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MODELLING THE NESTING HABITAT OF THE WHITE-BELLIED SEA-EAGLE *Haliaeetus leucogaster* IN TASMANIA

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The nesting habitat of the White-bellied Sea-Eagle *Haliaeetus leucogaster* was assessed and modelled in a region of south-eastern Tasmania. The selected habitat was assessed by comparing the habitat parameters of 28 nest sites with those of the entire study area. The activity status of nests during the 1997–98 breeding season, and some variables, were measured or observed in the field, and other data were obtained from existing databases. Characteristics of the habitat selected included low altitudes, less exposed aspects, proximity to the coast, and the presence of short, dense and mature forests including superdominant trees. Geographical Information Systems were used to assess habitat selection and in the construction of models. The well-defined habitat selection allowed an efficient ratio of nest-site prediction probability (89%) to area modelled (17.8%). The potential applications of such models include increasing the efficiency of searches for nest sites and the identification of potential habitat, thus allowing strategic protection from human encroachment.

INTRODUCTION

White-bellied Sea-Eagles *Haliaeetus leucogaster* construct and re-use nests in tall trees, low bushes, mangroves, on cliffs, rocky outcrops, islets and in caves and crevices (Marchant and Higgins 1993). The status of populations in Australia varies, with stable populations in the tropical north and declining populations in the south and east (Bilney and Emison 1983; Marchant and Higgins 1993; Clunie 1994; Dennis 2004; Dennis and Lashmar 1996; Dennis and Baxter 2006). The species is listed as *vulnerable* on the Tasmanian *Threatened Species Protection Act 1995*, *threatened* under the *Victorian Flora and Fauna Guarantee Act 1988*, *endangered* in the South Australian *National Parks and Wildlife Act 1972*, and *migratory* under the Commonwealth of Australia *Environment Protection and Biodiversity Conservation Act 1999*. A survey of 83 White-bellied Sea-Eagle nests in Tasmania found that 28 per cent of nests, recorded from the late 1970s, had disappeared (Thurstans 2009). Such a turnover rate highlights the need to identify habitat utilised, as nest sites are only temporary foci of reproduction, so that potential habitat can to be conserved to allow future nest sites to be established (Thurstans 2009).

The most significant threats to White-bellied Sea-Eagles are those human activities that encroach on their habitat (Clunie 1994; Dennis and Baxter 2006). Such threats lead to the displacement of breeding eagles and have caused birds to nest in suboptimal habitat, consequently producing declines in their breeding productivity (Bilney and Emison 1983). More immediate responses can arise from human activity near nests. Breeding adults are shy, and intrusions may lead to abandonment of eggs or nestlings (Mooney 1986; Marchant and Higgins 1993; Dennis 2004; Denis and Lashmar 1996; Stokes 1996; Dennis and Baxter 2006; Threatened Species Section 2006). Populations of other species of large raptors, such as the Bald Eagle *Haliaeetus leucocephalus* of North America, have also been threatened by the reduction of habitat (McEwan and Hirth 1979).

Effective management strategies for a particular raptor species experiencing significant threats to its habitat, and from direct disturbance, require knowledge of those habitat requirements (McEwan and Hirth 1979). Assessing only the current population at any one time can give an inaccurate picture of the effects of habitat loss, because a population decline can be delayed before a lower equilibrium establishes or the species goes extinct (Lamberson *et al.* 1992). When the features of habitat are known, critical areas can be designated and conserved.

Habitat selection by raptors has been little studied in Australia, despite intensive efforts overseas, particularly in the areas of nest-site selection and habitat preferences (e.g. Andrew and Mosher 1982; Reynolds *et al.* 1982). With increasing computing power, such studies have become more quantitative (Donazar *et al.* 1993; Sanchez-Zapata and Calvo 1999; Rodriduez-Estrella 2000; Suarez *et al.* 2000). Geographical Information Systems (GIS) allow the organisation, synthesis and analysis of data from several sources, leading to understanding of both spatial and non-spatial relationships (Chandler *et al.* 1994). Variables from datasets can be tested statistically as prospective predictors of a species' distribution (Bustamante and Seoane 2004), and can then be used to construct models and generate predictive and 'probability of occurrence' maps (Osborne *et al.* 2001). This approach has allowed the prediction of species' requirements when designing strategies for the conservation of endangered species (Donazar *et al.* 1993; Suarez *et al.* 2000) and for predicting potential habitat, which is useful in assessing impending land-use change (Fielding and Haworth 1995), or the suitability of areas for reintroductions (Donazar *et al.* 1993).

The aim of this study was to construct a nesting-habitat model for the White-bellied Sea-Eagle in a region of south-eastern Tasmania, based on the characteristics of nests and nest sites. The techniques used for the habitat-selection assessment and modelling were similar to those used for a similar-sized species in Tasmania, the Wedge-tailed Eagle *Aquila audax fleayi* (Brown and Mooney 1997), but differed in the construction of a Gradated Probability Model (GPM) in the present study. Field studies gathered data from nest sites, and were complemented by existing datasets in GIS describing topography and forest heights and densities. The datasets were assessed for accuracy and relevance to the scale of habitat selection. Variables were then assessed as prospective predictors by testing the values at nest sites against values generated from the whole study area. The ranges of parameters thought to be instrumental in the selection of nesting habitat were used to designate areas that would have a high probability of being selected for nesting sites at some time. Models were constructed and assessed through comparison in terms of nests covered per unit area modelled and accuracy of predicting nine other nest locations. The use of such models can predict areas of suitable habitat, without the presence of nests. Protection can then occur, managing human activities that may be incompatible with the wellbeing of White-bellied Sea Eagles, and allowing establishment of nests in the future.

METHODS

Study area

The project was based in an area of south-eastern Tasmania, Australia, with the study area encompassing the Forestier and Tasman peninsulas and Bruny Island (Figure 1). This study area was thought to be suitable because of the large length of complex coastline, with varying directions to water bodies, and similar ecological conditions (rainfall, geology and forest types) throughout. In Tasmania, White-bellied Sea-Eagles are known to nest as far as 100 kilometres from the coast although they are heavily concentrated along the coast and on islands (Tasmanian Raptor Nest Database, DPIW). Thus, the whole of the study area can be considered available habitat for the species.

The study area was already known to contain several active breeding pairs of White-bellied Sea-Eagles, many more nests, and a large range of human activities. Residential dwellings are found in varying densities, along with tourism ventures, agricultural operations, walking tracks, boating (both recreational and commercial), expanding marine and land-based aquaculture operations (Anon. 1997), forestry operations, and other land-clearing.

The area used for development of the habitat models (Figure 2) was a subset of the larger study area, including those TASMAP 1:25 000 map sheets that covered the nests measured in the project, and excluded landforms where nests were not found (e.g. water bodies, South Arm Peninsula and areas farther north than Forestier Peninsula). This subset area was used to test the null hypothesis that the birds choose nest sites randomly from the habitat available, and the alternative hypothesis that nest sites are chosen for, and therefore are characterised by, particular aspects or parameters out of proportion to those available.

The study site (Figure 2) was used for testing because it is a more precisely defined area of available habitat, potentially searched by White-bellied Sea-Eagles when prospecting for the nest sites on which the modelling is based. The rest of Bruny Island and the Tasman Peninsula had not been searched extensively for nests, and were therefore excluded from the area used for model development lest they should give an inaccurate impression of 'available habitat' for the nest sites used.

The results of the tests on the modelling area (Figure 2) were used to decide which parameters would be used in the model. The model, however, was applied to the whole study area (Figure 1), implying that this larger area has similar ecological conditions throughout, and that White-bellied Sea-Eagles would be consistent in their nest-habitat selection across this whole area. The parts that were excluded from the modelling area (compare Figures 1 and 2) would therefore be useful areas to test the accuracy of predictions made by the model.

Nest-site selection

Twenty-eight nests were used to assess the parameters that the species uses when selecting nesting habitat. The nests were found by a variety of methods and from many observers over several years. They are recorded in the Natural Values Atlas, a Web-based database of the Tasmanian Department of Primary Industries and Water (DPIW).

Multiple nests in each territory were treated as independent nests for all tests except for nearest-neighbour distance. The activity status of each nest was assessed from the farthest distance possible through a high-powered telescope, an 'active' nest having at least one nestling. This observation and assessment stage was conducted during the usual nestling period from September to early December, but mostly in November, when most chicks were larger and more active. This led to the potential for nests being classed as 'inactive' if there had been unsuccessful breeding attempts with no chicks raised.

Towards the end of the breeding season, in early December 1997, an aerial survey was conducted over the Tasman and Forestier peninsulas to assess the activity status of nests, in particular those with contents that were hard to see from the ground (Cessna 206, air speed 70 knots, altitude 300 m, flying into the wind).

For each of the nests, characteristics or parameters of the nest tree and nest site were measured or estimated in the field (Table 1), in January and early February 1998 when all chicks had left the nests. The co-ordinates of the nest sites were obtained with the use of a Global Positioning System (GPS), GPS 45 Personal Navigator, Software Version 2.20 (1994 Garmin International). Two readings in units of the Australian Metric Grid (AMG) were taken for each site. Since the GPS had to be used in non-differential mode, the level of accuracy of this system meant that the co-ordinates were only used as a guide. The nest site in the field was defined as the area within a 50-metre radius of the nest tree, but the GIS data resolution assumed that this was within a 25-metre square cell. Most locations were verified with the use of known landmarks and 1:25 000 topographic maps (accuracy ~20 m). Other data were extracted from 1:25 000 topographic maps and a Digital Elevation Model (DEM) of the same scale (25 m). Wind speed and frequency data were obtained from the Bureau of Meteorology.

Forest structure data as photo-interpreted (PI)-type maps, including predominant forest height, density and age (Appendix 1), were obtained from Forestry Tasmania for the variable NEST SITE FOREST. This classification of Tasmanian forests was formulated through the interpretation of aerial photographs

TABLE 1

Variables used to characterise White-bellied Sea-Eagle nest-site selection.

Variable	Definition
NEST TREE HEIGHT	Measured in field with clinometer (m).
NEST-SITE FOREST HEIGHT	Average height (m), extracted from PI-type classification.
NEST-SITE FOREST DENSITY	Crown cover (%), extracted from PI-type classification.
NEST-SITE FOREST AGE	Mature or regrowth, extracted from PI-type classification.
SLOPE ANGLE	Degrees above horizontal, calculated from 25-m DEM using GenaMap SLOPE SU (m)
POSITION ON SLOPE	% of height and % of incline, calculated from 1:25 000 maps.
WIND SPEED	Km/h, measured at two wind stations (Cape Bruny and Palmers Lookout) for the period 1993–1998.
WIND DIRECTION	Degrees, measured as for wind speed.
NEST ASPECT	Direction (degrees) of nest from trunk of tree, measured in field with compass.
NEAREST NEIGHBOUR: STRAIGHT-LINE	Measured on 25-m DEM, straight-line distance (m) between active nests.
NEAREST NEIGHBOUR: COASTLINE	Measured on 25-m DEM, length of coastline (m at 1:25 000 scale) between active nests.
ALTITUDE	Above sea level (m), obtained from 25-m DEM.
DISTANCE TO WATER	Measured on 1:25 000 map as straight-line distance (m) from nest tree to water body.
PROXIMITY TO HUMAN HABITATION	Measured on 1:25 000 map as straight-line distance (m) from nest tree to building.
TREE CONDITION	Live or dead.
N SIMILAR TREES WITHIN NEST SITE	Trees similar in dimensions to nest tree, estimated in field.
SIZE OF NEST TREE	Tallest and/or widest (dbh) in nest site?, estimated in field.
TIME SINCE LAST FIRE	Years, calculated by counting nodes on typically sized *Banksia marginata*.
RESERVATION STATUS	Obtained from 1:25 000 land-tenure map.

into polygons on vector-based datasets, carried out in 1996 as a precursor to the negotiation of the Regional Forestry Agreement for Tasmania (1997). The classifications of NEST SITE FOREST were compared with the descriptions observed in the field, to test the accuracy of the PI-type data. Three nest sites (10.7%) were on areas classified as 'bare ground' or 'non-forest scrub' in the PI maps, owing to the close proximity of cliffs or coastal banks, and the resolution of the PI data being too course to distinguish between nest trees on cliff edges and the cliffs themselves. Those sites were eliminated from tests of NEST SITE FOREST, but they could be included in models, by including the areas classified as bare ground and non-forest scrub.

The PI-type height classifications of the nest sites and the height estimations in the field were found to be very similar, with only four (14%) of the 25 forest classifications different from the field estimates, by a maximum of eight metres. The PI-type classifications were therefore used for all tests of nest-site forest selection (NEST-SITE FOREST HEIGHT and MATURE NEST-SITE FOREST HEIGHT). When the three nest sites classified as 'bare ground' or 'non-forest scrub' were excluded, the sample size was reduced to 25, with expected frequencies generated accordingly.

For NEST SITE FOREST DENSITY, the PI-type density classifications of the nest sites and the density estimations in the field were also found to be similar, with nine (36%) of the 25 density classifications different from the field estimates: seven by only 10 per cent (of crown cover) and two by 20 per cent. These differences were not considered large enough to discount the use of the PI-type classification for modelling purposes. A problem arose from classes of density being assigned to different groupings for mature and regrowth forests. Consolidation, however, was attempted; mature density classes (a and b) ranging from 40 to 100 per cent were grouped with regrowth classes (a, b and c) ranging from 50 to 100 per cent, and the remaining lower densities were assigned to another group.

The heights of 28 nest trees were measured in the field with the use of a clinometer and converted to relevant mature or regrowth height classes to test against the available forest heights. The classifications were tree specific, whereas the PI-types are based on the average forest height rather than the heights of emergent trees. Hence, the test is only a guide to available heights of individual trees. The height classes were tested against the frequencies that would be expected if selection were random from the available habitat (in the area shown in Figure 2).

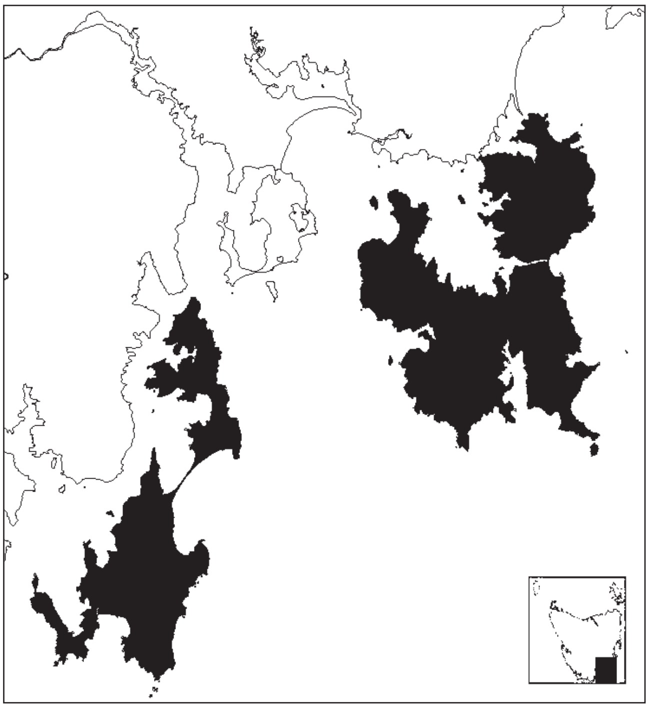

Figure 1. *The study are in south-eastern Tasmania used for the application of modelling.*

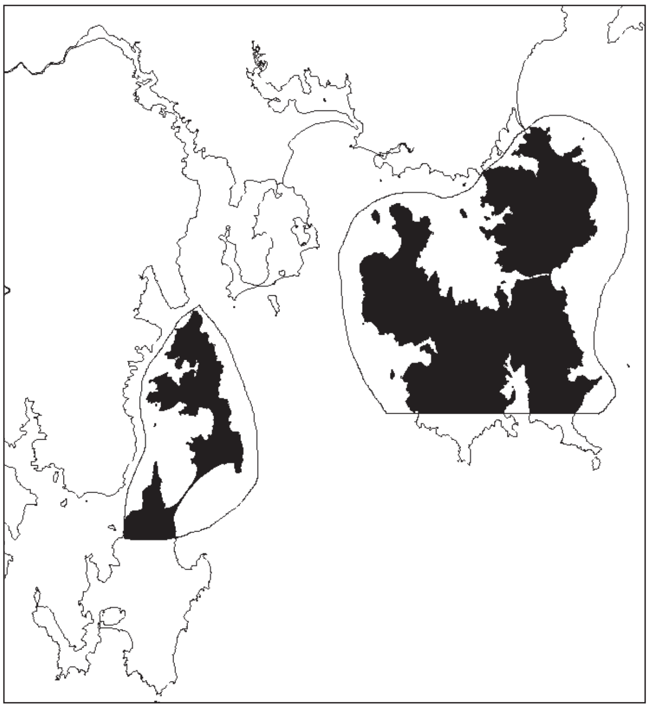

Figure 2. *Available White-bellied Sea-Eagle habitat (a subset of the study area).*

The estimates of number of trees similar in size to the nest tree within the nest site (50-m radius) were compared (by chi-square test) with a quarter of the number estimated to be within a 100-metre radius ($n = 16$ sites where these variables were measured).

The heights of 23 nest sites found in mature forest were tested against the availability of height classes within the available 'Mature' habitat. The expected frequencies of height classes were calculated from the proportion of each within those parts of the subset area (Figure 2) classed as mature forest.

The altitude at the co-ordinates of nest trees derived from the 25-metre DEM were compared with those derived from hard-copy 1:25 000 maps, but no significant variation was found between them ($\chi^2 = 1.17$, d.f. = 3, $P = 0.75$). To test whether the 28 nest trees were randomly distributed with respect to altitude, the altitudes of the nest sites were compared against the available altitudes across the modelled area (Figure 2). The expected frequencies for each 50-metre altitude class were calculated from the 25-metre DEM as a proportion of each class.

The aspect of the slope on which each nest tree was situated was measured in the field using a compass. The slope aspect was tested against the direction of high wind events, which can destroy nests (selection by the environment, not the animals), and against the direction of prevailing winds, which can affect the welfare of the nest occupants. Wind data were obtained from two Bureau of Meteorology stations, Palmers Lookout and Cape Bruny, at southern points of Tasman Peninsula and Bruny Island, respectively. These data were in the form of percentage frequencies for the period 1993 to 1998, with separate categories for each of eight compass directions, five speed classes, and for each month of the year. High wind events were defined as winds over 52 kilometres per hour. The mean angle of slope aspect, with a 95 per cent confidence interval, as calculated by the Oriana software package (Version 1.0, Kovach 1994), was tested for difference from the closest possible high wind event.

For slope angle, there were two sets of data: one from the DEM extracted from all nest sites, and the second set measured in the field (obtained for 24 of the 28 nest-sites). The DEM slope-angle figures were thought to be more suitable because: (a) they were found not to be significantly different from the field measurements ($\chi^2 = 0.2812$, d.f. = 23, $P = 1.0$), even though the DEM only has a resolution of 25 metres whereas the field measurements were taken at a smaller scale, localised at the nest sites; (b) data for all 28 nests were available and so the test would be more powerful than using the 24 field measurements; and (c) the DEM would be used for the model, so it was appropriate to use this data source for the tests leading to its construction.

The position on slope was calculated as a percentage of slope height and slope incline for each nest site. These positions were graphed against the slope height.

The distances between the 13 active nests in the 1997–98 breeding season were assessed by two different measures: straight-line distance, and length of coastline between the nests. For straight-line distance, two of the distances were excluded from analysis, as it was suspected that White-bellied Sea-Eagles there were nesting closer than these distances. For coastline lengths, distances were eliminated that were almost certainly not between the closest active nests.

The variable PROXIMITY TO HABITATION (any building) was measured from maps as a straight-line distance, as in several Bald Eagle habitat studies (Andrew and Mosher 1982; Chandler *et al.* 1994).

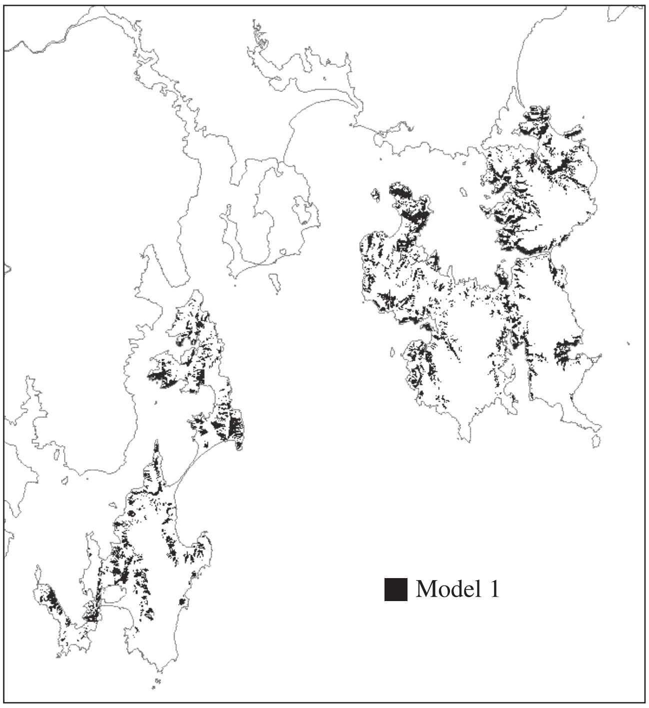

Figure 3. *Sea-Eagle breeding habitat Model 1.*

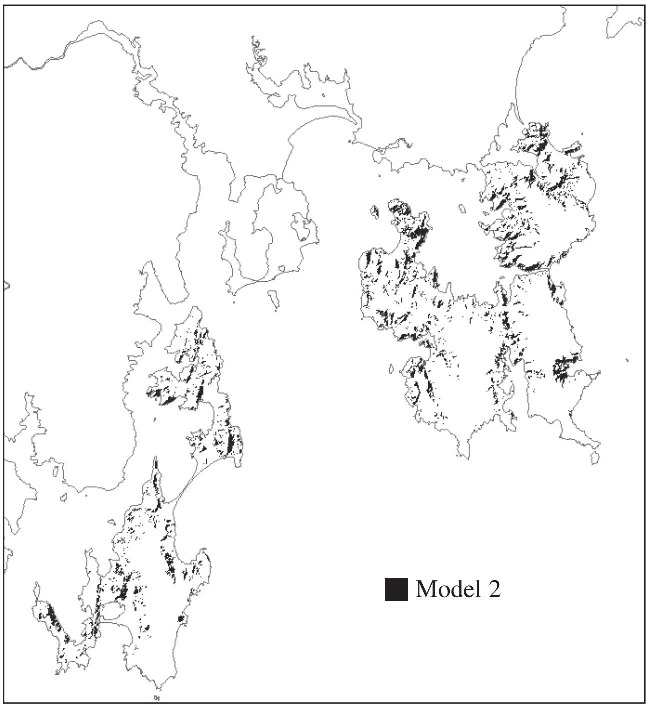

Figure 4. *Sea-Eagle breeding habitat Model 2.*

Statistical analysis

The PI-type data and DEM covered the total study area (Figure 1). The GIS application could also give absolute totals for area covered by individual classes of forest and topographical variables. This allowed an accurate, fragmented representation of the available habitat, nullifying the need for random points, a common technique in studies of habitat selection (Donazar *et al.* 1993; Osborne *et al.* 2001).

Although the forest data described continuous variables (forest height and crown cover density), the PI-type data were organised in classes. This allowed the use of chi-square testing with the forest data as well as with the topographic variables, comparing the frequencies of the habitat classes selected with the frequencies available. The values for expected frequencies were calculated from the proportion of the total available habitat (Figure 2) covered by each forest class. Some consolidation of classes was necessary, in order to obtain expected frequencies of at least five, but also for consolidating height and density classes of mature and regrowth forest. SLOPE ASPECT was crudely tested with chi-square, for frequency selected versus expected per 90-degree quadrant; expected frequencies were calculated by dividing the total (28) into the four compass directions (N, E, S and W). This method assumes that there is an equal area of slopes facing each compass direction. This variable was also tested for uniformity of distribution using Rayleigh's test (Oriana Version 1, Kovach 1994; this is a test of the uniformity of distribution, a result of 0.00 indicating that the distribution is not uniform around compass bearings). The 95 per cent confidence interval for the mean angle of SLOPE ASPECT was tested against the nearest possible high wind event, and compared with the frequency of other prevailing winds.

Those variables found to be significantly selected ($P < 0.05$) were regarded as suitable variables for modelling the nesting habitat of White-bellied Sea-Eagles. The ranges of parameters of these variables that efficiently covered most nests with the least area were chosen as layers for the model(s). Several ranges of parameters were used to assemble different layers and were used in varied combinations for different models. The different models were assessed for the proportion of nests included compared to area covered.

Ground-truthing

Nine nest locations, which were not used in the construction of the models, were used to test the prediction accuracy of different models, and so allow a comparison of the different models. This procedure was carried out using GIS, by displaying the locations and the model being tested and seeing whether the nest location was in an area prescribed as habitat by the model.

RESULTS

All Sea-Eagle nests were found in trees, in forest. The data were tested to assess the importance of each variable alone for habitat selection (Tables 2 and 3). The models were constructed using variables showing significant potential as predictors of habitat.

Habitat selection

Sea-Eagles showed significant habitat selection within most of the topographic and forest parameters tested, with the exception of slope angle and forest height (Tables 2 and 3).

Most nests were at low altitude. Ninety-three per cent of the nest sites were less than 85 metres above sea level, but this altitude range covers only 52 per cent of the available habitat. All

TABLE 2

Summary of results from chi-square tests on Sea-Eagle habitat parameters (*significant).

Parameter	Tested against	Sample size *(n)*	χ^2	d.f.	P
ALTITUDE	Available in 50-m classes	28	30.84	3	<0.001*
SLOPE ASPECT IN QUADRANTS	Random distribution (28 ÷ 4)	28	24.29	3	0.002*
NEST-SITE FOREST AGE	Mature vs regrowth	25	10.1	1	0.005*
N SIMILAR TREES WITHIN NEST SITE	(N within 100-m radius)/4	16	31.57	15	0.007*
MATURE NEST-SITE FOREST HEIGHT	Available mature heights	23	7.64	2	0.022*
NEST-TREE HEIGHT	Available heights	28	7.82	2	0.021*
NEST-SITE FOREST DENSITY	Available densities	25	6.37	1	0.012*
MATURE NEST-SITE FOREST DENSITY	Available mature densities	23	7.34	2	0.024*
SLOPE ANGLE (from DEM)	Available slopes	28	2.28	1	0.131
NEST-SITE FOREST HEIGHT	All forests	25	1.73	2	0.427

TABLE 3

Summary of results from other tests on Sea-Eagle habitat parameters.

Parameter	Test	Sample size *(n)*	Result
SLOPE ASPECT	Rayleigh test of uniformity if significantly distinct from 157.5°	28	*P* = 0.00, distribution not uniform, trend to SE (mean 127.52°)
AND HIGH WINDS		28	Yes, aspect significantly isolated from high wind events
AND PREVAILING WINDS	No test	28	Trend for avoidance
NEAREST NEIGHBOUR (STRAIGHT LINE)	Least known distance	9	Minimum 4.4 km
NEAREST NEIGHBOUR (COASTLINE)	Least known distance	10	Minimum 18 km
PROXIMITY TO HUMAN HABITATION	Least known distance	12	Minimum 320 m
POSITION ON SLOPE (% height and incline)	Any trend	28	Most <60% of slope height and incline

the nest-sites were less than 122 metres above sea level, only 70 per cent of the available habitat. Altitude was therefore included in the model, with 85 or 122 metres above sea level as limits.

Nest sites were more frequent on south-east facing slopes, with a mean bearing of 127.53 degrees. To capture 93 per cent or 26 of the 28 nests within the smallest arc, aspects between 32 and 215 degrees could be used for a layer in the nesting-habitat model. For 100 per cent or all 28 nests to be contained, aspects within the arc of 32 to 281 degrees would be used for an aspect layer.

Height classes E1 to E–3 and ER3 to ER6, representing forests of heights of 27–76 plus metres, encompassed 82 per cent of nest trees, but were only 56 per cent of the available landscape. Most (68%) nest-tree heights were taller than the height class of the forest surrounding the nest tree, 20 per cent were equal to that of the surrounding forest, and only 12 per cent were in a lower height class. Ten of 27 (37%) nest trees were the tallest and 14 (52%) had the greatest diameter at breast height (dbh) within each nest site. That is, White-bellied Sea-Eagles often select nest trees that are taller and wider than the predominant forests. Because of this result, the PI-type data, with its classification of predominant forests, does not specify the presence of actual nest trees.

Breeding pairs select for nests in forests of density classes *a* and *b* in both mature and regrowth forest, as well as regrowth density class *c* (χ^2 = 6.37, d.f. = 1, *P* = 0.0116). These classes represent 40 to 100 per cent crown density in mature forest and 50 to 100 per cent crown density in regrowth forest. Such forests cover only 32 per cent of forests in the study site (Figure 2), and capture 14 (56%) of the 25 nests tested and 50 per cent of the total 28 nests. Using the area with density classes *a*, *b* and *c* for mature forests and just *a* and *b* for regrowth forests, 21 (75%) of the 28 nests are contained within 34 per cent of the study site. Using the area with density classes *a* to *d* for mature forests, with just *a* and *b* for regrowth forests, captures 25 (89%) of the nests within 52 per cent of the forests in the study site.

From the 16 nest sites where NUMBER OF SIMILAR TREES WITHIN NEST SITE was estimated, the densities of trees similar to nest trees were significantly greater ($\chi^2 = 31.57$, d.f. = 15, $P = 0.0074$) within 50 metres than farther away. Of the 28 nests, nine (32%) were found to be above the surrounding canopy, 17 (61%) were below the surrounding canopy, and two were in situations with no prominent canopy.

Twenty-three of the 28 nests were in sites classified as mature forest, as opposed to 'regrowth' forests and 'non-forest classes'. Nest sites were predominantly in mature forests. This result suggests that mapping of mature forest only (61% of all forests in Figure 2) would capture 82 per cent of 28 nest sites within the model. Further investigation and analysis within the area of mature forest are therefore warranted, and would also eliminate the consolidation of mature and regrowth classes.

Nest sites in mature forest were skewed towards the shorter height classes. By isolating the group E1 to E+3 from the other two (E–3 and E4 to E5), the nest-site sample is split 3:20. Therefore 20 (87%) of the 23 nests in mature forest are in forests of height classes E–3 to E5 (representing heights <15 m to 34 m). Adding the class E+3 to this range increases the number of nests covered to 82 per cent (23 of 28, within 50% of the forests in Figure 2). These groupings were found to be useful in the model construction phase.

The eagles did not select for particular forest densities in mature forests, other than avoiding areas classed *f*, which is forest with less than five per cent crown cover ($\chi^2 = ?7.34$, d.f. = 2, $P = 0.024$). This result was in contrast to the selection for denser regrowth forest (class *b*, 70–90% crown cover) and denser forest when considering regrowth and mature together, but the exclusion of class *f* was still significant and useful in the layer construction stage.

For 18 nest sites, there was a wide variation in stages of succession from fire or time since the last fire. This result rejects any suggestion that the species selects nest sites in forest of a particular successional stage.

Because the wind data were for 45-degree sectors, the closest possible high wind event, a 'southerly' wind event, could have come from any direction between 157.5 degrees and 202.5 degrees. The closest of these possible directions to the mean angle of slope aspects is 157.5 degrees, which was found to be outside the 95 and 99 per cent confidence intervals for the mean of slope aspect angles. Therefore, the slope aspects are significantly distinct from aspects exposed to high wind events. The range of possible directions for which high winds were recorded included the directions south, south-west and west (157.5 to 292.5 degrees). Five of the nest sites were situated on aspects facing into this range of high winds. However, the NEST ASPECT for these five nests all faced the more unexposed compass directions (north: one nest, east: two nests, and south-east: three nests).

Of mean wind frequencies (<52 km/h) measured at Palmers Lookout for the months August to November (the main Sea-Eagle breeding period), 68 per cent were from the north (21%), north-west (10%) and west (37%). Only two per cent of mean wind frequencies came from the south-east, with all mean speeds from this direction being less than 26 kilometres per hour. A similar pattern was evident at Cape Bruny, with 64 per cent of mean wind frequencies coming from N, NW and W directions. South-easterlies accounted for only 3 precent of mean wind frequencies (again all <26 km/h).

The non-significant result for DEM slope angles was repeated for the field measurements, with a similar, yet almost significant result ($\chi^2 = 3.72$, d.f. = 1, $P = 0.0538$). Therefore, the slope angle of available habitats as represented by the 25-m DEM has little influence on the selection of nest sites. If this parameter were to be used in a model(s), slopes greater than 6.8 degrees would capture 26 (93%) of the 28 nest sites. The slope at a smaller resolution (which may be recognisable in the field) was more skewed towards higher slopes than those slopes available, almost significantly so, but that test had less power, because of a smaller sample size, than that applied to the DEM results. This result is not applicable to the model, because data at this scale are not available in mappable form.

No trend in POSITION ON SLOPE was found in the graph of per cent slope height and slope incline against slope height, or a similar one correlating height of slope with position on slope (neither shown). The only useful recommendation from these results may be that most nest-sites are under 60 per cent of the slope heights and inclines. This result could not be mapped in the model, but may be useful for nest-searching procedures.

For STRAIGHT-LINE DISTANCE between nests, nearest neighbours were 4.4–9.5 kilometres apart (mean 6.6 km, s.d. = 2.1). The average distance along the coastline between active nests was 49.2 kilometres (s.d. = 26.3 km), but this result is unreliable. The measurements, carried out on the 25-m DEM, may not be appropriate representations of the behavioural minimum. For example, an isthmus between nests may not divide the area as it would on the digital map. For those distances where it was certain that they were the closest active nests, and where the coastline represented territory size well, the three results were very close (mean 21.3 km, s.d. = 3.8). The most useful figure for the model would be the minimum distance measured (i.e.18 km). The use of such a prescription is dependent on the scale of the map used, so this result is only applicable to the 1:25 000 scale.

Proximity to human habitation averaged 1.9 kilometres, ranging upwards from a minimum of 320 metres.

Attribute layers

The results from the assessment of habitat selection were used to construct layers for the modelling in the GIS (Table 4). Each layer considered a single attribute of habitat, with the parameters calculated to maximise the number of nests covered. Some attributes were covered by multiple layers, with different parameters, to allow flexibility in the model construction phase.

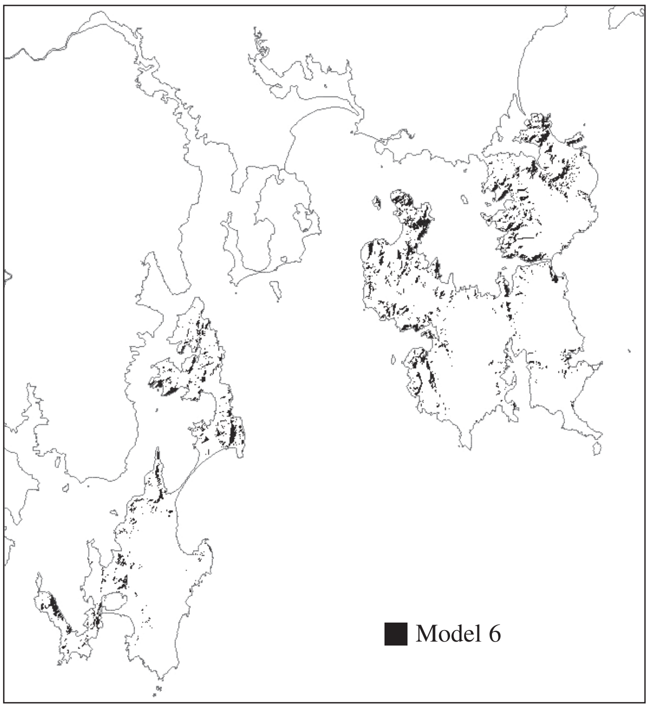

Figure 5. *Sea-Eagle breeding habitat Model 6.*

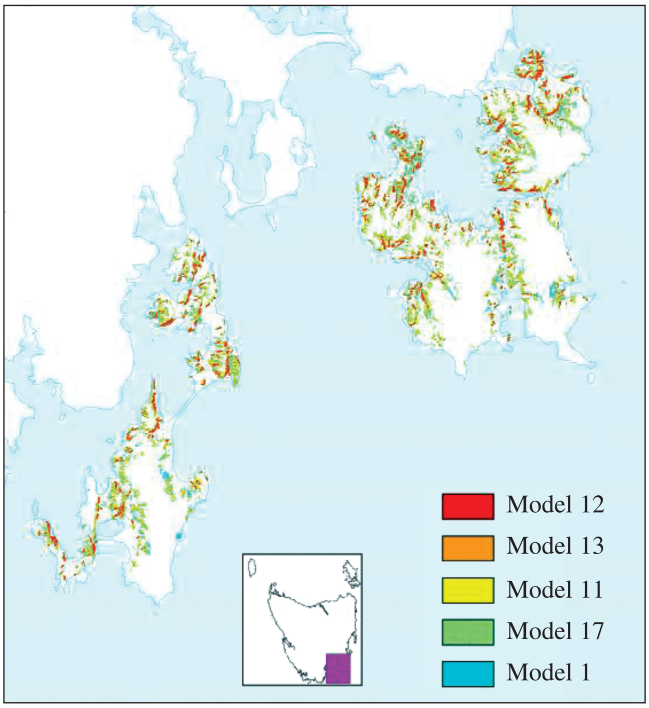

Figure 6. *Sea-Eagle Gradated Probability Model.*

All the attribute layers indicated that they might be useful, except for Layers 8 and 11. Layer 8 was an attempt to include the areas of 'bare ground' for models, because three nests, close to rocky coastline, were found with this classification. The 'bare ground' category, however, also included vast areas of ground unsuitable for nesting habitat, such as cleared land. Consequently, the layer only excluded 7 per cent of the modelling area, which was not useful. Layer 11 was proposed to map the extent of mature forests, regardless of height and density. It was not useful, since Layers 12 and 13 are subsets of it, and exclude the same area (regrowth forests and non-forest).

Model construction

The models were constructed in the GIS by adding layers (e.g. 4, 6 and 10), such that the area modelled would have attributes that meet all parameter settings in the layers (e.g. area within Layer 4 parameters and Layer 6 parameters and Layer 10 parameters). These models are listed in Table 5.

The combinations of parameters used in the various models allowed flexibility in selecting the most appropriate model(s) (Figures 3–5). Some attribute layers were not useful when included together, because one was a subset of the other and/or each of the layers excluded different nests, so together they excluded too many nests to have a useful probability of predicting nesting sites. Conversely, some attribute layers were complementary, e.g. mature densities (Layer 13) and mature heights (Layer 12), because they excluded the same nests, so together they would exclude more area than alone, but still maintain the same nest coverage.

Gradated Probability Model

The Gradated Probability Model (GPM) was constructed by overlaying a series of models, each one a subset of the previous one (Figure 6). The effect is a multi-coloured model covering the same area as Model 1 (Figure 3), but divided up into areas of with different sets of attributes, which are the result of spatial subtraction (Table 6).

DISCUSSION

Topography

Topography was the most significant landscape property selected by White-bellied Sea-Eagles in this study. Altitude was found to be the parameter that best discriminated the nest sites from the available habitat. The choice of low elevation is presumably basic to minimising energy expenditure between foraging at sea level and climbing to nests. Wind speed, soil and moisture could all be contributing factors to making lower altitudes more favourable and allowing larger trees to develop. The possibility that elevation simply reflects the fact that all nests are within 400 metres of the coast is dispelled by the absence of nests in areas of forest on high cliffs at the shoreline.

White-bellied Sea-Eagles' nests were on sheltered south- and east-facing situations, either because the eagles selected such sites or because the windy conditions destroyed nests in exposed positions. Some nests were found on exposed, south-west-facing slopes, but those nests were on the southern or eastern sides of the tree. Elsewhere, White-bellied Sea Eagles also nest on sheltered aspects (Dennis and Lashmar 1996; Williams 1997), as do Tasmanian Wedge-tailed Eagles (Mooney and Holdsworth 1991), which may reflect protection from chilling: especially important for eggs and nestlings (Janes 1985). More southerly slope aspects also receive less solar radiation and experience less evaporation and thus have a lower fire hazard than the drier, more open northern and western slopes (Brown and Mooney 1997). Such conditions are also conducive to greater soil moisture and therefore support greater

TABLE 4

Layers used in White-bellied Sea-Eagle nesting habitat models.

Layer	Parameter	Range	Units	% of nests	% study area (Fig. 1)
1	Study site (Fig. 2)	All		100	72
2	Study area (Fig. 1)	All		100	100
3	Altitude	<85 m	m asl	93	43
4	Altitude	<122 m	m asl	100	57
5	Aspects	32–215°	degrees	93	45
6	Aspects	32–281°	degrees	100	66
7	Slope angles	>6.8°	degrees	93	64
8	Forest heights and bare ground	Mature: E+3 to E5 and z Regrowth: ER4	classes	100	93
9	Forest heights	Mature: E+3 to E5 Regrowth: ER4	classes	89	60
10	Forest density	Mature: a–d Regrowth: a and b	classes	89	50
11	Mature forests	Mature: E1 to E5	classes	82	No value
12	Mature forest heights	Mature: E+3 to E5	classes	82	56
13	Mature forest densities	Mature: a–d	classes	82	39
14	Forests not too tall	Mature: E–3, E4, E5 Regrowth: ER1, ER2, ER3	classes	75	51
15	Forests not dense enough	Mature: f Regrowth: c, d, f	classes	14	44

tree densities, as found for site aspects and gorges selected by some other raptors (Reynolds *et al.* 1982).

Forest characteristics

The typical forest where nest sites were found, and where nests could persist, consisted of a mature and relatively short forest. Nests in regrowth forest and forests overall were preferentially found in areas with denser canopy cover. This characteristic was noted to enhance the success of Bald Eagle nests in such forests, even though this species is known to select more open vegetation (Andrew and Mosher 1982).

The distribution of dense forests, represented by Layer 10, was found to be unrelated to distance from coastline. The benefits of dense forest may be in shade beneath the canopy, protection from wind (reducing chill factors) and production of dead limbs for nest-building material (cf. Reynolds *et al.* 1982). Screening eggs and chicks from direct sunlight may allow passive temperature regulation (Reynolds *et al.* 1982), and protection from harassment by Wedge-tailed Eagles (Terry and Wiersma 1997) may also have been a reason for the selection of dense forests (cf. Reynolds *et al.* 1982). Wedge-tailed Eagles nest in a broad range of forest densities (Brown & Mooney 1997), so selection of dense forests by White-bellied Sea Eagles may be a mechanism to reduce interspecific competition (cf. Reynolds *et al.* 1982).

Selection of heights from mature and regrowth forests combined was not significant, probably because of the greater area with shorter classes in regrowth forests, inherent in their definition. The shorter forest heights at nest sites may be a reflection of distance from coast, but may also be selected as a result of selecting superdominant trees.

Emergent nest trees, those exceeding the height of the surrounding forest, are preferred by several raptor species including the White-tailed Sea-Eagle *Haliaeetus albicilla* (Shiraki 1994), Bald Eagle (Livingston *et al.* 1990), Osprey *Pandion haliaetus* (Edwards and Collopy 1988) and Tasmanian Wedge-tailed Eagle (Brown and Mooney 1997). Advantages of nesting in such trees include an unobstructed flight path to the nest (Edwards and Collopy 1988), enhanced visibility of prey, intruders or family members returning to the nest (Livingston *et al.* 1990), or (for Ospreys) temperature regulation (Edwards and Collopy 1988). However, in Australia the Eastern Osprey *Pandion cristatus* only occurs at lower latitudes than northern Tasmania (Marchant and Higgins 1993). The fact that only nine Sea-Eagle nests were found above the surrounding canopy suggests that superdominant (i.e. large) trees provide greater support for the nest (Shiraki 1994), probably through rigid trunks, sturdy limbs and forks suitable for supporting nests. This conclusion is reinforced by the observation that although only 10 nest trees were the tallest tree within the site, 14 were judged as the widest in the site.

TABLE 5

Models generated of White-bellied Sea-Eagle nesting habitat.

Model #	Layers	Layer #	Area covered (ha)	% nests	% study area	Area (ha) per nest	n nests predicted*
1	Altitude 100, Aspect 100, all density	4,6,10	18091.7	89	17.8	726	8
2	Altitude 100, Aspect 93, all density	4,5,10	11964.1	82	11.77	521	6
3	Altitude 93, Aspect 100, all density	3,6,10	12589.8	82	12.39	548	7
4	Altitude 100, mature heights and densities	4,12,13	23503.3	82	23.13	1024	7
5	Altitude 100, Aspect 100, mature heights and densities	4,6,12,13	14881.4	82	14.64	648	6
6	Altitude 100, Aspect 93, mature heights and densities	4,5,12,13	9536.3	75	9.38	454	4
7	Altitude 93, Aspect 100, mature heights and densities	3,6,12,13	10724.1	75	10.55	511	8
8	Altitude 100, Aspect 100, slope	4,6,7	22178.3	93	21.82	852	N/A
9	Altitude 100, Aspect 100, slope, all densities	4,6,7,10	12296.1	82	12.1	536	5
10	Altitude 100, Aspect 100, slope, mature heights and densities	4,6,7,12,13	10037.1	75	9.88	478	4
11	Altitude 100, Aspect 100, slope, all heights and densities	4,6,7,9,10	11668.8	82	11.48	508	4
12	Altitude 93, Aspect 93, slope, mature heights and densities	3,5,7,12,13	4492.5	61	4.42	263	2
13	Altitude 93, Aspect 93, slope, all heights and densities	3,5,7,9,10	5256.9	68	5.17	276	2
14	Altitude 100, Aspect 100, forests not too tall	4,6,14	16895	75	16.62	805	4
15	Altitude 100, Aspect 100, forests not dense enough	4,6,1	15337	14	15.09	3913	4
16	Altitude 100, Aspect 100, mature heights and all densities	4,6,10,12	16209	82	15.95	706	7
17	Altitude 100, Aspect 100, all heights and densities	4,6,9,10	17164	89	16.89	689	7

*out of nine

The presence of superdominant trees is a property more likely to occur in mature forests. There may be other properties, besides the preferred heights and densities (that also occur in regrowth forests), that mature forests provide, including other components necessary for a nesting territory, i.e. several potential nest trees and associated foraging area, stable perches, and roosting sites.

Nearest-neighbour distances

Distances in this study of 4.4–9.5 kilometres (mean 6.6 km) are comparable to those reported for the densest populations of White-bellied Sea-Eagles in the Furneaux and Hunter groups (3–5 km apart: Mooney 1986). Other records of inter-nest distances are summarised in Table 7. Such a dense population indicates good food availability (Marchant and Higgins 1993), which may be a function of the length of coastline available for foraging.

Length of coastline between nests was clustered at approximately 20 kilometres (at a scale of 1: 25 000), in those cases where the closest active nests were confidently known. The low level of variation indicates that a measure of this kind is more useful for the species than straight-line distances, especially in an area with a complex coastline. This analysis

TABLE 6

Gradated probability model generated of White-bellied Sea-Eagle nesting habitat.

Model #	Layers included	% area	% nests	Area showing
1	4, 6, 10	17.8	89	Forest heights too tall
17	4, 6, 9, 10	16.89	89	Slopes <6.8°
11	4, 6, 7, 9, 10	11.48	82	Altitude 85–122 m, aspect 215–281°
13	3, 5, 7, 9, 10	5.17	68	Regrowth densities, altitude 85–122 m, aspect 215–281°
12	3, 5, 7, 12, 13	4.42	61	Slopes >6.8°, mature heights and densities

depends on the availability of data-manipulation tools such as GenaMap (Version 2.1) and a map of coastline with consistent scale. Although length of coastline was a useful indication of neighbouring active nests, there presumably is a behavioural minimum distance for the species, whatever the food supply. The closest reported active nests of White-bellied Sea Eagles were three kilometres apart, but the behavioural minimum is likely to be considerably less. In times of food superabundance, Wedge-tailed Eagles have been known to nest 700 metres apart (Cupper and Cupper 1980), much less than the usual 5–7 kilometres (Marchant and Higgins 1993). The only problem in making this assessment of inter-nest distances, other than lack of confidence in the location of the nearest nests, was not being able to assess which landforms would be considered a partial barrier by the birds when foraging.

Proximity to habitation

The 320-metre minimum is small compared with the average of 1.9 kilometres, possibly because of the method of assessment or because buildings were constructed after the eagles built nests. An alternative method for assessing the spatial relationships is by investigating viewsheds (Camp *et al.* 1997). This method incorporates the fact that the effect of disturbance is related to whether wildlife can see it, rather than the distance between the source and the nests or roosting site (Richardson and Miller 1997).

Modelling

Altitude and aspect were used in all layer combinations (except Model 4, which proved that discarding aspect was expensive, resulting in the highest area covered of all models), because of their significance in habitat selection and the coverage of all nests by the DEM. Aspect was also utilised in the Wedge-tailed Eagle model (Brown and Mooney 1997), because of its relevance to provision of shelter, whereas altitude was found not to be useful.

Models 1, 2, and 3 incorporated these two fundamental attributes with densities of both mature and regrowth forests. Model 1 (Figure 3) gave a good coverage of nests (89%), with only the three nests on 'bare ground' eliminated, while covering only 17.8 per cent of the study site (i.e. area in Figure 2), which is a reasonable ratio of area to number of nests (cf. Donazar *et al.* 1993, Bustamante 1997, Bustamante and Seoane 2004 and Suarez *et al.* 2000, who obtained accuracies of 40–78 per cent for models of various raptor nest sites).

Model 2 (Figure 4) had a better ratio of area to nests than both 1 and 3, with 82 per cent of nests covered. This outcome is a result of better area exclusion with the lower aspect coverage.

Models 4 to 7 incorporated the heights and densities of mature forests, taking into account significant selection of mature forests, and then selection of heights and densities within mature forests. Model 6 (Figure 5) produced the lowest ratio of area to proportion of nests, with 75 per cent nest coverage on 9.38 per cent of the study site (= Figure 2). This ratio is more efficient than both Models 1 and 2, in keeping with the inclusion of more significant variables than the first two models.

Models 8 to 13 all included slope as an attribute, although this parameter was not found to be significant in habitat selection. The latter three models (11–13), however, were useful in the formation of the Gradated Probability Model. Model 8, an initial attempt to model potential habitat, was a representation of purely topographic attributes, with the theory that if forest was nurtured or regenerated, nesting habitat would result. Along with the significant topographic attributes (altitude and aspect), Model 14 incorporated all forests, mature and regrowth, that were not over the maximum height of nest sites sampled. In 16.62 per cent of the study site (i.e. Figure 1), it prescribes which forests could be managed to reach the relevant forest height for nesting habitat. Model 15 considers the area of forest (15.09% of the study site) on preferred topography that is not dense enough to warrant habitat selection, so maybe these forests could be nurtured to increase density. The logistics of achieving such forest manipulation are probably impossible, but these models may provide a useful template of where it is most appropriate, if attempted.

Model 17 achieved a greater efficiency of area to nests than Model 1, with the identical 89 per cent of nests encompassed. This was with the use of an insignificant attribute (heights of regrowth forests), but it was used in the probability model. A modification, in the form of Model 16, eliminated heights of regrowth forest, but at the expense of two nests. The resultant area-to-nests efficiency does not improve on that of Models 6 or 2, which have the same number of nests covered.

Gradated Probability Model (GPM)

The Gradated Probability Model fragments Model 1 into five components, illustrated by separate colours (Figure 6), which provides a map where the different attributes, with differing significance for nesting habitat, make up the total of Model 1.

TABLE 7

Inter-nest distances recorded for the White-bellied Sea-Eagle.

Region	Range (km)	Mean (km)	Reference
Furneaux & Hunter Is groups	3–5		Mooney 1986
Gippsland Lakes, Victoria	4–13		Bilney and Emison 1983
Edward River, NSW	8–10		Marchant and Higgins 1993
North Kangaroo Is, SA	5.5–20	11	Dennis and Lashmar 1996
South Kangaroo Is, SA	22–64	49	Dennis and Lashmar 1996
Eyre Peninsula, SA	6–170	84	Dennis and Lashmar 1996
Murray River, Victoria	>40		Marchant and Higgins 1993

Smaller units or individual landholdings can thus be assessed and assisted when setting priorities for nest-searching efforts, or for regeneration or landscape manipulations to achieve prime nesting habitat. The GPM could be used in conjunction with the potential habitat Models (14 and 15) for such exercises.

Model 1 covered 89 per cent of the nests efficiently, and the GPM breaks it down into five different attributes. It also predicted more nest locations in the ground-truthing exercise than any other model, so it is adopted as the most useful model. Model 2 is a subset of Model 1 (not used in the Gradated Probability Model), maintaining a good nests-to-area efficiency. Model 6 is theoretically the most efficient at covering nests per area, and utilises more significant variables than Models 1 and 2. This model, however, covers only 75 per cent of the nests used, only a fair result (Bustamante and Seoane 2004).

CONCLUSIONS

The habitat-selection assessment revealed several significant variables and well-defined ranges of parameters that were not obvious from simple observation of nests of the species. The availability of high-resolution forest and landform data, along with the tools to analyse and manipulate data from several sources within GIS systems, were vital for such an assessment (cf. Livingston *et al.* 1990; Chandler *et al.* 1994; Camp *et al.* 1997; Bustamante and Seoane 2004), and the field study gave insight into how the nest-site characteristics were related to the properties of nest trees. The significant selection of several physical and vegetation factors has also been found for the nest sites of several *Accipter* species (Reynolds *et al.* 1982), but Bald Eagles, in particular, select nesting habitats that can be well defined, to varying degrees, by habitat parameters (Wood *et al.* 1989; Livingston *et al.* 1990; Garret *et al.* 1993).

Habitat modelling, based on significantly preferred attributes, was dependent on all the forests in the area being classified in a database. Other species-specific habitat studies have used information from satellite images (Lyon 1983; Ormsby and Lunetta 1987; Palmeirim 1988; Pereira and Itami 1991; Osborne *et al.* 2001). The cell size is critical in such studies, because the habitat has to be represented at a scale that identifies the species–habitat relationships (Periera and Itami 1991). The DEM with cell size of 25 metres for Tasmania was found to be a relevant and useful resource for the habitat assessment and modelling of the White-bellied Sea-Eagle nesting habitat. The PI-type mapping used in the present study was up to date, with higher resolution than most vegetation classifications used for modelling purposes (Sanchez-Zapata and Calvo 1999; Osborne *et al.* 2001), and appeared to have sufficient resolution to be relevant to the species' habitat selection. The establishment of such a database is usually a prohibitively expensive proposition for the purpose of a habitat study (Lyon *et al.* 1987).

The well-defined habitat selection made the nesting habitat of the White-bellied Sea-Eagle a suitable entity to model, while a more focused habitat selection allowed a greater predictability of nests within a lower percentage of the area covered than that by the Tasmanian Wedge-tailed Eagle nesting habitat model (Brown and Mooney 1997). The other important contrast with that Wedge-tailed Eagle project is the GPM for the White-bellied Sea Eagle, allowing a more directive model, rather than a simple identification of potential habitat. The attempt to model potential habitat was not thought to be useful, because the heights of forests may not attain the minimum height classes required, and the density of forest would be difficult to manipulate towards the denser forests required.

Model 1 and the GPM may be applied in the region. The most practical uses of the models will be in making searches for nests more efficient, and predicting potential nesting habitat for land-management decisions. The non-mapped information, such as the upper limit for position on slope and the tendency to use superdominant trees, may be useful for nest searches. The Wedge-tailed Eagle model is used to prioritise areas to search when regions are assessed for forestry harvesting operations and other proposed land-use changes. With current habitat known, measures to mitigate disturbances to the habitat can complement those used to protect nest sites. The need to identify both current and potential habitat is amplified by the observation of a turnover of White-bellied Sea Eagle nests in Tasmania (Thurstans 2009).

MANAGEMENT IMPLICATIONS

Human activities that disturb nests and degrade nesting habitat are the primary threat to White-bellied Sea-Eagles (Mooney 1986). With the locations of nest sites known, several measures can be applied to prevent disturbances occurring. The most commonly listed management approach is the use of spatial buffers and exclusion zones around nests (Andrew and Mosher 1982; Grubb and King 1991; Mooney and Holdsworth 1991; Mooney and Taylor 1996; Camp *et al.* 1997; Richardson and Miller 1997; Gende *et al.* 1998). Such buffer zones are usually based on the flushing distances of a species (Camp *et al.* 1997), but impact may be graduated (Grubb and King 1991), and physiological responses, such as a rise in heart rate, occur at a greater distance than behavioural responses (Richardson and Miller 1997).

Other management tools, complementary to spatial buffers, include temporal buffers, an enlarged exclusion zone during the breeding season (Grubb and King 1991), and viewsheds (Camp *et al.* 1997). The latter method can involve GIS and GPS technology, so the view from a nest can be mapped, and human presence banned from that view (Camp *et al.* 1997). Buffers should be custom-designed for nests, taking into account the specific site characteristics and the disturbance type (Richardson and Miller 1997). Bald Eagle individuals vary in their tolerance of disturbance, and appropriate buffers may be varied accordingly (Fraser *et al.* 1985). For human activities, choice of less intrusive alternatives may ameliorate human presence.

FURTHER STUDIES

For a fuller understanding of habitat utilisation and selection, and reproductive success further work is recommended. This includes:

- Verification of locations of nests used for testing models should be carried out.
- A Gradated Probability Model could be constructed that integrates Models 1, 2 and 6. This would require the construction of new models to work coherent subsets between Model 2 and Model 6.
- Distance from coastline could be incorporated into the models. The simplest way of incorporating this attribute would be to exclude from the models areas beyond a certain distance. An alternative is to generate available habitat from just this area, which may change the assessment of habitat selection and, fundamentally, the modelling.
- Distance to habitation could also be included in models, but would be problematic, because structures used rarely may not be as disturbing to nesting as those used frequently, and decisions would need to be made about whether nests or buildings were there first.
- The modelling should be expanded to other regions. This would require further habitat assessments, as different conditions may shape different selection.
- Regular monitoring of reproductive success should be conducted for a random sample of nests: necessary for an accurate assessment of breeding productivity of the species, and invaluable when incorporated with habitat studies. Differences in occupation rate and reproductive success may lead to a more refined quantitative analysis of habitat (Kruger 2002).

MANAGEMENT RECOMMENDATIONS

It is therefore recommended that the following management tools be instigated to better manage the White-bellied Sea-Eagle's survival:

- The current habitat as represented by Model 1 should be conserved to prevent habitat alteration incompatible with its potential use by nesting White-bellied Sea-Eagles.
- The protection of nests on private land should be encouraged (e.g. through covenants and schemes such as the Land for Wildlife scheme).
- Information and interpretation materials should be developed to raise awareness of:
    - which activities should be avoided within the breeding season and why (this is especially important for the tourism industry), and
    - which areas are potential habitat, and what is appropriate development in such areas.
- The nests known in formal reserves should have spatial buffers around the nesting territory, defined as all alternative nest trees and perch trees. These buffers should exclude human presence within 500 metres on land, but could be only 100 metres by sea, because White-bellied Sea-Eagles are less sensitive to approach by sea. Viewsheds from nests could also be considered and/or measured precisely in the field. These buffers should be applied from 1 July to 1 December, but could be reduced sometime in October if sensitive monitoring reveals that the nests are not active.
- The use of loud machinery, such as for track maintenance, should be avoided in the breeding season, within a much greater buffer zone around known nests.
- Disturbance directed at the nest (e.g. research or photography) should be restricted to incidental or passing disturbance.

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APPENDIX 1

PI-type forest codes for Tasmanian Forests, as used by Forestry Tasmania.

Height class	Mean height (m)	Crown density class	% crown cover
Mature eucalypt:			
E1	>76	a	70–100
E1	55–76	b	40–70
E2	41–55	c	20–40
E+3	34–41	d	5–20
E–3	27–34	f	<5
E3	27–41	(P)	patches/scattered
E4	15–27		
E5	<15		
Regrowth eucalypt:			
ER1	<15	a	90–100
ER2	15–27	b	70–90
ER3	27–37	c	50–70
ER4	37–44	d	10–50
ER5	44–50	f	1–10
ER6	>50	(P)	patches/scattered