)

One adult wedge-tailed eagle was seen perched in a dead tree on the side of a hill in the valley of the nesting area, <50 m from the nest active in 2005. The following afternoon, the area below the tree was searched thoroughly, and fresh scats were visible on vegetation below the perch tree but no pellets were found.

Paruna, 15th April 2006, ~ 1100 hours

Two adult wedge-tailed eagles were observed flying low over a large granite outcrop known to be used as shelter by a group of black-flanked rock wallabies. The eagles circled <50 m above the ground, slowly gained height on a rising thermal, then soared to the east before disappearing from view.

Dartnall Road, Parkerville, 17th April 2006

~ 1530 hours **-** Two adult wedge-tailed eagles were observed in the same location as the previous 'Parkerville' observations, flying very low (<40 m) over a small 'hobby-farm' property where a flock of domestic geese were kept in an outdoor run. The eagles perched in several trees, and appeared to be reluctant to leave the area, perhaps because of the potential food source. They remained in this location for at least an hour before the observer lost sight of them as they flew over the treetops and out of sight. Two immature wedge-tailed eagles are known to have landed and carried away two dead geese from this property several years before the beginning of this study, and there is a record of a wedge-tailed eagle taking a captive magpie goose *Anseranas semipalmata* from a pen in Mount Helena *c.* 6 km away (S. Davies pers. comm.).

~ 1945 hours **-** At dusk two adult wedge-tailed eagles (presumably the same two) were seen perched in a large dead tree on top of a hill overlooking the locations discussed above. The tree was located at 0600 hours the next morning, and fresh white scats were present on vegetation below the perch. Despite thorough searching, no pellets or prey remains were found.

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4.4.2. 2007 Non-breeding Season (December 2006 - April 2007)

West Swan, 2nd December 2006, ~ 1530 hours

An immature wedge-tailed eagle was observed circling quite low (*c.* 60 m) over open farmland paddocks, where a flock of 30 - 50 straw-necked ibis *Threskironis ruficollis* was foraging. The location of this sighting lies *c.* 5 km south-east of the Whiteman Park nesting territory, and the eagle appeared to be one of the two fledglings from the nest active in 2006.

Red Hill Tip, 19th December 2006, ~ 1130 hours

Two adult wedge-tailed eagles were observed circling *c.* 40 m above the rubbish dump at Red Hill Tip, which is north of and directly adjacent to John Forrest National Park. The pair circled for several minutes then one bird stooped suddenly, and went into a fast dive towards the ground with its talons outstretched. The eagle disappeared from view below the tree-line, but appeared to have landed as the second bird continued to circle very low above this spot before descending to apparently land. No prey animal was sighted, but high numbers (up to 50 individuals) of Australian ravens were flying near the rubbish dump at the time. Raven remains were collected from the Gidgegannup eagles' nest active in 2004, which lies *c.* 200 m south of this location.

Karakamia, 19th December 2006, 1840 hours

One adult wedge-tailed eagle was seen perched in a dead tree on top of a hill, *c.* 50 m away from the nest active in 2005. The bird sat preening itself and watching over the valley until it was dark. An adult and an immature wedge-tailed eagle were then seen perched in a dead tree *c.* 100 m north of the first bird and only 20 m from the nest active in 2006. The immature bird repeatedly called 'yes-sir, yes-sir' but ceased calling as darkness set in. Both perch trees were located the following day at 1430 hours, and the area under each was thoroughly searched. Fresh scats were present at both sites but no pellets or prey remains were found.

Karakamia, 20th December 2006, 1300 hours

A continuous 'yes-sir, yes-sir' call alerted the observer to three wedge-tailed eagles, two adults and an immature, which were perched in a large dead tree in the nesting valley. One adult took off and flew low over the trees and out of sight. As the observer approached the tree, the other two eagles also flew from the tree and out of view behind the tree-line. Despite extensive searching under the dead tree, no scats were visible and no pellets or prey remains were located.

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Whiteman Park, 17th January 2007, ~ 0830 hours

Two adult wedge-tailed eagles were observed perched in a dead tree *c.* 1 km west of the nest active in 2006 M. Brooker (pers. comm.). A repeated 'yes-sir, yes-sir' call was then heard and two immature eagles were seen perched lower down in another dead tree close to the two adults.

Whiteman Park, 10th February 2007

The author visited the location described above with M. Brooker and the area below the two perch trees was searched thoroughly. Fresh scats were observed below each tree, as well as some feathers of a common bronzewing *Phaps chalcoptera*. Although the feathers seemed old and perhaps were not left there recently, they may still have indicated earlier feeding by the wedge-tailed eagles described above. No pellets were located.

Whiteman Park, 11th February 2007

A large dead tree, *c.* 100 m south of the nest active in 2006 and known to be used as a perch by eagles during the 2006 breeding season, was visited. Fresh scats were observed beneath the tree and two fresh pellets were located.

Paruna, 16th February 2007, ~ 1000 hours

A wedge-tailed eagle was observed flying low over treetops in the vicinity of the 'rock wallaby' granite outcrop described above. A large dead tree on the edge of a gully suitable for an eagle perch tree was observed and located. Eagle feathers and fresh tufts of rabbit fur were discovered, possibly indicating eagle feeding at this perch earlier that day.

Karakamia, 16th February 2007, ~ 1600 hours

Two adults and one immature wedge-tailed eagle were disturbed from the edge of open paddock. All three birds flew above the canopy and soon disappeared. Two brush wallaby carcasses were located in the vicinity, however neither appeared to have been fed on by eagles.

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Figure 12. Carcass of western grey kangaroo *Macropus fuliginosus* fed on by wedge-tailed eagle during the non-breeding season near Paruna Wildlife Sanctuary, 12th April 2007. The carcass was entered via the ear and part of the face tissue consumed (inset).

Reserve Road, Gidgegannup, 12th April 2007

~ *0930 hours* - An adult wedge-tailed eagle was disturbed from a fresh (presumably road-killed) western grey kangaroo carcass on Reserve Road in Gidgegannup, *c.* 4 km south-east of the Paruna nesting territory. The eagle landed in a nearby tree and was mobbed by other birds before flying away and gradually gaining height to soar high above the ground. The kangaroo carcass was untouched and had no signs of the eagle feeding on it.

~ *1645 hours* - The kangaroo carcass was revisited and part of its face had been consumed (Figure 12). It appeared that the body had been entered via the auditory canal, consistent with wedge-tailed eagle feeding (Brooker and Ridpath 1980).

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5. Discussion

5.1. Nest Location and Characteristics

The number and characteristics of nests in the Perth region was consistent with the findings of previous research on the wedge-tailed eagle in Australia (Ridpath and Brooker 1987; Sharp *et al.* 2001; Dennis 2006; Collins and Croft 2007; Debus *et al.* 2007; Silva and Croft 2007), and the closely related golden eagle in Europe and North America (Dixon 1937; Brown and Watson 1964; Cramp 1980; Haworth *et al.* 2006).

The Karakamia, Gidgegannup and Helena Valley wedge-tailed eagle pairs had an unusually high number of nests in their territory (8, 7 and 10 respectively), compared to the other pairs in this study (3 and 4), and compared to wedge-tailed eagles in general (usually 2 - 3), although there is a record of 11 nests in one territory, built up to 5 km apart over 15 years (Marchant and Higgins 1993). These high nest numbers could be attributed to multiple pairs occurring in some of these territories which have not bred simultaneously during this study (Gidgegannup and Helena Valley), or that many inactive nests were old and probably belonged to pairs of eagles that had either died or vacated the territory before the present pairs took up residence (Karakamia). Eagle nests are bulky, robust structures that can persist in the environment for 20 years or more (Debus *et al.* 2007), and it was unlikely that every nest discovered in this study was built by each pair of eagles currently active in the territories. It is possible that a new pair occupying an inactive territory may prefer to build new nests of their own, despite the presence of a number of older structures that could be suitable for nesting (for more detail see 'Nest Building Behaviour' in Section 5.7.1).

Nest dimensions and height above ground were also consistent with previous findings (Marchant and Higgins 1993; Ridpath and Brooker 1987; Sharp *et al.* 2001; Collins and Croft 2007; Silva and Croft 2007). The average dimensions of nests in this study (1.30 x 1.10 m) were comparable to nests in western New South Wales (1.14 x 0.83 m, Silva and Croft 2007; 1.88 x 1.00 m, Collins and Croft 2007). That nests do not reach substantial sizes until added to for several years (Gaukrodger 1924; Pizzey 1958; Olsen 2005) may not always be the case: Karakamia Nest 8 and Paruna Nest 1 were both newly built, reaching their respective sizes of 1.2 x 1.8 m and 1.8 x 2.1 m in one season. The nature of the fork probably influences initial nest size (Mooney and Holdsworth 1991), with nests in vertical forks being deeper and those built on horizontal forks being shallower. Nest 10 in the Helena Valley territory was particularly small (0.9 x 0.4 m) and very low to the ground (4 m) compared to other nests in the region, built in a stunted marri very close (<300 m) to human

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habitation. This was perhaps a rushed breeding attempt as the nest was constructed late in the year (August-September), incubation was still in progress in early October, and subsequently the nest was found empty (breeding failed) in late October.

With the exception of Helena Valley Nest 10 discussed above, all Darling Scarp nests in the Perth region were high in large trees either on ridges or at least half-way up steep hills, and nests on the Swan Coastal Plain at Whiteman Park were found in the largest available trees often on dune crests. This is also consistent with previous research. In the Mediterranean zone of Western Australia, Ridpath and Brooker (1987) discovered that most nests were built at heights of 2 - 20 m in eucalypts. In New South Wales, Sharp *et al.* (2001) found eagle nest trees were commonly associated with slope habitat, and Silva and Croft (2007) found nest trees were significantly taller than non-nest trees. As suggested by Silva and Croft (2007), large trees situated below the ridgeline with a prominent view of the surrounding landscape are probably chosen as they provide the eagles with advantages for easy access, vigilance, security and shelter from prevailing weather conditions. Presumably wedge-tailed eagles near Perth selected the tallest trees in their territories in which to build nests, and did not show preference for any tree species in particular (Sharp *et al.* 2001; Silva and Croft 2007). However, in many cases nest trees were wandoo, and although eagles probably did not select this over other eucalypt species, they may have selected wandoo woodland as a habitat, preferring to nest in the more rugged valleys of the Darling Scarp where wandoo dominates (especially at Gidgegannup, Paruna and Helena Valley), rather than the less steep terrain where jarrah and marri trees dominate. The open understorey of wandoo woodland (Markey 1997) may also facilitate hunting below the canopy. In contrast, eagles would probably find this difficult in the more dense understorey associated with jarrah and marri woodland.

5.2. Territory Size

A territory size of 36 km² in the Perth region is comparable to that determined for wedge-tailed eagles in other parts of Australia. Near Canberra in south-eastern Australia, territory size was 31 km² (Leopold and Wolfe 1970), in South Australia, 34 km² (Dennis 2006), and at two sites in the south-east of Western Australia, 32 and 42 km² (Ridpath and Brooker 1987). It is also similar to some territory sizes calculated for golden eagles: 29 - 36 km² in the Montana-Wyoming area (Phillips *et al.* 1990), 30 km² in Scotland (Haworth *et al.* 2006), and where the same technique employed in this study was used, 33 km² in south-western Idaho (Collopy and Edwards 1989). However, some wedge-tailed eagle territory sizes have differed considerably from that in the present study, either being much larger (up to 1200 km², Gaffney and Mooney 1992; 103 km²,

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Ridpath and Brooker 1987; 53 km², Robertson 1987) or much smaller (3 - 9 km², Sharp *et al.* 2001). These differences are probably attributable to different habitat characteristics and prey populations (see 'Territory Size and Diet' in Section 5.6 below). The territory size of a raptor usually varies within the geographic range of a species (Newton 1976; Ridpath and Brooker 1987).

It should also be noted that different methods have been used to calculate territory size in the examples above. The figures given by Leopold and Wolfe (1970), Ridpath and Brooker (1987), Robertson (1987) and Gaffney and Mooney (1992) were all calculated by dividing the whole study area by the number of eagle pairs present. This is probably accurate if all the eagle pairs in a given area are known, and the whole area considered contains habitat utilized by eagles. If the same technique is applied to this study, the five eagle pairs in the Perth region (minimum area from Whiteman - Chidlow, Bullsbrook - Kalamunda *c.* 1140 km²) would have territories of 228 km². However, there is evidence that all pairs from the study area are not known, as a territory *c.* 3 km north-east of Nest 1 at Gidgegannup was newly discovered in 2007 (B. Exell pers. comm.) and appeared active (S. Cherriman unpub. data.). Also, the Perth region contains much unsuitable eagle habitat and there are considerable distances between nest areas of the different pairs over which residential zones occur. Therefore, although this figure may be useful as an indicator of the eagle pairs' total home range, it is probably a gross overestimate and the calculated figures of 23.5 - 46.9 km² more accurately reflect actual territory sizes.

Apart from food availability, eagle territory size in the Perth region may be further constrained by landforms (Ridpath and Brooker 1987; Olsen 2005). The use of the minimum area technique to calculate eagle territory size in this study was effective as it facilitated observations that accurately recorded territorial boundaries through eagle behaviour. This was particularly relevant to Paruna, Helena Valley and Gidgegannup, where territorial display flights by the males were usually oriented in an east-west direction and performed at some height directly above the confining ridgelines or 'walls' of the Avon and Helena Rivers and Susannah Brook/Christmas Tree Creek, respectively. These display flights indicated that some of the Darling Scarp territories were more or less bounded by the landforms within them, and consequently were not symmetrical in shape. This was found also with golden eagle territories in San Diego, which were of varying shapes and their boundaries were often denoted by higher-altitude peaks (Dixon 1937). Thus, the assumption by Dennis (2006) that territories are symmetrical may be not always be accurate, as landforms rather than a constant distance from the nest site probably denote actual territorial boundaries. Some eagle pairs may even nest on opposite sides of the same ridge, with their respective foraging grounds occurring over the

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low land below the nest site (Sharp *et al.* 2001; Olsen 2005), and thus the assumption of symmetrical territories should be used with caution unless the behaviour of breeding eagle pairs under study is fully understood.

Vegetation structural characteristics (Olsen 2005) and the proximity of regular human activity and disturbance probably also play a role in the size and spacing of wedge-tailed eagle territories near Perth. As discussed in Section 5.1 'Nest Location and Characteristics' above, eagles can hunt more successfully in the open (Marchant and Higgins 1993), so territories with habitat suitable for hunting may be smaller as a result of nest sites being in proximity to productive hunting grounds. As eagles are shy and generally wary of humans (Brooker 1974; Gaffney and Mooney 1992; Olsen 2005; Debus *et al.* 2007; Silva and Croft 2007), a combination of the above factors together with isolation from people further explains the locations of their territories. All territories near Perth were located in remnant bush of well above 10 ha in area, which is thought to be a minimum buffer zone around a nest site (Mooney and Holdsworth 1991).

5.3. Diet Study Methods

The study methods used to determine wedge-tailed eagle diet have presented a variety of challenges, and most problems encountered in this study were similar to those previously documented. These included: eagles selectively eating portions of larger prey whose remains were not always present in pellets (Glading *et al.* 1943; Sharp *et al.* 2002a); prey being captured and eaten away from the nest site and thus not occurring in remains or pellets (McGahan 1967; Debus 1983); whole consumption of smaller prey animals which did therefore not appear in prey remains (Brooker and Ridpath 1980; Real 1996); adult eagles removing prey remains from the nest and discarding them away from the nest site (Tjernberg 1981; Real 1996); and differing results being achieved from the pellets and prey remains techniques (Collopy 1983b; Redpath *et al.* 2001; Lewis *et al.* 2004; Parker *et al.* 2007).

The most significant of these, however, was the variation in obtaining a reliable collection of prey remains equally from the five study sites, which created discrepancies in thorough examination of the diet of each eagle pair. It is probable that scavenging of remains and pellets by foxes, which are present at most sites in the Perth region, caused this variation (Sharp *et al.* 2002a; N. Birks pers. comm.). There is some evidence that this suggestion is valid from data collected at Karakamia. In 2005 the eagles used Nest 2 within the feral-proof fence where no mammalian scavengers were present, and 130 prey items were collected from below the nest and perch trees (Appendix 2). In

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2006, the eagles used a different nest (Nest 8), located outside the fence where foxes are often seen, and subsequently only 30 prey remains were found during the nesting period. Also, fox scats were frequently discovered below eagle nest and perch trees, confirming the observations of Birks (pers. comm.) that foxes regularly visit these sites. The scats contained bone fragments, hair, fur and feathers that were also detected in wedge-tailed eagle pellets at Karakamia Nest 8, suggesting consumption of pellets and/or prey remains by foxes. This was also the case at some other eagle nests in the Perth region, including Helena Valley Nest 9.

A tarpaulin suspended below active eagle nests was used to obtain collections of prey remains and pellets in a wedge-tailed eagle diet study in north-eastern New South Wales (Harder 2000). This technique may have been employed to avoid a possible scavenging problem, but the reasons for the use of a tarpaulin or its effectiveness were not discussed. It is also the only time this method is known to have been used for diet research on wedge-tailed eagles. It was not used in the present study for fear of disrupting eagle nesting behaviour and causing possible breeding failure. Tarpaulins placed under active eagle nests in the Perth region may disturb the breeding pair in a similar way to video cameras used by Silva and Croft (2007) and Collins and Croft (2007), given their known sensitivity to humans at their nest sites in this area.

Adult nest-cleaning behaviour (Tjernberg 1981; Real 1996), which probably occurred in conjunction with scavenging by foxes, may have also resulted in the lack of prey remains at some nests during the present study in the Perth area. Observations of breeding behaviour at several nests revealed that some female wedge-tailed eagles dropped remains either directly below the nest or at a nearby perch tree, while others removed old prey items and discarded them well away from the nest site altogether (Pizzey 1958; S. Cherriman this study). On one occasion where the nesting eagles appeared to show very little nest cleaning behaviour (Whiteman Park Nest 3, 2006), two fledglings were reared. It is possible that the survival of both eaglets increased the demand for food supply such that nest cleanliness (removal of old prey) was neglected. It has been suggested that the smaller food demands of a single chick may leave more time for adults to partake in preening and other nest activities (Silva and Croft 2007).

Vegetation characteristics also made collections of prey remains and pellets difficult to obtain. Some bones were well hidden beneath shrubs and leaf litter below eagle nests, and took extensive searching to locate. Therefore, occasional prey remains could have been missed and not included in

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analyses. This problem may not occur in other regions, especially in the arid zone where prey remains were easily found below most eagle nests (M. Brooker pers. comm.).

Given there was a large variation in the reliability of collecting prey remains, this technique should not be used as the sole approach for diet quantification in future research on eagle diet. However, if suitable prey remains collections can be obtained successfully, they are more useful than pellets for determining prey quantities. The use of the prey remains 'minimum number' technique (e.g. Leopold and Wolfe 970; Brooker and Ridpath 1980) was accurate in quantifying eagle prey animals, which was not possible using pellet data alone when considering the findings of some previous research (e.g. Glading *et al.* 1943; Collopy 1983b; Sharp *et al.* 2002a; Parker *et al.* 2007).

It appears that the findings of Glading *et al.* (1943) have been widely misinterpreted. It was emphasised that assuming the presence of a prey species in a pellet indicates the consumption of one item of that species was only accurate for owls, and Glading *et al.* (1943, p. 102) concluded that '…pellets of the hawks tested were unreliable as a quantitative indication of food habits' and '…even a rough qualitative list of items found in hawk pellets is open to question as being truly representative of items eaten'. Despite this, many subsequent Australian raptor studies (e.g. Baker-Gabb 1984; Hull 1986; Aumann 1988, 2001) seem to have made a general assumption that Glading *et al.*'s (1943) findings applied to all raptors, and have still used pellet analysis to quantify the diet of hawks and eagles. Apart from this difficulty in enumerating the number of individual items in a pellet, Glading *et al.* (1943) discussed further errors in the pellet analysis procedure, some of which included the following: (1) prey items are occasionally withheld by the raptor and may not appear in pellets until several days after they are consumed, leading to double-counting of the same species; (2) with larger prey some hawks consumed fleshy material only, a pellet was not formed as a result of indigestible material (e.g. fur) not being eaten, and thus a species could be fed upon without being present in regurgitated pellets; and (3) every hair or feather in a pellet cannot be examined as hairs are grouped macroscopically, so different hairs may be classified as belonging to the same species. Furthermore, the laboratory procedure for the pellet analysis method in the present study did not always allow the identification of prey animals to the species level (especially some macropods) without intensive analyses of individual pellets, thus leaving gaps in qualitative diet sampling.

More recently some research has employed a more accurate method of diet quantification (Olsen *et al.* 2006; Debus *et al.* 2007; Fuentes *et al.* 2007). This has involved: (1) using prey remains to

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determine minimum numbers of prey animals consumed; (2) using pellets to add to this minimum number data but not double-counting individual species and not assuming one pellet represented one prey item; and (3) supplementing the minimum number data from prey remains and pellets with observations of prey deliveries or kills that were not identified by either of the first two methods. This approach was chosen to minimise sources of bias found in other studies (Collopy 1983b; Real 1996; Sharp *et al.* 2002a), and is probably much more accurate than the pooling of prey remains and pellet data.

The use of multiple techniques in this study was more effective than relying on only one, and the fact that the results of each was presented separately increased the accuracy of both the quantitative and qualitative sample. Pellet data added to the prey species sample size, with fox, sheep and goat being undetected in the prey remains at nests or fresh observational data, consistent with previous findings (Brooker and Ridpath 1980; Olsen *et al.* 2006; Fuentes *et al.* 2007). The inclusion of occasional direct observations of fresh prey further increased the qualitative sample at some sites, with chuditch and juvenile emu being added to the qualitative prey sample, which follows the recommendations of Collopy (1983b), and is consistent with Olsen *et al.* (2006), Debus *et al.* 2007 and Fuentes *et al.* (2007). Wedge-tailed eagle pellets would be of greater use for diet studies if there were a means to accurately assign a minimum number of prey animals (especially larger ones) consumed to each pellet. As Parker *et al.* (2007) recommended, this could be determined by captive feeding trials which may, for example, indicate the number of pellets an eagle would cast after consuming a whole kangaroo of known weight.

5.4. Breeding Diet

The broad range of prey taken by wedge-tailed eagles in the Perth region, which consisted of mostly mammals (82.1% of biomass) and birds (17.2%) with few reptiles (0.8%) is consistent with the findings of previous research in Western Australia (Brooker and Ridpath 1980; Richards and Short 1998), and in general for this eagle in other parts of its range (Leopold and Wolfe 1970; Baker-Gabb 1984; Hull 1986; Sharp 1997; Debus and Rose 1999; Davey and Pech 2004; Olsen *et al.* 2006; Debus *et al.* 2007; Fuentes *et al.* 2007; Parker *et al.* 2007; Winkel 2007). That rabbits were by far the most frequently predated animal is also similar to Brooker and Ridpath’s (1980) findings in the arid zone of south Western Australia, and to Leopold and Wolfe’s (1970) research near Canberra, where some hares were also taken. However, the large number of rabbits taken at Whiteman Park no doubt skewed the composition of eagle prey in the Perth region as a whole, so it

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appeared that rabbits were more important in general than they perhaps were for breeding pairs at the other sites studied.

5.4.1. Mammals

On a global scale, large *Aquila* eagles have generally been shown to have a preference for Lagomorphs as a primary food source. Diet of the golden eagle has predominately consisted of rabbits and mountain hare *Lepus tidimus* in Scotland (Brown and Watson 1964) and Sweden (Tjernberg 1981), white-tailed jack rabbit *L. townsendii* in Montana (McGahan 1967), black-tailed jack rabbit *L. californicus* in south-western Idaho (Collopy 1983b) and other parts of North America (Olendorff 1976), and Japanese hare *L. brachyurus* in Japan (Takeuchi *et al.* 2006). Golden eagles have also shown preference for some Lagomorphs (e.g. black-tailed jack rabbits in south-western Idaho) even when the abundance of this prey species declined below that of other prey (Steenhoef and Kochert 1988).

There are mixed findings within Australian studies as to whether the wedge-tailed eagle shows a definite preference for certain prey. On Bernier Island in Western Australia, native mammals were taken in proportion to their abundance, indicative of unselective feeding (Richards and Short 1998). Selective predation of rabbits irrespective of their environmental abundance has been demonstrated in central-western New South Wales (Davey and Pech 2004), and possibly at Shark Bay in Western Australia (Richards 2006 unpub. data), however rabbit proportion in eagle diet was greatly reduced when their numbers dropped rapidly following an outbreak of RCD (Sharp *et al.* 2002b). At Whiteman Park, signs of rabbit activity (e.g. active warrens, diggings, scats and actual sightings) increased substantially from mid 2004 to late 2006 and if these observations indicated a legitimate increase in rabbit numbers, it is not surprising that wedge-tailed eagles at this site ate mostly rabbits.

The variety of mammal assemblages in the Perth region (rabbits were of varying abundance at the five study sites) and the eagles' predation on these support the general conclusion that eagles select mammals >500 g (Brooker and Ridpath 1980). It is likely that the European rabbit is the most common mammal that occupies this weight category across the eagles' distribution in Australia, and studies demonstrating wedge-tailed eagle selectivity of this species probably have low diversity and abundance of alternative prey in this weight class. Furthermore, the accuracy of methods used to determine prey abundance must be questioned in some cases, as errors in these could invalidate conclusions of eagle prey selectivity. For example, the abundance of jack-rabbits during a golden eagle study in south-western Idaho were in some years predicted using a correlation model

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(Steenhof and Kochert 1988), increasing the likelihood that errors were present in the prey availability data of this research.

It has also been hypothesised that wedge-tailed eagles show preference for other mammal species. Parker *et al.* (2007) commented that eagles may have selected lambs and travelled some distance (20 km) to obtain this prey rather than alternate sources. It would be unusual, however, for a large eagle to stray so far from a breeding site which is normally chosen because of its proximity to available food (Newton 1976). Golden eagles ranged shorter distances from the nest site during breeding and still stayed within their home range (Haworth *et al.* 2006). Also, the territorial behaviour of eagles (Brooker 1974) would limit them from ranging across the active territories of neighbouring pairs regularly for one prey source. Parker *et al* 's (2007) suggestion of eagles being efficient at finding the few feral lambs that were available closer to the nest in the National Park study site is more likely.

It would be unusual for a native predator to select an introduced prey animal based on its species, as some research appears to indicate. The abundance of rabbit-sized native Australian marsupials prior to European settlement and the introduction of the rabbit (Menkhorst and Knight 2004; Burbidge 2004) would no doubt have provided wedge-tailed eagles with sufficient prey. That the Karakamia pair of eagles in this study preyed almost exclusively on reintroduced native marsupials shows that a natural predator-prey relationship can be restored in some areas, and is similar to the findings of Richards and Short (1998), where eagles consumed only native marsupials on Bernier Island in Shark Bay. It also indicates that highly adaptable raptors like the wedge-tailed eagle can maintain stable breeding territories and continue a successful reproductive cycle despite changes in the composition of mammal communities on which they feed.

Wedge-tailed eagles at Karakamia ate mostly mammals 500 - 4000 g, including the brush-tailed possum, woylie (not previously recorded as wedge-tailed eagle prey), quenda and small wallabies, animals that are all high in abundance at this study site (AWC 2006). There are previous records of eagle predation on other bettongs (Fawkner 1991; Fulton 2006; Richards and Short 1998), bandicoots (Marchant and Higgins 1993; Harder 2000; Fuentes *et al.* 2007) and possums (Hull 1986; Burnett *et al.* 1996; Harder 2000) as well as smaller macropods (Marchant and Higgins 1993; Sharp 1997; Parker *et al.* 2007), and it is of interest that each prey species has very different sheltering behaviour and habitat preference. The brush-tailed possum is nocturnal and at Karakamia readily feeds on the ground as well as in the trees, but it is mostly arboreal when roosting by day

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where it normally occupies high tree hollows (Gemmell and Nelson 2004); the woylie is virtually strictly nocturnal, sheltering in a grass nest among thick vegetation on the ground by day (Christensen 2004a); the quenda is often active in broad daylight (Menkhorst and Knight 2004); and both brush and tammar wallabies shelter in dense vegetation during the day but emerge to feed from late afternoon to well after dark (Christensen 2004b; Smith and Hinds 2004).

Despite the difficulties these variations in activity may present to a diurnal predator, wedge-tailed eagles were capable of regularly capturing nocturnal species. Richards and Short (1998) also found it abnormal for the diet of a diurnal predator to consist wholly of nocturnal prey. Possible explanations for this include eagles hunting in darkness or moonlight (Marchant and Higgins 1993), flushing of prey by eagles during daylight (Lansell 1937; Mooney 1984a), or crepuscular behaviour of both predator and prey, scavenging of prey animal carcasses that had died of other causes, and the lack of competing scavengers in a feral-free environment making carcasses available to eagles (Richards and Short 1998). All these suggestions are relevant to the present study, however it is less likely that scavenging is applicable as observations of prey at a Karakamia nest in 2007 indicated that woylie and quenda carcasses were freshly killed (S. Cherriman unpub. data).

Wedge-tailed eagles are known to be active well before sunrise (Brooker 1974; N. Birks pers. comm.), have been observed feeding on carrion on moonlit nights (Marchant and Higgins 1993), and adult birds that have been flushed from nests at night are capable of flying and finding their way back in complete darkness (Ellis 1960, S. Cherriman this study). Although their visual acuity is reduced at lower light levels (Reymond and Wolfe 1981), some conditions may still create shadows which are sufficient for eagles to detect movement and capture prey successfully (Richards and Short 1998), especially if the eagles at Karakamia and Paruna are crepuscular. Despite mostly nocturnal habits, woylies have been observed active in twilight *c.* half an hour before dark, and this would make them easily available to eagles. Another explanation for predation of nocturnal prey is that the possum, woylie and quenda are regularly trapped during monitoring at both Karakamia and Paruna (AWC 2006) and released in daylight, which would occasionally make them vulnerable to eagles if they did not seek shelter quickly. Richards and Short (1998) noted that a bandicoot released after trapping on Bernier Island was predated by a wedge-tailed eagle an hour before dawn in almost complete darkness.

It is probable that the wedge-tailed eagles in this study may have used a combination of the above behaviours, but were mostly diurnal predators that were alert to the behavioural patterns of their

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main mammalian prey. Some raptors are able to see into the ultra violet spectrum and therefore may see animal scent trails (Olsen 2005). If this is applicable to wedge-tailed eagles it is likely that prey can be detected in daylight, despite being otherwise inconspicuous, and readily flushed to be captured by a single eagle or a pair hunting cooperatively (Brooker and Ridpath 1980; Garrett 2002; Geary 1932; Marchant and Higgins 1993). This applies to terrestrial mammals; brush-tailed possums have been extracted from tree hollows during daylight (Le Souëf 1918; Marchant and Higgins 1993).

There has been speculation that predation by wedge-tailed eagles upon native mammal species following large reductions in the eagles' principal prey (especially rabbits) will impact upon the population of these mammals (Davidson 2002; Sharp *et al.* 2002b), which is significant if the species is threatened. The evidence from the two AWC sanctuaries in this study, especially Karakamia, suggests that this is not the case. In fact, the natural predator-prey relationship is probably a healthy ecological process, provided the native mammals are able to become established, as predation can help maintain a healthy population of prey animals (Olsen 1995; Campbell 1999). The founder animals of 18 woylies at Karakamia have probably coped with eagle predation since their reintroduction. This has not been detrimental to their survival as the population, which was *c.* 500 in 2007 (J. Richards pers. comm.), continues to grow despite this predation and regular translocations (210 woylies have been translocated from Karakamia in the last two years; AWC 2006). However, the diversity of mammals available to the eagles at this site probably acts as a buffer to the targeting of one particular species, and eagles may indeed hinder efforts to re-establish certain species such as reintroduced mammals if those species are preferred to other local prey such as birds. Conversely, the removal of a species which constitutes the main prey of eagles could impact the predator's success, however this is unlikely to be the case with such an adaptable predator as the wedge-tailed eagle.

Several other mammals were taken as wedge-tailed eagle prey in the Perth region. The cat found at Karakamia could have belonged to a nearby farmhouse, or may have been feral, and was probably hunted in cleared paddocks surrounding the northern areas of Cookes Brook outside the feral-proof fence. Cats are often recorded as wedge-tailed eagle food (e.g. Leopold and Wolfe 1970; Brooker and Ridpath 1980; Mooney 1984b; Hull 1986; Parker *et al.* 2007; Winkel 2007). The fox taken at Helena Valley is also consistent with other studies (Lewis 1957; Marchant and Higgins 1993). Chuditch, which have not been previously recorded as wedge-tailed eagle prey, have recovered in the Avon Valley since the establishment of Paruna Wildlife Sanctuary and regional fox control. As

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they are occasionally diurnal, especially if cold wet weather restricts nocturnal foraging (Serena and Soderquist 2004), this would facilitate their predation by eagles. The feral piglet recorded at Paruna is not unusual: large numbers of feral pigs have been observed by DEC staff since feral pig control began in late 2006 (A. Dugand pers. comm.), and pigs have been found as eagle food previously (Marchant and Higgins 1993; Watts 2004; Parker *et al.* 2007). Although raptor diet studies sometimes reveal the presence of animals that have not been located by traditional fauna surveys (Fuentes *et al.* 2007), there were no mammal species that were expected prey that did not appear in wedge-tailed eagle diet in the Perth region.

5.4.2. Birds

The high diversity of birds taken in the Perth region was similar to that recorded elsewhere in Western Australia by Brooker and Ridpath (1980). Apart from musk duck *Biziura lobata*, rainbow lorikeet *Trichoglossus haematodus* and spotted turtle-dove *Streptopelia chinensis*, which have not been recorded in eagle diet in other research (Marchant and Higgins 1993), all other species are known prey of wedge-tailed eagles. The musk duck, which is highly aquatic and seldom observed on the wing (Pizzey and Knight 1999), may have been taken from the surface of a water body. The other two introduced birds are common on the Swan Coastal Plain and readily available as eagle prey. A pair of rainbow lorikeets was observed nesting in a hollow in the jarrah tree in which Nest 2 of the Whiteman Park wedge-tailed eagles was situated. With the exception of magpie lark *Grallina cyanoleuca* all birds were >100 g, a finding consistent with that of Brooker and Ridpath (1980). Wedge-tailed eagles are known to occasionally prey on birds <100 g, (Marchant and Higgins 1993; Sharp *et al.* 2002b; Debus *et al.* 2007; Parker *et al.* 2007; Winkel 2007; Fuentes *et al.* 2007), but there is little indication that these sized birds are frequently taken (Brooker and Ridpath 1980).

Ravens and wood ducks were the most common birds eaten by wedge-tailed eagles in the Perth region. These two avian prey species were abundant in the study area. Most raven wing feathers in the prey remain collections belonged to immature birds with primary and secondary feathers still emerging from the calamus: these inexperienced birds may be taken when feeding on the ground in open areas (Johnstone and Storr 2004), or robbed from nests before fledging. Wood ducks, which are known to congregate in large flocks at the edge of water bodies at all study sites, could be predated in this situation (Olsen 2005), or were possibly taken in flight. The majority of bird species that were preyed upon by eagles are known to feed on the ground, mostly in open grassland/woodland, which is probably where they are predated by eagles. For example, in late 2007, a wedge-tailed eagle that was soaring high above cleared farmland at the Gidgegannup site

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suddenly stooped into a fast dive for *c.* 200 m and struck a ringneck parrot that was feeding in an open paddock. Larger cockatoo species have also been predated while on the ground (Brooker and Ridpath 1980) as well as in flight (Haby 1997). The nocturnal birds found as eagle prey in this study (tawny frogmouth *Podargus strigoides* and southern boobook *Ninox novaeseelandiae*) may have been flushed from roosts during the day or taken as carrion. Nocturnal species of bird including owls, the tawny frogmouth and spotted nightjar *Eurostopodus argus* have often been found road-killed in the Perth region, especially in the Darling Range where they may be attracted to insects swarming at street lights at night.

The data from Gidgegannup and Helena Valley indicated that more birds were taken at these sites. It has been suggested that birds can easily be underestimated in dietary studies that rely on prey remains from nests, especially when collections are made some time after use of the nest, as their remains deteriorate in the environment more rapidly than mammalian bones (Sharp *et al.* 2001) and may not truly be represented in collections. If this was the case at the aforementioned Perth region sites, then birds would be expected to contribute a greater proportion in eagle diet than documented here. Most collections were made at inactive nests where at least six months had elapsed since the study nests had been active, thus eagles probably preyed on legitimately more birds at the Gidgegannup and Helena Valley sites than eagles elsewhere in the Perth region. This is consistent with previous inferences at these locations (Cherriman 2004). That eagles preyed upon more birds may be due to birds occurring in higher numbers in the vicinity of active nests, or that favoured mammal prey species were less common at these sites, causing eagles to switch to birds as a secondary prey preference (Sharp *et al.* 2002b).

5.4.3. Reptiles

Reptiles were taken by wedge-tailed eagles in very low proportions in the Perth region (4% by number, 0.8% of biomass), but have played a more important role in eagle diet elsewhere in Australia (*cf.* 17.6% by number, Leopold and Wolfe 1970; 23%, Harder 2000; 22.6%, Sharp *et al.* 2002b; 34%, Silva and Croft 2007). This probably reflects differences in climate and vegetation structure in these areas. In Perth reptiles may be in lower abundance than mammals and birds, and harder to capture in the eucalypt woodland of the five study sites. Bobtail skinks, the main reptilian species taken by wedge-tailed eagles in this study, commonly bask in the sun in open areas (Bush *et al.* 1995) which may make them more available as eagle prey. They are also killed in large numbers on roads throughout the Perth region in spring during the middle of the eagles' nestling period, so could be taken as carrion. Other dragon *Pogona* species known to be preyed on by wedge-tailed

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eagles which are similar to the *P. minor* taken as prey in this study include central bearded dragons *P. vitticeps* (Leopold and Wolfe 1970; Sharp *et al.* 2002b; Collins and Croft 2007; Silva and Croft 2007; Parker *et al.* 2007; Winkel 2007) and eastern bearded dragons *P. barbata* (Debus and Rose 1999; Dennis 2006). Varanids have also been previously recorded as eagle food in Australia (Leopold and Wolfe 1970; Brooker and Ridpath 1980; Harder 2000; Sharp *et al.* 2002b; Winkel 2007), and may be readily captured on the ground (Geary 1932) or from tree-trunks (Hollands 2003).

5.5. Non-breeding Diet

The method of attempting to locate roost sites and use these to source eagle pellets was largely unsuccessful. However, the time spent in the field searching for roosts was valuable as it provided the observations documented in Section 4.4 ‘Non-breeding Diet’ (above). The limited non-breeding data obtained from pellets that were found showed a similar range of prey species consumed during breeding that was consistent with Brooker and Ridpath (1980), who also compared ‘summer’ and ‘winter’ food types in pellets. In general, the trend in eagle behaviour in the non-breeding season was consistent with previous research and/or inferences (Brooker and Ridpath 1980; Ridpath and Brooker 1986a, 1986b; Olsen 2005; Debus *et al.* 2007). Adult behaviour is concentrated around the nest site until offspring fledge, distances travelled from the nest progressively become larger as the fledgling(s) gain confidence at flying, then after the immature eagle(s) leave the territory, adults may roam large distances within their territory and not return to the nest site for several days.

It is difficult to document seasonal changes in diet given the limited non-breeding data obtained in this study. A diet of mostly live prey while breeding is consistent with there being a high demand for food at nest sites which is ‘easily portable.’ Live prey is probably also taken in high proportions during the post-fledging period while the immature eagles learn hunting techniques form adults who continue to provision them (Debus *et al.* 2007). When the young eagles achieve independence and leave the territory, the adults could become more opportunistic while roaming larger distances from their nest site, and may well eat more carrion during this time, as evident from the ‘12th April 2007’ observation under ‘2007 Non-breeding Season’ above. However, it is likely that resident breeding pairs of wedge-tailed eagles only eat more carrion than live prey during the short period that their behaviour is not focussed on breeding and young, and eagles that feed primarily on carrion are those immature or sub-adult birds that have not yet commenced breeding. This is consistent with Brooker and Ridpath (1980), who observed that an increase in the number of immature eagles coincided with a higher abundance and availability of carrion.

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5.6. Territory Size and Diet

Raptor territory size is thought to be influenced by food and nest site availability (Newton 1976). Although the latter is likely to be less relevant, the former, in addition to those factors discussed in Section 5.2 'Territory Size' above, is probably largely the case for wedge-tailed eagles in the Perth region. Although no data on prey population densities and/or fluctuations were collected, it can be inferred that eagles with the smallest territories (i.e. Karakamia, territory size 23.5 km² and Whiteman Park, 29.4 km²) had access to higher densities of prey animals. This was the case with golden eagles in south-western Idaho, where the smallest territory occurred in habitat with the highest density of the eagles' main prey, the black-tailed jack rabbit (Collopy and Edwards 1989).

Limited data on prey numbers at one site in this study, however, were available. Based on trapping and spotlighting data from Karakamia, numbers of favoured eagle prey at this site were: at least 266 woylies, 58 quenda, 48 brush-tailed possums, 40 western grey kangaroos, 38 tammar wallabies and 16 western brush wallabies present within the *c.* 260 ha feral-proof fence area during 2005 and 2006 (AWC 2006). By discounting the two species of larger macropod (i.e. kangaroos and brush wallabies: an unknown proportion of the population of these mammals, if any, were available as eagle prey due to unknown age/size characteristics), the above data gives a total of 410 mammals in *c.* 260 ha, which equates to a potential prey density of at least 158 per km² inside the fenced area alone. This figure would be much higher if animal numbers outside the fence were known and included, and is well above the minimum prey threshold of 60 rabbits per km² for eagle breeding to occur in arid Western Australia (Ridpath and Brooker 1986b), where eagle territory size at two sites was slightly greater than that at Karakamia (23.5 km², *cf.* 32 and 42 km², Ridpath and Brooker 1987).

Further considering the influence of food on territory size, it is interesting to note that the wedge-tailed eagle pairs in this study with the largest territories (i.e. Gidgegannup, 42.4 km² and Helena Valley, 46.9 km²) were also those which preyed upon significantly more birds (see 'Breeding Diet' in Section 5.4.2 above). Eagles would require a broad area to capture more birds that contribute less food biomass than mammals, hence the larger territories at these study sites. In other words, eagles that have access to mostly mammals as prey receive greater biomass per capture and consequently require smaller territories than those feeding primarily on birds.

Bald Island, a small granite landform located east of Albany *c.* 1 km off the coast of Western Australia, is home to one pair of wedge-tailed eagles (Storr 1965), and provides another comparison

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of the relationship between eagle territory size and prey abundance. The eagles are known to prey on great-winged petrels, and as these occasionally sit outside the entrance to their nest burrows (Storr 1965), it is probable that they are hunted from the land. It is less likely that petrels are taken on the wing over the ocean, as golden eagles are known to avoid open water for hunting (Watson *et al.* 1992). Quokkas, which have a population of 200 - 600 animals on the island and are found in all habitat types (Main and Yadav 1971), fall into the category of mammals >500 g favoured as prey by wedge-tailed eagles (Brooker and Ridpath 1980), and along with petrels, are probably the principal prey of the resident eagles here. On a visit to Bald Island in 2007, prey remains under the eagle nest consisted mostly of quokka (S. Cherriman unpub. data). If this is the case, and most prey is taken from the Bald Island landmass, then its *c.* 8 km² area probably forms the bulk of the eagles' territory, even though the birds undoubtedly visit the mainland. This is unlikely to be an underestimate of the true size of this pair's foraging ground, and gives an indication of how wedge-tailed eagles nesting in locations of high prey density (quokka density *c.* 25 - 75 per km² on Bald Island, Main and Yadav 1971) can occupy relatively small territories.

Wedge-tailed eagles in the Perth region appear to adapt well to changes in prey diversity and abundance, and are able to feed on a variety of vertebrate animals. The densities of their favoured prey, together with other aspects such as landscape and vegetation characteristics and human activity (discussed in Section 5.2 'Territroy Size' above), are the main factors influencing the size of the territories they occupy. This study has shown that the eagles in the Perth region have the ability to expand and contract their territories according to these factors, and remain successful on the fringes of a rapidly growing capital city in Australia.

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5.7. Additional Observations of Wedge-tailed Eagles in the Perth region

5.7.1. Nest Building Behaviour

It is possible that wedge-tailed eagles spend some time 'settling in' if a newly formed pair has taken up residence in a vacant territory. Observations of the Helena Valley birds early in this study showed that in three consecutive years, nests were lined but not used for breeding. In June 2002, Nest 3 was newly constructed and continuously lined with fresh leaves until late August (Cherriman 2004). The adults were often seen perched on the nest, and on one occasion they fed on a freshly killed wood duck, but no eggs were laid. Then in early September, Nest 1 was newly constructed but not lined and subsequent observations of the eagles in 2002 were of the pair soaring high on thermals, often several kilometres from the nest area. In late May 2003, both adult eagles were observed alternately adding large branches to Nest 1, and by late July the nest was freshly lined with leaves, but by early September still no eggs had been laid. Throughout June 2004, there was no activity at any known nest, however in early August an adult eagle was seen with fresh eucalypt sprigs on Nest 4, an apparently old nest that had not been used for many years. Once again breeding did not take place despite continuous lining of this nest. Breeding was then recorded in 2005 at yet another new nest (Nest 9), freshly built approximately 8 km west of Nests 1 - 6 (Figure 2), and used successfully to rear one offspring. Both adults partaking in nest construction is consistent with Fleay (1952) and Olsen (2005), but contrasts with Hughes and Hughes (1984), who observed only the female to carrying branches to the nest. The building of new nests which are not immediately used for breeding has also been documented for golden eagles (Dixon 1937).

These observations perhaps indicate that this pair of eagles was new to the territory and took some time building several new nests before actually breeding, or that prey populations fluctuated throughout each year and did not maintain the threshold required for eagles to continue breeding. Alternatively, they may have been attempting to breed in consecutive years but were continuously disrupted by human disturbance in the Helena Valley. On numerous visits to this territory, many illegal four-wheel drive vehicles and trail-bikes were encountered, some of which spent long periods on a track *c.* 100m from Nest 1. Additional disturbance may have been caused by finding and occasionally approaching the nests in this study. However, on most occasions the eagles were observed from a distance >400m with binoculars, and the fact that normal eagle behaviour (e.g. nest-building and feeding) was witnessed during visits when no recreational vehicles were encountered would indicate the eagles were not affected by a single person in their territory.

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There is also the possibility that a different pair altogether built and used Nest 9, given its distance from Nests 1 - 6, or that the same pair had decided to nest in another part of their territory far from their previous encounters with humans. However, Nest 9 is *c.* 200m from a public quarry used frequently by abseiling groups, and only 800 m from residential area, far less remote than the location of Nests 1 - 6.

Reactions by *Aquila* eagles to disturbance are known to vary, and habituation may occur gradually over time, depending on the species. There was a high probability of reaction from Spanish imperial eagles *A. adalberti* when disturbance occurred at distances <450 m from the nest, and the eagles were less often flushed by passing people than other disturbances such as campers and hunters (González *et al.* 2006). Similarly, one pair of wedge-tailed eagles in the New England Region of New South Wales could not be approached through dense woodland without flushing before an observer was 'within viewing distance' of their nest (Debus *et al.* 2007). However, other pairs in the same region appeared habituated to routine human activities near their nests, even at distances of *c.* 100 m. The apparently unsettled nesting behaviour of the Helena Valley pair of wedge-tailed eagles in the Perth region may be the result of a combination of the above factors of territorial behaviour, fluctuations in prey numbers and human disturbance, and requires ongoing study to quantify these factors and determine which most influence eagle behaviour.

<u>5.7.2. Adult Behaviour at Nests</u>

Most pairs of eagles in the Perth region showed behaviour similar to that described for the species in general, being shy and unapproachable at the nest (Olsen 2005). The adults often soared high above the nest while the observer collected prey remains from below the nest and perch trees (Ellis 1960). One exception was the female at the Paruna study site, who was highly protective of the nest site on several occasions. This bird often remained at the nest when it was approached, and flew from the nest tree and followed the observer closely, perching in trees above and calling continuously. On two occasions this female disappeared from view, soared high for several minutes, then performed a series of dives from *c.* 100 m in the air directly at the observer with wings folded in, alulae prominent and legs fully extended. This behaviour is unusual and rarely recorded in the wedge-tailed eagle (Cupper and Cupper 1981). Aggressive defence of the nest site could be expected if an eagle had become readily habituated to humans and was aware of intentional nest disturbance by them (*cf.* Debus *et al.* 2007), but not at a location such as Paruna, which is remote from intensive human activities.

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6. Conclusion

Wedge-tailed eagle territory size in the Perth region, which averaged approximately 36 km², appears to be influenced by landforms, proximity to human disturbances, the availability of certain sized prey animals, and to some extent vegetation structure which may determine how easily some prey types are captured.

Given that eagle territories mostly occur in large remnants of bushland, and these areas are either partially or fully in conservation reserves, this should hold the eagles in good stead for persistence into the future. However, at some sites where human disturbance is high, land managers should be aware that care is needed for future habitat maintenance as these sites are particularly prone to 'edge effects' and intrusions from the human footprint.

This study has shown that the variety of techniques available in researching wedge-tailed eagle diet are effective but all methods have associated difficulties and biases that can cause spurious results and influence their interpretation. It is emphasised that the results of any one method should be presented separately, unless it is certain that prey animals are not counted twice using some methods simultaneously. Attempting to find eagle roosts and hence pellets in the non-breeding season is not an effective way to study diet during this time. Future research using radio- or satellite-tracking methods would increase the reliability of obtaining non-breeding data.

Wedge-tailed eagle breeding diet in this study consisted of a diverse range of vertebrate prey animals, where mammals (82.1% of diet biomass) and birds (17.2%) were favoured as prey and reptiles were (0.8%) rarely taken. The predation on threatened mammal species at the two AWC sanctuaries does not appear to have placed the populations of these species under any threat, but rather is a natural predator-prey relationship that has been restored. The wedge-tailed eagle's diverse diet, which includes both diurnal and nocturnal species, and its capacity to expand or contract territory size according to food availability, further illustrates its capability as a highly adaptable predator that is able to succeed in a variety of habitats, hence its broad distribution across the Australian continent.

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8. Appendices

APPENDIX 1.

Range of wedge-tailed eagle prey species as determined by three methods of analysis.

Prey Species			Approximate weight (g)
MAMMALS			
	Chuditch	*Dasyurus geoffroii*	1100
	Quenda	*Isoodon obesulus*	800
	Brush-tailed Possum	*Trichosurus vulpecula*	2600
	Woylie	*Bettongia penicillata*	1300
	Tammar Wallaby	*Macropus eugenii*	4000
	Western Grey Kangaroo (juv.)	*Macropus fuliginosus*	3800
	Western Brush Wallaby	*Macropus irma*	2500
	*Fox	*Vulpes vulpes*	5000
	*Cat	*Felis catus*	4350
	*Sheep	*Ovis aries*	5000
	*Goat	*Capra hircus*	5000
	*Pig	*Sus scrofa*	4100
	*Rabbit	*Oryctolagus cuniculus*	1500
	Unidentified mammal		3160
BIRDS			
	Emu (juv.)	*Dromaius novaehollandiae*	2420
	*Domestic Chicken	*Gallus gallus*	1000
	Black Swan	*Cygnus atratus*	5000
	Musk Duck	*Biziura lobata*	1900
	Australian Wood Duck	*Chenonetta jubata*	820
	Pacific Black Duck	*Anas superciliosa*	1100
	Wedge-tailed Eagle (nestling)	*Aquila audax*	1800
	*Feral Pigeon	*Columba livia*	335
	*Spotted Turtle-dove	*Streptopelia chinensis*	160
	Common Bronzewing	*Phaps chalcoptera*	340
	Black Cockatoo	*Calyptorhynchus* spp.	685
	Galah	*Cacatua roseicapilla*	310
	Corella	*Cacatua* spp.	585
	*Rainbow Lorikeet	*Trichoglossus haematodus*	120
	Ringneck Parrot	*Barnardius zonarius*	210
	Southern Boobook	*Ninox novaeseelandiae*	280
	Tawny Frogmouth	*Podargus strigoides*	330
	Magpie Lark	*Grallina cyanoleuca*	80
	Australian Magpie	*Cracticus tibicen*	300
	Australian Raven	*Corvus coronoides*	540
	Unidentified bird		915
REPTILES			
	Bearded Dragon	*Pogona minor*	80
	Gould's Monitor	*Varanus gouldii*	415
	Black-tailed Monitor	*Varanus tristis*	155
	Bobtail Skink	*Tiliqua rugosa*	290
	Unidentified reptile		235

* = introduced species

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APPENDIX 2.

Minimum number of individuals (**bold**) and number of prey remains analysed (*italics*), collected from wedge-tailed eagle nests at five study sites in the Perth region.

Prey Species		Whiteman Park						Karakamia						Gidgegannup				Paruna		Helena Valley		Total All Sites	
		2004		2005		2006		2004		2005		2006		2004		2005		2006		2005			
MAMMALS:																							
Quenda	*Isoodon obesulus*	**1**	*1*					**1**	*3*	**7**	*20*	**1**	*1*									**10**	*25*
Brush-tailed Possum	*Trichosurus vulpecula*							**7**	*15*	**5**	*8*	**3**	*8*							**1**	*3*	**16**	*34*
Woylie	*Bettongia penicillata*							**3**	*6*	**9**	*27*											**12**	*33*
Tammar Wallaby	*Macropus eugenii*									**3**	*14*							**2**	*3*			**5**	*17*
Western Brush Wallaby	*Macropus irma*							**1**	*1*													**1**	*1*
Western Grey Kangaroo	*Macropus fuliginosus*			**1**	*5*	**3**	*9*	**6**	*25*	**2**	*9*	**1**	*5*	**1**	*2*	**3**	*8*	**4**	*27*	**2**	*5*	**23**	*95*
*Cat	*Felis catus*											**1**	*1*									**1**	*1*
*Pig	*Sus scrofa*																	**1**	*3*			**1**	*3*
*Rabbit	*Oryctolagus cuniculus*	**1**	*1*	**6**	*15*	**56**	*134*	**2**	*8*					**1**	*2*	**1**	*2*	**2**	*4*	**3**	*6*	**72**	*172*
Unidentified mammal																**1**	*1*					**1**	*1*
	Total Mammals:	**2**	*2*	**7**	*20*	**59**	*143*	**20**	*58*	**26**	*78*	**6**	*15*	**2**	*4*	**5**	*11*	**9**	*37*	**6**	*14*	**142**	*382*
BIRDS:																							
*Domestic Chicken	*Gallus gallus*																			**1**	*7*	**1**	*7*
Black Swan	*Cygnus atratus*							**1**	*5*													**1**	*5*
Musk Duck	*Biziura lobata*													**1**	*1*							**1**	*1*
Australian Wood Duck	*Chenonetta jubata*	**1**	*2*	**1**	*1*	**2**	*4*	**1**	*2*	**2**	*10*	**1**	*2*	**1**	*8*			**1**	*2*	**1**	*5*	**11**	*36*
Pacific Black Duck	*Anas superciliosa*			**1**	*1*	**1**	*1*	**2**	*4*	**1**	*5*			**1**	*4*							**6**	*15*
Wedge-tailed Eagle (nestling)	*Aquila audax*																			**1**	*3*	**1**	*3*
*Feral Pigeon	*Columba livia*			**1**	*1*	**2**	*3*															**3**	*4*
*Spotted Turtle-dove	*Streptopelia chinensis*																			**1**	*1*	**1**	*1*
Common Bronzewing	*Phaps chalcoptera*									**1**	*2*									**1**	*1*	**2**	*3*
Black Cockatoo	*Calyptorhynchus* spp.													**1**	*2*			**1**	*6*			**2**	*8*
Galah	*Cacatua roseicapilla*			**1**	*3*	**1**	*1*			**1**	*1*	**1**	*1*	**1**	*1*	**1**	*1*					**6**	*8*
Corella	*Cacatua* spp.	**1**	*1*			**1**	*1*															**2**	*2*
*Rainbow Lorikeet	*Trichoglossus haematodus*			**1**	*1*																	**1**	*1*
Ringneck Parrot	*Barnardius zonarius*			**1**	*2*							**2**	*4*	**1**	*2*	**1**	*3*			**1**	*1*	**6**	*12*
Southern Boobook	*Ninox novaeseelandiae*			**1**	*1*							**1**	*1*									**2**	*2*
Tawny Frogmouth	*Podargus strigoides*							**1**	*2*											**1**	*1*	**2**	*3*
Magpie Lark	*Grallina cyanoleuca*			**1**	*2*																	**1**	*2*
Australian Magpie	*Cracticus tibicen*			**1**	*1*					**2**	*12*	**1**	*1*							**1**	*3*	**5**	*17*
Australian Raven	*Corvus coronoides*	**3**	*3*	**3**	*6*	**6**	*14*	**2**	*8*	**4**	*12*	**3**	*5*	**3**	*10*	**4**	*9*	**2**	*3*	**1**	*2*	**31**	*72*
Unidentified bird				**1**	*1*	**1**	*1*			**2**	*2*	**1**	*1*	**3**	*3*	**1**	*1*	**1**	*1*			**10**	*10*
	Total Birds:	**5**	*6*	**13**	*20*	**14**	*25*	**7**	*21*	**13**	*44*	**10**	*15*	**12**	*31*	**7**	*14*	**5**	*12*	**9**	*24*	**95**	*212*
REPTILES:																							
Bearded Dragon	*Pogona minor*									**1**	*4*											**1**	*4*
Gould's Monitor	*Varanus gouldii*							**1**	*1*	**1**	*2*											**2**	*3*
Black-tailed Monitor	*Varanus tristis*							**1**	*1*													**1**	*1*
Bobtail Skink	*Tiliqua rugosa*							**2**	*2*	**1**	*1*					**2**	*4*					**5**	*7*
Unidentified reptile										**1**	*1*											**1**	*1*
	Total Reptiles:							**4**	*4*	**4**	*8*					**2**	*4*					**10**	*16*
	TOTAL:	**7**	*8*	**20**	*40*	**73**	*168*	**31**	*83*	**43**	*130*	**16**	*30*	**14**	*35*	**14**	*29*	**14**	*49*	**15**	*38*	**247**	*610*
* = introduced species																							

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APPENDIX 3.

Minimum number of individuals and percentage by number of prey animals consumed by wedge-tailed eagles at five study sites in the Perth region.

Prey Species		Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total All Sites
MAMMALS:							
Quenda	*Isoodon obesulus*	1 (1.0)	9 (10.0)				10 (4.0)
Brush-tailed Possum	*Trichosurus vulpecula*		15 (16.7)			1 (6.7)	16 (6.5)
Woylie	*Bettongia penicillata*		12 (13.3)				12 (4.9)
Tammar Wallaby	*Macropus eugenii*		3 (3.3)		2 (14.3)		5 (2.0)
Western Brush Wallaby	*Macropus irma*		1 (1.1)				1 (0.4)
Western Grey Kangaroo	*Macropus fuliginosus*	4 (4.0)	9 (10.0)	4 (14.3)	4 (28.6)	2 (13.3)	23 (9.3)
*Cat	*Felis catus*		1 (1.1)				1 (0.40
*Pig	*Sus scrofa*				1 (7.1)		1 (0.4)
*Rabbit	*Oryctolagus cuniculus*	63 (63.0)	2 (2.2)	2 (7.1)	2 (14.3)	3 (20.0)	72 (29.1)
Unidentified mammal				1 (3.6)			1 (0.4)
	Total Mammals:	**68 (68.0)**	**52 (57.8)**	**7 (25.0)**	**9 (64.3)**	**6 (40.0)**	**142 (57.5)**
BIRDS:							
*Domestic Chicken	*Gallus gallus*					1 (6.7)	1 (0.4)
Black Swan	*Cygnus atratus*		1 (1.1)				1 (0.4)
Musk Duck	*Biziura lobata*			1 (3.6)			1 (0.4)
Australian Wood Duck	*Chenonetta jubata*	4 (4.0)	4 (4.4)	1 (3.6)	1 (7.1)	1 (6.7)	11 (4.5)
Pacific Black Duck	*Anas superciliosa*	2 (2.0)	3 (3.3)	1 (3.6)			6 (2.4)
Wedge-tailed Eagle (nestling)	*Aquila audax*					1 (6.7)	1 (0.4)
*Introduced Pigeon	*C. livia and S. chinensis*	3 (3.0)				1 (6.7)	4 (1.6)
Common Bronzewing	*Phaps chalcoptera*		1 (1.1)			1 (6.7)	2 (0.8)
Black Cockatoo	*Calyptorhynchus* spp.			1 (3.6)	1 (7.1)		2 (0.8)
Galah	*Cacatua roseicapilla*	2 (2.0)	2 (2.2)	2 (7.1)			6 (2.4)
Corella	*Cacatua* spp.	2 (2.0)					2 (0.8)
*Rainbow Lorikeet	*Trichoglossus haematodus*	1 (1.0)					1 (0.4)
Ringneck Parrot	*Barnardius zonarius*	1 (1.0)	2 (2.2)	2 (7.1)		1 (6.7)	6 (2.4)
Southern Boobook	*Ninox novaeseelandiae*	1 (1.0)	1 (1.1)				2 (0.8)
Tawny Frogmouth	*Podargus strigoides*		1 (1.1)			1 (6.7)	2 (0.8)
Magpie Lark	*Grallina cyanoleuca*	1 (1.0)					1 (0.4)
Australian Magpie	*Cracticus tibicen*	1 (1.0)	3 (3.3)			1 (6.7)	5 (2.0)
Australian Raven	*Corvus coronoides*	12 (12.0)	9 (10.0)	7 (25.0)	2 (14.3)	1 (6.7)	31 (12.6)
Unidentified bird		2 (2.0)	3 (3.3)	4 (14.3)	1 (7.1)		10 (4.0)
	Total Birds:	**32 (32.0)**	**30 (33.3)**	**19 (67.9)**	**5 (35.7)**	**9 (60.0)**	**95 (38.5)**
REPTILES:							
Bearded Dragon	*Pogona minor*		1 (1.1)				1 (0.4)
Gould's Monitor	*Varanus gouldii*		2 (2.2)				2 (0.8)
Black-tailed Monitor	*Varanus tristis*		1 (1.1)				1 (0.4)
Bobtail Skink	*Tiliqua rugosa*		3 (3.3)	2 (7.1)			5 (2.0)
Unidentified reptile			1 (1.1)				1 (0.4)
	Total Reptiles:		**8 (8.9)**	**2 (7.1)**			**10 (4.0)**
	TOTAL:	**100 (100)**	**90 (100)**	**28 (100)**	**14 (100)**	**15 (100)**	**247 (100)**

* = introduced species

(orange) = most significant mammal prey species in the Perth region (from Chi-squared test: χ^2 = 297.58, df = 9, P < 0.001)

(yellow) = most significant bird prey species in the Perth region (from Chi-squared test: χ^2 = 176.40, df = 18, P < 0.001)

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APPENDIX 4.

Total mass (g) and percentage of biomass from remains of prey animals consumed by wedge-tailed eagles at five study sites in the Perth region.

Prey Species		Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total All Sites
MAMMALS:							
Quenda	*Isoodon obesulus*	800 (0.6)	7200 (5.1)				8000 (2.2)
Brush-tailed Possum	*Trichosurus vulpecula*		39000 (27.4)			2600 (12.9)	41600 (11.6)
Woylie	*Bettongia penicillata*		15600 (11.0)				15600 (4.3)
Tammar Wallaby	*Macropus eugenii*		12000 (8.4)		8000 (23.7)		20000 (5.6)
Western Brush Wallaby	*Macropus irma*		2500 (1.8)				2500 (0.7)
Western Grey Kangaroo	*Macropus fuliginosus*	15200 (11.9)	34200 (24.1)	15200 (43.5)	15200 (45.0)	7600 (37.6)	87400 (24.3)
*Cat	*Felis catus*		4350 (3.1)				4350 (1.2)
*Pig	*Sus scrofa*				4100 (12.1)		4100 (1.1)
*Rabbit	*Oryctolagus cuniculus*	94500 (73.8)	3000 (2.1)	3000 (8.6)	3000 (8.9)	4500 (22.3)	108000 (30.1)
Unidentified mammal				3160 (9.0)			3160 (0.9)
	Total Mammals:	**110500 (86.3)**	**117850 (82.9)**	**21360 (61.2)**	**30300 (89.6)**	**14700 (72.8)**	**294710 (82.1)**
BIRDS:							
*Domestic Chicken	*Gallus gallus*					1000 (5.0)	1000 (0.3)
Black Swan	*Cygnus atratus*		5000 (3.5)				5200 (1.4)
Musk Duck	*Biziura lobata*			1900 (5.4)			1900 (0.5)
Australian Wood Duck	*Chenonetta jubata*	3280 (2.6)	3280 (2.3)	820 (2.3)	820 (2.4)	820 (4.1)	9020 (2.5)
Pacific Black Duck	*Anas superciliosa*	2200 (1.7)	3300 (2.3)	1100 (3.1)			6600 (1.8)
Wedge-tailed Eagle (nestling)	*Aquila audax*					1800 (8.9)	1800 (0.5)
*Feral Pigeon	*Columba livia*	1005 (0.8)					1005 (0.3)
*Spotted Turtle-dove	*Streptopelia chinensis*					160 (0.8)	160 (<0.1)
Common Bronzewing	*Phaps chalcoptera*		340 (0.2)			340 (1.7)	680 (0.2)
Black Cockatoo	*Calyptorhynchus* spp.			685 (2.0)	685 (2.0)		1370 (0.4)
Galah	*Cacatua roseicapilla*	620 (0.5)	620 (0.4)	620 (1.8)			1860 (0.5)
Corella	*Cacatua* spp.	1170 (0.9)					1170 (0.3)
*Rainbow Lorikeet	*Trichoglossus haematodus*	120 (0.1)					120 (<0.1)
Ringneck Parrot	*Barnardius zonarius*	210 (0.2)	420 (0.3)	420 (1.2)		210 (1.0)	1260 (0.4)
Southern Boobook	*Ninox novaeseelandiae*	280 (0.2)	280 (0.2)				560 (0.2)
Tawny Frogmouth	*Podargus strigoides*		330 (0.2)			330 (1.6)	660 (0.2)
Magpie Lark	*Grallina cyanoleuca*	80 (0.1)					80 (<0.1)
Australian Magpie	*Cracticus tibicen*	300 (0.2)	900 (0.6)			300 (1.5)	1500 (0.4)
Australian Raven	*Corvus coronoides*	6480 (5.1)	4860 (3.4)	3780 (10.8)	1080 (3.2)	540 (2.7)	16740 (4.7)
Unidentified bird		1850 (1.4)	2745 (1.9)	3660 (10.5)	915 (2.7)		9250 (2.5)
	Total Birds:	**17595 (13.7)**	**22075 (15.5)**	**12985 (37.2)**	**3500 (10.4)**	**5500 (27.2)**	**61635 (17.2)**
REPTILES:							
Bearded Dragon	*Pogona minor*		80 (0.1)				80 (<0.1)
Gould's Monitor	*Varanus gouldii*		830 (0.6)				830 (0.2)
Black-tailed Monitor	*Varanus tristis*		155 (0.1)				155 (<0.1)
Bobtail Skink	*Tiliqua rugosa*		870 (0.6)	580 (1.7)			1450 (0.4)
Unidentified reptile			235 (0.2)				235 (0.1)
	Total Reptiles:		**2170 (1.5)**	**580 (1.7)**			**2750 (0.8)**
	TOTAL:	**128075 (100)**	**142095 (100)**	**34925 (100)**	**33800 (100)**	**20200 (100)**	**359095 (100)**
* = introduced species							

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APPENDIX 5.

Frequency of pellets and percentage mass of species in pellets (n = 164) at five study sites in the Perth region.

		Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total All Sites
	Total Pellets Collected:	(73)	(55)	(9)	(12)	(15)	(164)
MAMMALS:							
Quenda	*Isoodon obesulus*		16 (16.9)			8 (19.3)	24 (6.7)
Brush-tailed Possum	*Trichosurus vulpecula*		14 (17.2)			2 (19.1)	16 (6.8)
Woylie	*Bettongia penicillata*		8 (17.1)				8 (4.9)
Other Macropods	*Macropus* spp.	23 (14.9)	10 (13.9)	2 (32.6)	7 (19.0)	4 (12.1)	46 (15.6)
*Fox	*Vulpes vulpes*					1 (5.0)	1 (0.5)
*Sheep	*Ovis aries*		3 (4.6)		2 (5.8)		5 (1.7
*Goat	*Capra hircus*		2 (1.2)				2 (0.3)
*Pig	*Sus scrofa*				1 (7.3)		1 (0.5)
*Rabbit	*Oryctolagus cuniculus*	71 (81.7)	8 (10.2)	7 (41.5)	4 (40.3)	3 (10.7)	93 (49.1)
Unidentified Mammal			1 (0.4)	1 (2.1)			2 (0.2)
	Total Mammals:	**94 (96.6)**	**62 (81.3)**	**10 (76.1)**	**14 (72.4)**	**18 (66.1)**	**198 (86.4)**
BIRDS:							
*Domestic Chicken	*Gallus gallus*					1 (2.5)	1 (0.2)
Australian Wood Duck	*Chenonetta jubata*		6 (6.9)			1 (4.3)	7 (2.4)
Pacific Black Duck	*Anas superciliosa*		2 (1.8)	2 (15.0)			4 (1.3)
Common Bronzewing	*Phaps chalcoptera*		1 (0.6)				1 (0.2)
Black Cockatoo	*Calyptorhynchus* spp.				2 (12.6)		2 (0.9)
Galah	*Cacatua roseicapilla*	2 (0.8)					2 (0.4)
Ringneck Parrot	*Barnardius zonarius*	5 (0.2)	9 (2.1)	3 (5.7)		2 (2.1)	19 (1.2)
Australian Raven	*Corvus coronoides*	10 (1.9)	10 (3.2)	1 (0.5)	4 (5.3)		32 (2.3)
Unidentified bird		11 (0.3)	10 (2.4)	3 (0.9)	5 (8.8)	7 (25.0)	29 (4.0)
	Total Birds:	**28 (3.2)**	**38 (17.1)**	**9 (22.1)**	**11 (26.8)**	**11 (33.9)**	**97 (12.9)**
REPTILES:							
Bobtail Skink	*Tiliqua rugosa*	2 (0.2)	9 (1.5)	1 (1.8)	2 (0.8)		14 (0.7)
	Total Reptiles:	**0.2**	**1.5**	**1.8**	**0.8**	**0.0**	**14 (0.7)**
	TOTAL:	**124 (100)**	**109 (100)**	**20 (100)**	**27 (100)**	**29 (100)**	**309 (100)**
* = introduced species							

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APPENDIX 6.

Number of pellets and pellet mass (g) collected from five study sites in the Perth region.

		Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total All Sites
Breeding Data							
	2004	1 (5.3)	10 (43.2)				11 (48.5)
YEAR	2005	3 (8)	23 (166.2)	9 (58.9)		15 (105.8)	50 (338.9)
	2006	69 (518.7)	22 (101.5)	DID NOT BREED	12 (78.2)		103 (698.4)
	TOTAL:	**73 (532)**	**55 (310.9)**	**9 (58.9)**	**12 (78.2)**	**15 (105.8)**	**164 (1085.8)**
	Mean mass ± St. D.	7.29 ± 3.61	5.65 ± 3.35	6.54 ± 3.48	6.52 ± 3.76	7.05 ± 2.82	6.62 ± 0.85
Mean no. spp./pellet ± St. D.		1.71 ± 0.72	1.96 ± 0.96	2.22 ± 0.97	2.25 ± 0.62	1.93 ± 0.96	1.88 ± 0.85
Non-breeding Data							
	2005/06		3 (18.7)				3 (18.7)
YEAR	2006/07	2 (12.4)					2 (12.4)
	TOTAL:	**2 (12.4)**	**3 (18.7)**	**0**	**0**	**0**	**5 (31.1)**

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APPENDIX 7. Chi-squared statistical analyses on prey remains and pellet data.

<u>From FINAL PREY REMAINS DATA:</u>

Chi-square analysis on totals of mammals, bird and reptiles at each site:

Crosstabs

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
animal group * location	247	100.0%	0	.0%	247	100.0%

animal group * location Crosstabulation

			location					
			Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	Total
animal group	mammals	Count	68	52	7	9	6	142
		Expected Count	57.5	51.7	16.1	8.0	8.6	142.0
		Residual	10.5	.3	-9.1	1.0	-2.6	
		Std. Residual	1.4	.0	-2.3	.3	-.9	
	birds	Count	32	30	19	5	9	95
		Expected Count	38.5	34.6	10.8	5.4	5.8	95.0
		Residual	-6.5	-4.6	8.2	-.4	3.2	
		Std. Residual	-1.0	-.8	2.5	-.2	1.3	
	reptiles	Count	0	8	2	0	0	10
		Expected Count	4.0	3.6	1.1	.6	.6	10.0
		Residual	-4.0	4.4	.9	-.6	-.6	
		Std. Residual	-2.0	2.3	.8	-.8	-.8	
Total		Count	100	90	28	14	15	247
		Expected Count	100.0	90.0	28.0	14.0	15.0	247.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	28.896[a]	8	.000
Likelihood Ratio	32.688	8	.000
Linear-by-Linear Association	7.177	1	.007
N of Valid Cases	247		

a. 5 cells (33.3%) have expected count less than 5. The minimum expected count is .57.

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Preference for species of mammal across whole Perth region:

NPar Tests

Chi-Square Test

Frequencies

species

	Observed N	Expected N	Residual
quenda	10	14.2	-4.2
brush-tailed possum	16	14.2	1.8
woylie	12	14.2	-2.2
tammar wallaby	5	14.2	-9.2
western brush wallaby	1	14.2	-13.2
western grey kangaroo	23	14.2	8.8
cat	1	14.2	-13.2
pig	1	14.2	-13.2
rabbit	72	14.2	57.8
unidentified	1	14.2	-13.2
Total	142		

Test Statistics

	species
Chi-Square[a]	297.577
df	9
Asymp. Sig.	.000

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 14.2.

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Preference for species of bird across whole Perth region:

NPar Tests

Chi-Square Test

Frequencies

species

	Observed N	Expected N	Residual
domestic chicken	1	4.8	-3.8
black swan	1	4.8	-3.8
musk duck	1	4.8	-3.8
Australian wood duck	11	4.8	6.3
pacific black duck	6	4.8	1.3
wedge-tailed eagle nestling	1	4.8	-3.8
feral pigeon	3	4.8	-1.8
spotted turtledove	1	4.8	-3.8
common bronzewing	2	4.8	-2.8
black cockatoo	2	4.8	-2.8
galah	6	4.8	1.3
corella	2	4.8	-2.8
rainbow lorrikeet	1	4.8	-3.8
ringneck parrot	6	4.8	1.3
southern boobook	2	4.8	-2.8
tawny frogmouth	2	4.8	-2.8
magpie lark	1	4.8	-3.8
Australian magpie	5	4.8	.3
Australian raven	31	4.8	26.3
unidentified bird	10	4.8	5.3
Total	95		

Test Statistics

	species
Chi-Square[a]	176.400
df	18
Asymp. Sig.	.000

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 5.0.

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Preference for pooled prey categories across the whole Perth region:

NPar Tests

Chi-Square Test

Frequencies

prey category

	Observed N	Expected N	Residual
quenda	10	20.6	-10.6
brush-tailed possum	16	20.6	-4.6
woylie	12	20.6	-8.6
macropod	29	20.6	8.4
rabbit	72	20.6	51.4
other mammal	3	20.6	-17.6
ducks, geese	19	20.6	-1.6
pigeons, doves	6	20.6	-14.6
parrots	17	20.6	-3.6
songbirds	37	20.6	16.4
other birds	16	20.6	-4.6
reptiles	10	20.6	-10.6
Total	247		

Test Statistics

	prey category
Chi-Square[c]	187.575
df	11
Asymp. Sig.	.000

c. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 20.6.

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From FINAL PELLET DATA:

Chi-square analysis on totals of mammals, bird and reptiles at each site:

Crosstabs

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
species * location	309	100.0%	0	.0%	309	100.0%

species * location Crosstabulation

			location					Total
			Whiteman Park	Karakamia	Gidgegannup	Paruna	Helena Valley	
species	mammals	Count	94	62	10	14	18	198
		Expected Count	79.5	69.8	12.8	17.3	18.6	198.0
		Residual	14.5	-7.8	-2.8	-3.3	-.6	
		Std. Residual	1.6	-.9	-.8	-.8	-.1	
	birds	Count	28	38	9	11	11	97
		Expected Count	38.9	34.2	6.3	8.5	9.1	97.0
		Residual	-10.9	3.8	2.7	2.5	1.9	
		Std. Residual	-1.8	.6	1.1	.9	.6	
	reptiles	Count	2	9	1	2	0	14
		Expected Count	5.6	4.9	.9	1.2	1.3	14.0
		Residual	-3.6	4.1	.1	.8	-1.3	
		Std. Residual	-1.5	1.8	.1	.7	-1.1	
Total		Count	124	109	20	27	29	309
		Expected Count	124.0	109.0	20.0	27.0	29.0	309.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.108[a]	8	.020
Likelihood Ratio	19.528	8	.012
Linear-by-Linear Association	4.320	1	.038
N of Valid Cases	309		

a. 4 cells (26.7%) have expected count less than 5. The minimum expected count is .91.

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Preference for pooled prey categories across the whole Perth region:

NPar Tests

Chi-Square Test

Frequencies

preyspecies

	Observed N	Expected N	Residual
Quenda	24	25.8	-1.8
B-T Possum	16	25.8	-9.8
Woylie	8	25.8	-17.8
macropods	46	25.8	20.3
rabbit	93	25.8	67.3
other mamm	11	25.8	-14.8
ducks, swan, geese	11	25.8	-14.8
Pigeons and doves	1	25.8	-24.8
parrot, cockatoos	23	25.8	-2.8
songbirds	32	25.8	6.3
other birds	30	25.8	4.3
reptiles	14	25.8	-11.8
Total	309		

Test Statistics

	preyspecies
Chi-Square[a]	256.165
df	11
Asymp. Sig.	.000

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 25.8.

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