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Effects of human disturbance on productivity of White-bellied Sea-Eagles (*Haliaeetus leucogaster*)

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Abstract. Nest productivity among the White-bellied Sea-Eagle (*Haliaeetus leucogaster*) population on Kangaroo Island (South Australia) was monitored over 11 breeding seasons between 1985 and 1999. Territories were assessed against standardised measures of relative isolation from human disturbance and assigned to Low-, Moderate- or High-disturbance categories. When productivity data were compared between categories, the level of disturbance was found to significantly affect fledging outcomes, with high-disturbance territories having significantly lower fledging success. Of 164 occupied territory-years, 119 (72.6%) were active and fledged 0.8 (mean) young per year. Territories with high-disturbance levels produced eggs less often (65% of territories active cf. 79% active in more isolated locations), fledged fewer young (0.5 young per year cf. 1.1), and had higher rates of nesting failure (46% cf. 13%). These results indicate that to mitigate further Sea-Eagle population decline in South Australia, site-specific habitat management prescriptions, which include buffer-zone refuge provisions, are required to minimise the effects of human activity on breeding outcomes. Such prescriptions need to take into account that, unique to South Australia, most nests are on cliffs in open coastal landscapes with little visual screening over long distance, thus refuge dimensions should be double those prescribed elsewhere for nests in tall forest habitat.

Additional keywords: breeding habitat refuge, buffer zones, cliff nests, conservation, core territory, disturbance sensitivity, endangered population, guard-roosts, landscape view-sheds, management prescriptions, productivity outcomes.

Introduction

Top-order predatory species such as sea-eagles (*Haliaeetus* spp.), which rely on prey from aquatic and marine environments, are regarded as sentinel species that can be used to measure anthropogenic effects and ecosystem stability (Romin and Muck 1999). In Australia, the White-bellied Sea-Eagle (*Haliaeetus leucogaster*) occupies coastal environments, including offshore islands, and inland river systems and lakes, from the tropical northern Australia to southern Tasmania. Although the population appears to be stable in tropical regions, there is evidence of declines in some regions in the southern part of its range (Dennis and Lashmar 1996; Olsen 1998; Clunie 2003; Shephard *et al*. 2005; Dennis *et al.* 2011). These declines have been linked to clearance of native forest and bushland for agricultural development, urbanisation, recreation and tourism, and expansion of activities associated with industries such as mining, forestry and windfarms into coastal environments (Bilney and Emison 1983; Dennis and Lashmar 1996; Clunie 2003; Threatened Species Section 2006; Dennis and Baxter 2006*a*). Subsequently specific White-bellied Sea-Eagle conservation strategies have been developed in Victoria (*Flora and Fauna Guarantee Action Statement* 60; Clunie 2003) and in Tasmania (*Threatened Tasmanian Eagle Recovery Plan 2006–2010*; Threatened Species Section 2006).

In South Australia (SA), the White-bellied Sea-Eagle was listed as Endangered in 2008 (*National Parks and Wildlife Act* 1972 as amended). It is listed as Vulnerable in Victoria and Tasmania, and is listed under the China–Australia Migratory Bird Agreement, with consequent conservation obligations on the Australian Government under the *Environment Protection and Biodiversity Conservation Act* 1999 (Commonwealth).

Comprehensive surveys completed in 2010, estimated the White-bellied Sea-Eagle population in SA at 70–80 breeding pairs, with the majority of these (79%) found occupying territories in offshore island habitats, including Kangaroo Island (Dennis *et al.* 2011). These surveys also confirmed a decline over parts of its historical breeding range, particularly the upper-Spencer Gulf, on the River Murray floodplain and in the South East region, and that the SA population was somewhat isolated from those in adjoining states (Dennis and Lashmar 1996).

With the introduction of vastly improved transportation services to Kangaroo Island during the early 1980s, the tourism, agricultural and silvicultural industries expanded rapidly, resulting in broad-scale clearance of native vegetation, including in coastal landscapes. In these circumstances, the White-bellied Sea-Eagle was considered an obvious sentinel species for monitoring the effect of land-use changes and increasing human activity in the landscape.

The aims of this study were to (1) measure nest productivity over time among the Kangaroo Island population and compare data from territories close to human activity with those in more

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remote locations; and (2) identify appropriate habitat management and threat abatement strategies for Sea-Eagles on Kangaroo Island.

Methods

Study area

Kangaroo Island lies ~110 km south-west of Adelaide and ~15 km off the Fleurieu Peninsula, mainly between 35°40′S and 36°10′S (Fig. 1). It is ~4350 km^2 in area and its longest (east–west) axis ~155 km long. Much of the island's coastline of ~500 km consists of rugged cliffs, infrequently dissected to sea-level by creeks and minor rivers, some of which retain open brackish estuaries during summer. The southern and western coastlines are exposed to prevailing weather and heavy ocean swells. The sheltered northern coastline includes several shallow bays, which feature extensive sea-grass meadows with abundant fish and seabird populations (Paton *et al*. 2002; Womersley and Edmonds 2002; Dennis and Baxter 2006*b*).

The island has a resident population of 4200 people. Tourism is the largest industry with ~160 000 visitors annually, who experience, among other aspects, the abundant and accessible wildlife and an aesthetically attractive coastal environment (Manidis Roberts Consultants 1997). Approximately 60% of the island has been developed for agricultural or silvicultural production, with the rest being remnant natural landscape, most of which is preserved in conservation reserves.

Population and nest productivity surveys on Kangaroo Island

Between 1983 and 1985, opportunistic surveys were conducted by fixed- and rotary wing aircraft and by boat to determine the location of White-bellied Sea-Eagle territories in remote locations around the Kangaroo Island coastline. Information was obtained from local ornithologists, bushwalkers and fishers, and nesting sites were located by ground survey (Dennis and Lashmar 1996). Subsequently, most territories were systematically monitored to determine productivity over 10 consecutive breeding seasons between 1985 and 1994, and again in 1999. The number and timing of monitoring visits were scheduled and conducted to minimise disturbance and to maximise return for effort, as most sites were in remote locations.

Nest-monitoring protocol

To minimise disturbance, approach routes to nesting sites and nearby guard-roosts were planned before the 1985 breeding season for each territory and observation positions selected for most. This enabled subsequent observations to be made with partial concealment (e.g. through thick vegetation or under camouflage netting) at most sites, using a high-resolution spotting scope (Kowa TSN-4, 25–60x, Kowa Co. Ltd, Nagoya, Aichi, Japan) from distances >400 m to avoid interruption to normal behaviours.

Monitoring involved 2–4 visits to each territory during breeding seasons. Initial visits were brief, mainly to confirm that the territory was occupied and, from behaviours, if the nest was active. Second visits were made to confirm inactivity (or nesting failure), or to assess the age of nestlings. Based on this information, final visits were scheduled to determine fledging outcomes. In most years, some initial territory assessments were conducted with volunteer assistance. All second and subsequent data gathering visits were conducted by one observer (T. E. Dennis).

Assessment of the isolation and level of disturbance of nesting sites

A standardised method to measure relative isolation of nesting sites from human disturbance was adapted from a similar study assessing landscape characteristics and human disturbance factors leading to reproductive failure in the closely related Bald Eagle (*Haliaeetus leucocephalus*) (Mathisen 1968). Criteria used to allocate a nesting site to a disturbance category are summarised in Table 1. Territories were classified into disturbance categories in 1989 and these remained unchanged.

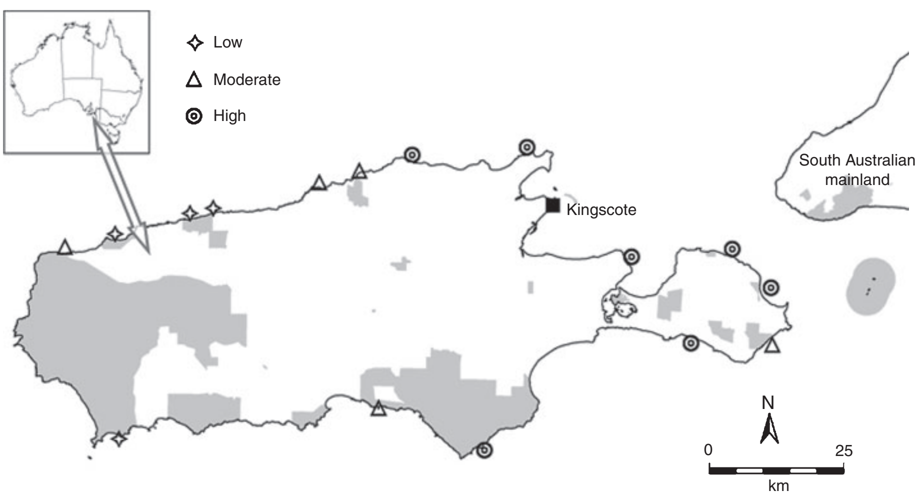

Fig. 1. Map of Kangaroo Island showing its proximity to mainland SA, conservation reserves and the location of White-bellied Sea-Eagle territories monitored between 1985 and 1999, with symbols representing disturbance levels.

Table 1. Criteria used to classify White-bellied Sea-Eagle nesting sites for levels of human disturbance during the breeding season (May–January)
Adapted from Mathisen (1968)

Low	Moderate	High
• No road, track or walking trail within 1000 m of nest	• A minor road or bush track 500–1000 m from nest	• Road, track or walking trail <500 m from nest
• Little or no recreation activity (fishing, surfing, bushwalking, hunting) or industry (commercial tourism, timber or brush cutting, agriculture or aquaculture) within sight of primary nest during breeding season and rarely or never within 1000 m	• Human activity may periodically occur within sight of nest during breeding season, 500–1000 m distant	• Human activity frequently occurs within sight of nest during breeding season and often within 500 m
• Surrounding landscape has natural vegetation cover not modified by land treatments	• Surrounding landscape may be partially modified by grazing or occasional burning	• Surrounding landscape appreciably modified, e.g. natural vegetation largely cleared or regularly burnt
• Nest difficult to locate without specific knowledge; location may be known to only a few individuals	• Nest may be seen from track or sea, but considerable effort required to reach it; location not generally known	• Nest is readily visible from road, track or sea; access requires little effort; location is generally known

To assess land-use characteristics and to calculate the proximity of nesting sites to physical features, such as roads and agricultural activities, aerial photographs and 1 : 50 000 topographic maps were examined, followed by ground-truthing where required. Direct observations or evidence of human activity (e.g. off-road vehicle activity, feral animal carcasses, fuel reduction burns and wildfire) were routinely recorded, as were disturbances causing one or both Sea-Eagles to flush. Proximity distances associated with the latter were determined using topographic maps or calculated from a waypoint location using a handheld GPS (global positioning system; Magellan 315, MiTAC Digital Corporation, Santa Clara, CA, USA).

Data analysis

To examine the association between level of disturbance and nesting success, the data were arranged in contingency tables with level of disturbance as one classification and numbers of successful and non-successful nests the other. These data were analysed for the number of territory-years in which territories were occupied and the number in which they were active using a Chi-square statistic with 2 degrees of freedom. All statistical tests were run at the 5% level of significance.

A backwards stepwise logistic regression was performed to determine if there was a relationship between the likelihood of successfully fledging young (the dependent variable, with values 0 = no young fledged that year or 1 = at least 1 young fledged that year) and potential predictor variables: year of occupation, individual territory (16 territories) and habitat disturbance level (High, Moderate, Low). The level of habitat disturbance was analysed as a categorical variable with High set as the reference (using dummy coding) to obtain a comparison between High and Low, and between High and Moderate. To obtain a comparison between Moderate and Low the reference was set to Low. Breeding pairs were assumed to be the same throughout the study. A large coefficient of a predictor variable (the estimate) relative to its standard error (the *t*-ratio) indicates an important predictor. However, this estimate has low reliability and lacks power for small sample sizes (Quinn and Keough 2002). At each step, the effect with the largest probability value (P) was identified and removed if its significance level was 0.15 above other levels. Owing to the low reliability in using the estimate and *t*-ratio, the odds ratios ($P/(1-P)$, expressed as OR) of the estimates and their 95% confidence limits (CL) were used to determine genuine risk factors. OR is the multiplicative factor by which the odds for an estimate change when the predictor variable increases by one unit. When the lower bound of the CL of the OR included 1, it was identified as genuine predictor of fledging success (following Kleinbaum *et al*. 1982). As recommended by Quinn and Keough (2002), an additional test was performed as a more robust measure of a genuine risk factor and the fit of the model. The log-likelihoods of the full model were compared with the log-likelihoods of the reduced model by $G^2 = -2$(log-likelihood reduced – log-likelihood full).

Larger log-likelihoods mean a better fit of the model and the G^2 statistic is equivalent to the log-likelihood Chi-square statistic. The full model represents all the variation in the data, whereas the reduced model aims to explain the source of the significant component of the variation and hence the genuine risk factor.

Terminology

The following terminology is used:

- Occupied territory – where an adult pair appear together in the breeding season near the nest(s) and repair of the nest or territorial defence against other eagles is observed.
- Active nest or territory – a site where eggs are laid (based on incubation behaviour) or young recorded.
- Successful nest or territory – a nesting site at which young fledge.
- Failed nest or territory – where eggs are produced but fail to hatch, or where all eggs or young are lost.
- Core territory – the defended area around a nesting site (nominally 1000-m radius).
- Guard-roosts – strategic vantage points within the core territory, which are used as day-roosts or loafing locations by the non-incubating bird.

- Primary nest – the most frequently used nest within a territory.
- Alternate nest – one of sometimes several nest-structures within a territory.

Results

Selection of nesting sites

Continuous use of one favoured nesting site was apparent in most territories monitored, with new nests, or relocation to a nearby alternate site recorded infrequently ($n = 7$ of 164 records); alternate sites were <200 m distant from the favoured nesting site in each case. Three territories had tree nests, one was completely sheltered inside a cave opening on a vertical cliff-face and the rest were on ledges of cliffs, ranging in height from ~8 to ~110 m above mean sea-level. All but one nest were <250 m (horizontally) inland, and visible from the sea; the exception was situated on a cliff ledge in a steep watercourse ~350 m inland.

Nest productivity and human disturbance

An average of 15 occupied territories were monitored annually to determine productivity, providing data from 164 occupied territory-years (Tables 2, 3). Of these, 119 territory-years (72.6%) were active, with 84 (70.6% of active territories, 51.2% of occupied territories) successfully fledging young. A total of 98 young fledged, resulting in an average of 0.60 young fledged per year for occupied territories, 0.84 in active territories and 1.17 in successful territories.

Occupied territories were distributed among the three disturbance categories: Low, four; Moderate, five; and High, seven (Table 2, Fig. 1). In High-disturbance territories, eggs were produced less frequently than in Low-disturbance territories, with 65% ($n = 74$) and 79% ($n = 38$) of nests becoming active respectively. Furthermore, active nests in High-disturbance territories had lower rates of success (54%, $n = 48$) than active nests in Low-disturbance territories (87%, $n = 30$).

The frequency with which occupied territories successfully fledged young in a season decreased as the level of disturbance increased: Low-disturbance territories were successful every 1.5 years, Moderate-disturbance territories every 1.6 years, and High-disturbance territories every 2.9 years. The proportion of territories in which two young fledged in a year also was related to the level of disturbance (31% in Low-, 16% in Moderate-, and 4% in High-disturbance territories). The number of years in which monitored territories were successful was associated with the level of disturbance; those data were analysed in terms of numbers of occupied territories ($\chi^2 = 14.4$, $P < 0.001$) and in terms of numbers of active territories ($\chi^2 = 11.1$, $P < 0.001$).

For occupied territories, similar percentages of young were successfully fledged at Low and Medium levels of disturbance (68 and 62% respectively), but the percentage fledged was lower for High-disturbance territories (35%). A similar result is obtained

Table 2. Breeding activity and outcomes at 16 White-bellied Sea-Eagle territories over 11 breeding seasons (1985–99) on Kangaroo Island, with each territory categorised for the level of human disturbance

Territory ID (code)	*n* of years territory monitored: Occupied	Active	Successful	*n* of young fledged	Average *n* of young fledged per year: Occupied territory	Active territory	Successful territory
Low disturbance							
NC02[A]	6	6	6	8	1.33	1.33	1.33
NC03	11	8	6	8	0.73	1.00	1.33
NC04	10	8	7	7	0.70	0.87	1.00
SC19	11	8	7	11	1.00	1.37	1.57
Total	38	30	26	34			
Mean					0.94	1.14	1.31
Moderate disturbance							
NC01	10	7	5	5	0.50	0.71	1.00
NC05	10	8	7	9	0.90	1.12	1.29
NC06	10	7	7	9	0.90	1.29	1.29
SC16[B]	11	10	6	7	0.64	0.70	1.16
SC18	11	9	7	7	0.64	0.78	1.00
Total	52	41	32	37			
Mean					0.72	0.92	1.15
High disturbance							
NC07[B]	11	6	3	3	0.27	0.50	1.00
NC08	11	8	5	5	0.45	0.62	1.00
NC09[A,B]	10	8	5	6	0.60	0.75	1.20
EC10	11	9	4	4	0.36	0.44	1.00
EC14[A,B]	10	6	2	2	0.20	0.33	1.00
SC15	10	4	0	0	0.00	0.00	0.00
SC17	11	7	7	7	0.64	1.00	1.00
Total	74	48	26	27			
Mean					0.36	0.52	0.89

[A]Tree nest.
[B]Territories where pairs moved to an alternate nesting site in the year following a known disturbance event.

Table 3. Reproductive outcomes among White-bellied Sea-Eagle territories on Kangaroo Island over 11 breeding seasons between 1985 and 1999

Year	*n* of territories Occupied	Active	Successful	*n* of young fledged	Average *n* of young fledged per year Occupied territory	Active territory	Successful territory
1985	13	10	6	7	0.54	0.70	1.17
1986	14	11	7	8	0.57	0.73	1.14
1987	16	12	8	10	0.62	0.83	1.25
1988	15	14	9	12	0.80	0.86	1.33
1989	15	13	12	13	0.87	1.00	1.08
1990	16	10	7	8	0.50	0.80	1.14
1991	14	10	8	10	0.71	1.00	1.25
1992	15	13	7	8	0.50	0.61	1.14
1993	16	8	5	6	0.37	0.75	1.20
1994	14	9	8	8	0.57	0.89	1.00
1999	16	9	7	8	0.50	0.89	1.14
Total	164	119	84	98			
Mean	14.90	10.82	7.64	8.91	0.60	0.82	1.17

when examining the percentage of young successfully fledged from active territories: 87 and 78% respectively for territories with Low and Medium disturbance, compared with 54% for territories with High disturbance.

For all nest-territory data ($n = 164$ territory-years) the backwards stepwise logistic regression rejected both year and individual territory as predictor variables, whereas level of habitat disturbance was an important predictor of fledging success (log-likelihood of reduced model = –106.318). The lowest fledging success was in territories with High-disturbance (Table 4). In the pairwise comparison of High- with Moderate-disturbance territories, and of High- with Low-disturbance territories, the lower CL for the odds ratios exceeded 1 (Table 5), indicating that level of habitat disturbance represents a genuine risk factor and that territories in the High-disturbance category were significantly more likely to fail than territories classed as Moderate- or Low-disturbance. For the pairwise comparison of Low- and Moderate-disturbance categories, the estimate was low and the result non-significant; additionally, the lower CL for the odds ratio did not exceed 1, indicating that fledging success of Moderate- and Low-disturbance categories did not differ. To complete the analysis, the comparison between the log-likelihoods of the reduced and full models also showed that habitat disturbance was a genuine risk factor ($G^2 = 14.619$, d.f. = 2, $P = 0.001$).

Table 4. Fledging success and levels of habitat disturbance for all White-bellied Sea-Eagle territory-years

Levels of habitat disturbance	Failed fledging (0)	Successful fledging (1)	Total	Proportion fledged successfully
Low	12	26	38	0.684
Moderate	20	32	52	0.615
High	48	26	74	0.351
Total	80	84	164	

Table 5. Backwards stepwise logistic regression of the relationship between fledging success of White-bellied Sea-Eagles and levels of habitat disturbance: pairwise comparison of the three levels of habitat disturbance

s.e., standard error; CL, confidence limit

	High *v.* Low	High *v.* Moderate	Low *v.* Moderate
Estimate	1.386	1.083	0.303
s.e.	0.426	0.375	0.451
t-ratio	3.258	2.889	0.673
P	0.001	0.004	0.501
Odds ratio	4.000	2.954	1.354
Lower 95% CL	1.737	1.417	0.560
Upper 95% CL	9.211	6.159	3.275

Discussion

Population stability and nest productivity

In contrast to historical declines of populations of White-bellied Sea-Eagles shown for mainland SA (Dennis and Lashmar 1996; Dennis *et al.* 2011), the population of Kangaroo Island remained stable between 1985 and 2005, with an average of 17.5 (range 16–18) occupied territories identified each survey year ($n = 12$) (Dennis and Baxter 2006*a*; Dennis *et al.* 2011). However, the monitoring period of <20 years is inadequate to confidently identify population trends, as these are unlikely to become apparent until after several generations (Newton 1979). It is more likely that this apparent stability reflects the longevity of individuals, their long-term pair-bonds, and that territories are in a region with consistent prey availability. Supporting this, individual territory and survey year were found not to be important predictors of fledging success.

Productivity outcomes in this study indicate that breeding pairs from territories with High levels of disturbance are significantly less productive than those with Low levels of disturbance: they fledge fewer young (0.36 per year cf. 0.94), less often (every 2.9 years on average cf. 1.5), experience higher rates of nesting failure (46% cf. 13%), and rarely fledge more than one young (4% cf. 31%). These outcomes were supported by the logistic regression, with disturbance being a significant predictor of fledging outcomes, and more young were fledged in Moderate- and Low-disturbance territories. Furthermore, productivity was slightly less than in a similar study in Victoria, with the overall average number of young per occupied territory-year being 0.60 on Kangaroo Island (0.8 in Victoria), 0.84 per active territory (1.1 in Victoria), and 1.17 per successful territory (1.3 in Victoria) (Bilney and Emison 1983).

Low productivity and human disturbance

The categorised nest-productivity data presented here strongly indicate an adverse relationship between human activities in the coastal landscape and Sea-Eagle breeding outcomes. With the continuing growth of human populations in Australia, the spread of urbanisation will inevitably follow historical patterns and concentrate in coastal regions (Hamilton and Cocks 1996). In view of this trend, it is likely that more Sea-Eagle territories on Kangaroo Island and elsewhere in SA could be adversely affected and become less productive.

In some areas of Tasmania there are many inactive Sea-Eagle nests each year, which is attributed to high levels of disturbance (Threatened Species Section 2006). In recent decades on Kangaroo Island and in other coastal regions of SA, tourism developments, land subdivision, penetration into remote coastal areas by off-road vehicles and various forms of recreation, have each been implicated in the abandonment of Sea-Eagle nesting sites (Dennis 2004; Dennis and Baxter 2006*a*). Access routes to pursue these activities invariably follow the exposed seaward edge of sloping terrain or the cliff-edge itself, where salt-laden winds have modified the natural vegetation to a low (<1 m) heath formation (Ball 2002). Although this enables ease of progress for hikers and vehicles, they become visible from a long distance to Sea-Eagles and invariably appear above nest level, which is more threatening than approaches from below the nest (Mooney and Holdsworth 1991; Olsen 1998). Many species of eagle, including White-bellied Sea-Eagles, are particularly sensitive to disturbance during courtship and early in the breeding season when eggs or small young may be abandoned (Olsen 1998; Clunie 2003; Forest Practices Authority 2006).

Habitat management and threat mitigation

A range of human activities affect the breeding success of threatened species of eagle, including deliberate persecution, disruption to normal behaviours, chemical pollutants entering the food chain, and physical alterations to the landscape habitat (Newton 1979, 1998; Olsen 1998; Thiollay 2007). To counter these direct and indirect threats, management agencies worldwide have sought to enhance the refuge quality of breeding habitat through seasonal access restrictions and spatial buffer zones to limit the effect of human activity within a prescribed radius of nesting sites (Camp *et al*. 1997; Richardson and Miller 1997; Romin and Muck 1999; Forest Practices Authority 2006; Thurstans 2009). The dimensions of buffer zones have been determined based on distances at which individuals flush on approach to the nest (Camp *et al*. 1997; Richardson and Miller 1997). Before flushing, an agitation response (e.g. increased heart-rate and forced attention focus) occurs at a considerably greater distance than the behavioural response (McGarigal *et al*. 1991; Anthony *et al*. 1995; Richardson and Miller 1997). Studies assessing the effect of various forms of disturbance affecting the Bald Eagle during the breeding season found that passive terrestrial activity, such as hikers and anglers, caused the highest frequency of response (i.e. alert at approach distances of ≥1000 m) and longest duration of absence from the nest (Grubb and King 1991).

To protect the breeding sites of White-bellied Sea-Eagles and Wedge-tailed Eagles (*Aquila audax fleayi*) in Tasmania the *Threatened Tasmanian Eagles Recovery Plan 2006–2010* prescribes disturbance buffers of 500 and 1000 m in line-of-sight in the breeding season (Threatened Species Section 2006, p. 26). However, these parameters were prescribed for mature forest habitats (>27 m tall), where nests are often in super-dominant trees at the top of or above the canopy (Thurstans 2009), providing high levels of visual screening and any approach or disturbance typically occurs well below the level of the nest. In contrast, most nests in SA are on exposed coastal cliffs or islands, with little or no screening and where disturbance invariably occurs above the nest. In these open landscapes Sea-Eagles are aware of approach or unusual activity at greater distances than has been addressed in site-management prescriptions elsewhere and they are likely to become agitated and flush earlier, particularly in remote areas where pairs have had little opportunity to habituate to human activity (Newton 1979).

Flushing distances up to 800 m were recorded in a study in northern New South Wales in open terrain with remnant woodland (Debus 2008). Similarly, during 2008 and 2009 breeding season surveys in SA, flushing distances (calculated by rangefinder in six territories) of between 450 and 850 m were recorded (T. E. Dennis, unpubl. data). The effect of this behaviour is exacerbated by the location of guard-roosts within the core territory (often >500 m from the nest) from which flushing reaction is most often triggered, causing the nest-tending bird to leave the nest unattended while the 'threat' remains. Although behaviour varies individually, White-bellied Sea-Eagles are not known to demonstrate agonistic response to human approach to an active nest and will more typically appear to leave the area when an intrusion occurs. When these behaviours are considered together with the contrasting open landscape habitat characteristics that predominate in SA, the fixed buffer-zone dimensions developed for forested Tasmanian habitats appear clearly inadequate.

Elsewhere, studies reviewing the adequacy of set-distance spatial refuge zoning around cliff-nesting eagle sites have recommended buffer-zone dimensions and shape be determined by mapping landscape 'view-sheds' from nests and roosting sites, in most cases greatly increasing the overall refuge area and its effectiveness (Camp *et al*. 1997; Richardson and Miller 1997; Thurstans 2009). However, existing digital elevation model (DEM) data necessary for the application of this technology using geographical information systems (GIS) software, is not considered to have adequate resolution or accuracy for all coastal regions with White-bellied Sea-Eagle habitat in SA (S. Detmar, Coastal Management Branch, SA Department of Environment and Natural Resources, pers. comm., 10 November 2010). DEM landscape modelling could be used in future as data become available.

Without the ability to prescribe view-shed based buffer zones in SA, we contend that a precautionary approach should be used, with refuge dimensions for nesting site protection set considerably greater than has been determined for forested landscapes, and minimally at 2000 m. Furthermore, it may be crucial to the stability of the remaining population in SA that remnant breeding habitats (particularly territories on islands) be prescriptively managed to minimise the effects of human activity.

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References

Anthony, R. G., Steidl, R. J., and McGarigal, K. (1995). Recreation and Bald Eagles in the Pacific Northwest. In 'Wildlife and Recreationists: Coexistence through Management and Research'. (Eds R. L. Knight and K. J. Gutzwiller.) pp. 223–241. (Island Press: Covelo, CA.)

Ball, D. (2002). Vegetation. In 'Natural History of Kangaroo Island.' 2nd edn. (Eds M. Davies, C. R. Twidale and M. J. Tyler.) pp. 54–65. (Royal Society of South Australia: Adelaide.)

Bilney, R. J., and Emison, W. B. (1983). Breeding of the White-bellied Sea-Eagle in the Gippsland Lakes region of Victoria, Australia. *Australian Bird Watcher* **10**, 61–68.

Camp, R. J., Sinton, D. T., and Knight, R. L. (1997). Viewsheds: a complementary management approach to buffer zones. *Wildlife Society Bulletin* **25**, 612–615.

Clunie, P. (2003). White-bellied Sea-Eagle *Haliaeetus leucogaster* – Action Statement No. 60. Department of Conservation and Natural Resources, Melbourne.

Debus, S. J. S. (2008). Biology and diet of the White-bellied Sea-Eagle *Haliaeetus leucogaster* breeding in northern inland New South Wales. *Australian Field Ornithology* **25**, 165–193.

Dennis, T. E. (2004). Conservation status of the White-bellied Sea-Eagle, Osprey and Peregrine Falcon on western Eyre Peninsula and adjacent offshore islands in South Australia. *South Australian Ornithologist* **34**, 222–228.

Dennis, T. E., and Baxter, C. I. (2006*a*). The status of the White-bellied Sea-Eagle and Osprey on Kangaroo Island in 2005. *South Australian Ornithologist* **35**, 47–51.

Dennis, T. E., and Baxter, C. I. (2006*b*). Resident and migratory birds of coastal marshland habitats in the Bay of Shoals and Western Cove area of Kangaroo Island, South Australia. *South Australian Ornithologist* **34**, 267–275

Dennis, T. E., and Lashmar, A. F. C. (1996). Distribution and abundance of White-bellied Sea-Eagles in South Australia. *Corella* **20**, 93–102.

Dennis, T. E., Detmar, S. A., and Brooks, A. V. (2011). Distribution and status of White-bellied Sea-Eagle and Eastern Osprey populations in South Australia. *South Australian Ornithologist* **37**, 1–16.

Forest Practices Authority (2006). Eagle nest searching, activity checking and nest management. Fauna Technical Note No. 1. Forest Practices Authority, Hobart.

Grubb, T. G., and King, R. M. (1991). Assessing human disturbance of breeding Bald Eagles with classification tree models. *Journal of Wildlife Management* **55**, 500–511. doi:10.2307/3808982

Hamilton, N., and Cocks, D. (1996). Coastal growth and the environment. In 'Population Shift: Mobility and Change in Australia'. (Eds P. W. Newton and M. Bell.) pp. 182–191. (Australian Government Publishing Service: Canberra.)

Kleinbaum, D., Kupper, L., and Chambliss, L. (1982). Logistic regression analysis of epidemiologic data: theory and practice. *Communications in Statistics Theory and Methods* **11**, 485–547. doi:10.1080/03610928208828251

Manidis Roberts Consultants (1997). Developing a Tourism Optimisation Management Model (TOMM). South Australian Tourism Commission, Adelaide.

Mathisen, J. E. (1968). Effects of human disturbance on nesting of Bald Eagles. *Journal of Wildlife Management* **32**, 1–6. doi:10.2307/3798229

McGarigal, K., Anthony, R. G., and Isaacs, F. B. (1991). Interactions of humans and Bald Eagles on the Columbia River estuary. *Wildlife Monographs* **115**, 1–47.

Mooney, N. J., and Holdsworth, M. (1991). The effect of disturbance on nesting Wedge-tailed Eagles *Aquila audax fleayi* in Tasmania. *TASFORESTS. Forestry Commission* **3**, 15–31.

Newton, I. (1979). 'Population Ecology of Raptors.' (Poyser: Berkhamsted, UK.)

Newton, I. (1998). 'Population Limitations in Birds.' (Academic Press: London.)

Olsen, P. (1998). Australia's raptors: diurnal birds of prey and owls. Birds Australia Conservation Statement No. 2. *Wingspan* **8**(3, Suppl.), 1–16. Available at http://www.birdsaustralia.com.au/images/stories/wingspan_supplements/WSS_Raptors.pdf [Verified 5 May 2011].

Paton, D. C., Gates, J. A., and Pedlar, L. P. (2002). Birds. In 'Natural History of Kangaroo Island.' 2nd edn. (Eds M. Davies, C. R. Twidale and M. J. Tyler.) pp. 164–171. (Royal Society of South Australia: Adelaide.)

Quinn, G. P., and Keough, M. J. (2002). 'Experimental Design and Data Analysis for Biologists.' (Cambridge University Press: Cambridge, UK.)

Richardson, C. T., and Miller, C. K. (1997). Recommendations for protecting raptors from human disturbance: a review. *Wildlife Society Bulletin* **25**, 634–638.

Romin, L. A., and Muck, J. A. (1999). Guidelines for raptor protection from human and land use disturbances. US Fish and Wildlife Service, Salt Lake City, UT.

Shephard, J. M., Catterall, C. P., and Hughes, J. M. (2005). Long-term variation in the distribution of the White-bellied Sea-Eagle (*Haliaeetus leucogaster*) across Australia. *Austral Ecology* **30**, 131–145. doi:10.1111/j.1442-9993.2005.01428.x

Thiollay, J. M. (2007). Raptor declines in West Africa: comparisons between protected, buffer and cultivated areas. *Oryx* **41**, 1–8. doi:10.1017/S0030605307000809

Threatened Species Section (2006). Threatened Tasmanian Eagles Recovery Plan 2006–2010. Department of Primary Industries and Water, Hobart.

Thurstans, S. D. (2009). Modelling the nesting habitat of the White-bellied Sea-Eagle *Haliaeetus leucogaster* in Tasmania. *Corella* **33**, 51–65.

Womersley, H. B. S., and Edmonds, S. J. (2002). Intertidal Ecology of Marine Organisms. In 'Natural History of Kangaroo Island.' 2nd edn. (Eds M. Davies, C. R. Twidale and M. J. Tyler.) pp. 164–171. (Royal Society of South Australia: Adelaide.)

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