Nest Sites, Breeding, Satellite Telemetry and Diet of the Wedge-tailed Eagle *Aquila audax* at Lorna Glen, Western Australia.

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EXECUTIVE SUMMARY

In late 2011 an investigation into the ecology of the wedge-tailed eagle (*Aquila audax)* commenced at Lorna Glen Proposed Conservation Reserve in the Murchison/Gascoyne region of Western Australia. This study aimed to confirm the status of this species, determine the location of breeding territories, examine nests for activity and collect prey remains from nests to determine eagle diet. The diet study specifically aimed to determine possible impacts of eagle predation on mammal reintroductions to the fenced enclosure at Lorna Glen, and to gather information on diet in context of the broader landscape.

A preliminary field survey was conducted during October 2011 to assess the status of eagles at Lorna Glen. Four subsequent field surveys were conducted during 2012-2013. These involved extensive nest searches, locating and mapping of eagle nests and their characteristics, collection of prey remains and regurgitated pellets, and recording of all eagle observations. Laboratory work involved prey remain and pellet analysis to quantify eagle diet.

The wedge-tailed eagle was confirmed as a breeding resident at Lorna Glen. Almost all birds sighted were adult birds of breeding age. Sixty-five wedge-tailed eagle nests were located during the nest searching surveys, and the presence of 28 breeding territories was confirmed. Nests were typically 6-7 m above the ground, usually on a ridge or breakaway with a commanding view over the surrounding landscape. Sixty nests (92%) were built in gidgee *Acacia pruinocarpa* trees, a tall tree common in the Gascoyne and Murchison regions and a species which prefers stony soil on higher ground. The remaining 5 nests were built in either *Grevillea berryana* (3), white cypress *Callytris columellaris* (1) or river red gum (1). Eagle territories were confined to the rockier, undulating mulga shrubland habitats present across the north-eastern half of Lorna Glen, or to 'islands' of this habitat occurring in the south-west of the property. The broad areas of sandplain/spinifex habitat dominating the south-west of the reserve contained no eagle nests.

Twenty-four of the 28 eagle territories located at Lorna Glen were occupied by adult wedge-tail breeding pairs in 2012. Of the 24 pairs confirmed as present, 13 attempted to breed (i.e. laid eggs), and the remaining 11 pairs remained present within their territory, refurbished and/or lined nests, either partially or fully, but did not lay eggs. None of the 13 pairs which laid eggs successfully reared young, probably as a result of low food abundance across the landscape, and temperature extremes in October 2012, which likely caused the death of two eaglets aged 6-7 weeks. Data from the 2011 breeding season is limited as the study had only just commenced, however it was confirmed that one fledgling was produced by one pair.

Two adult eagles were trapped and fitted with GPS/Satellite Platform Transmitter Terminals (PTTs) to gather detailed information on habitat use: an adult female from Territory 3 which overlaps the fenced enclosure, and an adult male from an adjacent territory to the west (Territory 25). Tracking data for one month after release, together with breeding territory density obtained by nest-searching, suggest that wedge-tailed eagle territory size is in the order of 20-50 km^2. Further information on eagle movements, such as any variation in home range that occurs throughout the year, will come to light as the PTTs yield more data in the future.

Analysis of 987 prey fragments and 80 regurgitated pellets collected from nests and associated perch trees in 2011 and 2012 yielded 231 individual prey animals, representing 24 species of vertebrate animal taken by wedge-tailed eagles at Lorna Glen. Eagle diet comprised ten mammal, ten bird and four reptile species. The most frequently eaten prey animals were large macropods (euros *Macropus robustus* and red kangaroos *M. rufus*), emu *Dromaius novaehollandiae* chicks, Australian bustards *Ardeotis australis* and large varanids (yellow-spotted monitor *Varanus panoptes* and Gould's monitor *V. gouldii*).

Two eagle pairs were recorded as preying on species of reintroduced Threatened mammal, and only one of these pairs utilised the fenced enclosure for hunting. The first pair used Nest 3 in 2011 and Nests 3 and 56 in 2012, and took the following reintroduced mammals: golden bandicoot (at least 5), boodie (1) and mala (1). The second pair (whose nest was nearly 9 km from the pen) took one bilby, identified by a skull found at Nest 33. No other pairs were recorded preying on reintroduced mammals.

The overall impact of eagles on reintroduced Threatened mammals appears to be low, given that only one pair uses the fenced enclosure as a hunting area, and their presence here probably excludes other eagles. That the pen is surrounded by habitat containing a variety of alternate prey, both native and introduced, no doubt reduces the probability that boodies and mala, for instance, are taken. Such assemblages of eagle prey are probably quite important in maintaining threatened mammal numbers, at least until they become established. Anecdotal observations of eagle behaviour in relation to mammal trapping, both prior to and during this study, indicate that wedge-tails will readily learn to follow vehicles and investigate cage traps in the hope of obtaining prey, and such behaviour should be kept in mind by field biologists conducting trapping/monitoring work both at the fenced enclosure, and elsewhere on the property. Adaptive management which takes eagle behaviour into account will aid the survival of mammals reintroduced in the future, especially those taken to new release sites. It would also be useful to plan future mammal releases away from wedge-tailed eagle nests, both old and new, as these sites might readily be used by eagles as hunting areas.

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1 INTRODUCTION

Lorna Glen is a 260 000 ha former pastoral lease property situated across the border of Western Australia's Gascoyne and Murchison regions. The property was acquired by the WA government in 2000 and is managed as a Proposed Conservation Reserve by the Department of Parks and Wildlife (DPaW, formerly DEC) (Dunlop and Morris 2009). Initially, the project focussed on fauna reintroductions following intensive introduced predator (cat *Felis catus*, wild dog *Canis familiaris*) control, which were largely successful for common brushtail possum (*Trichosurus vulpecula*) and bilby (*Macrotis lagotis*). However, predator vulnerable species such as mala (*Lagorchestes hirsutus*) did not survive trial translocations in 2008, and the decision was made to construct an 1100 ha fenced enclosure, intended as a soft release pen and breeding enclosure for release into the wider Lorna Glen habitat. Golden bandicoot (*Isoodon auratus*) and boodie (*Bettongia lesueur*) were released into the enclosure in 2010 and have been breeding successfully for two years. More recently, Shark Bay mice (*Pseudomys fieldii*) and mala from Trimouille Island were also released into the enclosure.

The reasons for failure to establish after translocation have included predation by feral cats and wild dogs, failure to find sufficient food, exposure following wet/cold periods and predation by birds of prey (raptors). The initial release of mala in 2008 failed (primarily due to cat predation and starvation), and early observations of a second translocation inside the enclosure in 2011 indicate raptors may have had some impact on the survival of founder animals. Even though Mala were translocated from Trimouille Island where they are known to be eaten by white-bellied sea eagles (*Haliaeetus leucogaster*), they were still observed to rest during the day in exposed locations with limited cover, making them easy prey for local raptors (J. Dunlop pers. comm.).

Several species of Australian raptor are likely culprits but the wedge-tailed eagle is known to frequent Lorna Glen, being sighted regularly in the vicinity of the fenced enclosure and occasionally flushed from freshly killed reintroduced mammals inside it. This eagle is the largest and one of the best studied raptors in Australia (Olsen 2005). In southern Australia it is known to feed mainly on the introduced rabbit (*Oryctolagus cuniculus*) and young macropods (*Macropus* spp.), as well as a variety of birds, but it displays a general preference for mammals >500 grams in mass and birds >100g (Brooker and Ridpath 1980; Sharp *et al.* 2002; Olsen *et al.* 2006; Cherriman 2007; Fuentes *et al.* 2007; Parker *et al.* 2007). Its preference for mammals has also lead to studies on the diet of this eagle in areas where remnant populations of threatened mammals occur (Sharp 1997; Richards and Short 1998; Cherriman 2007).

Limited research has been conducted on possible impacts of the wedge-tailed eagle on mammal reintroductions in WA. One study in the Jarrah Forest suggested that eagles had little impact on survival of a variety of native mammals in a 260 ha fenced enclosure in the Perth Hills (Cherriman 2007; 2008*a*), although this was forest with patches of very dense understorey and involved mammals displaying a variety of diurnal sheltering behaviour. There is anecdotal evidence from the Avon-Wheatbelt region that raptors including wedge-tailed eagles feed regularly on animals in reintroduction enclosures (Friend and Beecham 2004, B. Macmahon pers. comm.), and have caused the failure of some numbat translocations (T. Friend pers. comm.). On the other hand, evidence from some habitats with established diverse mammal assemblages shows many threatened mammal species cope with continuous wedge-tailed eagle and other raptor predation, for

example on Bernier Island (Richards and Short 1998) and at Tutanning Nature Reserve (Cherriman 2008*b*). However, the impact of wedge-tailed eagles on mammal reintroductions, and how this may differ in varying habitats, remains largely unknown.

In light of this information, the DPaW commissioned Insight Ornithology to conduct an investigation into the ecology of the wedge-tailed eagle at Lorna Glen Proposed Conservation Reserve. This report contains the results of 5 field surveys carried out at Lorna Glen between October 2011 and June 2013. The aims of the this study were as follows:

- To determine the status (whether breeding resident, visitor, vagrant, etc) of the wedge-tailed eagle at Lorna Glen, locate as many nests as possible, and if breeding, determine the eagles' breeding success;
- To quantify the diet of the wedge-tailed eagle at Lorna Glen;
- To relate eagle diet to the reintroduction of Threatened mammal species present at Lorna Glen, both in the 1100ha fenced enclosure, and across the broader landscape;
- To gather detailed information on eagle home range and habitat use via satellite telemetry, and relate this to Threatened mammals.

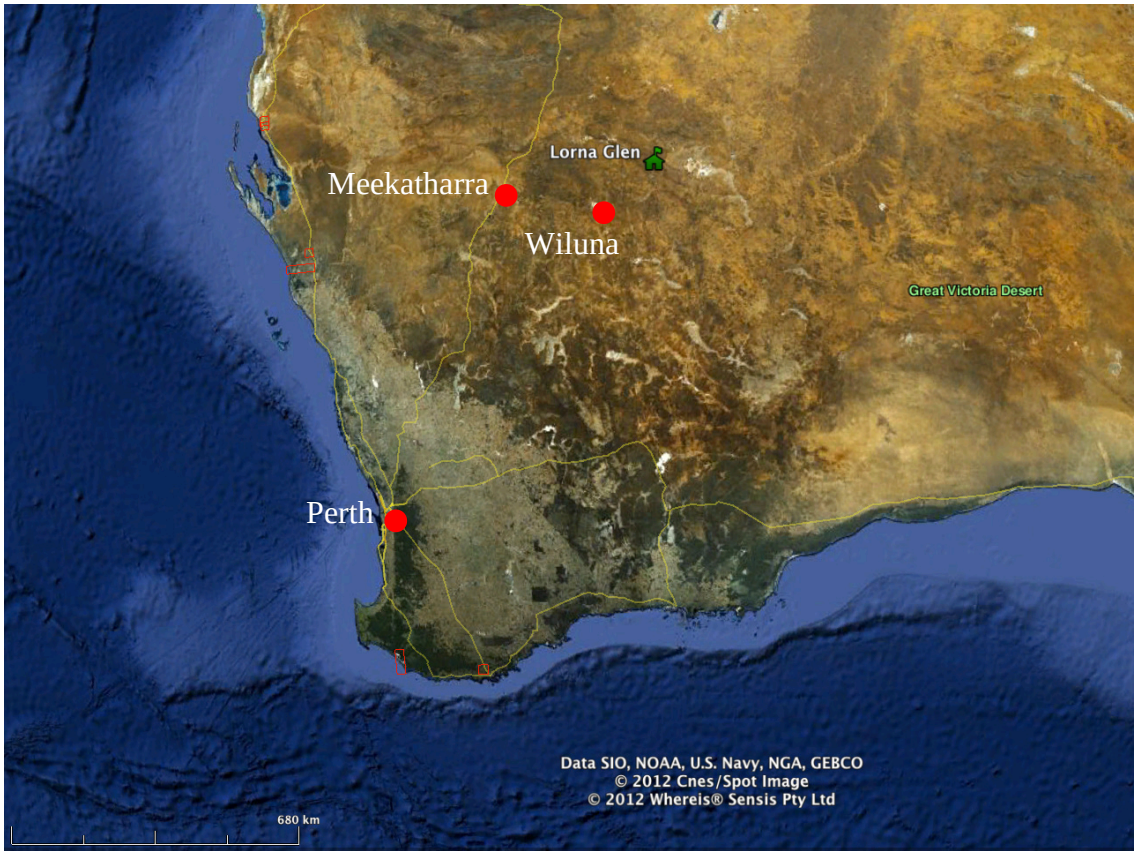

Figure 1. Map of Western Australia showing location of Lorna Glen Proposed Conservation Reserve and major towns.

2 METHODS

2.1 Study Area

Lorna Glen Proposed Conservation Reserve is located approximately 150 km east north-east of Wiluna in Western Australia (Figure 1). The vegetation in this region consists mainly of mulga *Acacia aneura* plains, open areas of samphire, spinifex *Triodia* spp. grassland and dunes, and occasional drainage lines of river red-gum *Eucalyptus camaldulensis* (Dunlop and Morris 2009).

2.2 Personnel

The following personnel were involved in the preparation of this report:

- Mr Simon Cherriman *BSc. Hons (Env. Biol.), MSci Comm. (Nat. Hist. Film.)*
- Ms Gillian Basnett *BSc. (REM), MSc., MSc. (Res.)*
- Mr Jeff Turpin *BSc (Zool.).*
- Mr Michael McDonnell *Dip. Marine Science*
- Mr Daniel Hunter *BSc. (Zool.), MSci Comm. (Nat. Hist. Film.)*

The field surveys were undertaken by Simon Cherriman, Gillian Basnett, Jeff Turpin, Michael McDonnell and Daniel Hunter, and the report was prepared by Simon Cherriman.

2.3 Field Surveys

Five field surveys were conducted on the following dates:

28th – 31st October 2011, 7th – 18th August 2012, 8th – 16th December 2012, 15th – 24th March 2013 and 10th – 29th June 2013. Weather conditions varied throughout the project depending on the time of year. Activities undertaken during the field survey included the following:

2.3.1 Wedge-tailed eagle Nest Searching

Surveys were conducted by systematically driving internal roads and access tracks to inspect vegetation either side of the road for wedge-tailed eagle nests. Nest searching is best conducted from a prominent viewing point (e.g. the top of hills or breakaways, the roof of a vehicle, or sometimes from tall trees) and the surrounding plains are scanned with binoculars. More inaccessible areas away from roads, as determined by viewing aerial photos on Google Earth, were reached via walking and/or driving on a quad-bike. Eagle nests are large structures of sticks which are usually conspicuous in open landscapes such as that at Lorna Glen (Ridpath and Brooker 1987). Particular attention was given to ridges and drainage lines containing tall trees which are favoured sites for eagles (Silva and Croft 2007).

Once an eagle nest was spotted, a GPS unit was used to record a compass bearing and project an approximate site location of the nest, provided the observer could estimate its distance. Then, using a vehicle to access the nearest point via road, the nest was approached on foot and its exact location recorded with a GPS.

2.3.2 Breeding Territory Mapping

The locations of all wedge-tailed eagle nests identified during the field survey were mapped using Google Earth software. Spatial information together with eagle nest activity data was used to estimate the approximate territory boundaries of breeding eagles.

2.3.3 Opportunistic Observations

Observations of wedge-tailed eagles were made at all times. Notes were made on the location, number and behaviour of birds sighted. Where possible, wedge-tailed eagles were aged using plumage colour (see Ridpath and Brooker 1986*a*). Observations of adult eagles, especially those seen in pairs during the breeding season, can often indicate the location of a breeding territory containing nests. Thus, thorough searches for eagle nests were initiated in areas where sightings of such adult pairs were made.

2.3.4 Eagle Trapping and Satellite Telemetry

In order to gain more detailed information about adult wedge-tailed eagle home range size, and to study the movements of adults breeding close to the fenced enclosure, satellite telemetry of two birds was planned. Two solar-powered GPS/Satellite Platform Transmitter Terminals (PTTs), manufactured by Microwave Telemetry Inc. (Columbia, Maryland, USA), were purchased in January 2013. Each unit was programmed to record hourly GPS fixes every day from sunrise to sunset.

Three ‘crow traps’, each consisting of a large wire cage approximately 2 m square and 2 m high with an open roof, were built during March 2013. These were placed under suitable perch trees in which an eagle could land and drop into the trap from above when it was baited with carrion (Ridpath and Brooker 1986*a*).

2.3.5 Diet Analysis

Prey remains (e.g. bones, fur and feathers) and regurgitated pellets were collected from all located wedge-tailed eagle nest sites to acquire information on diet. Eagle dietary material was analysed in the laboratory at DPaW’s Science Division in Woodvale following the methods of Cherriman (2007), which involved:

1) Identification of prey remains to genus, and if possible, to species, using a reference collection of animal skeletal material and bird feathers.
2) Quantification of a minimum number of individual prey animals using the prey remains.
3) Analysis and identification of material in regurgitated pellets using the skeletal reference collection for bones/feathers, and the Hair ID Interactive CD (Triggs and Brunner 2002) for mammalian hair.
4) Combining data from prey remains and pellets *only* when material in pellets could be used to reliably quantify numbers of animals within a pellet, and when animal parts could be considered in context of prey remains data to eliminate any possibility of ‘double-counting’ individuals.

3 RESULTS

3.1.1 Wedge-tailed eagle Status

The wedge-tailed eagle was confirmed as a breeding resident at Lorna Glen. Almost all birds sighted were adult birds of breeding age. One observation of 4 juvenile or immature birds in June 2013 suggests these individuals were visitors, as no breeding success was reported in 2012 (see below). A map of eagle sightings, which clearly emphasises the adult population present at Lorna Glen, is provided in Figure 2.

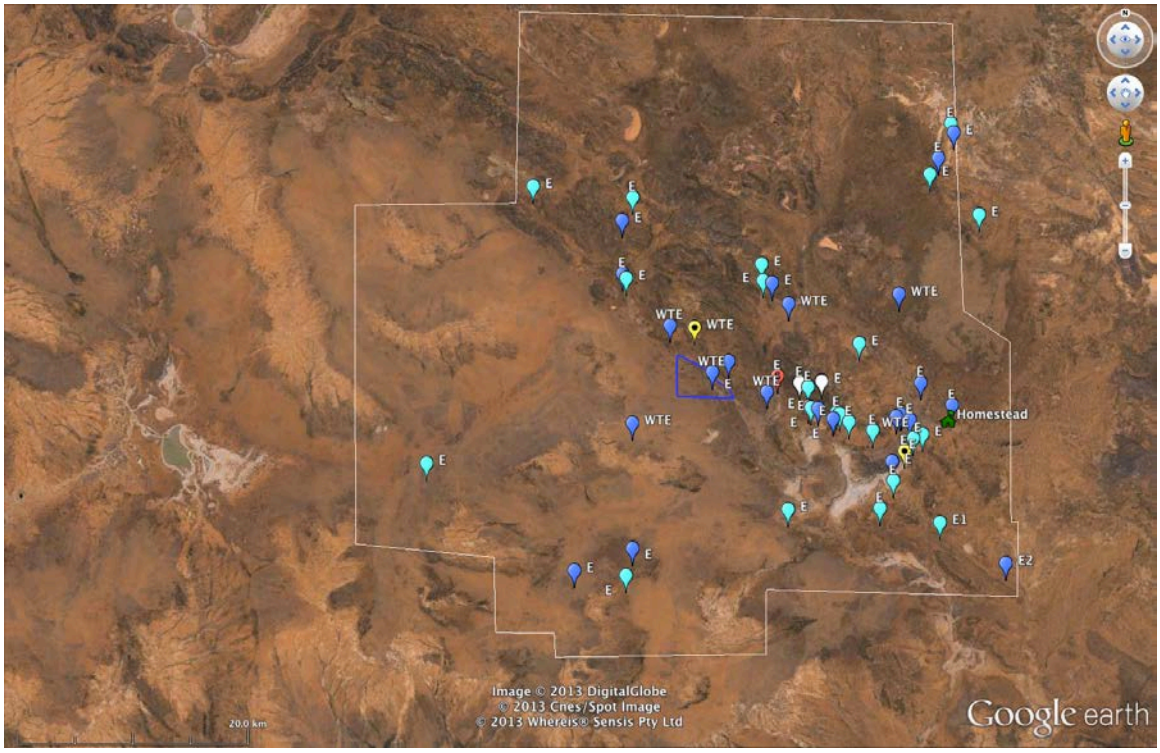

Figure 2. Map of Lorna Glen Proposed Conservation Reserve showing opportunistic wedge-tailed eagle sightings made between October 2011 and June 2013. Blue pins represent adults (dark blue = pair, pale blue = single adult); red pins represent sub-adults, and yellow pins represent juvenile/immature birds. Note that sightings of birds at nests are not shown.

3.1.2 Nests and Territories

The area traversed during nest searching at Lorna Glen is shown in Figure 3. Approximately 70% of the property was covered, with some areas to the north-east remaining unvisited.

Sixty-five wedge-tailed eagle nests were located during the nest searching surveys, and the presence of at least 27 (probably 28) breeding territories was confirmed. The characteristics of all nests are shown in Appendix 1 and the locations of those most recently active in Figure 4. Nests were typically 6-7 m above the ground, usually on a ridge or breakaway with a commanding view over the surrounding landscape. Sixty nests (92%) were built in gidgee *Acacia pruinocarpa* trees, a tall tree common in the Gascoyne and Murchison regions and a species which prefers stony soil on higher ground. The remaining 5 nests were built in either *Grevillea berryana* (3), white cypress *Callytris columellaris* (1) or river red gum (1) trees.

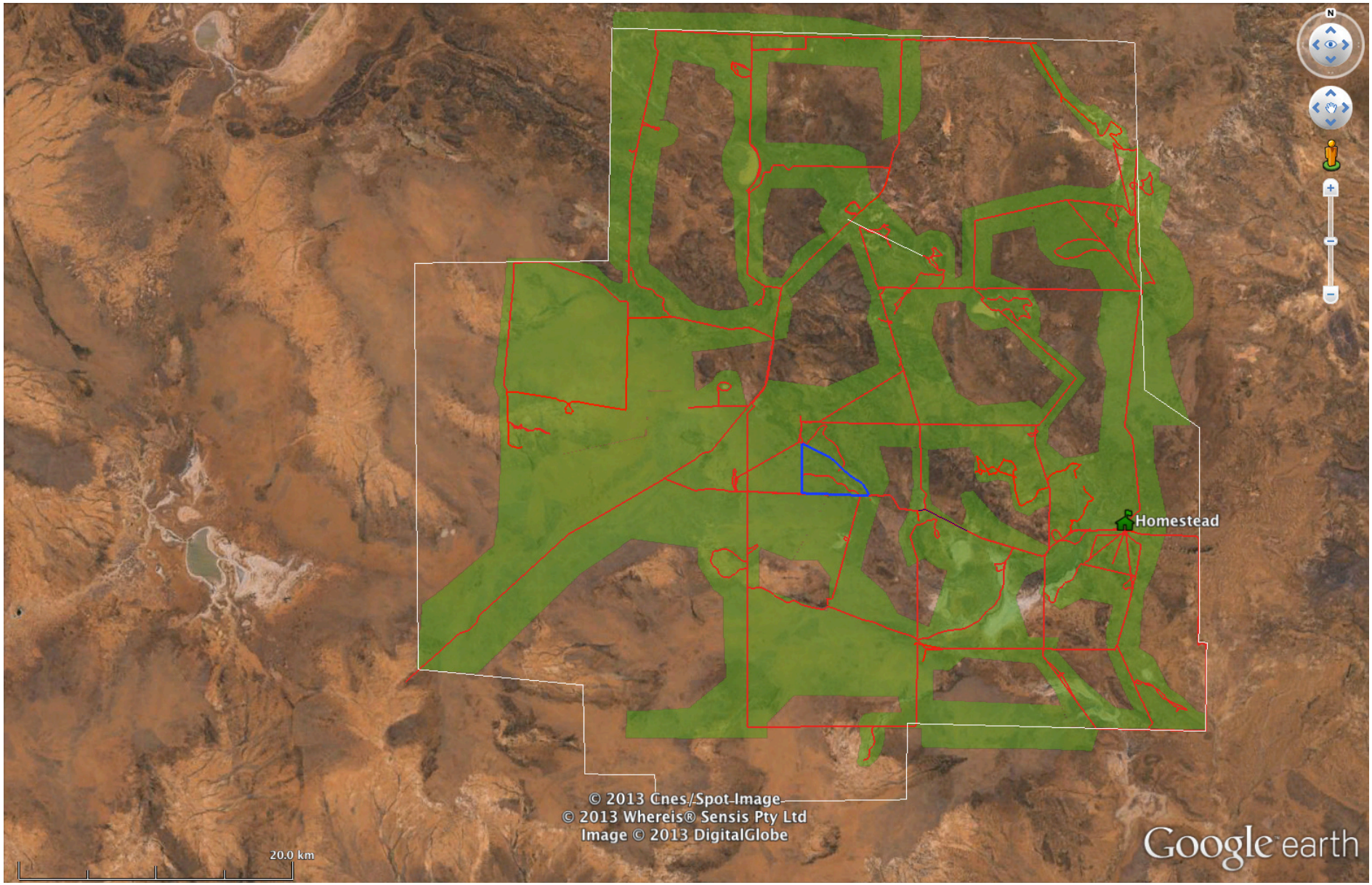

Figure 3. Map of Lorna Glen Proposed Conservation Reserve showing areas covered by searches for wedge-tailed eagle nests. Tracks are indicated by red lines, and the area surveyed is shown by green shading. The fenced enclosure is marked with a blue triangle.

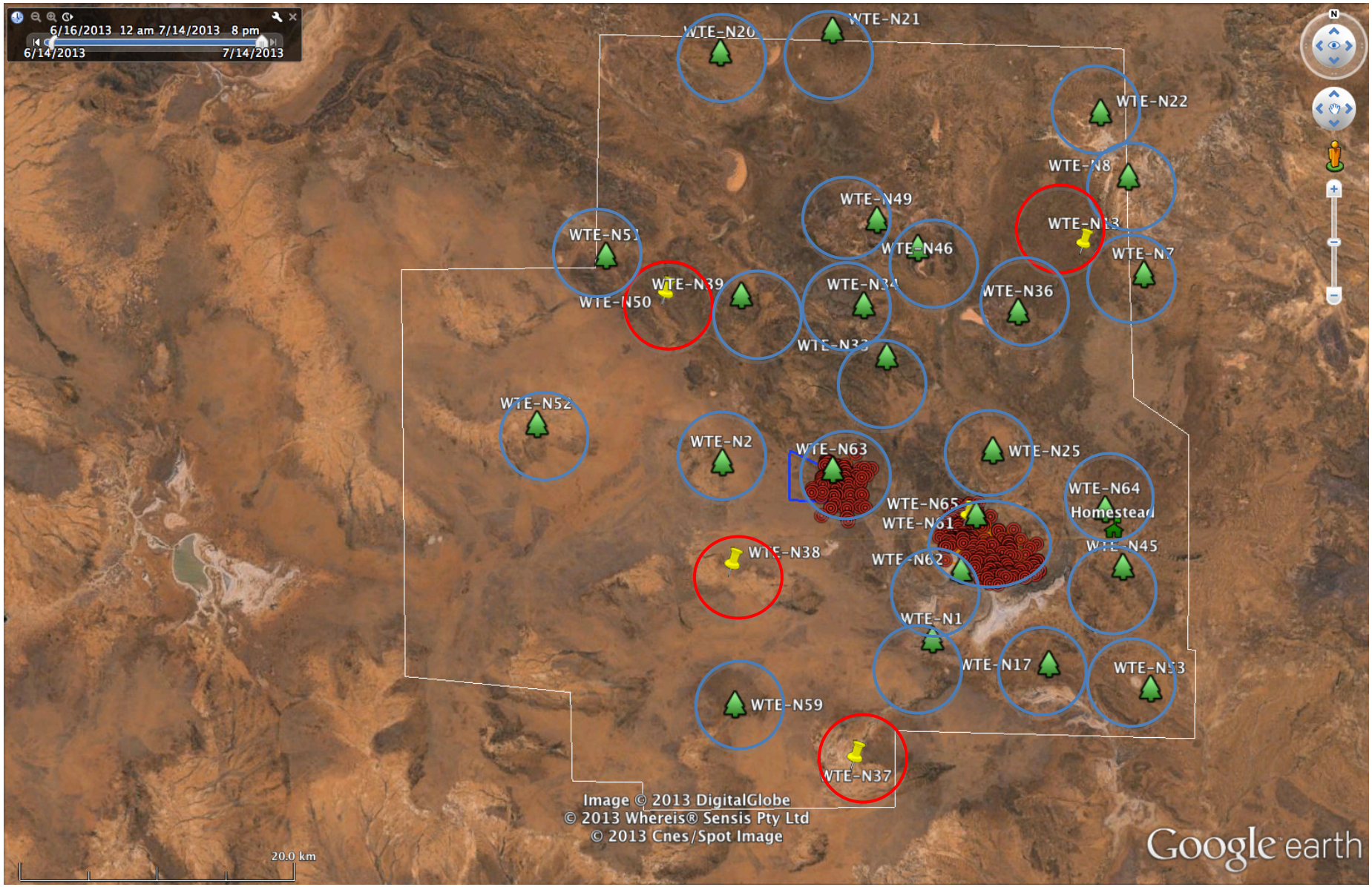

Figure 4. Map of Lorna Glen Proposed Conservation Reserve showing locations of 28 wedge-tailed eagle breeding territories and most recently active nests within each. Red circles indicate territories which have not yet been confirmed as active. Tree symbol = active nests lined/laid in during 2012; yellow pin = inactive nest. Note that eagle territories are unlikely uniform in shape – circles used for demonstrative purposes only. Large clusters of red dots show movements of adult eagles tracked by satellite (see next section).

3.1.3 Breeding

Twenty-four of the 28 eagle territories located at Lorna Glen were occupied by adult wedge-tail breeding pairs in 2012. The remaining 4 territories may also have been occupied but no data was collected to confirm this. Of the 24 pairs confirmed as present, 13 attempted to breed (i.e. laid eggs). The remaining 11 pairs remained present within their territory and refurbished and/or lined nests, either partially or fully, but did not lay eggs.

None of the 13 pairs which laid eggs in 2012 successfully reared young. Nest 2, which when visited on 16th August 2012 contained a small chick aged *c.* 1 week, had numerous juvenile eagle wing feathers in the nest cavity when inspected on 9th December the same year. A dead nestling eaglet aged 6-7 weeks was located beneath a perch tree *c.* 20 m from the nest, suggesting it had died on the nest cavity and been removed and taken to the perch by an adult eagle. A similar scenario was observed at Nest 65, which also contained a dead chick aged 7-8 weeks when visited on 26th June 2013. This chick was hatched in the 2012 breeding season but also died.

Data from the 2011 breeding season is limited as the study had only just commenced, however it was confirmed that one fledgling eagle was produced by one pair. These birds bred in Nest 3 located < 2 km from the fenced enclosure.

3.1.4 Satellite Telemetry

The three crow traps were baited on 13th June 2013 with road-killed kangaroo. On 14th June an adult male wedge-tailed eagle was caught in Trap 2 (GPS: 343880N, 7098559E) and fitted with a PTT before release at about 17:00h that day. This bird's territory is situated about 5 km west of the Homestead and straddles the two large lake systems in this area. It is believed this territory is the 'adjacent neighbour' of that based at the fenced enclosure. An adult female was trapped in similar fashion at Trap 1 (GPS: 336570N, 7101825E), near the south-eastern corner of the fenced enclosure, the following day (15th June). She was also fitted with a PTT and released around 18:45h.

Each PTT was mounted using a Teflon harness, made from two large loops stitched together with Nylon dental floss, with each loop fitting around the eagles' bodies and being riveted in place. Rivets were padded using small circles of Neoprene to prevent injury. This permanent mount design was chosen in preference to a 'weak-link' method after advice from experts in the USA, who, after attaching PTTs to over 100 Bald Eagles, discovered weak-link harnesses may not dismount properly and posed a risk of becoming snagged on vegetation (Centre for Conservation Biology 2013). All methods were approved by the DEC Animal Ethics Committee (Approval No. 2012/16).

Both birds were sighted several days after release and were noted to be in healthy condition, moving freely without hindrance from their PTTs. Tracking data for one month after release is shown in Figure 5.

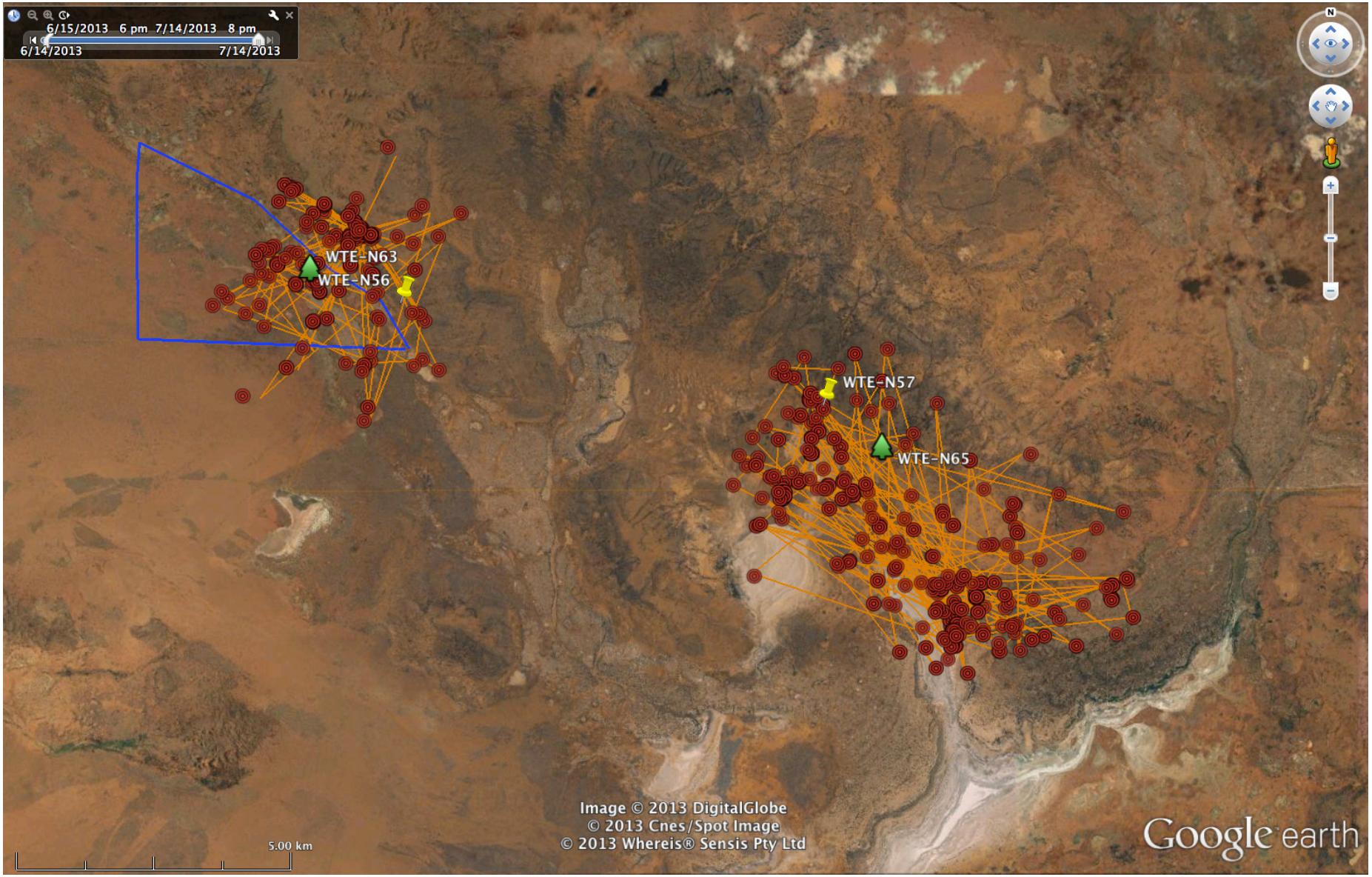

Figure 5. Map of Lorna Glen Proposed Conservation Reserve showing locations of two adult wedge-tailed eagles tracked by satellite. Red dots show hourly fixes taken between sunrise and sunset each day, between 14th June and 14th July 2013. The fenced enclosure is indicated by a blue triangle. Pin and tree icons represent recently used nests in each eagle territory.

3.1.5 Diet Analysis

Analysis of 987 prey fragments and 80 regurgitated pellets collected from nests and associated perch trees yielded 231 individual prey animals, representing 24 species of vertebrate animal taken by wedge-tailed eagles at Lorna Glen. Appendix 2 shows a detailed list of prey species eaten by each pair of eagles. Note that no prey data was collected for 6 of the 28 pairs. All data presented was collected in 2011 and 2012, and in the case of many nests, represents an unknown period of time leading up to the commencement of this study (i.e. most nests yielded only old remains of unknown age which cannot be linked to any particular breeding season). Many bird bone fragments were unable to be identified past the family level.

Eagle diet comprised ten mammal, ten bird and four reptile species. The most frequently eaten prey animals were large macropods (euros *Macropus robustus* and red kangaroos *M. rufus*), emu *Dromaius novaehollandiae* chicks, Australian bustards *Ardeotis australis* and large Varanids (yellow-spotted monitor *Varanus panoptes* and Gould's monitor *V. gouldii*). Two pairs were recorded as preying on species of reintroduced Threatened mammal, and only one of these pairs utilised the fenced enclosure for hunting. The first pair used Nest 3 in 2011 and Nests 3 and 56 in 2012, and took the following reintroduced mammals: golden bandicoot (at least 5), boodie (1) and mala (1). The second pair (whose nest was nearly 9 km from the pen) took one bilby, identified by a skull found at Nest 33. No other pairs were recorded preying on reintroduced mammals.

4 DISCUSSION

4.1.1 Wedge-tailed eagle status, nests and territories

The wedge-tailed eagle was confirmed as a breeding resident at Lorna Glen. That most observations were of adult birds of breeding age (Figure 2) provides evidence of this, and although sightings were anecdotal and not made in a standardised survey, it suggests the population is composed mostly of such birds. This is consistent with the species' biology in other parts of arid Western Australia (Ridpath and Booker 1987). The sighting of 4 juveniles in June 2013 suggests that eagles of this age category, which are thought to be nomadic (Ridpath and Brooker 1986*a*), also visit Lorna Glen occasionally. At the time of this observation a large number of waterbirds were present on Lindsay Gordon Lagoon, so these eagles were possibly taking advantage of the abundant food source in this area.

The extent of nest-searching carried out at Lorna Glen (Figure 2) covered nearly three-quarters of the property. Several areas in the north-east remain unsearched, so it is likely that a few other nests occur here. There is also a gap in the known eagle territories across the north of the property, as shown in Figure 4. Thus, although the number of eagle breeding pairs is probably approaching maximum, it is highly likely that several as yet undiscovered territories are present.

The site, situation and characteristics of the 65 wedge-tailed eagle nests reported at Lorna Glen were similar to those reported by Ridpath and Brooker (1987), who found them to be typically 2-6m above the ground in the arid zone of Western Australia. Nest sites were also similar to those reported in other studies (see Cherriman 2007 for a full review) in that they were built in the upper half of the tallest trees available. Eagle territories were confined to the rockier, undulating mulga shrubland habitats present across the north-eastern half of Lorna Glen, or to 'islands' of this habitat occurring in the south-west of the property (Figure 4). The broad areas of sandplain/spinifex habitat to the south-west

visited during nest-searching contained no eagle nests (Figure 4), despite the presence of many suitable tall nest trees (mostly *Eucalyptus gongylocarpa*). It is unlikely that this is owing to lack of survey effort, but rather that the densities of suitable prey animals in sandier soils is too low to support breeding eagles. Adult pairs were seen soaring high above the sandplain south and south-east of Nest 2, and north of Nest 38, suggesting they may occasionally forage over it, but prefer rockier ridges situated among pockets of larger prey animals for nest sites.

The density of breeding territories at Lorna Glen is similar to that observed by Ridpath and Brooker (1987) in other locations of the arid zone of Western Australia. Their study recorded that clusters of nests usually occurred more than 5 km or apart, a similar pattern to those at Lorna Glen, where active nests were 4-6 km from their nearest neighbour. Breeding territory density obtained by nest-searching the broader study area (Figure 4), together with home range data from the preliminary results of satellite-tracking two adult birds (Figure 5), suggest that wedge-tailed eagle territory size is in the order of 20-50 km^2. This also aligns with the findings of Ridpath and Brooker's (1987) research. Further information on eagle movements, such as any variation in home range that occurs throughout the year, will come to light as the PTTs yield more data in the future.

4.1.2 Breeding

During the 2012 breeding season, 24 of the 28 wedge-tailed eagle territories (86%) were confirmed as occupied, each containing one active nest. It should be noted that the proportion of territory occupancy may be higher as in some territories only one old nest was located, and newer active nests may have been present nearby. Eleven nests (46%) were lined partly or wholly with fresh sprigs (mostly *Acacia* or *Eucalyptus*), and 13 (54%) were fully lined and had eggs laid in them. This was confirmed either by observing eggs during August (in seven nests), or by locating a freshly lined, depressed nest cavity containing eggshell fragments in December, March and June (six nests). In August only one of the seven nests (Nest 2) was observed to have hatched chicks.

None of the 13 pairs which laid eggs in 2012 successfully reared young. Eleven of these 13 nests in which eggs were laid contained no evidence that chicks had hatched, or developed for more than one week. This was clear because the lined cavity of these nests remained compressed into a concave cup, which had subsequently become faded by the sun. The continuous addition of fresh leaves by parent birds during eaglet development soon turns the concave cup into a flat platform. Therefore, one expects to find the nest cavity transformed significantly during a successful breeding event. Conversely, the nest cavity remains relatively unchanged when breeding has failed. This 'before and after' scenario is shown in Figures 6 and 7, where on Nest 20 eggs were present in August 2012, but had disappeared four months later in December, with no evidence of hatching.

Such widespread breeding failure is probably due to overall food shortages across Lorna Glen, given that most pairs did not continue past the incubation stage. However, the eaglets that survived for 6-7 weeks on Nests 2 and 65 but later died may indicate that environmental factors were responsible. For ten consecutive days after 13th October 2012, the daily maxima exceeded 35˚C, at times being more than 40˚C, at both Wiluna (~120 km south-west of Lorna Glen, as the crow flies) and Lake Carnegie (~60 km east; Bureau of Meteorology 2013). On exposed nests with little shade nestling eagles are vulnerable to overheating, especially being at a size too large for parent birds to protect them from direct sun. In arid New South Wales, Silva and Croft (2007) observed that adult eagles

spent more time shading chicks on nests built in dead trees with no canopy cover. Deaths caused by high temperature are probably not uncommon in the arid interior but are seldom recorded and difficult to prove for certain. Continued documentation of eagle productivity at Lorna Glen may provide further evidence on the impact of weather extremes on nesting success.

Figure 6. Wedge-tailed eagle Nest 20 at Lorna Glen, photographed in August 2012 when it contained 2 eggs. The freshly lined, depressed nest cavity is visible.

Figure 7. Wedge-tailed eagle Nest 20 at Lorna Glen, photographed in December 2012. The faded lining is obvious and the depressed nest cavity is visible. Eggshell fragments were collected from this nest.

Such high failure rate in wedge-tailed eagle breeding in one particular year is not unusual. In a long-term study in south-east Western Australia, and on the west coast near Carnarvon, Ridpath and Brooker (1986*b*) determined that eagle breeding success was related directly to food supply. Pairs remained in their territory and each year either partly or fully lined an existing nest, or attempted to breed by laying eggs. In years where the food supply reached or exceeded a minimum threshold density of prey animals, breeding usually succeeded. However, breeding often failed when this threshold was not met, especially in areas of erratic rainfall. Such breeding failures (or lack of attempts) sometimes occurred for up to four consecutive years. Based on this information it is likely that 2012 was a lean year for wedge-tailed eagle breeding at Lorna Glen, with prey not reaching the minimum threshold required for success across most of the landscape. If the rapid failure of Nests 2 and 65, with both chick dying after 6-7 weeks, was caused by lack of food, this may provides some evidence. Low prey density may be a result of low rainfall during 2011-12, as well as a lag in the time taken for native mammal numbers to replace introduced species removed as a result of different land management. It is unusual, however, that the breeding attempt by eagles in Nest 3 failed, seeing as this nest is situated very close to the fenced enclosure containing densities of boodies and golden bandicoots which are presumably quite high, as well as rabbits. This nest succeeded in producing one young in 2011 .

It should be clarified that researcher-induced failures are unlikely to have influenced eagle breeding in this study. In cases where incubating adults were disturbed, all nests were observed with binoculars from a distance of more than 500 m to ensure the birds returned to their nest. At Nest 2 in August, a brooding female eagle flushed as researchers approached, but was observed to return about half an hour later just as the researchers returned to their car *c.* 2 km away. Breeding failures for many raptors can be attributed to nest predation (e.g. by cats and goannas), but this is highly unlikely with a dominant predator such as the wedge-tailed eagle.

Where possible, eggshell fragments were collected in December, March and June from active nests that failed. These were further evidence that hatching had not occurred because adult eagles remove the two halves of eggshell soon after the eggs hatch, often dropping it below a nearby perch (S. Cherriman pers. obs.). Small rocks were located on the cavity of two nests which had contained eggs in December. It is possible that these were brought by black-breasted buzzards and used to break into abandoned eagle eggs; buzzards are known to use this technique to feed on emu eggs (Olsen 1995).

4.1.3 Eagle diet

It should first be noted that there was a large variation in the amount of prey remains collected from different eagle nests in this study. Although the 987 individual prey remain items from Lorna Glen yielded 231 prey animals, there was significant variation the number of animals identified at each nest (range = 1 to 29; mean = 10.5 per pair; Appendix 2). The quantity of food samples available for collection by researchers can be influenced by several factors, including the degree of removal by scavenging animals, the individual nest-cleaning behaviour of adult eagles, and the frequency of visits to nests (Cherriman 2007). Furthermore, many prey fragments collected in 2011 and 2012 represent prey taken over an unknown period. For some nests (e.g. Nest 2), fragments gathered were representative of 2012 diet only, but for most other old nests not in use when located, the remains represent animals taken over a much longer timeframe. Such samples usually overestimate the number of mammals because mammal bones are more

resistant to weathering than the fragile bones of birds and reptiles (Brooker and Ridpath 1980). Information presented in this report therefore only offers insight into eagle diet at Lorna Glen, and cannot be used to accurately quantify differences in diet between pairs.

Overall, wedge-tailed eagle diet at Lorna Glen consisted mainly of mammals (50% by number), with macropod species (i.e. euro and red kangaroo) being taken most frequently. This finding is consistent with previous research. For example, Brooker and Ridpath (1980) found red kangaroos and euros to contribute significantly to eagle food at their Dry West Coast study site near Carnarvon. In south-west Western Australia, immature western grey kangaroos *Macropus fuliginosus* were frequently preyed on in the Perth region (Cherriman 2007), and tammar wallabies *Macropus eugeneii* were the most favoured prey animal at bush reserves near Narrogin (Cherriman 2008). At two locations near Canberra in New South Wales, macropods contributed to more than half of wedge-tailed eagle diet biomass (Olsen *et al.* 2006; Fuentes *et al.* 2007). Sharp (1997) also found macropods to be dominant in a nest diet sample from Idalia National Park in south-central Queensland. Such dominance of red kangaroos and euros as eagle food is probably a reflection of these species being the most abundant suitable-sized mammals at Lorna Glen. In a study in Shark Bay, Richards and Short (1998) found wedge-tailed eagles ate burrowing bettongs and banded hare-wallabies in proportion to their relative occurrence in the environment.

Most Australian studies on wedge-tailed eagle diet have reported introduced rabbits *Oryctolagus cuniculus* as the main prey species. The relative scarcity of rabbit prey at Lorna Glen (14.3% by number *cf.* 90%+ in other arid WA sites, Brooker and Ridpath 1980) is probably due to their low abundance within the study site. Except for in the fenced enclosure where water is reliable in artificial watering stations, rabbits have been in low numbers throughout the landscape since bores ceased to operate when DEC assumed management of the property in 2000 (J. Dunlop pers. comm.). Observations of eagles tracked by satellite show that the adult male in Territory 25 (which straddles the lake systems) visits a large rabbit warren at least once every 2 days. Examination of this rabbit warren found a high level of rabbit activity, suggesting rabbit numbers may well be on the increase. This follows from there being several good seasons of rainfall in the last few years, creating a lag in the build-up of rabbit numbers.

Despite its proximity to the fenced enclosure, Nest 2 contained no evidence that the eagles occupying it (Pair 2) took reintroduced Threatened mammals surviving there. This was contrary to Pair 3 breeding in Nest 3 during 2011 which preyed on several reintroduced boodies, mala and golden bandicoots (Appendix 2). Although the diet sample from Nest 2 in 2012 was limited and the number of prey items collected was reduced by the nest's failure (i.e. death of eaglet), this may indicate that the distance (Nest 2 *c.* 4.9km from pen *cf.* Nest 3 *c.* 2.4km) is too great for this pair to forage in the pen, or that eagle territoriality prevents this. Perhaps a combination of these factors is true. Further research into the diets of these neighbouring pairs will shed light on this situation.

One bilby skull was identified in the prey remains sample collected from Nest 33. This is the first known record of eagles preying on a reintroduced mammal outside of the fenced enclosure, and is one case where a natural predator-prey relationship has been restored. Bilbies were released at several locations in the broader Lorna Glen landscape and are known to have become well established throughout (Miller *et al.* 2010), but it is interesting to confirm that eagles are capable of hunting them. It is possible the bilby was

killed by another predator and taken as carrion, although when breeding, eagles usually prefer live prey (Olsen 2005). Other studies (e.g. Richards and Short 1998, Cherriman 2007) have shown wedge-tailed eagles are capable of regularly taking nocturnal animals.

The remaining diet sample consisted of 27% birds and 23% reptiles by number, respectively. Birds taken included emu chicks, Australian bustards (both large and small individuals), galah *Eolophus roseicapillus*, crested pigeon *Ocyphaps lophotes*, Australian ringneck *Barnardius zonarius* and Torresian crow *Corvus bennetti*, all species which have been previously recorded as wedge-tailed eagle food (Brooker and Ridpath 1980). Each of these species are common at Lorna Glen, and known to feed on the ground making them vulnerable to eagle attack. The barn owl *Tyto javanica* and tawny frogmouth *Podargus strigoides* recorded at Nests 2 and 3 were probably taken on dusk. Wedge-tails are known to wait on perch trees at sunset and ambush nocturnal species emerging to forage (S. Cherriman pers. obs.). Varanids were the most commonly eaten reptiles, probably because once again these are an abundant large vertebrate in the arid zone. These species, as well as Centralian bluetongues *Tiliqua multifasciata* and thorny devils *Moloch horridus* have also been recorded as eagle food in other parts of WA (Brooker and Ridpath 1980).

5 CONCLUSIONS AND RECOMMENDATIONS

This study provides a comprehensive baseline dataset for the wedge-tailed eagle at Lorna Glen Proposed Conservation Reserve. It has shown that the species has a relatively large breeding population, although the extent to which it relies on emigration to sustain itself is not yet known. Future field surveys conducted during the breeding season in successive years will build a more detailed picture of the species' productivity, and shed light on how food across the landscape aids breeding as reintroduced mammals become more abundant. It appears at present that most breeding pairs rely on rabbits, macropods and varanids to produce young successfully, and the minimum threshold of such prey at Lorna Glen in 2012 was not met. This may also have been the case in 2011, though there are insufficient data to support this.

Predation by eagles may have contributed to the translocation failure of mala in 2008, along with predation by terrestrial species (especially cat; Miller *et al.* 2010) which had easy access to mala prior to the fence being built. The 2010-released mala have continued to survive inside the fenced enclosure, which has no doubt prolonged the life of founder animals, and provides at least some evidence that wedge-tailed eagles are not alone responsible for all deaths. The presence of several medium-sized mammal species (which are increasing in abundance) acts as a buffer to the targeting of vulnerable species such as mala, as wedge-tailed eagles are thought to prey on animals according to relative abundance (Ridpath and Brooker 1986*b*). Golden bandicoots have faired well since release into the enclosure and there is evidence (e.g. tracks, diggings) of colonisation into the broader landscape. This population increase would aid predator-vulnerable mala by reducing the probability that mala are taken by eagles.

The overall impact of eagles on reintroduced Threatened mammals appears to be low, given that only one pair uses the fenced enclosure as a hunting area, and their presence here probably excludes other eagles. That the pen is surrounded by habitat containing a variety of alternate prey, both native and introduced, no doubt reduces the probability that boodies and mala, for instance, are taken. Such assemblages of eagle prey are probably

quite important in maintaining threatened mammal numbers, at least until they become established. Anecdotal observations of eagle behaviour in relation to mammal trapping, both prior to and during this study, indicate that wedge-tails will readily learn to follow vehicles and investigate cage traps in the hope of obtaining prey, and such behaviour should be kept in mind by field biologists conducting trapping/monitoring work both at the fenced enclosure, and elsewhere on the property. Adaptive management which takes eagle behaviour into account will aid the survival of mammals reintroduced in the future, especially those taken to new release sites. It would also be useful to plan future mammal releases away from wedge-tailed eagle nests, both old and new, as these sites might readily be used by eagles as hunting areas.

The work carried out so far adds to the comprehensive literature on the wedge-tailed eagle, and confirms that adult pairs occupy permanent territories, remaining there even in years when breeding conditions may not be suitable. The satellite telemetry component of this study is a new and exciting aspect, considering it has not been conducted before in Australia.

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Appendix 1. Characteristics, location and status of wedge-tailed eagle nests located during the field survey carried out at Lorna Glen Proposed Conservation Reserve, 2011-2013.

Nest No.	Easting	Northing	Tree Species	Ht. (m)	2012 Status	Content	Notes
1	342747	7089819	*Grevillea berryana*	6	**ACTIVE**	Fresh leaves	Fresh sticks and a few sprigs added since 2011 visit but not bred in.
2	327309	7102443	*Acacia pruinocarpa*	6	**ACTIVE**	2 chicks	Lined in 2011 but no breeding.
3	333956	7105899	*A. pruinocarpa*	7	**ACTIVE**	2 eggs	Used to successfully rear one chick in 2011.
4	357722	7115942	*A. pruinocarpa*	5	inactive		Very old and partially disintegrated.
5	358496	7115582	*A. pruinocarpa*	8	inactive		Old but recently refurbished in last 6 months.
6	358936	7115311	*A. pruinocarpa*	5	inactive		Flat, bleached platform; last used to fledge young some years ago.
7	357785	7116438	*A. pruinocarpa*	10	**ACTIVE**	1 egg	Incubating bird reluctant to leave on first visit.
8	356569	7123479	*A. pruinocarpa*	3	**ACTIVE**	Fresh leaves	Very old, new leaves added in last 6 months, recently used as feeding platform.
9	357186	7124291	*Callitris columellaris*	4	inactive		Very old, faded stick platform, not used for many years.
10	357355	7122897	*A. pruinocarpa*	6	inactive		Scats below, some sticks added to edges but no fresh lining.
11	357502	7122998	*A. pruinocarpa*	4	inactive		Very old, partially collapsed, recent use as feeding platform, no lining.
12	357149	7123218	*A. pruinocarpa*	4	inactive		Very old, collapsed, not used for many years.
13	353083	7119003	*A. pruinocarpa*	8	inactive		Old nest, one fresh sprig in cup placed in last few months, few scats below.
14	335775	7121531	*A. pruinocarpa*	3	inactive		Very old, small nest, used many years ago.
15	335974	7121713	*A. pruinocarpa*	3	inactive		Old and collapsed.
16	335929	7121398	*A. pruinocarpa*	-	inactive		Old and collapsed.
17	351234	7088143	*A. pruinocarpa*	6	inactive		Appeared refurbished for use but not lined or bred in.
18	351488	7088146	*A. pruinocarpa*	6	inactive		Very old, a few fresh sprigs indicating recent visitation.
19	351469	7088105	*A. pruinocarpa*	-	inactive		Totally collapsed and fallen to ground.
20	326786	7132078	*A. pruinocarpa*	6	**ACTIVE**	2 eggs	Many scats below nest.
21	334919	7133799	*A. pruinocarpa*	10	**ACTIVE**	2 eggs	Very close to road; incubating bird flushed from road.
22	354483	7128110	*A. pruinocarpa*	2	**ACTIVE**	Fresh leaves	Very fresh eucalypt sprigs, laying may still occur.
23	348112	7100290	*A. pruinocarpa*	6	inactive		Old and partially collapsed, last used to fledge young some years ago.
24	347732	7103123	*A. pruinocarpa*	9	inactive		No fresh material in nest, last used 2+ years ago, some scats below.
25	346947	7103550	*A. pruinocarpa*	8	**ACTIVE**	Fresh leaves	Very fresh mulga/eucalypt lining placed in last few weeks but no eggs.
26	346333	7102540	*A. pruinocarpa*	9	inactive		Very old and collapsed, not bred in for years, recent use as feeding platform.
27	345853	7102531	*A. pruinocarpa*	6	inactive		Several fresh sprigs placed in last month but not bred in.
28	345558	7103104	*A. pruinocarpa*	7	inactive		Two fresh sprigs placed but no other signs of use.
29	344818	7102621	*A. pruinocarpa*	5	inactive		Very old nest, no fresh lining or signs of recent use.
30	241749	7109332	*A. pruinocarpa*	7	inactive		Not lined or visited recently but still in good condition.
31	340130	7111025	*A. pruinocarpa*	4	inactive		Very old and collapsed, not used for many years.
32	339605	7110987	*A. pruinocarpa*	8	inactive		Probably used in last 2-3 years, still in good condition.
33	339154	7110237	*A. pruinocarpa*	6	**ACTIVE**	1 egg	Many scats below nest.
34	337437	7113940	*A. pruinocarpa*	5	**ACTIVE**	Fresh leaves	Very fresh mulga/eucalypt lining placed in last few weeks but no eggs.
35	347830	7113622	*A. pruinocarpa*	7	inactive		Old, collapsed and not used for many years.
36	348668	7113606	*A. pruinocarpa*	6	**ACTIVE**	2 eggs	Incubating bird flushed on arrival.
37	336909	7081533	*A. pruinocarpa*	4	inactive		Partly collapsed, not bred in for several years, recent use as feeding platform.
38	327823	7095393	*A. pruinocarpa*	7	inactive		Probably used in last 2-3 years, still in good condition but no recent lining.
39	328527	7114524	*A. pruinocarpa*	10	inactive		Probably used in last 2-3 years to lay, still in good condition.

40	357227	7087542	*A. pruinocarpa*		inactive		Old and collapsed.
41	356358	7094416	*A. pruinocarpa*	5	inactive		Old and partly deteriorated, last used 5+ years ago for laying.
42	356077	7094425	*A. pruinocarpa*	9	inactive		Old and partly collapsed, not used for many years.
43	355944	7094282	*A. pruinocarpa*	7	inactive		Old and partially collapsed, last used to fledge young some years ago.
44	355744	7094548	*A. pruinocarpa*	9	inactive		Lind in 2012 but no breeding, nest still in good condition
45	356536	7095255	*A. pruinocarpa*	4	**ACTIVE**	eggs	Eggs laid in 2012 but no evidence of young surviving.
46	341313	7118131	*A. pruinocarpa*	7	active		Some fresh sprigs placed in last 2 months, no evidence of breeding .
47	354182	7121477	*A. pruinocarpa*	8	inactive		Old and mostly collapsed, may only have been used as a feeding platform.
48	337882	7119614	*A. pruinocarpa*	8	inactive		Still in good condition but no recent lining, last used for laying, old leaves present.
49	338315	7120123	*A. pruinocarpa*	3	**ACTIVE**	eggs	Eggs laid in 2012 but no evidence of young surviving. Eggshell collected
50	322742	7114939	*A. pruinocarpa*	6	inactive		Very old and parlty collapsed, not used for many years.
51	318660	7117275	*A. pruinocarpa*	8	inactive		Still in good condition, some signs of refurbishment, recent use as a feeding platform.
52	313807	7105028	*A. pruinocarpa*	11	**ACTIVE**	eggs	Eggs laid in 2012 but no evidence of young surviving, fresh scats below.
53	358671	7086464	*A. pruinocarpa*	6	**ACTIVE**	eggs	Eggs laid in 2012 but no evidence of young surviving.
54	359716	7085407	*A. pruinocarpa*	6	inactive		Old and mostly collapsed, may only have been used as a feeding platform.
55	360512	7085525	*A. pruinocarpa*	5	inactive		Still in good condition but no recent lining.
56	336989	7101659	*A. pruinocarpa*	7	active	eggs	Recently built in late 2012 as second breeding attempt, fresh lining and one very fresh sprig. Eggshell below.
57	344726	7099885	*A. pruinocarpa*	9	inactive		Still in good condition but no recent lining.
58	344381	7100755	*A. pruinocarpa*	5	inactive		Very old and collapsed, not bred in for years, older collapsed nest below tree.
59	328448	7084952	*A. pruinocarpa*	9	active		Recently refurbished suggesting use in 2013. Pair sighted nearby.
60	327745	7085659	*A. pruinocarpa*	11	inactive		Still in good condition but no recent lining.
61	344901	7099216	*A. pruinocarpa*		inactive		*located from distance but not visited yet.
62	344766	7094823	*G. berryana*	12	**ACTIVE**	fresh leaves	Newly constructed in 2013 and freshly lined with Grevillea leaves.
63	335332	7102002	*E. camaldulensis*	10	active	fresh leaves	Newly constructed in 2013 and freshly lined.
64	355192	7099410	*G. berryana*	8	active	fresh leaves	Well established nest freshly lined in 2013. Cat carcass on nest.
65	345818	7098860	*A. pruinocarpa*	4	active	eggs	Eggs laid in 2012 and one chick reared but found dead on nest, aged ~7-8 weeks.

Appendix 2. List of prey animals identified as being eaten by different wedge-tailed eagle breeding pairs at Lorna Glen Proposed Conservation Reserve.

Prey Species		TERRITORY NUMBER																					
		1	2	3	4	5	6	7	8	9	10	11	12	14	17	18	20	21	22	23	24	25	28	TOTAL
MAMMALS:																								
Echidna	*Tachyglossus aculeatus*			1																				1
Bilby	*Macrotis lagotis*												1											1
Golden Bandicoot	*Isoodon auratus*			5																				5
Burrowing Bettong	*Bettongia leseuri*			1																				1
Rufous Hare-Wallaby	*Lagorchestes hirsutus*			1																				1
Red Kangaroo (juv.)	*Macropus rufus*			1		1				1				2		2	3							10
unidentified Kangaroo	*Macropus rufus/robustus*	1	3	2	2	11	1	5	1			12	8	1		2	2	1	1	1	1	3	1	59
Total Macropods		**1**	**3**	**4**	**2**	**12**	**1**	**5**	**1**	**1**	**0**	**12**	**8**	**3**	**0**	**4**	**5**	**1**	**1**	**1**	**1**	**3**	**1**	**70**
*Feral Cat	*Felis catus*		1	1	1																		1	4
*Rabbit	*Oryctolagus cuniculus*	1		5		1		13			1	1	1	1			2				2	3	2	33
Unidentified Mammal											1													1
	Total Mammals:	**2**	**4**	**17**	**3**	**13**	**1**	**18**	**1**	**1**	**2**	**13**	**10**	**4**	**0**	**4**	**7**	**1**	**1**	**1**	**3**	**6**	**4**	**116**
BIRDS:																								**0**
Emu (juv.)	*Dromaius novaehollandiae*		7	1			1																	9
Emu (eggshell)	*Dromaius novaehollandiae*				1								1											2
Australian Bustard	*Ardeotis australis*		1	1	2	1			1				1						1					8
Button Quail			1							1														2
Crested Pigeon	*Ocyphaps lophetes*		1	1	1	2									1									6
Galah	*Eolophus roseicapillus*		2																					2
Australian Ringneck	*Barnardius zonarius*	1		1													1							3
Tawny Frogmouth	*Podargus strigoides*	1	1					1			1													4
Barn Owl	*Tyto javanica*		1	1																				2
Grey Butcherbird	*Cracticus torquatus*															1								1
Torresian Crow	*Corvus orru*		2	1									1											4
Unidentified Large Bird						1		3				3	2				1							10
Unidentified Medium Bird				2										1			1	1						5
Unidentified Small Bird								1					1				1	1						4
	Total Birds:	**2**	**16**	**8**	**4**	**4**	**1**	**5**	**1**	**1**	**1**	**3**	**6**	**1**	**1**	**1**	**4**	**2**	**1**	**0**	**0**	**0**	**0**	**62**
REPTILES:																								**0**
Centralian Bluetongue	*Tiliqua multifasciata*		3	1				1																5
Thorny Devil	*Moloch horridus*		1					1																2
Yellow-spotted Monitor	*Varanus panoptes*		1		1		2	2					1		3	3						2		15
Unidentified Goanna	*Varanus gouldii/panoptes*			1		3		2	1	2	1	3	6	1		2	2	1	1		1	4		31
Total Varanids		**0**	**1**	**1**	**1**	**3**	**2**	**4**	**1**	**2**	**1**	**3**	**7**	**1**	**3**	**5**	**2**	**1**	**1**	**0**	**1**	**6**		**46**
	Total Reptiles:	**0**	**5**	**2**	**1**	**3**	**2**	**6**	**1**	**2**	**1**	**3**	**7**	**1**	**3**	**5**	**2**	**1**	**1**	**0**	**1**	**6**	**0**	**53**
	TOTAL ANIMALS:	**4**	**25**	**27**	**8**	**20**	**4**	**29**	**3**	**4**	**4**	**19**	**23**	**6**	**4**	**10**	**13**	**4**	**3**	**1**	**4**	**12**	**4**	**231**