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NEST-SITE CHARACTERISTICS OF THE WEDGE-TAILED EAGLE *Aquila audax* IN SOUTHERN VICTORIA

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Nest-site characteristics of the Wedge-tailed Eagle *Aquila audax* were investigated in the outer Melbourne region of Victoria in 1999–2000. Nests (n = 20) were found in a range of local habitats (isolated trees to forest) and forest or woodland types. Nests averaged 12.6 metres above the ground (5–20 m, n = 14) and were placed mainly in the top one-third of live eucalypts, within the canopy level of surrounding trees, if present. Nest trees averaged 18.1 metres tall (8–28 m, n = 14), and were located in sheltered positions, in gullies or on moderate slopes (<30°) with south-westerly to easterly aspects; most nests and nest-trees were situated below the top of the slope on which they were located. These characteristics conferred shelter from prevailing winds and bushfires during the breeding cycle (mid-winter to early summer), and security from nest predators. Most nests were on private land or Crown land with restricted access. Nearest-neighbour distances averaged 4.7 kilometres (4–5.5 km, n = 5), giving a calculated core breeding territory averaging 17.6 square kilometres (12.6–23.8 km^2).

INTRODUCTION

The availability of nest sites is one of the main factors, along with food supply, governing the breeding density of raptors (Newton 1979). Territorial behaviour results in the regular spacing of breeding pairs, within the constraints of food and nest sites (Ridpath and Brooker 1987; Olsen 1995, 2005). Maximal nearest-neighbour distance ensures minimal interaction between adjacent pairs during breeding and hunting, although regular spacing would not be expected where habitats are patchy or nest sites are restricted (Newton 1979). The characteristics governing the selection of a suitable nest site by eagles appear to vary in their importance according to regional, climatic and other factors; elevation being a primary consideration for vigilance, defence and protection from the weather (e.g. Olsen 1995, 2005; Silva and Croft 2007). The availability of nest sites may be influenced directly by human activities such as logging and land clearance, but also indirectly by other human disturbance that renders nests non-viable (Mooney and Holdsworth 1991).

Nest-site selection has been studied in the Wedge-tailed Eagle *Aquila audax*, mainly in the Australian arid zone (Ridpath and Brooker 1987; Sharp *et al.* 2001; Collins and Croft 2007; Silva and Croft 2007), with one study in coastal South Australia (Dennis 2006) and one unpublished study, still in the 'grey' literature, for the temperate forests of Tasmania (Brown and Mooney 1997). There is little, mainly anecdotal, information on nest-site characteristics of the Wedge-tailed Eagle elsewhere (Leopold and Wolfe 1970; Hull 1986; Marchant and Higgins 1993; Harder 2000; Olsen 2005; Debus *et al.* 2007; Parker *et al.* 2007). However, in undulating or rugged, forested or wooded terrain in temperate south-eastern Australia these characteristics are likely to be similar to those in Tasmania and South Australia, where topographic position and nest-tree features are key factors (cf. Brown and Mooney 1997; Dennis 2006). This study aimed to identify some of the main characteristics of the Wedge-tailed Eagle's nest sites in the south-central region of Victoria.

STUDY AREA AND METHODS

Study area

The study area encompassed the outer urban-rural fringe within a 60-kilometre radius of the city of Melbourne (37º50'S, 145º00'E), in a temperate climate with warm to hot summers (mean minimum and maximum 14–25º C) and cool to cold winters (mean minimum and maximum 6–14º C), and winter-dominant rainfall (500 mm p.a. in the west of the study area to 1400 mm in the east). In summer, winds are generally light north to north-easterlies in the mornings and southerlies in the afternoons, and in winter the prevailing winds are north to north-westerlies (Land Conservation Council (LCC) 1973; Australian Survey and Land Information Group 1986).

Vegetation in the west (Bacchus Marsh to Torquay) is mainly isolated remnant stands of Bull Mallee *Eucalyptus behriana* in agricultural land of the significantly altered tussock grasslands on the Western Basalt Plains. Lerderderg State Park, north of Bacchus Marsh (37º41'S, 144º26'E), is Dry Stringybark-Box forests and Box-Ironbark forests dominated by Grey Box *E. microcarpa*, Red Box *E. polyanthemos*, Yellow Box *E. melliodora*, Long-leaved Box *E. goniocalyx* and others such as Yellow Gum *E. leucoxylon* and Red Stringybark *E. macrorhyncha* (Parks Victoria 1999). In the central region (Brisbane Ranges, Pyrete Ranges and Werribee Gorge State Park) vegetation is Open Forest Type I and low Open Forest Type II of stringybark–box forests, with riparian forest of Manna Gum *E. viminalis* and Blackwood *Acacia melanoxylon*. In the east (Yellingbo to the Yarra Valley) the habitat is open farmland bordered by Open Forest Types I and II of Narrow-leaved Peppermint *E. radiata*, Messmate *E. obliqua* and Long-leaved Box, and Open Forest Types II and III of Messmate and Long-leaved Box. In the south-east (Mornington Peninsula) the vegetation varies from coastal woodlands to fern gullies, with riparian sheoak *Casuarina* sp. and Messmate forests, and woodlands surrounded by extensively cleared agricultural land (LCC 1973, 1985).

Nest-site characteristics

Nests in this study were all previously known, and their locations were obtained via consultation with Parks Victoria (PV) and Department of Natural Resources and Environment (DNRE) staff, local residents, and special-interest groups. Some informants were contacted via PV or DNRE referrals, or by posting flyers in districts known to have resident eagles, during the two-year data collection phase of the study (1999–2000). Because of the bias inherent in the use of known nests, and the lack of control sites (potential nest sites or areas without nests), the study identified some common nest-site characteristics in the region but did not attempt to define nest-site selection.

The parameters used to describe the 20 known nest sites (Table 1) followed those of Brown and Mooney (1997) in their modelling of the nesting habitat of Tasmanian Wedge-tailed Eagles. However, the data are descriptive rather than predictive.

Slope profiles (10-m contour intervals for 200–350 m in the direction of and 90º to the aspect) were drawn to illustrate the position of the nest tree on the slope, the relationship between nest height and slope height, and surrounding topography. The positions of nest trees and nests at each site were plotted and expressed as a percentage of slope height. The relationship between nest-tree height and nest height to slope height were expressed as a percentage of slope height.

The 20 nest trees were distributed between what was assumed to be 11 eagle territories, with a maximum of four nest trees in a territory (i.e. the alternative or disused nests of a given pair). Although possibly biasing the results, these extra nests were included to increase the sample size, and because old nests may have been built by eagles other than those currently resident (e.g. dilapidated nests in a territory held by eagles in immature plumage). The number of eagle territories was inferred from local informants familiar with the birds, the distribution of simultaneously occupied or active nests, and the plumage characteristics of the male and female eagles in attendance at each (e.g. the presence of subadults).

TABLE 1

Parameters of 20 Wedge-tailed Eagle nest sites measured or estimated in southern Victoria.

Parameter	Definition
Nest-tree species	
Tree condition	Live or dead
Height of nest tree	(m)
Height of nest	Above ground at base of nest tree (m)
Altitude	Derived from 1:25 000 Vicmap topographic maps at the Australian Map Grid coordinates for each nest site
Aspect	Compass bearing of steepest slope falling away from base of nest tree. Aspects assumed to be evenly distributed in four 90º classes: N–NE = 337.5–67.5º; E–SE = 67.5–157.5º; S–SW = 157.5–247.5º; W–NW = 247.5–337.5º. Expected frequency for each aspect class (n nests/n aspect classes) = 20/4 = 5. In cases where nest was not on a discernible slope (e.g. gully floor), aspect was taken as the direction faced by the closest adjacent slope falling towards nest tree.
Slope angle	Derived from 1:25 000 Vicmap topographic maps at the Australian Map Grid coordinates for each nest site. Angles were estimated, by trigonometry, from contour intervals above and below the nest, and the horizontal distance between them. Slope angles were grouped in two classes (0–9º and 10–34º), to avoid expected frequencies <5. Distribution of nests between classes was expected to be equal (expected frequency 20/2 = 10).
Land tenure	Grouped into four categories: private (farmlets, small agricultural and pastoral holdings), private-commercial (restricted-access catchments, mines, large agricultural and pastoral holdings), public (state or national forests and reserves with no access restrictions), and Crown (state or federal land with access restrictions, e.g. defence-force bases, special management areas).
Nearest neighbour	Straight-line distance (km); Bacchus Marsh district only.
Core territory size	Bacchus Marsh district only (km^2); estimated by calculating the area of a circle with radius equal to half the nearest-neighbour distance (assumes territory shape to be circular).

Seven of the 20 nests were verified as being active (incubating or brooding observed, or chicks sighted) during this study. Five closely observed nests were monitored in all seasons of two years 1999–2000, observations of behaviour were made in most months, and nests were checked frequently from the time chicks were visible until juveniles dispersed.

RESULTS

Breeding chronology

In the Bacchus Marsh district, green foliage was observed in eagle nests up to two months (i.e. in late May) before the onset of the breeding season. Egg-laying and incubation began in late July–early August, when pairs were frequently observed on nests. Laying dates were not obtained precisely (by nest inspection), but incubation was estimated to have started by mid-August in 1999 and early August in 2000 at all five active nests observed closely. Chicks were first visible approximately 55 days later, respectively, with brooding observed until October. Growth from hatching to fledging took 11–12 weeks, with fledglings leaving the nest by mid-December 1999 and early December 2000. Family groups were frequently seen during December and January, less frequently in February and March, and not observed thereafter, in both years, suggesting juveniles dispersed approximately four months after fledging.

Nest-site characteristics

Nest sites were found in a range of habitat types from tall open forest to isolated trees in grassland, and in all the main forest or woodland types. All nests were sited more than five metres above the ground, and all nest trees were native species (all eucalypts except for one cypress-pine *Callitris* sp.: Table 2). Live trees were favoured (85%), with all active nests in live trees (Table 2). However, with live trees far outnumbering dead trees in the study area, this result was not significant (χ^2_1 = 0.52, P >0.05; 2 × 2 contingency table).

Nests were all at greater than 60 per cent of nest-tree height and, in cases where surrounding vegetation was present, the nest tree formed part of the upper stratum of the vegetation. Nests were generally located in a sturdy fork within or just below the canopy of the tree, with the exception of the three dead trees (but this feature would have applied while those trees were alive). Nests were also generally located within the canopy level of the surrounding vegetation, if present. For example, in the Bacchus Marsh district, Bull Mallee trees (with a sparse and low canopy) were unsuitable for large nests; two nests in that habitat were in an emergent Manna Gum and a peppermint (taller and more robust than mallees), but in positions that did not breach the canopy level of the local vegetation.

TABLE 2

Characteristics of nest trees selected by Wedge-tailed Eagles in southern Victoria. *E* = *Eucalyptus*; Nests 1–14 = Bacchus Marsh district; heights (ht) are ±2 m.

Nest	Tree species	Live/dead	Tree ht (m)	Nest ht (m)	Aspect (°)	Altitude (m)	Slope angle (°)
1	*E. viminalis*	L	17	12	225	270	22
2	*Callitris* sp.	L	10	6	0	220	22
3	*E. cladocalyx*	L	19	14	90	270	11
4	*E. radiata*	L	12	8	125	300	28
5	*E. viminalis*	L	25	18	80	130	22
6	*E. radiata*	L	16	11	175	120	22
7	*E. radiata*	L	28	18	165	135	22
8	*E. viminalis*	L	22	16	170	140	22
9	*E. viminalis*	L	26	20	95	160	11
10	*E. viminalis*	L	20	15	120	205	6
11	*E. viminalis*	L	24	17	172	150	0
12	*E. viminalis*	D	14	9	185	300	15
13	*E. viminalis*	D	8	5	220	270	15
14	*E. viminalis*	D	12	8	200	250	5
15	*E. viminalis*	L	25	19	125	90	22
16	*Eucalyptus* sp.	L	30	22	165	100	30
17	*Eucalyptus* sp.	L	35	25	165	160	22
18	*Eucalyptus* sp.	L	22	16	85	170	11
19	*Eucalyptus* sp.	L	15	10	150	80	17
20	*Eucalyptus* sp.	L	16	12	150	85	17

In the Bacchus Marsh district (14 nests, six territories), Manna Gum (50%) and Narrow-leaved Peppermint (42%) were the most commonly used nest trees, 79 per cent of which were alive. Nest heights averaged 12.6 metres (5–20 m), and nest-tree heights averaged 18.1 metres (8–20 m: Table 2). Breeding was confirmed in five of the six territories. The active nest of the presumed sixth pair was not located; the occupied and inactive nests in that territory (partly refurbished and lined with fresh eucalypt foliage) were all in dead trees. (This cluster of nests was inferred to be a sixth territory on the basis of distances between the active nests in the other five territories).

Aspect of nest sites showed a significant deviation from the expected distribution (χ^2_3 = 16.4, P<0.05): 50 per cent in the S–SW class, 45 per cent in the E–SE class; the N–NE and W–NW classes were under-represented, with only one nest in the former (Table 2). In the Bacchus Marsh district, aspect was also significantly different from expected (χ^2_3 = 9.2, P <0.05), with 50 per cent of nests in the E–SE class and 43 per cent in the S–SW class, and other classes under-represented.

Altitude of nest sites ranged from 80 to 300 metres across the study area. Slope angles of nest sites ranged from 0 to 30 degrees, with 85 per cent of nests on moderate slopes (<10º); their distribution in slope classes deviated significantly from expected, both in the whole study area (χ^2_1 = 9.8, P <0.05) and the Bacchus Marsh district (χ^2_1 = 4.6, P <0.05). Only one nest was found on flat ground.

The bases of 85 per cent of nest trees were situated below 60 per cent of slope height (mean 38% of slope height; Figure 1). For 75 per cent of nest trees, the maximum height of the tree did not broach the top of the slope (Figure 2). Ninety per cent of nests were located below the top of the slope.

Eagle nests were located in topographic positions that gave protection from the north and west, and shade from the hot afternoon sun. Sites with easterly and southerly aspects offered greater protection from the prevailing winds (north-westerlies). When combined with slope angle, these locations appeared to offer protection from low- to medium-intensity bushfires, especially in the nestling period (November–December). Where nests were located in forested or wooded areas, the protection offered by the surrounding topography would have been further enhanced by the vegetation upslope and to the windward side of the nest.

The positioning of nests can be represented schematically on a hill with an altitude of 400 metres (Figure 3), but such a schematic may over-represent some aspect classes, notably those nests in the northern and western classes. Topography adjacent to the nest site also appeared to influence the position of nests. Nest-site profiles, which gave a better representation of nest positioning than the schematic view of nest aspect (Figure 3), show that all nest trees were positioned below the top of the slope of their primary aspect (Figure 4 a–d). For example, the gentle slope adjacent to Nest 10 (Figure 4b), which had an aspect of 30 degrees, gave the nest tree the most protection from the weather. Similarly, although Nest 1 had a rather open and exposed primary aspect (Figure 3), it was in a gully protected from two directions (Figure 4a).

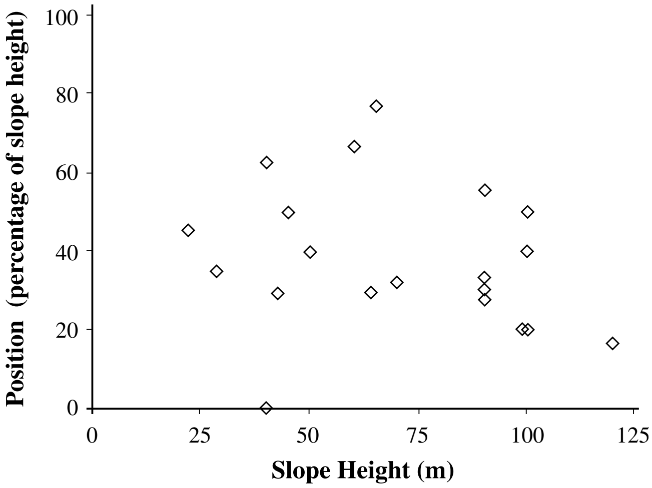

Figure 1. *Topographic position of Wedge-tailed Eagle nest trees in southern Victoria, as a percentage of slope height versus slope height (i.e. the higher the slope, the more basal the nest tree was situated on that slope).*

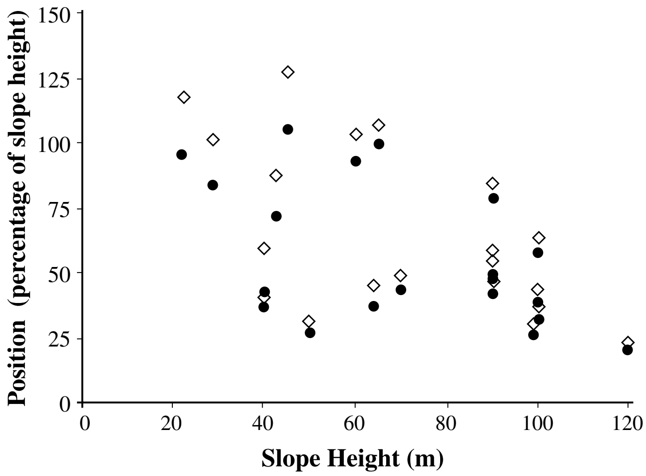

Figure 2. *The relationship between Wedge-tailed Eagle nest-tree height and nest height, expressed as a percentage of slope height, versus slope height. Each circle (indicating nest height) and corresponding vertically aligned diamond (indicating tree height) immediately above it represent one nest location.*

Sixty-five per cent of nests were located on private land, with 15 per cent on Crown land. For the Bacchus Marsh district, most (57%) were on private land, with 21 per cent on Crown land (Table 3). Eighty per cent of nests were located within view of, or within 200 metres of, roadways or houses. Nesting eagles varied in their response to human proximity. At one nest on private land and seldom visited, the adults appeared unconcerned by the observer, and often stayed on the nest for the duration of observation. The neighbouring nest, on public land bordered by housing estates, was well known and frequently disturbed by bushwalking activities; the adults left the nest well before the observer reached a viewing position and stayed away (though sometimes soared overhead) for the duration of the visit. Two nests (of one pair of eagles) on public

TABLE 3

Land tenure of Wedge-tailed Eagle nests in southern Victoria, 1999–2000 (n, %). See Table 1 for definitions of tenure.

Sample	Private	Public	Private-commercial	Crown
Study region (n = 20):	13 (65%)	2 (10%)	2 (10%)	3 (15%)
Bacchus Marsh area (n = 14):	8 (57%)	2 (15%)	1 (7%)	3 (21%)

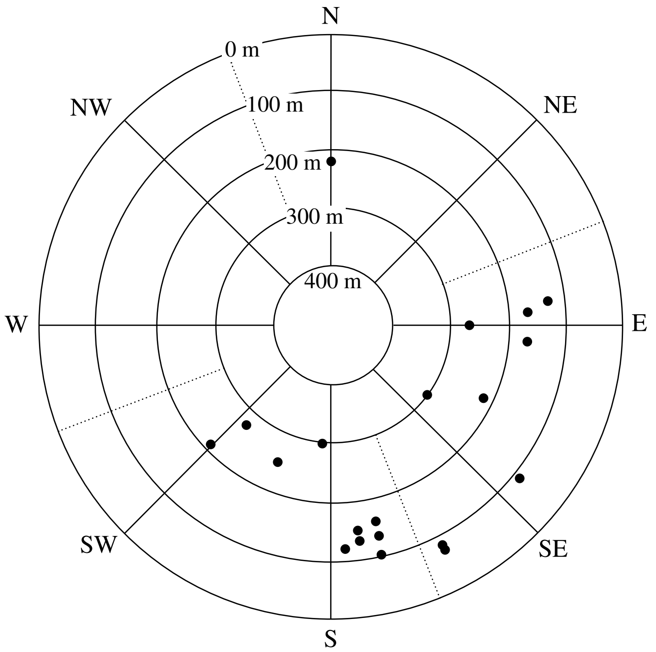

Figure 3. *Distribution of nest aspects of Wedge-tailed Eagle, southern Victoria: 20 nests on a schematic circular hill, for altitude and aspect across the study area. Dotted lines represent the limits of aspect classes used in analyses (see Table 1). Figure modelled on a similar representation by Brown and Mooney (1997).*

TABLE 4

Number of Wedge-tailed Eagle nests per territory, nearest-neighbour distances (km) and estimated core breeding-territory sizes (km^2) in the Bacchus Marsh district of southern Victoria.

Territory	*n* nests	Nearest neighbour (km)	Territory size (km^2)
1	2	4	12.6
2	1	4	12.6
3	3	5.5	23.8
4	4	5	19.6
5	1	5	19.6

land in the Bacchus Marsh district were in a small, infrequently used reserve, whereas a large nearby reserve (heavily used by recreationists) contained no eagle nest in 1999–2000, although historically two pairs of eagles were known to use it for nesting. During this study, one pair of eagles in the vicinity of this reserve nested in nearby private land without public access, and hence less potential for human disturbance.

Nearest-neighbour distances in the Bacchus Marsh district were highly consistent at 4–5.5 kilometres (Table 4), with Territories 3, 4 and 5 separated by open farmland, housing developments and the township. Territories 1 and 2 were located within the same patch of remnant bushland, at extreme opposite ends. Observations of their hunting and other diurnal activity showed that these two pairs rarely approached each other's territory. Nearest-neighbour distances gave calculated breeding-territory sizes of approximately 13 to 24 square kilometres per pair (mean 17.6 km^2: Table 4).

The eagles of Territory 5 had moved their nest site several times over the previous ten years, whereas the eagles in Territories 3 and 4 used the same sites consistently for more than five years. For Territory 5, the shifts progressively took the pair farther from neighbouring pairs, ultimately to 5.5 kilometres away.

DISCUSSION

Breeding chronology (egg-laying season) was consistent with previous knowledge and latitudinal patterns (cf. Olsen 1995, 2005). The eagles laid about a month later, and hence hatching and fledging dates were correspondingly a month later, than on the Northern Tablelands of New South Wales seven degrees (~1,000 km) farther north (cf. Debus *et al.* 2007). Otherwise, aspects of parental attendance, chick growth, nestling period and post-fledging dependence period were consistent with that previously recorded (cf. Debus *et al.* 2007).

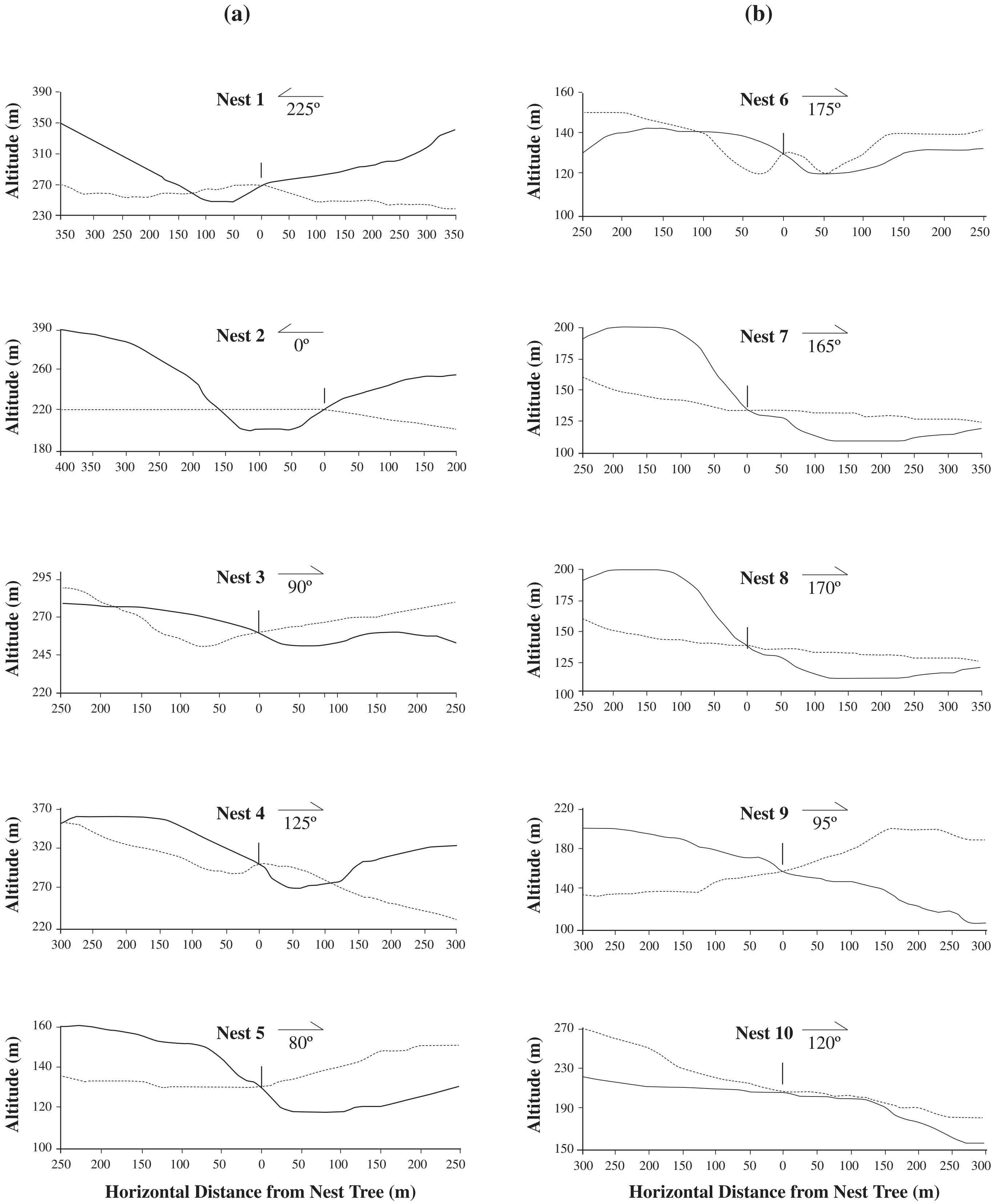

Figure 4. *Slope profiles of 20 Wedge-tailed Eagle nests, southern Victoria. Solid lines represent the profiles of the primary aspect; dotted lines the profile at 90° (clockwise) to the primary aspect; vertical line represents the position of the nest tree; angle and arrow represent the direction and compass bearing of the primary aspect.*
(a) Nests 1–5 (b) Nests 6–10

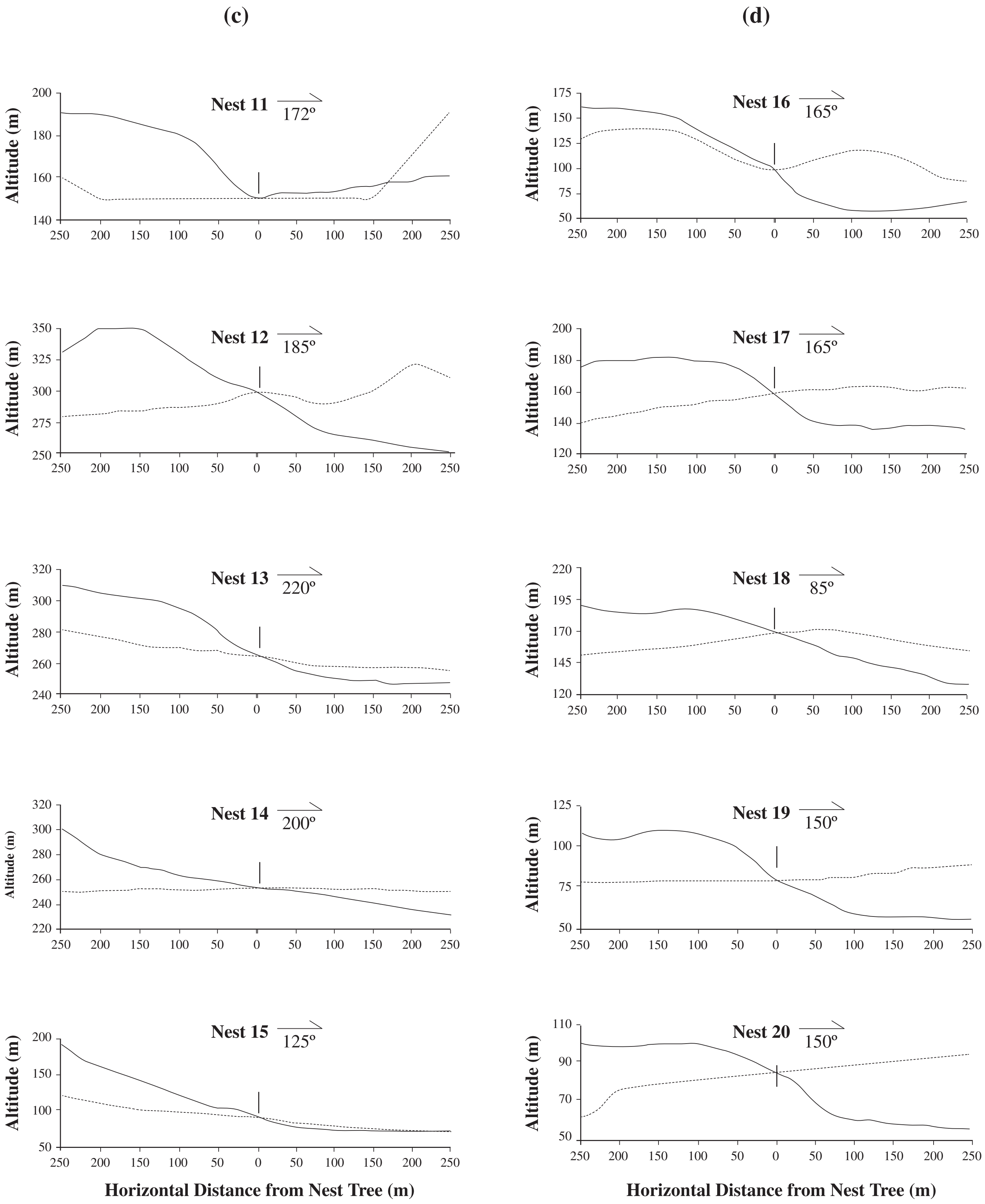

Figure 4. (continued) *(c) Nests 11–15 (d) Nests 16–20*

Wedge-tailed Eagle nests were found in a variety of habitat and vegetation types in the outer Melbourne region, and the site characteristics they shared mainly included nest-tree attributes, nest position and topographic position. Nests were in the top one-third of eucalypts, within the level of the surrounding tree canopy if present, and mostly in live trees. These features confer benefits such as shelter from inclement weather, shade from the midday sun, and security from predators. Nests in dead trees may have been built when the trees were alive, and abandoned after the tree died.

Nest trees were in sheltered topographic positions and aspects that provided maximum protection from prevailing winds and bushfires at appropriate stages of the breeding cycle (incubation and brooding in August–October, unattended large nestlings through November). A maximum slope angle of 30 degrees also maximises the horizontal distance from the nest (or nest-tree branches) to the ground on the adjacent slope, and thus minimises accessibility of the nest to ground predators, as well as minimising fire velocity and flame height around the nest. All the foregoing benefits have been identified for the nest sites selected by Wedge-tailed Eagles in Tasmania (Brown and Mooney 1997). Similarly, the site and orientation of cliff nests of Peregrine Falcons *Falco peregrinus* are selected to maximise protection from the weather (Olsen and Olsen 1989).

In southern Victoria, the distribution of Wedge-tailed Eagle nests across land tenures may have been partly influenced by human disturbance; for example, private landowners were usually aware of and protective of 'their' nesting eagles. Conversely, the low number of nests located on public land may reflect the lack of knowledge of nest sites in these reserves, and perhaps a low level of public use of those areas. Fuentes *et al.* (2007) similarly found some Wedge-tailed Eagle nests within 200 metres of roads and 300 metres of houses around Canberra.

The results of this study are in general agreement with those of Brown and Mooney (1997) for similar habitats, terrain and climatic zone, except that Tasmanian eagles have a more stringent requirement for nest stands of at least ten hectares of old-growth forest (although this shyness may be related to persecution, or acute disturbance such as clearfell logging). The results of this study are also broadly similar to those of Sharp *et al.* (2001), Dennis (2006), Collins and Croft (2007) and Silva and Croft (2007) for rugged or undulating terrain in the south-eastern arid and semi-arid zones, in terms of topographic position and nest-tree attributes, given the different tree species and sizes in a warmer and drier climate. However, in the arid zone the eagles' acceptance of apparently lower-quality sites (e.g. low or dead trees on ridges, versus live trees on creeks) may occur only during times of abundant food (Silva and Croft 2007). In the western arid zone, many eagle nests were sited in low dead trees (Ridpath and Brooker 1987), whereas in the present study nearly all nests were in live trees. These differences may relate to the flat terrain, low trees and abundance of dead trees in the arid zone, thus limiting the eagles' choice of topographic position and nest-tree attributes, and the much drier and hotter climate shaping different requirements for shelter. Eagles may choose 'better' sites in temperate regions because there are more and better sites available.

In this study it was difficult to separate selection, by the eagles, from availability in the landscape. For instance, a lack of nests on slopes greater than 35 degrees is probably because slopes with greater inclines are unable to support large trees, and a lack of nests on flat to gently sloping ground may be a legacy of past clearing for agriculture (as suggested by Brown and Mooney 1997). However, in the shire of Melton, which adjoins the Bacchus Marsh district, there are no eagle nests in a flat landscape lacking the protection of topography and surrounding forest, despite the abundance of potential prey and the presence of apparently suitable stands of trees for nests.

Nearest-neighbour distances calculated in this study were similar to those previously reported for the Wedge-tailed Eagle, especially for the temperate zone (reviewed by Marchant and Higgins 1993 and Olsen 2005). The results on estimated core territory size are smaller than previously reported for Wedge-tailed Eagles (cf. Marchant and Higgins 1993; Olsen 2005), perhaps because eagle densities in temperate areas are higher than in the arid zone; density of prey (rabbits) was also high at Bacchus Marsh (Foster and Wallis 2010). However, the previously published figures are eagle densities, without implying a circular defended area or home range for given pairs. In this study, the calculated areas (based on circles with radii of half the inter-nest distance) probably do not reflect the total home ranges used by the pairs of eagles. Home-range size and shape for Wedge-tailed Eagles have not been determined by radiotelemetry: an obvious avenue for further research.

Other factors, including human disturbance and interspecific interactions, may influence nest-site selection by Wedge-tailed Eagles. For instance, in Victoria a resident pair of Wedge-tailed Eagles was displaced by a pair of White-bellied Sea-Eagles *Haliaeetus leucogaster* (M. Herman pers. comm.), and a resident pair of Wedge-tailed Eagles, that was subjected to the aggressive behaviour of a pair of Peregrine Falcons, occupied an alternative nest site (AF pers. obs.). However, topography and forest cover are likely to be the more important factors. Nest-site selection by Wedge-tailed Eagles in southern Victoria appears to be more specific than previously believed, and therefore further study is warranted to enable land managers to take the nesting requirements of the eagles into account when developing future management strategies. Future study could usefully incorporate statistical comparison of actual and 'control' (non-nest or potential) sites, in order to better define nest-site characteristics and achieve predictive ability, as in Tasmania (cf. Brown and Mooney 1997).

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