

CEE review 07-003

WHAT ARE THE IMPACTS OF HUMAN RECREATIONAL ACTIVITY ON THE DISTRIBUTION, NEST-OCCUPANCY RATES AND REPRODUCTIVE SUCCESS OF BREEDING RAPTORS?

Systematic Review

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SYSTEMATIC REVIEW SUMMARY

Background

One of the most common topics in environmental impact assessment is the effects of human disturbance on bird species, and particularly on birds of prey. However, scientific information available on this topic has never been properly synthesized so that decisions taken by managers can be based on evidence rather than on personal experience or on individual pieces of information which may be inconsistent with the whole.

Objectives

To systematically collect and synthesize the available published and unpublished evidence in order to answer the question ‘what are the impacts of human recreational activities on nest-occupancy rates and reproductive success of breeding raptors?’

Search strategy

Seven electronic databases were searched using 19 sets of specific keywords. Unpublished information was sought by means of web-based search engines and by writing to individual experts and institutions involved in raptor study and protection.

Selection criteria

We included studies that fulfilled the following criteria:

1. Subject: breeding raptors (both diurnal and nocturnal)
2. Intervention: human recreational activities performed close to nesting sites during the breeding period.
3. Outcomes: changes in nesting-site location, nest-occupancy rate and breeding success parameters.
4. Types of study: any field *in situ* study carried out in any part of the world involving wild-breeding raptors, comparing occupied nests (treatment) with random points in unoccupied areas suitable for reproduction or comparing nest location and performance before and after human disturbance took place (BACI experiments).

Data collection and analysis

Agreement between two independent researchers was assessed and a high degree of accordance was found for study inclusion, suggesting a repeatable procedure. Data (all original statistics from which an effect size could be calculated) were extracted following an a priori data extraction protocol regarding subject, intervention and outcome. Random-effects meta-analysis was performed by means of the software Metawin 2.1 on twenty-four independent data points, consisting of means, standard deviations and sample sizes of both control and treatment. The overall data set was divided into subgroups and meta-analysis was performed for each subgroup individually to account for heterogeneity. We modelled causes of heterogeneity by means of the software and environment R, taking individual effect sizes as the response variable, species and nesting site (tree vs. cliff-nesting) as factors and body size as a covariate (both as a continuous variable and as a dichotomous one). Models were built both for Hedge’s d and the log response ratio (lnR), as effect size metrics. Model selection was carried out taking into account the loss of Kullback-Leibler information by means of information theoretic criteria linking classical likelihood

theory with theoretical information criteria (Akaike Information Criterion and Akaike weights).

Main results

A total of 3887 articles were detected by our specific searches. The final number of articles considered for data extraction was 52. The only outcome that we could meta-analyze was the displacement distance of nests from roads, compared to random points in suitable areas for breeding. Although the literature also provided comparable information on other anthropic variables, such as distance to unpaved tracks, we decided to consider only one of these variables (roads) as surrogate of human access to the countryside. A total of 24 studies were found to provide comparable information on this outcome.

A modest statistically significant effect of the presence of paved roads (as a proxy of human accessibility to the countryside) on raptor nest location was found after performing a random-effects meta-analysis on 24 independent data points (Pooled effect size ($\ln R$)=0.22 (Bootstrap 95%CI 0.036 to 0.423; back-transformed \ln Response Ratio 1.28; 1.07-1.57 bootstrap 95% CI). The mean absolute magnitude of nest displacement from roads, compared to random control points, was 663.46 ± 389.23 m.

Species negatively affected by roads included Cooper's hawk, Spanish Imperial Eagle, Cinereous Vulture, Booted eagle, Eagle owl, Common buzzard, Bald eagle, and Peregrine falcon, some of them endangered species. Species which showed a tendency to be positively affected by roads included: Peregrine falcon, Booted eagle and Common Buzzard. The fact that some species such as Booted eagles and Common buzzards are present in both categories suggests that distance to roads is, to some extent, a population-specific trait, rather than a species-specific trait.

When exploring heterogeneity by means of Generalized Linear Mixed Models two explicative variables were considered: size of the raptor (body length), and nature of nesting substrate (tree-nesting vs. cliff-nesting) in addition to species which was incorporated as a random variable to prevent pseudoreplication. The longest displacement distances to roads were shown by big raptors breeding on trees, a group including many threatened species such as Cinereous vulture and Spanish Imperial eagle. Mean distance for this group of species was 1375 ± 922.4 m. In fact, model selection by means of information theoretic criteria indicated the influence of body size and nesting substrate on effect size was similar, especially when using Hedges' d as an effect size metric.

Conclusions

Implications for management / policy / conservation: In countries where forested areas are very fragmented, the fact that big and tree-nesting raptors tend to nest far from roads can be a serious handicap for reproduction. Big raptors commonly nesting on trees (e.g. Booted eagle) which are found nesting on cliffs eventually, might reflect local human disturbance if trees are not scarce. Similarly, typically cliff-nesting raptors found breeding on trees (e.g. Golden eagle) might indicate low local human disturbance, if cliff availability is not a limiting factor locally.

Implications for research: Further empirical work (BACI experiments) to quantify the effect of human recreational activities on breeding raptors needs to be carried out if conservation decisions are to be based on evidence. No substantive progress on knowledge accumulation regarding this topic has been detected in the last 30 years.

1. BACKGROUND

The risk of impact of recreational human activities (i.e. including all non-consumptive human activities) to wild ranging breeding birds of prey is a topic commonly addressed in environmental impact assessments (EIAs) (Pomerantz et al. 1988; Martínez et al. 2003) owing to the dramatic increase of these activities worldwide during the last decades. However, typically environmental impact studies fail to provide proper evidence of the impact (or absence of impact) of these activities on breeding success and breeding-site fidelity of individual raptor pairs, and especially of the population and meta-population consequences of human activities (Martínez et al. 2003; Suárez et al. 2003). Faced with this uncertainty, managers often use the precautionary principle to limit or ban these activities.

The question arises whether individual pairs can have their breeding success and fidelity to nesting sites (local fitness) affected by human recreational use of their breeding grounds. Breeding success can be influenced by a number of factors such as reduced nest attendance and consequent cooling or overheating of eggs, permanent clutch abandonment, absence of replacement clutches, lower success of replacement clutches, reduced chick brooding owing to temporal abandonment, permanent chick abandonment or reduced foraging success and hence reduced feeding rates to chicks. In turn, nest-site fidelity can be affected within a breeding season (nest abandonment with subsequent re-occupation) or between seasons (no nest re-occupation between seasons or permanent dispersal).

Importantly, we also know from the application of behavioural science to conservation that impact of humans on birds can be, to a large extent, mitigated by cultural habituation to harmless human presence in protected areas. Large penguins, living in isolated areas with few or no predators become naïve and lose costly anti-predator behaviours, although not all such behaviour is affected (Blumstein & Daniel 2005). For example Humboldt penguins (*Spheniscus humboldti*), which are seldom exposed to human presence apparently do not fear the presence of humans in their breeding colonies, but are actually physiologically stressed (a person passing an incubating penguin at 150m distance provokes a significant heart rate response), which translates into reduced breeding success. Likewise, Magellanic penguins (*Spheniscus magellanicus*) show typical adrenocortical responses to stressors when humans are present in their breeding grounds, but only if the colony has not been exposed to very high levels of ordinary human presence. Colonies exposed to moderate or highly variable levels of disturbance do not show evidence of habituation over a period of a few years (Fowler 1999; Beale & Monaghan 2004). Hence a usual management suggestion made by scientists is allowing controlled but frequent human visitation so that birds habituate to harmless human presence (Ferrer et al. 2007; Martínez-Abrán et al. 2007).

Nevertheless, the degree and speed of habituation seems to be a species-specific trait as well as a site-specific trait (Blumstein et al. 2003). It also seems to be quite dependent on size and diet, with large predator species having less tolerance to human presence (Blumstein 2006). For example, although some habituation to pedestrians by Spanish Imperial Eagles was shown by González et al (2006) the same species, together with vultures, showed decreased local abundances during weekends associated with increased road traffic in these areas compared to week days (for a

similar case with wintering Bald eagles see Stalmaster & Kaiser 1998). However, the occurrence of other species did not change between working days and weekend days (Bautista et al. 2004). Habituation seems also to vary depending on age. Adult Bonelli's eagles (*Hieraetus fasciatus*) may seek the proximity of human settlements during breeding, since they take advantage of human-associated fauna such as pigeons to forage (Sanz et al. 2005), but dispersing juveniles choose areas located farther from villages and roads than expected by chance alone (Balbotin 2005).

Further proof of habituation comes from wild-ranging species, which in the past were not associated with urban areas at all, that are now colonising towns and cities as direct persecution by humans has decreased. This is the case of the common kestrels (*Falco tinnunculus*) breeding in many large European cities (Kubler et al. 2005) or peregrine falcons (*Falco peregrinus*), re-introduced to many urban areas around the world, such as North America (Cade & Bird 1990; Holroyd & Banasch 1990, Italy (Serra et al. 2001), Peru (Beingolea et al. 2003), Spain (Durany 2006) or Poland (Rejt 2003; 2004), to name just a few. Red-tailed hawks (*Buteo jamaicensis*) are also expanding into urban locations and seem to adjust well to urbanization (Stout et al. 1998; 2006). Raptors breeding in urban areas have high degrees of popular acceptance (Martell et al. 2000), show high plasticity in their diets to adapt to urban prey availability (eating mostly birds since urbanization increases bird biomass), and higher breeding success than their rural counterparts (Kauffman et al. 2003; 2004) or at least similar (Coleman et al. 2002), because they are often free from human persecution and have lower levels of nest predation and parasitism (Chace & Walsh 2006). In some instances, raptors can find safe places in urban areas to breed whilst moving to the rural outskirts to forage (op. cit.) or, on the contrary, breed in wild areas and move to urban or suburban areas to forage (Brambilla et al. 2006). However, sometimes urban environments act as ecological traps providing misleading cues of habitat quality to raptors such as Cooper's Hawks (Boal 1997). Hence, not only colonial breeding birds can get used to harmless human presence but also solitary breeders such as some falcons and hawks, since urban breeding entails habituation to humans. Some level of habituation to humans by raptors also occurs when humans visit the breeding grounds of raptors breeding in wild areas (Ferrer et al. 2007; González et al. 2006; 2007). However, habituation can only occur when two main requirements are met: a) lack of direct effect on birds by means of the proper ordination of human visits (McClung et al. 2004; Finney et al. 2005; Arroyo & Razin 2006) and b) high intrusion frequencies over a long time period (González et al. 2006; see Urios & Martínez-Abráin 2006 for a case of low habituation of a social raptor in an island colony with a low load of terrestrial visitation, but moderate levels of boat affluence during the breeding period). Raptors breeding in isolated sites are not used to human presence, and are most likely vulnerable to disturbance. The study of habituation hence leads directly to deal with the conflict between establishing buffer zones around nests versus allowing controlled human visitation to territories of breeding pairs to allow habituation to occur.

Although most information available on human disturbance to birds seems to deal with behavioural responses of birds when faced with disturbance (Boyle & Samson 1985; Richardson & Miller 1997; Steidl & Powell 2006), behavioural responses might not reflect appropriately fitness or population effects. The fact that an individual reacts by flying away or moving farther from the point of disturbance to breed may only reflect that there is abundant suitable habitat available to do so (Gill et al. 2001).

Many shorebird species fly away when faced with human presence along beaches or mudflats but that may only reflect that there are hundreds of linear meters of beaches and hundreds of square meters of wetlands to choose. Species more vulnerable to human presence may, on the contrary, have no choice and decide to stay because there are no alternative places to go.

One could hypothesize that both the size of the raptor species and the substrate in which they build their nests can have an influence on raptor response. Big raptors are more easily spotted from the distance and hence could be more vulnerable as are tree nesting species, breeding closer to the ground than cliff nesting species typically.

On the other hand, it is also important to keep in mind during the process of review of this question that human recreational uses could affect raptors not only by affecting the normal development of breeding in presently occupied sites but also reducing the quality of potentially good sites for breeding, which are presently unoccupied. Human occupation of potentially good sites may be the cause for density-dependent inter-specific competition among raptor species with positive growth rates, owing to site limitation, with negative effects for the less aggressive species (see Ontiveros et al. 2004). This general scarcity of high-quality breeding sites could explain the earlier breeding calendar of some raptor species syntopic to other such raptor species, with more aggressive behaviours, when the more aggressive one or both are showing increasing trends. In this sense, raptor habituation could be of paramount relevance to increase the carrying capacity of sites.

Another indirect way of affecting breeding raptors is by disturbing them in their foraging grounds which may prevent proper food provisioning for their offspring or cause extended periods out of the nest during incubation. This is especially so if food is scarce within territories. Raptors breeding on territories which are rich in prey should be less likely to be disturbed than those already stressed by lack of territory quality. This opens up room for thinking of possible interactive effects of global change and human disturbance as well as possible management options for areas necessarily affected by human disturbance.

To the best of our knowledge only Sidaway (1990) and Woodfield & Langston (2004) have made traditional reviews on the disturbance of human access on foot to birds. However these studies deal mainly with the effect to birds other than raptors. Boyle & Samson (1987) as well as Knight & Skagen (1987) devoted a short classical and non-quantitative review to the effect of recreational disturbance on birds of prey. They concluded that recreational disturbance can alter normal activity patterns of raptors by altering their distribution, disrupting nest attentiveness, causing abandonment of breeding territories, reducing productivity and affecting foraging behaviour. However they also discussed the need of further empirical information on the influence of outdoor recreation on raptors. Here we explore the literature on human recreational effects on nesting-site occupancy and breeding performance of diurnal and nocturnal raptors, and on the determinants of these effects, following the rigorous procedure of systematic reviews which renders the whole process repeatable and transparent and aims to achieve quantitative research synthesis by means of meta-analysis.

2. OBJECTIVES

2.1 Primary objective

To systematically collect and synthesize the available published and unpublished evidence in order to answer the following question:

- What are the impacts of human recreational activity on the distribution, nest-occupancy rates and reproductive success of breeding raptors? (see Table 1 for definitions of terms)

2.2 Secondary objective

Exploring what characteristics make raptors more vulnerable to breeding failure or nest abandonment owing to human disturbance. More specifically, to explore the influence of body size (as a continuous variable) and main substrate of nest location (tree nesting vs. cliff nesting) on the magnitude of displacement from nest to roads located close to raptor nests, as vectors of human access o the countryside.

Table 1. Definition of the components of the systematic review question.

Subject	Intervention	Outcome	Comparators	Designs
World breeding diurnal and nocturnal birds of prey	Recreational activities carried out close to nest sites	Changes in breeding success or rate of nest-site re-occupation	1. Random nests not affected by recreational activities or 2. breeding success and rates of nest re-occupation before human disturbance if long-term monitoring data are available	Annual monitoring of raptor nests and territories in areas subjected to recreational activities and areas without these activities or long-term annual monitoring of a sample of raptor nests and territories including information before and after human disturbance. Experiments measuring flight initiation distance.

3. METHODS

3.1 Question formulation

The environmental authorities (Conselleria de Medio Ambiente) of the regional government of Comunidad Valenciana (Generalitat Valenciana) in Eastern Spain

identified the need for a systematic review to assess the potential effects of human recreational activities on breeding raptors.

The specific question to evaluate was formulated through discussion between the environmental authorities and the researchers at the population ecology group of IMEDEA, the Mediterranean Institute for Advanced Studies (CSIC-UIB) as well as the Centre for Evidence-Based Conservation (Bangor University).

3.2 Search strategy

General sources

Relevant studies were identified through computerised searches of the following electronic databases: Digital Dissertations Online, Index to Theses Online, ISI Web of Knowledge (including ISI Web of Science and ISI Proceedings), Science Direct, CAB Abstracts and Scopus.

The Boolean search terms used were:

- “Flight initiation distance” AND (raptor* OR “bird of prey”)
- “Human disturbance” AND (raptor* OR “bird of prey”)
- “Breeding success” AND (raptor* OR “bird of prey”)
- “Nest site fidelity” AND (raptor* OR “bird of prey”)
- Human activit* AND (raptor* or “bird of prey”)
- Human approach* AND bird*
- Escape* AND (raptor OR “bird of prey”)
- Recreation* AND (raptor* OR “bird of prey”)
- Disturb* AND (raptor* OR “bird of prey”)
- Touris* AND (raptor* or “bird of prey”)
- Urban* AND (raptor* OR “bird of prey”)
- Impact* AND (raptor* OR “bird of prey”)
- Road* AND (raptor* OR “bird of prey”)
- Car AND human AND (raptor* OR “bird of prey”)
- Hiking AND (raptor* OR “bird of prey”)
- Research effect* AND (raptor* OR “bird of prey”)
- “Flushing distance” AND (raptor* OR “bird of prey”)
- “Nest success” AND (raptor* OR “bird of prey”)
- Leisure* AND disturbance*

Specialist sources

The RSPB library of reports was consulted. Only one report was found dealing with the topic.

North American specialists on human disturbance to raptors were consulted for possible sources of unpublished references in North America. No individual source was readily available, other than consulting authors of primary research. We did so in several instances (with Spanish researchers) to obtain complementary data to published papers that were lacking the information of interest for our meta-analysis.

3.3 Study inclusion criteria

The inclusion criteria comprised three key elements:

SUBJECT: All world breeding diurnal and nocturnal birds of prey.

INTERVENTION: Any kind of human recreational activities performed close to the nests of breeding raptors and during the breeding period.

OUTCOMES:

- Change in breeding success or nest-site fidelity after intervention compared to the situation before (Before/After)
- Change in breeding success or nest-site fidelity in areas affected by intervention compared to control areas (Control/Impact)

Articles from the initial database searches were filtered by title and abstract and any obviously irrelevant articles were removed. A subset of 300 papers was assessed for relevance by a second independent reviewer. Agreement on inclusion between the reviewers was deemed to be “substantial” (Cohen’s Kappa test: $K= 0.664$). Articles were accepted for viewing at full text if the abstract was ambiguous or missing, and did not allow inferences to be drawn about the article content. Studies obtained at full text were then assessed against the subject, intervention and outcomes listed above. Following this procedure a final set of only 13 papers was selected. However, we realized, by checking the literature, that the only outcomes addressed in a consistent and comparable way among studies were several metrics of the distance from occupied nests to anthropically-influenced sites. Out of these we chose as the outcome measure the displacement distance from occupied nests to the closest paved road, compared to control points selected at random in suitable areas for breeding. We decided to chose one “nest displacement distance” variable because a) this outcome was not the original purpose of the study, b) paved roads seemed a good surrogate of public access to the countryside and c) this outcome was available in a large number of studies in a comparable way. Hence we performed a secondary specific search under the terms “Habitat selection” and raptor* and “Habitat preference” and raptor* and “Habitat selection” AND “bird of prey” at the Web of Science. The final number of papers selected was increased to 52.

3.4 Study quality assessment

Quality of data for extraction was critically appraised by assessing consistency in the way in which the outcome was measured, independence of data points, and availability of means, standard deviations and sample size both for control and “treatment” areas. Quality of data regarding effects on breeding parameters was assessed by taking into account quality of design (especially regarding sample size), degree of dispersion of data and uncertainty in parameter estimation as well as magnitude of the effects observed.

3.5 Data extraction

We dichotomised data into: a) those containing quantitative data on effects of human disturbance on reproduction that were not suitable for data extraction owing to great heterogeneity of outcomes measured and b) those containing quantitative data suitable for data extraction owing to consistent measure of the same outcome (i.e. displacement distance from nests to nearest road compared to a random set of points taken from adjacent non-occupied areas suitable for reproduction).

3.6 Data synthesis

Means, standard deviations and sample sizes for treatment and control, considering all 24 studies with suitable data, were analyzed in Metawin 2.1 software by means of two metrics of effect size: Hedge's d and log response ratio (Mullen 1989). A random effects meta-analysis was performed to derive the pooled effect size. Similar meta-analyses were performed for subgroups. Specifically we calculated the individual and pooled effect sizes for small (i.e. falcons, buzzards, small eagles and small vultures) and big raptors (i.e. big eagles and vultures) as well as for raptors breeding on cliffs or on trees. We considered that these two variables were biologically meaningful regarding possible influence of human disturbance.

To explore factors introducing heterogeneity we built several Generalized Linear Mixed Models, accounting for several alternative nested ecological hypotheses. Modelling was performed using as metrics of effect size both the log response ratio and Hedge's d. Models were compared and selected by means of information theoretic criteria, including Akaike's Information Criterion (for model ordination) and Akaike weights (as a tool to judge about the relative strength of the model). The model selected was that minimising the loss of Kullback-Leibler information, that is, the one with the lowest AIC value, representing the best compromise between model fit to data and complexity of the model, that is, the most parsimonious model

4. RESULTS

4.1 Description of studies

Literature searching

A final library of 3887 articles was compiled after our systematic literature search, but only 13 fulfilled inclusion criteria. Inclusion of studies dealing specifically with displacement distance from nests to the nearest road increased our final pool of articles to 20. Consultation of cited references in those papers, and consultation of experts, led us to selecting 32 more articles, some of them offering more than one outcome. Hence the final number of articles handled was 52. From these, the number of studies providing information suitable for quantitative meta-analysis was 24.

Vote counting

Papers selected dealt with the effect of recreational activities on a number of variables such as changes in distribution range, foraging, nest occupancy, nest location, breeding parameters and behaviour at nest, although most information available (67%) dealt with the last two. A classical vote-counting procedure (Mullen 1989) of studies dealing with effects on reproductive parameters indicated that eight studies found negative effects, of variable magnitude, whereas nine studies did not show any substantial effect. The raptor species on which most information has been published on effects of recreational activities is the Bald Eagle (*Haliaeetus leucocephalus*) (31%) although information was found for up to 24 different species. Specific information on impact of recreational activities on breeding parameters was available for eleven species, although Peregrine Falcon (*Falco peregrinus*) together with Bald Eagles comprised 42% of the studies (Figures 1, 2, 3 and 4).

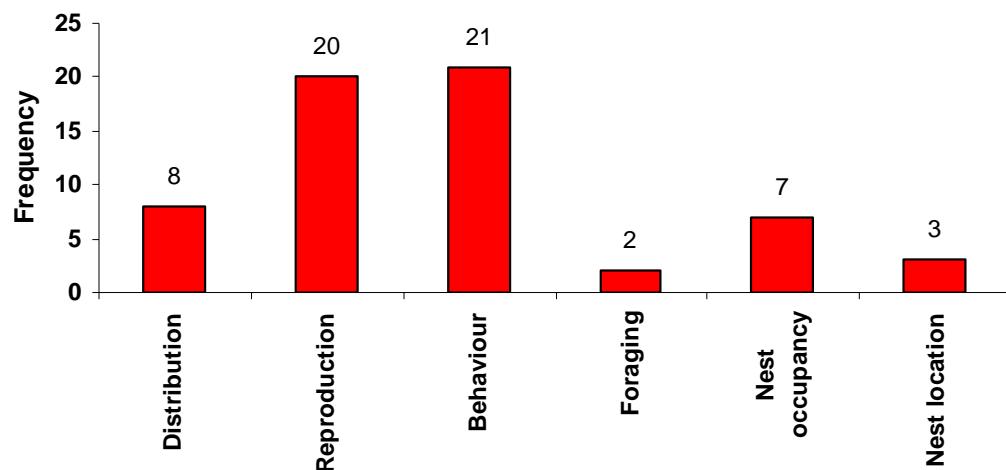


Figure 1. Histogram depicting graphically the number of data points available by topic for studies with no data suitable for meta-analysis.

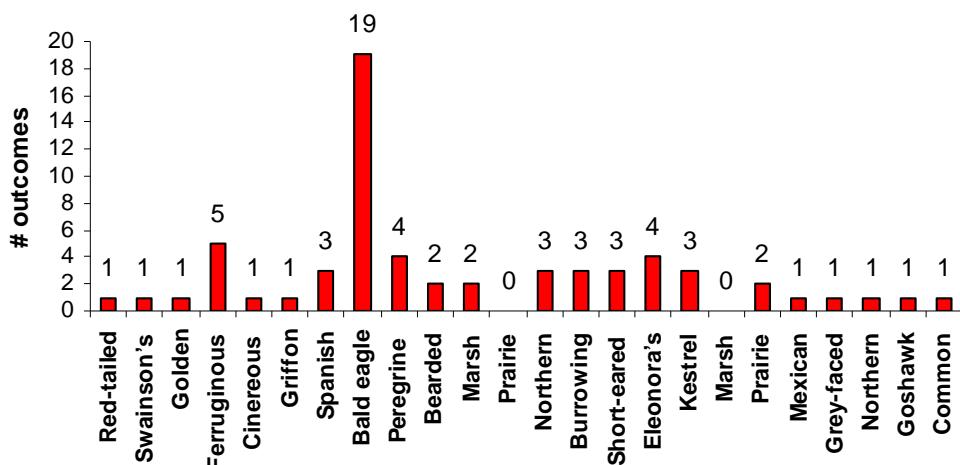


Figure 2. Histogram depicting the number of studies dealing with each species for studies with no data suitable for meta-analysis.

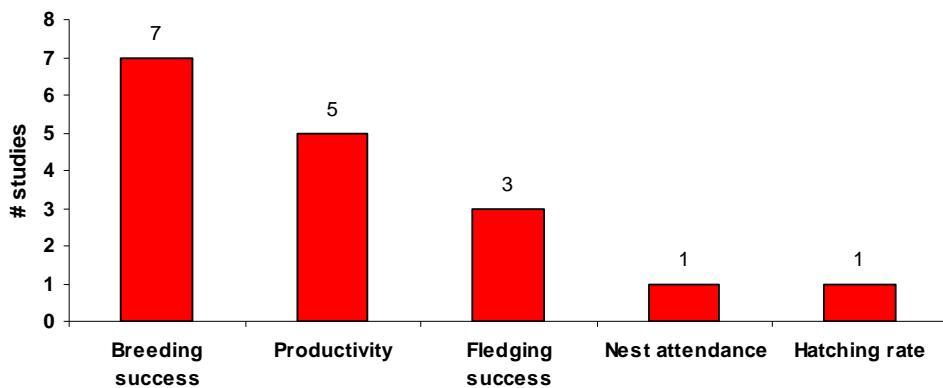


Figure 3. Histogram depicting the number of studies not suitable for meta-analysis specifically dealing with reproductive parameters.

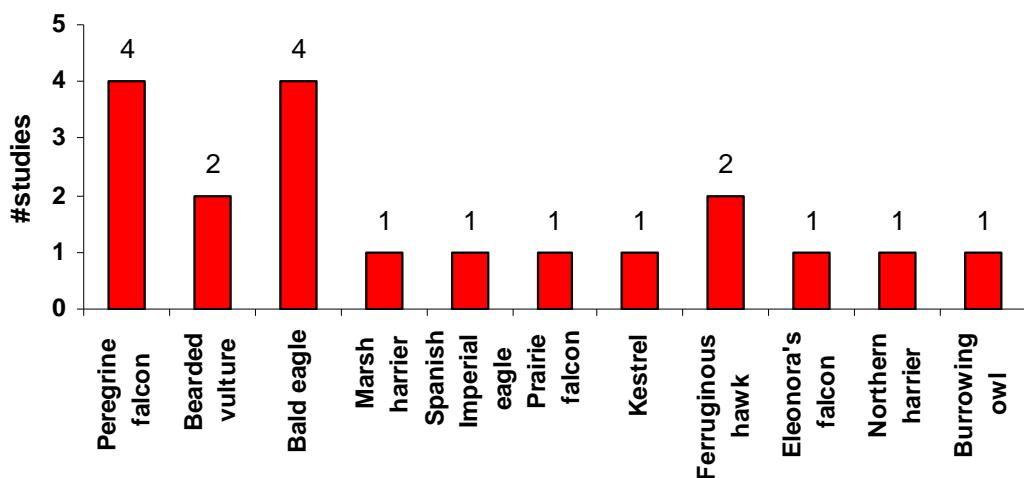


Figure 4. Histogram depicting the number of data points not suitable for meta-analysis classified by species.

4.2 Meta-analysis

Effect sizes (using log response ratio as the response variable) derived by comparing distance from nests to nearest road to a random set of points taken from adjacent non-occupied areas suitable for reproduction illustrated considerable heterogeneity between species ($Q=17.907$, $p=0.762$, $df=23$) (Figure 5a). Ten cases showed a clear impact of roads on nest location, 4 cases show an “attraction” for roads and for 10 cases it was not possible to conclude anything since the 95% CI brackets the value zero, indicating that zero effect was among the possible values of the parameter (Figure 5a).

Pooling species response ratio's using a random effects model, therefore results in a negative impact of roads (statistically significant) but with a huge uncertainty associated as shown by the wide bootstrap confidence interval ($\ln R$ 0.225, 95% CI 0.0396 to 0.4193; Back-transformed Response Ratio 1.28; 95% CI 1.07-1.57). Pooling absolute effect sizes results in a similarly large 95% confidence interval which crosses zero (Hedges' d 0.22; 95% CI -0.088 to 0.537; Figure 5a).

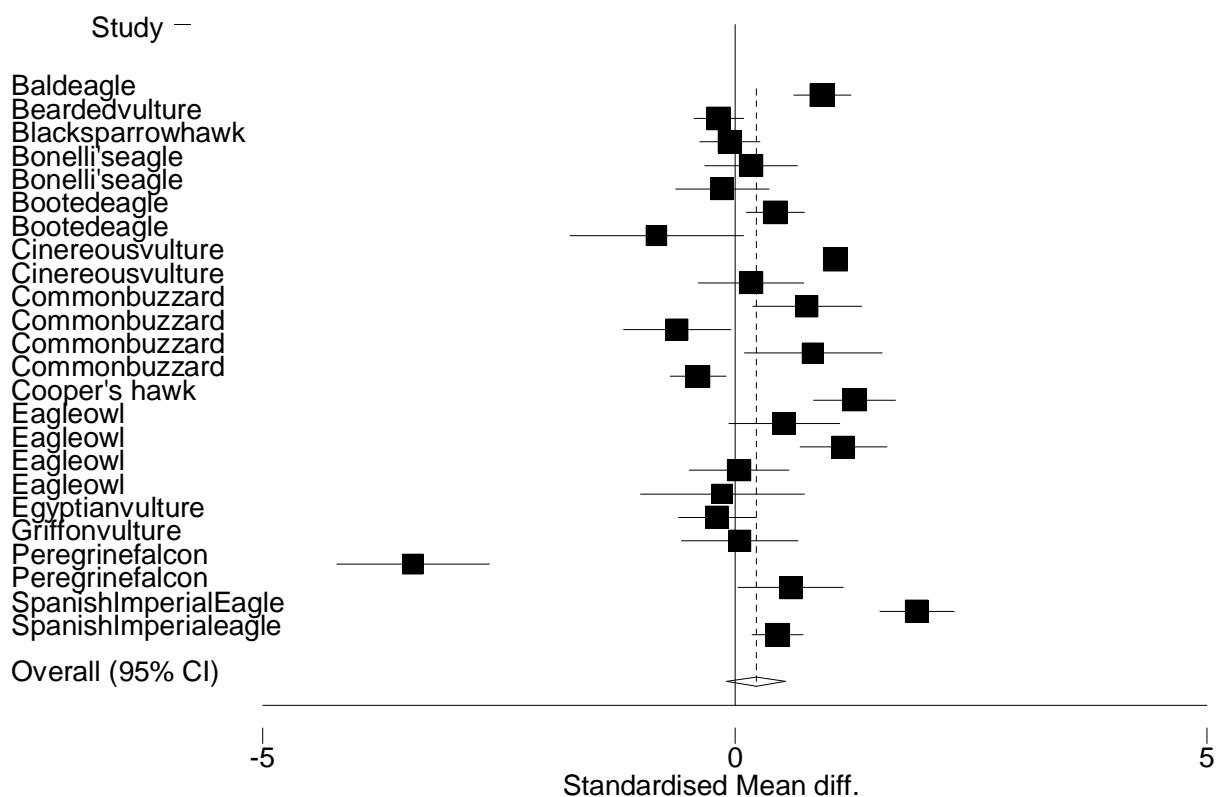


Figure 5a. Forest plot with the overall results of the meta-analysis showing individual effect sizes (Hedges' d) and 95% confidence intervals.

4.3 Assessing publication bias

Effect size quantile distributions were not normal for log response ratio (Figure 6) or standardised mean difference effect size metrics such as Hedges' d (Figure 7) suggesting some publication bias.

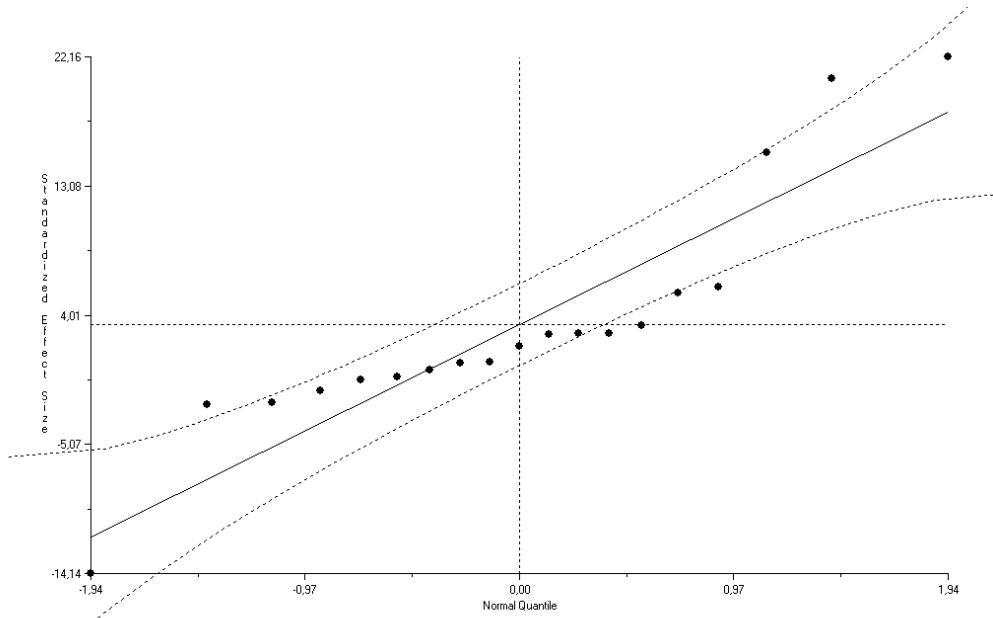


Figure 6. Distribution of the standardized effect sizes ($\ln R$) along quantiles of a normal distribution (dotted lines are 95% CIs).

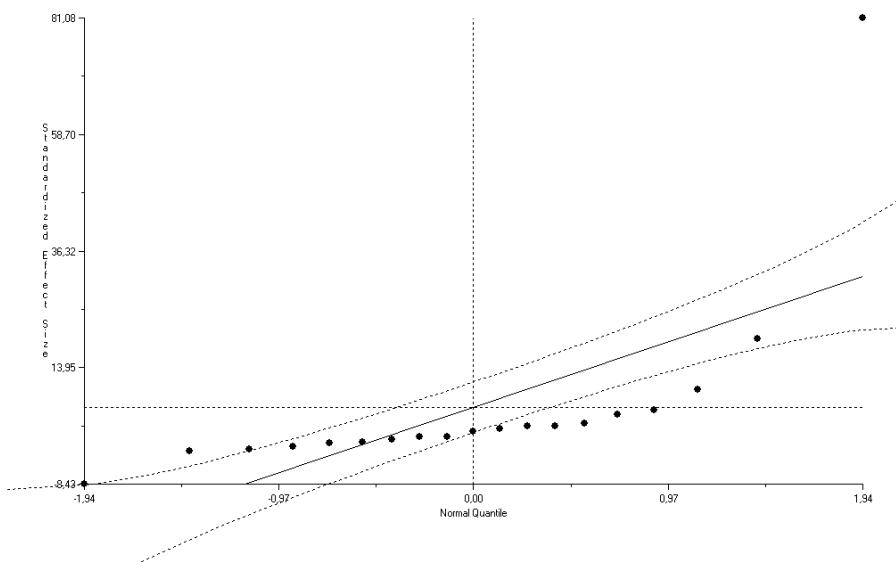


Figure 7. Distribution of the standardized effect sizes (Hedge's d) along quantiles of a normal distribution (dotted lines are 95% CIs).

Either using the log response ratio or Hedge's d as effect size metrics funnel plots indicate publication bias because at large sample sizes there is quite a

high variance in effect sizes contrary to expected by the Law of Large Numbers (Torgerson 2003, Figure 8a and b) .

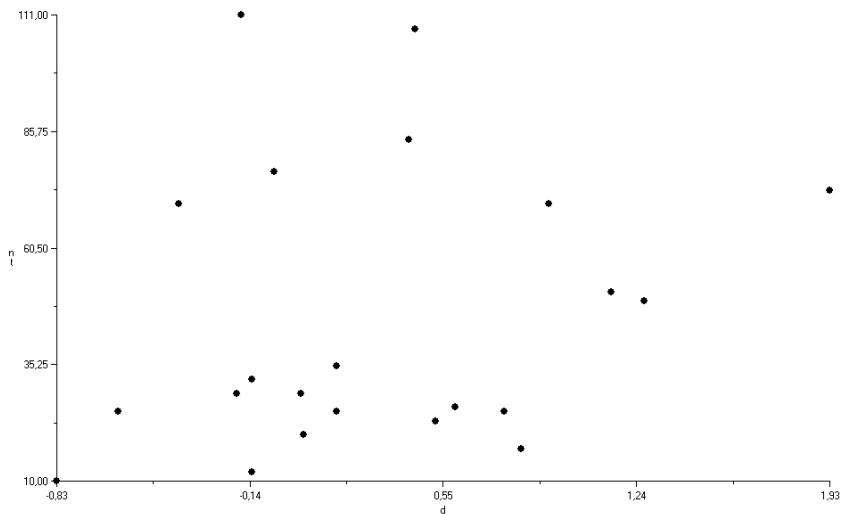


Figure 8a. Funnel plot of study outcome (Hedges' d) plotted as a function of sample size to assess publication bias. (Note that one outlier with a very large sample size was removed).

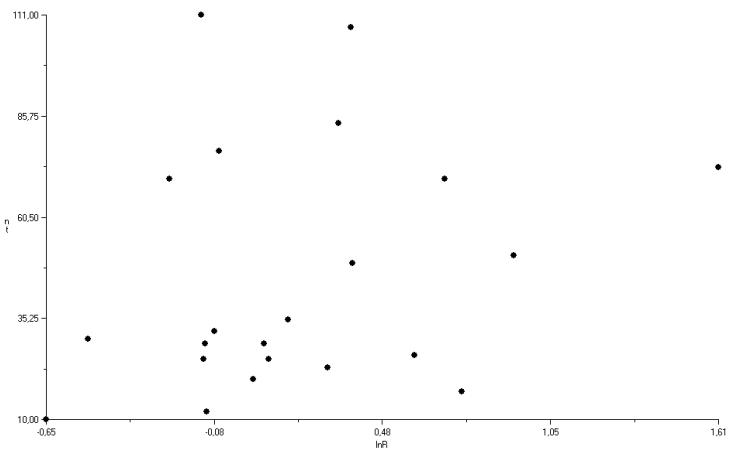


Figure 8b. Funnel plot of study outcome ($\ln R$) plotted as a function of sample size to assess publication bias. (Note that one outlier with a very large sample size was removed).

4.4 Exploration of heterogeneity

The high heterogeneity between studies may be attributed to the study of different species and populations. We explored this heterogeneity in relation to body size and nesting substrate, because the response to human presence is very likely influenced both by how easy is a raptor to be spotted from the distance (body size) and whether the nesting substrate is more or less vulnerable to human presence (cliff vs. tree-nesting). A priori we expected that big raptors and tree-nesting raptors were more vulnerable to human presence because they are easier to spot and breed closer to the ground. We examined the relationship between body size, nest location and effect size, quantified the magnitude of effect for different subgroups and modelled the relationships to explore our hypothesis.

Relationship between body size and effect size

There is a weak positive linear relationship between effect size and body size when taken as a continuous variable ($r^2=0.043$) 95% Confidence Interval limits for β (-0.005 and 0.014)((Figure 17).

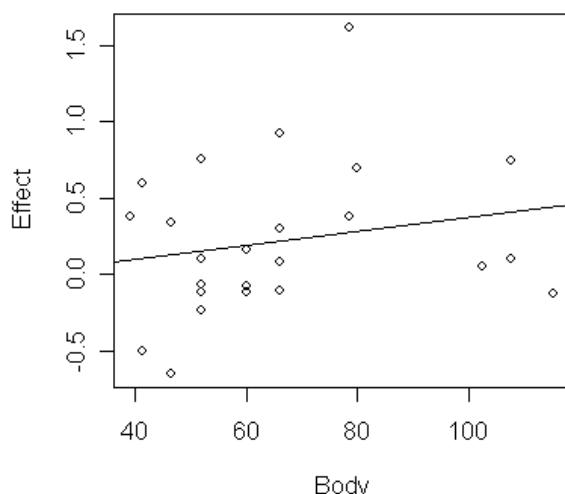


Figure 17. Linear relationship between effect size ($\ln R$) and body size as a continuous variable (all species).

However, if we analyze this relationship separating cliff and tree-nesting species (Figure 18a) it is clear that tree-nesting species have a higher response (nest displacement from roads) than cliff-nesting raptors when considering an additive model in which tree-nesters and cliff-nesters have the same regression slope but different intercepts (derived from a classical ANCOVA analysis).

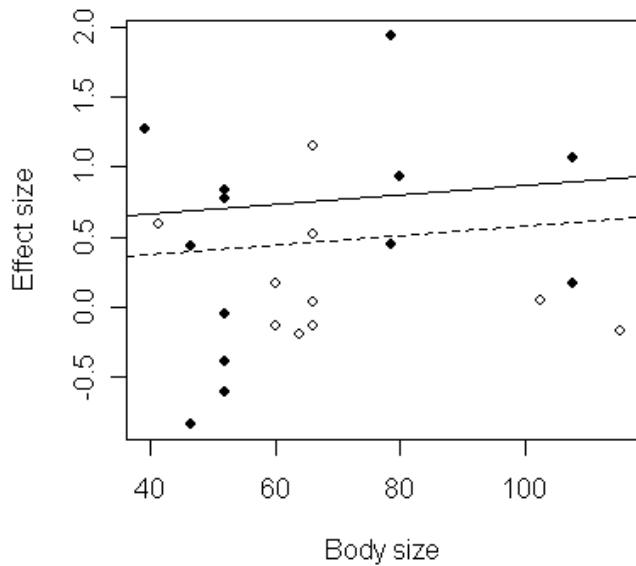


Figure 18a. Linear relationship between effect size (lnR) and body size for tree-nesting (solid dots) and cliff-nesting (open dots) raptor species.

Previously we checked that body size was not biased in relation to nesting substrate (Figure 18b).

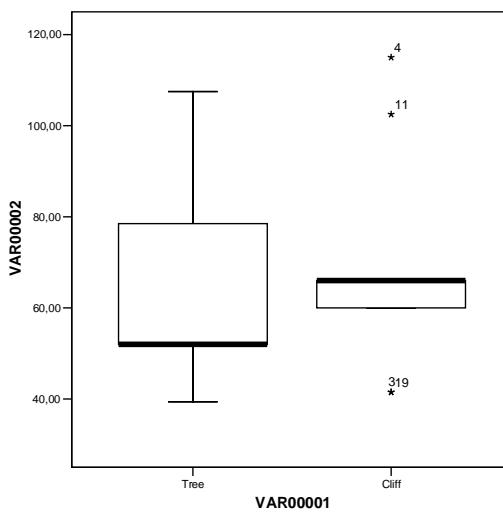


Figure 18b. Median body weight, interquartile range and maximum and minimum values of body weight for tree-nesting and cliff-nesting raptors.

Magnitude of the effect of roads on choice of nest location

Raptors nest far from roads especially if they are big and nest on trees (ca. 1400m farther than expected by chance), although uncertainty of the estimate is big owing to small sample size. Figure 19.

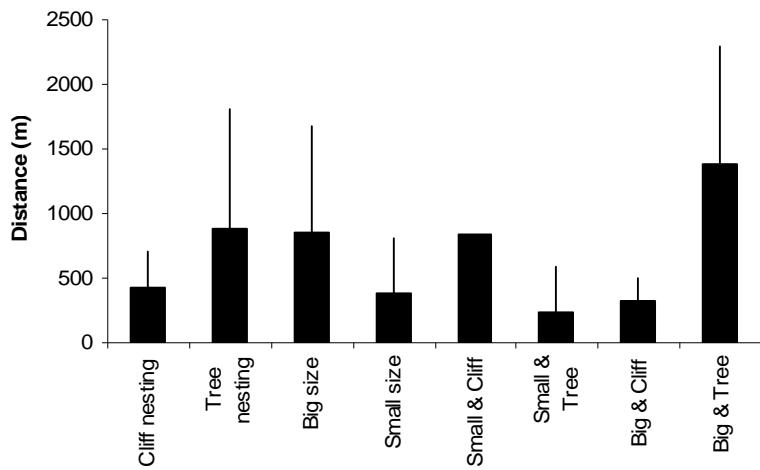


Figure 19. Difference (in meters) between treatment (nests) and control (random points in unoccupied areas) by subgroup for species negatively affected by roads. Only the upper part of the 95%CI is shown for the sake of simplicity.

Some raptor species nest 200-400m closer to roads than expected (although the precision of some estimates is not good). Interestingly, no big raptors breeding on trees do so. See Figure 20 (only the upper part of the 95%CI is shown for the sake of simplicity).

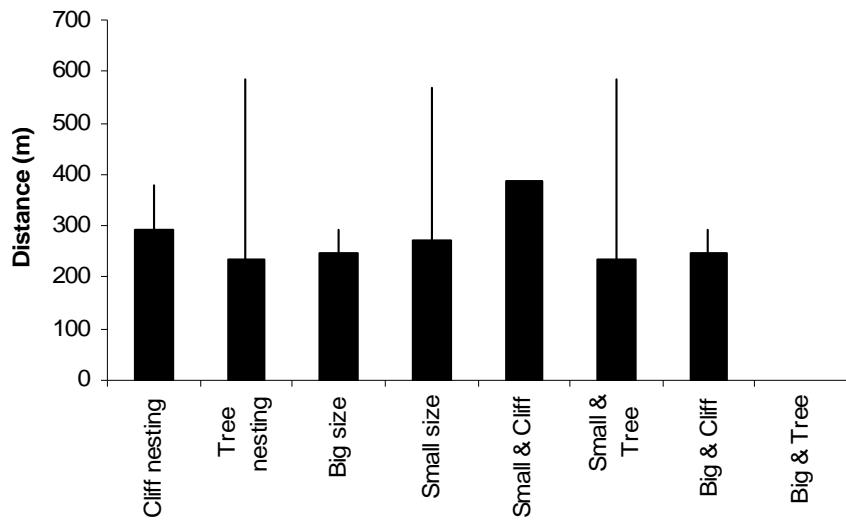


Figure 20. Difference (in meters) between treatment (nests) and control (random points in unoccupied areas) by subgroup for species “positively” affected by roads.

4.5 Modelling heterogeneity

We built in R *ad hoc* mathematical models corresponding to several biologically-sound working hypotheses to explain variability in effect size. We modelled the relationship of effect size with a number of independent variables, considering both additive relationships among them as well as interactions, by means of Generalized Linear Mixed Models (GLMM). The advantage of these models is that they prevent pseudoreplication (because the variable Species was introduced as a random variable) and they make linear those relationships that are not linear initially, by using appropriate links. In this case we assumed that effect sizes came from a Gaussian probability distribution.

Model selection based on loss of Kullback-Leibler information, using as effect size metrics both log response ratio and Hedges' d. In red we highlight the most parsimonious models, that is, those with the best compromise between model fit (deviance) and model complexity (number of parameters).

Table 2. Models expressing different biological hypotheses on the influence of body size and nesting substrate on the two effect size metrics considered and criteria for model selection.

Effect size metric	Model	AICc	K	wi
ln response ratio	<u>Site+Size+Site*Size</u>	29.36	6	0.06
ln response ratio	Site+Size	27.79	5	0.14
ln response ratio	Site	25.09	4	0.55
ln response ratio	Size	26.67	4	0.25
Effect size metric	Model	AICc	K	wi
Hedges' d	Site+Size+Site*Size	67.27	6	0.02
Hedges' d	Site+Size	64.17	5	0.10
Hedges' d	Site	61.01	4	0.46
Hedges' d	Size	61.20	4	0.42

AICc= Akaike Information Criterion corrected for small sample size; K= no. of estimable parameters: Intercept, Site, Size, Interaction term, Species and Error term; wi= Akaike weight.

4.6 Outcome of the heterogeneity analysis

When considering as a dependent variable the log response ratio, the best model of the set considered was the one containing only the explanatory variable “Site”. However, when taking as response variable Hedges’ d both the models containing as only explanatory variables Site and Size were the most parsimonious. Akaike weights were not very large in any case (they can range between 0 and 1) suggesting that in absolute terms we are missing some other relevant variable to improve model fit. However, regarding the variables included in the models, it turned out that both nesting substrate and body size had similar relevance. Models including additive relationships as well as interactions between these two variables did not improve model fit, despite large tree-nesting raptors exhibiting the largest response to human presence (figure 19).

5. DISCUSSION

5.1 Evidence of effect

Little can be concluded regarding the effect of human recreational activities on breeding parameters of birds of prey owing to the scarcity and heterogeneity of published data. Approximately 50% ($n=17$) of studies reported negative impacts, of variable magnitude, on several reproductive components, and the remainder reported absence of negative effects. These latter studies included a few cases of noisy human activities, e.g. military training, rather than human non-consumptive activities.

However, we identified a negative effect of presence of roads (presumably as facilitators of human access to the wild) on a large number of species. The overall effect represents a displacement in the order of 20-30% increase in distance from nests to roads, compared to what would be expected by chance. This distance ranges typically from 200 to 800m (mean and SD 663.46 ± 389.23 m) but it can be as high as ca. 1400m for raptors of big size breeding on trees.

5.2 Reasons for variation in effect

Nest displacement from roads was increased by large body size and tree-nesting habits although modelling did not demonstrate neither an additive effect nor an interaction between both variables. However, negative effects on breeding parameters resulting from human climbing to nests have not been identified in studies on large species breeding in trees, such as the bald eagle (see papers by Steidl and collaborators). Our results seem to support the idea that the main population effect of human presence close to nests of large tree-nesting raptors would be nest displacement.

5.3 Review limitations

The main limitation of this review was the small number of studies dealing consistently with the effects of human recreational activities on breeding parameters

of birds of prey. We were looking initially for BACI experiments reporting information on Before-After or Control-Impact experiments dealing with human disturbance on breeding parameters such as breeding success or between-years nest fidelity, but published information was only available for the Bald Eagle. Funnel plots detected potential publication bias reflecting the difficulty of obtaining grey literature. In addition, despite our subject included initially raptor species from all over the world, most articles meta-analyzed dealt with European and North American species. This probably reflects a true bias towards the study of raptor conservation in these regions.

Outcomes measured were very heterogeneous. A larger number of articles dealing with a comparable outcome were finally found only for the outcome measuring nest displacement owing to presence of roads close to nests, which was not initially a priority outcome. Even for this metric, sample size was small when subdividing the whole set in smaller subgroups to explore and model heterogeneity. Data extraction however was highly repeatable, since information on this latter outcome was taken and presented in a similar way in most studies.

6. REVIEWERS' CONCLUSIONS

6.1 Implications for *management / policy / conservation*

In countries where forested areas are very fragmented the fact that big tree-nesting raptors tend to nest far from roads can be a serious handicap for reproduction. This tendency to habitat fragmentation is increasing worldwide and hence presence of roads could become a problem for many countries in the near future.

Regulation of human access to the countryside could make presently unoccupied sites suitable for raptor use. Importantly, the capability of raptors to habituate to ordered human presence is also a management activity worth exploring to increase the carrying capacity of sites.

Our findings also suggest that the use of cliffs to breed by raptors which typically nest on trees may be an indicator of human disturbance locally. On the opposite, the use of trees by raptor species which typically nest on cliffs can be an indicator of low human disturbance, if cliffs are not saturated. In the absence of human disturbance and terrestrial predators many raptor species could probably just nest directly on the ground, such as Eleonora's falcons on Mediterranean islands.

6.2 Implications for research

Further empirical work to quantify the effect of human recreational activities on breeding raptors needs to be carried out if conservation decisions are to be based on evidence. No progress on knowledge accumulation regarding this topic has been detected in the last 30 years. The same doubts raised by the mid eighties are still

unanswered today. We badly need studies based on experimental work, either using natural or *ad hoc* experiments. Obviously, since raptors are often threatened species in many cases *ad hoc* experiments will not be feasible, but many natural experiments and precautionary monitoring could yield useful data if properly applied. Researchers need to move from the traditional studies on nesting habitat selection to studies measuring individual fitness components, which can provide managers with the appropriate information for population conservation. In this sense BACI experiments dealing with breeding parameters such as breeding success and nest-site fidelity should be the priority all over the world and with as many species as possible, with a special attention to raptors of big size and nesting on trees, which have shown to be the most vulnerable and are often threatened species.

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10. APPENDICES

Appendix 1. Main characteristics of studies not suitable for meta-analysis because of lack of constancy (heterogeneity) of outcome metric among studies.

Reference	Species	Ecological characteristics	Methods	Outcome	Results
Andersen et al. (1990)	Red-tailed hawk, Swainson's hawk, Golden eagle, Ferruginous hawk	Army manoeuvre site in south-eastern Colorado since 1985. Rim of the Purgatoire River Canyon. Short grass prairie with <i>Pinus edulis</i> and <i>Juniperus monosperma</i> .	Capture and radio tracking of 18 resident raptors divided in control (no military training activity, n=9) and experimental groups (n=8).	Several measures of change in home range (50% harmonic mean activity area, MCP, 95% ellipse)	Birds in experimental group showed increased MCPs, increased 95% ellipses and made extra-home range movements more frequently than control birds and moved farther in August compared to July MCP boundaries.
Arroyo & Razin (2006)	Bearded vulture	French Pyrenees	Observations of vulture behaviour at >700m from nests as a response to a range of human disturbances. Data from 129 breeding attempts from 22	Presence/absence of vultures and behavioural responses following human activities	Human activities decreased nest attendance of vultures, especially very noisy activities and hunting (even >1.5 km from nest). People on foot, car or planes only affected if close (500-700m). A linear relationship between the frequency of human activities and breeding success explained 21% of the variance. Very noisy activities seem to be the only that accounted for that effect.

			territories. 490 observations of human activities recorded within 2 km of a nest.		
Bautista et al. 2004	Common kestrel, Eurasian buzzard, Booted eagle, Red kite, Black kite, Goshawk, griffon vulture, European black vulture, Spanish Imperial eagle	Mediterranean forest and shrub land close to the city of Madrid. The area is crossed by a road that takes to recreational areas in the outskirts of the city. (24 pairs of the endangered Spanish imperial eagle present in the province).	Ten observations sites along a 19-km section of the road. Data gathered between November and June. N=47 week days and n=18 weekend days. 431 hours of observation.	Distance (near/far) at which raptors were observed from the road on week days and weekends.	Traffic load was two times greater on weekend days. 18 raptor species recorded. 9 recorded during weekend and week days at both distance categories. European black vultures, Griffon vultures and Spanish Imperial Eagles were observed closer to the road on week days. Imperial eagles restricted their activity to a smaller area on weekend days.
Brambilla et al. (2004)	Peregrine falcon	Pre-Alpine relieves in northern Italy and southern Switzerland. Broadleaved forest, farmland and towns.	Undisturbed sites (n=14) were compared to sites disturbed by the presence of ravens or climbers (n=10) and ravens and climbers (n=5).	Fledgling success of pairs affected by disturbance compared to control.	Control nests had a higher reproductive success (percentage of successful pairs) (78,6%, n=14) than nests with ravens or climbers (40%, n=10) and nests with ravens and climbers (0, n=5). A similar pattern was found for productivity (n° fledglings/territorial pair). However, fledgling rate (n° fledglings/successful pair) was similar in all groups.

Brown et al. (1999)	Bald eagle	Military installation (Aberdeen Proving Ground, Maryland), Chesapeake Bay.	Observations on eagle behaviour on nests and roosts after weapon testing at three nests (11 individuals). No control data were taken for nests, only for roosts. Breeding success was compared with that of adjacent areas.	Behavioural reaction of eagles when faced with loud noise compared to quiet zones. Breeding success of eagles nesting within the military zone compared to eagles nesting outside.	Eagles exhibited no activity following relatively loud noise events. Eagles at nests and roosts did not react to noise produced by weapon testing. Eagle nesting success was similar for the military zone and adjacent areas not affected by noise.
Fernández & Azcona (1993)	Marsh harrier	Dos Reinos Lake, Ebro Valley. 21 ha wetland with reedbeds. 11 nesting pairs of harriers and high human pedestrian visitation (50- 100 visitors) during weekends, including crayfish fishermen	6 breeding pairs were observed over reproductive period under different intensities of disturbance.	Parental care behaviour of harriers was compared in disturbed periods with undisturbed periods.	The number of food items delivered and the time spent by males and females in the nesting area and nest decreased during disturbed periods, especially during incubation. Behaviours related to stress increased with disturbance. However, annual productivity of the disturbed pairs was not affected, although disturbed chicks exhibited higher levels of blood urea than undisturbed birds suggesting a worse body condition.
Fraser et al. (1985)	Bald eagles	Intensive study area in north-central Minnesota. Glacial outwash and	Nests were monitored weekly from	Several outcomes measuring the effect of human	Nests were farther from houses than random shoreline points. Nests built on developed shorelines were farther from

		<p>lacustrine plain with lakes, rivers and streams. Boreal forest, deciduous forest and prairie. Many stands are monotypic and even-aged.</p>	<p>fixed-winged aircraft. Birds in nests were disturbed intentionally (n=32) by approaching researchers. Human activities were observed within 1.5km of a random sample of successful and unsuccessful nests. Success rate of eagles, whose nestlings were ringed the previous year, were compared to the success rate of sites in which young were not banded.</p>	<p>activities on choice of nest location, reproductive success owing to recreational activities and research activities.</p>	<p>water than nests on undeveloped shorelines. Breeding eagles flushed at 57-991m. (mean 476, SD=239). 91% flushing distances >200m. Flush distance increases 191.7m for each successive disturbance, decreases 6.8m/day as season progresses, is least early in the morning and late at night, and it is greatest at 8 hours after morning twilight. There was no evidence that there were more human activities within 500m of unsuccessful nests than within 500m of successful nests. Banding young did not reduce the probability of successful nesting the following year.</p>
González et al. (2006)	Spanish imperial eagle	<p>Central Spain. Smooth terrain with rolling plains dominated by olm oak. Dense density of wild rabbits, eagle's primary prey.</p>	<p>Observations on the reaction of nesting eagles to human activities within less than 1 km from nests.</p>	<p>Several outcomes measuring alert and flight behaviours as a function of different human</p>	<p>The probability that human activities close to nests provoked a flight reaction increased with decreasing distance to nests and with the number of people involved. Pedestrian activities caused more flight reactions than vehicles. The</p>

				activities.	probability of a reaction by eagles increased sharply when activities occurred at less than 450 m from the nest but was negligible if they occurred at >800m. Reaction probabilities were lower in territories with higher intrusion frequencies suggesting some degree of habituation. It was also lower where the nest was not visible from the tracks and in less accessible territories. Hatching rate was negatively affected negatively by the frequency of human activities. Critical buffer zones recommended at a minimum of 500m and vulnerable zones at a minimum of 800m.
Ferrer et al. (2007)	Spanish imperial eagle			A critique to González et al. (2006) on the role of buffer zones for the protection of imperial eagles	The authors criticize that González et al. (2006) may have underestimated the fact that eagles can habituate to non-lethal human activities. Works by Ferrer and colleagues suggest habituation of imperial eagles to human intruders. Authors also state that fecundity rates are not very relevant in long-lived species and that conservation effort should be devoted to preventing adult eagle mortality in power lines. They also are concerned with possible detrimental effects due to lack of satisfaction by land owners of pieces of land where eagles nest if restrictions on

					number of visitors are implemented. Eagle habituation can lead to a huge increase in potential nesting habitat for the species.
González et al. (2007)	Spanish imperial eagle			Response of González et al. to critiques by Ferrer et al. (2007)	The authors think that the risk to decrease productivity before total habituation takes place is not worth taking. They also state that compensations to landowners can balance temporary restrictions on number of visitors. They suggest the need to study the effectiveness of buffer zones as conservation tools.
Grier (1969)	Bald eagle	NW Ontario, Canada. Flat area with many lakes and rivers. Boreal forest dominated by white pine. 150 nests were found in 40,000 square miles.	36 nests were climbed by researchers and 118 were left untouched and observed from >100m. Data from two years.	Several outcomes on productivity of nests previously climbed vs. not previously climbed	No negative effects of climbing to nests were detected on 2-11 weeks old young. Productivity of nests climbed one or twice was also similar.
Grubb & King (1991)	Bald eagle	Central Arizona. Salt and Verde river drainages. Clustered mountain ranges and desert basins. Most nests located on 50-100m cliffs. Riparian vegetation.	5517 potentially disturbing events were recorded in the vicinity of 13 nests, comprising 13 types of human activity and 5	Ranking of importance of each activity type (overall and for each disturbance group).	Type and frequency of response varied inversely with distance from an eagle to disturbance. Bald eagles were more often flushed from perches than nests and were more easily disturbed when foraging. Pedestrian was the most disturbing human activity, whereas aircraft was the least. Eagles responded

			potential disturbance groups, within 2000m of breeding eagles. Only the 4188 with known behavioural responses were taken into account. No control.		64% of times at <215m, 45% between 216 and 583m, and 24% at >583m. Distance to disturbance was the most influential variable overall, followed by duration of disturbance, visibility, number of units per event, position relative to eagle and finally sound.
Grubb et al. (1992)	Bald eagle	Au Sable river and Manistee river in northcentral Michigan. Terrain was flat to rolling with an elevational range of 200 to 400m. Vegetation was continuous mixed forest. Rural area, sparsely populated.	Eagle responses to 714 events of potentially disturbing human activities recorded near 6 nests were analyzed.	Several outcomes measuring response frequencies and magnitude of the response. No controls.	Vehicles and pedestrians elicited the highest response frequency, although aircraft and aquatic activities were the most common activities. Magnitude of the response was inversely proportional to median distance of disturbance. 75% of all alert and flight responses when disturbance between 200-500m. Adults responded more frequently than nestlings and at greater distances when perched away from nests.
Holthuijzen et al. (1990)	Prairie falcon (<i>Falco mexicanus</i>)	SW Idaho. Western intermountain sagebrush steppe.	Three study locations (construction, experimental and control). 4 pairs of falcons in	Changes in behaviour of nesting birds following blasting, Changes in occupancy	Falcons reacted to blasting in 54% of the events, but resumed previous behaviour after 2.5 minutes (range 0-27 minutes). Incubating and brooding falcons flushed in 22% of events but returned to their nests within 3.4 ± 0.7

			<p>construction area and 4 in experimental blasting area. 24 blastings in construction area and 90 experimental blastings during incubation.</p> <p>Comparison of the instantaneous reaction, occupancy and productivity in the area of dam construction, a control undisturbed area and a zone of experimental blasting.</p>	<p>rates of nests from year to year in control and treatment areas.</p> <p>Differences in productivity between control and treatment.</p>	<p>minutes. The behavioural repertoire of falcons exposed to blasting was similar to that of control pairs. All pairs exposed to experimental blasting fledged young. 50% of pairs in construction zones fledged young. All territories exposed to experimental blasting were occupied the year after blasting. In the second year following blasting ¾ nests in experimental areas were vacant. Blasting associated with limited human activities does not need to be restricted at distances >125m from nests provided that the noise does not exceed 140dB and no more than 3 blasts occur per day or 90 blasts per season.</p>
Lehman et al. (1999)	Ferruginous hawks, northern harriers, burrowing owls and short-eared owls.	<p>Idaho, north of Snake river canyon. Topography of the plateaus flat to slightly rolling. Vegetation dominated by Artemisia, Atriplex and other shrub species. Military training camp within a conservation</p>	<p>Point counts and line transects to assess relative abundance of nesting raptors inside and outside the conservation area.</p>	<p>Change in relative abundance inside and outside the conservation area.</p> <p>Change in nesting success inside and outside.</p>	<p>Relative abundance of nesting raptors was similar inside and outside the military training area. Nesting success was also similar. Short-eared owls and burrowing owls nested closer to firing ranges used during the pre-laying period, one year.</p>

		<p>area for raptors, with high densities of raptors.</p>	<p>Nesting success evaluated inside and outside the training area on nests found during random plot surveys. Effects of military activities on nesting success assessed by comparing distances from successful and unsuccessful nests to the nearest range during postlaying. Productivity not assessed. Nest distribution in relation to military activity assessed by comparing distances from nests and random points to</p>		
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			the nearest range and tracking area used during pre-laying period.		
Martínez-Abraín et al. (2002)	Eleonora's falcon	Columbretes Islands, E Spain. Small volcanic archipelago.	Monitoring of breeding pairs and productivity in all islands of the archipelago.	Changes in overall population number with increased tourism pressure. Changes in the proportion of breeding pairs between islands. Changes in reproductive success associated to increased tourism.	Overall number of falcon pairs remained constant as well as productivity. However, proportions of birds on each island changed. Falcons moved to islands where tourist presence (number of boats per season) was lower.
Mathisen (1968)	Bald eagle	Chippewa National Forest. Minnesota. Large number of lakes and streams. Nests on overmature red and white pine. Also in aspen and hardwoods. Flat topography.	Three types of areas were defined: low accessibility areas, moderate and high, depending on the presence of roads, presence of timber cutting, other landscape	Changes in nest occupancy and success depending on the degree of accessibility of nests (low, moderate, high)	Rate of occupancy of nests was similar for each group. Nests were successful 54% of the time in low accessibility areas, 57% in the moderate category and 48% in the low category.

			treatments or visibility		
Mearns & Newton (1988)	Peregrine falcon	SW Scotland. Mixed farming, with pasture and arable in the low ground. The hill ground supports open grassy sheepwalk, heather moor and conifer plantation.	Monitoring of productivity of falcon nests from 1974 to 1982.	Percentage nests producing young depending on difficulty of access to nest ledge	73% of the nests with an extremely difficult accessibility were successful vs. 60% of the nests accessible with a rope and 51% of nests accessible without a rope.
Steidl & Anthony (2000)	Bald eagles	Southcentral Alaska. Gulkana National Wild river basin. 70-80 breeding pairs between 1989 and 1993.	Experimental camping at different distances from nests. Recording of time invested in each behaviour in a random set of nests.	Activity budgets of eagles when people were camped for 24h at 100m from nests compared to when they camped at 500m.	With humans near nests eagles decreased the time they preened by 53%, slept (56%), maintained nests (50%) and fed themselves and their nestlings (30%). Eagles increased the time they brooded their nestlings (14%). Overall activity decreased by 27% with humans near as well as the amount of prey consumed by adults (26%) and fed to nestlings (29%). Nest attendance did not change with humans near nests. Time adults were absent from nest area increased by 24%. Throughout 24h treatments responses to nearby humans diminished suggesting habituation to disturbance. During the last 4 hours of treatment adults still vocalized twice as frequently as controls.
Swarthout &	Mexican	Colorado Plateau. Southern	Experimental	Changes in	Overall activity budgets did not change

Steidl (2003)	spotted owls	Utah. Canyonlands and Capitol Reef national parks. 400,000 and 650,000 visitors per year.	hiking in canyons.	activity budgets of males and females with hikers close and far from nests.	substantially when hikers were near nests, although during treatments females reduced the time they handled prey by 57% and decreased the amount of time they performed maintenance behaviours by 30%. In the presence of hikers female and male owls increased frequency of contact vocalizations by 58% and 534% respectively.
Watson (2004)	Bald eagle	Puget Sound region, NW Washington. Diverse saltwater, brackish and freshwater ecosystems. Eagles nest on Douglas fir and black cottonwood along lakes and rivers.	Experimental pedestrian activity. Six hour treatments and controls applied to each eagle nest on consecutive days <200m away for 10 min/hr. 65 experimental trials.	Changes in activity budgets at nest	No damage or injury to eggs or young from flushes. Two-fold increase in mean egg exposure time. Responses were substantially lower at nests that were >40m high and highly screened and also when pedestrian distance to nests increased from 60 to 120m and during incubation compared to brood period.
White & Thurow (1985)	Ferruginous hawks	Raft river valley, south-central Idaho. Elevation 1,500m. Vegetation typical of northern desert shrub biome. Little agricultural and rangeland development.	62 nesting pairs monitored to record behaviour and nesting success. In 24 random nests researchers created	Changes in behaviour at nests when faced with experimental human presence. Changes in reproductive success.	Treated nests and control differed in the number that successfully fledged young. 33% of nests were deserted by adults, despite brief presence near nests. Disturbed successful nests fledged fewer young than undisturbed nests. Adults did not flush 60% of the time if activities were >120m from nests and

			disturbances (approaching on foot, approaching in vehicle, engine noise near nest, firing of rifles) to simulate those associated with land development. 38 nests were not disturbed.		90% if >250m. Buffer zone of 0.25 km recommended if prey are abundant. If prey scarce buffer should be expanded.
Van der Zande & Verstrael (1985)	Kestrel	Central areas of the Netherlands.	Information on 160 nest boxes obtained via mail questionnaires in the Netherlands over the period 1975-1980.	Occupancy rates of nest boxes and breeding success in relation to distance to disturbance.	Kestrels avoid recreational areas and areas 50m from sources of disturbance. Recreation influenced breeding success in areas with free human access. The effect of disturbance is strongest in years with low prey availability and especially during settlement and incubation stages. The effect of distance from roads can be strong both in prey- rich and prey- poor years and is of special influence in the incubating and young-raising stages.
Steidl & Anthony (1996)	Bald eagle	Gulkana river, Alaska. 1989-1992.	Experimental non-motorized recreational boating	Flush response rate and flush distance of breeding and non-	Breeding adults were much less likely to flush than non-breeding birds and flushed at lesser distances. Temporal rather than spatial restrictions

				breeding eagles.	recommended.
Deng (2006)	Grey-faced buzzard and Northern goshawks	Northeast China, Tumenling Mountains. Elevation range 200-500m. East monsoon climate. Vegetation consists of secondary forests. Seven primary tree species include <i>Quercus</i> , <i>Betula</i> , <i>Tilia</i> , <i>Ulmus</i> , <i>Pinus sylvestris</i> .	20 nests and 20 controls for buzzards and 15 nests and 15 controls for goshawks. 16 environmental variables considered at local and landscape scales.	Difference in the distance to nearest forest track and distance to nearest permanent disturbance from nests and control sites.	Distance to forest tracks was smaller from nests than control sites both in grey-faced buzzards and goshawks. Distance to permanent disturbance was larger from nests of both species compared to random controls.
Bielamski (2006)	Common buzzard and goshawk	Niepolomice forest. East of Krakov, Poland. Deciduous northern part and coniferous southern part. 98% forest.	N=15 nests of common buzzards vs. 13 random points in deciduous forest. N=18 nests of goshawks in coniferous forests versus 32 random points.	Distance from nests to nearest forest road	Distance from nests to roads was higher than expected by chance for buzzards in the deciduous forest and coniferous forest and much higher than expected for goshawks in the coniferous forest.
Swenson (1979)	Osprey	Yellowstone National Park. More specifically Yellowstone Lake and small streams.	47 nests located further than 1Km from campsite compared to 19 nests located at less than 1 km from campsite	Nest success and productivity comparing nests located closer and further from campsite	Nest success (0.49 vs. 0.16) and productivity (0.89 vs. 0.21) was higher in nests located further from campsite

Craighead & Mindell (1981)	Swainson's hawks, redtailed hawks, Cooper's hawk, Sharp-shinned hawk, Goshawk, American kestrel and Great horned owl	Western Wyoming	43 breeding pairs in 1947 vs. 23 pairs in 1975.	Number of breeding pairs and several reproductive parameters are compared between 1947 and 1975	Decreases in number of breeding pairs and reproductive parameters (hatching and fledging success) are linked to increased recreational activity in the area during the last 30 years
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Appendix 2. Summary table (articles grouped by topic) for papers with no data to meta-analyze.

EFFECT ON	OUTCOME	REFERENCE	SPECIES	EFFECT MAGNITUDE
Distribution		Andersen et al. (1990)	Red-tailed hawk, Swainson's hawk, Golden eagle, Ferruginous hawk	Extended home ranges in birds affected by military manoeuvres.
		Bautista et al. (2004)	European black vultures, Griffon vultures and Spanish Imperial Eagles	Changed home range during weekends owing to increased traffic.
		Fraser et al. (1985)	Bald eagle	Nests located further from houses than expected
Reproduction	Breeding success	Brambilla et al (2004)	Peregrine falcon	Higher in nests not affected by climbers and/or ravens (78.6%, 40%, 0%).
	Productivity	Brambilla et al (2004)	Peregrine falcon	Higher productivity in nests not affected by ravens and/or climbers
	Fledging success	Brambilla et al (2004)	Peregrine falcon	Similar in all three groups (control, ravens and climbers, ravens or climbers)
	Breeding success	Arroyo & Razin (2006)	Bearded vulture	Reproductive success explained by 21% due to human activities
	Nesting success	Brown et al. (1999)	Bald eagle	Similar nesting success in nests affected by noise derived from military training and control
	Productivity	Fernández & Azcona (1993)	Marsh harrier	Annual productivity was not affected, although chick condition reduced by pedestrian presence
	Nest attendance	Arroyo & Razin (2006)	Bearded vulture	Decreased nest attendance rate under very noisy activities.
	Breeding success	Fraser et al.	Bald eagle	Nests with pedestrian activity close to them and research

		(1985)		presence on nests had similar breeding success than unaffected nests
	Hatching rate	González et al. (2006)	Spanish imperial eagle	Hatching rate negatively affected by frequency of human activities
	Productivity	Grier (1969)	Bald eagle	No effects on productivity of nests previously climbed by researchers or not
	Fledging success	Holthuijzen et al. (1990)	Prairie falcon	Nests with experimental blasting showed similar success than controls
	Nesting success	Lehman et al. (1999)	Ferruginous hawks, northern harriers, burrowing owls and short-eared owls.	Nest success was similar inside and outside military training areas
	Productivity	Martínez-Abraín et al. (2002)	Eleonora's Falcon	Productivity not affected by aquatic tourism presence
	Nest success	Mathisen (1968)	Bald eagle	Similar nesting success in areas with different degree of accessibility
	Productivity	Mearns & Newton (1988)	Peregrine falcon	Less accessible nests were more productive, especially compared to nests accessible without a rope
	Fledging rate	White & Thurow (1985)	Ferruginous hawk	33% of nests deserted when faced with experimental human presence close to nests. Disturbed successful nests fledged fewer young than undisturbed nests.
	Breeding success	Van der Zande & Verstraet (1985)	Kestrel	Reproductive success affected by human presence especially under poor conditions of food availability and during settlement and incubation stages.
	Nesting success	Swenson (1979)	Bald eagle	Nest success was higher in nests located further than 1km from campsite at Yellowstone National Park compared to nests located at less than 1 km (0.40 vs. 0.16)
	Productivity	Swenson	Bald eagle	Productivity was higher in nests located further than 1km

		(1979)		from campsite at Yellowstone National Park compared to nests located at less than 1 km (0.89 vs. 0.21)
	Hatching and fledging success	Craighead & Mindell (1981)	Swainson's hawks, redtailed hawks, Cooper's hawk, Sharp-shinned hawk, Goshawk, American kestrel and Great horned owl	Decreases in number of breeding pairs and reproductive parameters (hatching and fledging success) are linked to increased recreational activity in the area during the last 30 years
Behaviour	Behaviour at nest	Brown et al. (1999)	Bald eagle	No reaction to noises associated with military training
	Parental care	Fernández & Azcona (1993)	Marsh harrier	Decreased food delivered and time spent at nest
	Flush distance	Fraser et al. (1985)	Bald eagle	Increased flush distance from nests in areas with human activity close to nests
	Behaviour at nest	González et al. (2006)	Spanish imperial eagle	Increased alert and flight reaction with approaching pedestrians but not vehicles, although lower in areas with high human intrusion
	Behaviour at nest	Grubb & King (1991)	Bald eagle	Pedestrian presence was the main cause of reaction at nest
	Alert and flush	Grubb et al. (1992)	Bald eagle	Pedestrians and vehicles elicited the highest responses
	Alert and flush	Holthuijzen et al. (1990)	Prairie falcon	Birds unaffected by strong blasting activities
	Behaviour at nest	Steidl & Anthony (2000)	Bald eagle	Reduced activity at nests with humans close (24% reduction) although some habituation occurred
	Feeding rates	Steidl & Anthony	Bald eagle	Reduced feeding rates of chicks

		(2000)		
	Activity budgets	Swarthout & Steidl (2003)	Mexican spotted owls	Activity budgets did not change substantially with hikers close to nests. Time handling prey reduced by 57% and nest maintenance by 30%.
	Behaviour at nest	Watson (2004)	Bald eagle	Two-fold increase in mean egg exposure
	Alert and Flushing	White & Thurow (1985)	Ferruginous hawk	Adults did not flush 60% of the time activities were >120m from nests
	Alert and Flushing	Steidl & Anthony (2000)	Bald eagle	Breeding adults are less likely to flush than non-breeding adults
Foraging	Disturbance while foraging	Grubb & King (1991)	Bald eagle	Eagles were more easily disturbed while foraging than at nests
	Feeding rate	Steidl & Anthony (2000)	Bald eagle	Reduced feeding rates of adults with humans close to nests
Nest occupancy	Abundance of nesting pairs	Lehman et al. (1999)	Ferruginous hawks, northern harriers, burrowing owls and short-eared owls	Similar nest abundance inside and outside military training area
	Rate of nest occupancy	Mathisen (1968)	Bald eagle	Similar rate of nest occupancy in low, moderate and high accessibility areas
	Abundance of nesting pairs	Martínez-Abraín et al. (2002)	Eleonora's falcon	Number of pairs did not change despite increased aquatic tourism abundance
	Occupancy rates of nest boxes	Van der Zande & Verstraet (1985)	Kestrel	Absence of nests at less than 50m from recreational areas
Nest location	Changes in nest location	Martínez-Abraín et al.	Eleonora's falcon	Some nesting pairs moved to less disturbed islands

		(2002)		
	Changes in nest location	Dung (2006)	Grey-faced buzzard and Northern goshawks	Distance to forest tracks smaller from nests than control sites in both species. Distance to permanent disturbance larger from nests of both species compared controls.
	Changes in nest location	Bielanski (2006)	Common buzzard and goshawk	Distance from nests to forest tracks was larger than expected for buzzards in deciduous forests and coniferous forests but much so for goshawks in coniferous forests.

Appendix 3. Summary table by species and topic covered by studies not suitable for meta-analysis.

Species	Distribution	Reprod	Behaviour	Foraging	Nest occup	Nest loc	Total
<i>Red-tailed hawk</i>	1	1	0	0	0	0	2
<i>Swainson's hawk</i>	1	1	0	0	0	0	2
<i>Golden eagle</i>	1	0	0	0	0	0	1
<i>Ferruginous hawk</i>	1	2	1	0	1	0	5
<i>Cinereous vulture</i>	1	0	0	0	0	0	1
<i>Griffon vulture</i>	1	0	0	0	0	0	1
<i>Spanish imperial eagle</i>	1	1	1	0	0	0	3
<i>Bald eagle</i>	1	6	11	2	1	0	21
<i>Peregrine falcon</i>	0	4	0	0	0	0	4
<i>Bearded vulture</i>	0	2	0	0	0	0	2
<i>Marsh harrier</i>	0	1	1	0	0	0	2
<i>Prairie falcon</i>	0	0	0	0	0	0	0
<i>Northern harrier</i>	0	1	1	0	1	0	3
<i>Burrowing owl</i>	0	1	1	0	1	0	3
<i>Short-eared owl</i>	0	1	1	0	1	0	3
<i>Eleonora's falcon</i>	0	1	1	0	1	1	4
<i>Kestrel</i>	0	1	1	0	1	0	3
<i>Marsh harrier</i>	0	0	0	0	0	0	0
<i>Prairie falcon</i>	0	1	1	0	0	0	2
<i>Mexican spotted owl</i>	0	0	1	0	0	0	1
<i>Grey-faced buzzard</i>	0	0	0	0	0	1	1
<i>Northern goshawks</i>	0	0	0	0	0	1	1
<i>Goshawk</i>	0	1	0	0	0	0	2
<i>Common buzzard</i>	0	0	0	0	0	0	1
<i>Cooper's hawk</i>	0	1	0	0	0	0	1
<i>Sharp-shinned hawk</i>	0	1	0	0	0	0	1
<i>Great-horned owl</i>	0	1	0	0	0	0	1
Total	8	29	21	2	7	3	70

Appendix 4. Description of papers with quantitative data suitable for meta-analysis. The metric of effect size is distance (in m) at which raptors located their nest relation to the closest paved road (PVRO) compared to random points within unoccupied sites suitable for reproduction.

Reference	Species	Ecological characteristics	Methods	PVRO	Control
Boal & Mannan (1998)	Cooper's hawk	Greater Tucson (SE Arizona) metropolitan area (70,000 ha). Sonoran vegetation types and riparian corridors. Much natural vegetation is replaced with exotics.	All trees within an intensive survey area were checked for nests. 49 nesting sites were located. 50 random locations within the ISA were selected, centered around the closest tree of 3 species. Sites used in different years within the same territory were considered as independent samples.	42.55	29.12
Bisson et al. 2002	Spanish imperial eagle	Doñana National Park. Mediterranean scrubland, marsh and sand dunes.	73 nest sites (trees) sampled in 14 territories and 73 randomly selected trees in 14 unoccupied territories. Each nest was visited 3 times to monitor reproductive success. Seven habitat variables measured. Modelling through logistic regression.	2811	561.2
Brambilla et al. (2006)	Peregrine falcon	Pre-Alpine relieves in northern Italy and southern Switzerland. Broadleaved forest, farmland and towns.	Fifteen habitat variables measured at 30 occupied cliffs, and 30 unoccupied cliffs.	582	969
Donázar et al. (1993)	Bearded vulture	Spanish Pyrenees. South-central slopes. Largest European population (52 occupied territories in 2001).	Thirteen variables measured on 111 cliffs with bearded vulture nests and 111 cliffs without nests selected at random. Vultures showed lower breeding success in areas with higher density of paved roads.	2060	2340
Gil Sánchez et al. (1996)	Bonelli's eagle	Granada province, SE Spain. 30-37 pairs of eagles nested in the province in 1995.	Eighteen variables of cliffs with nests (n=35) were compared to unoccupied cliffs (n=30) and to unoccupied cliffs without Golden eagle and temperature	1982.1	1684.1

			confounding effects.		
González et al. (1992)	Spanish imperial eagle	Data from the Spanish national census conducted from 1981-1986.	108 nesting sites were compared to 108 random sites. 19 variables were used to characterize nest sites.	3870	2660
Martínez & Calvo (2000)	Eagle owl	Murcia province, SE Spain. Semi-arid zone with less than 300mm of annual precipitation. Shrubs adapted to water scarcity, secondary <i>Pinus halepensis</i> forests and cultivation fields.	23 cliffs with eagle owl nests were compared to 23 unoccupied cliffs. 14 environmental variables considered, within a 1km radius of nests. Five describe the degree of human influence.	1600	1190
Martínez et al. (2003)	Eagle owl	Alicante province, SE Spain. The northern part is rugged with dry cultivated fields, scrubland and Aleppo pine. The south is less rugged with dry and irrigated fields.	51 occupied cliffs were compared with 36 non-occupied but apparently suitable cliffs.	828.82	329.44
Morán-López (2006)	Cinereous vulture	Extremadura region, W Spain.	562 nests were compared to 1157 non-occupied sites chosen randomly. 36 variables measured.	3600	1710
Penterani & Faivre (1997)	Common buzzard	Mountain area in central Italy (Abruzzi Apennines). Beech forest.	17 nesting sites compared to 15 control sites. 21 environmental variables considered	1592	753
Poirazidis et al. (2004)	Cinereous vulture	Daddia Nature Reserve, NE Greece	25 nesting sites were compared to 25 random sites. 31 variables considered	1637.45	1485.09
Ontiveros (1999)	Bonelli's eagle	Granada province, SE Spain. Largely mountainous area. Altitudes ranging 0-3482m. Vegetation includes Pine species and evergreen oaks mixed with cultivated areas.	32 occupied cliffs were compared to 32 unoccupied cliffs. 14 environmental variables considered.	1640.6	1856.20
Sergio et al. (2005)	Common buzzard	Central Italian pre-Alps, near the shore of Lake Lugano. Elevation range (275-1125m). Mountain slopes covered by deciduous forest	Comparison of 10 environmental variables recorded within 700m of 25 independent cliff nests with those recorded at 25 random cliffs.	459.9	412.5

		interspersed with small to medium-sized cliffs and scarce open areas. Valley floors intensively cultivated or urbanised.			
Sergio et al. (2005)	Common buzzard	Central Italian pre-Alps, near the shore of Lake Lugano. Elevation range (275-1125m). Mountain slopes covered by deciduous forest interspersed with small to medium-sized cliffs and scarce open areas. Valley floors intensively cultivated or urbanised.	Comparison of 10 environmental variables recorded within 700m of 25 independent tree nests with those recorded at 25 random trees.	258.0	291.1
García-Ripollés et al. (2005)	Griffon vulture	Castellón province, E Spain. Elevation rank 0-1814m. Vegetation is mainly <i>Pinus</i> spp. and Mediterranean forest.	Comparison of 20 occupied vs. 20 non-occupied cliffs, taking into account 8 environmental variables.	1440.8	1373.8
Suárez et al. (2000)	Booted eagle	Doñana National Park, SW Spain. Marshes, Mediterranean scrubland mixed with cork oaks and stone pines.	84 occupied nests compared to 84 control sites by means of 41 variables.	2250	1610
Bosch et al. (2005)	Booted eagle	Central Catalonia, NE Spain. Mainly pine forests and cereal crops.	10 occupied territories and 10 unoccupied territories are compared.	700	1340
Malan & Robinson (2001)	Black sparrowhawk	Commercial planted forests in different provinces in South Africa	77 occupied trees and 77 random trees	412	441
Andrew & Mosher (1982)	Bald eagle	Chesapeake Bay region, Maryland. Coniferous forest and deciduous forest.	70 occupied sites and 139 random sites	892	447
Rodríguez et al. (2007)	Falco peregrinus	Canary Islands (Tenerife)	26 nests and 26 random points	1065.1	590.2
Ceballos & Donázar (1989)	Egyptian vulture	Navarra (Northern Spain). Northern half of the province within Euro-Siberian region. Southern part within	Comparison of 29 occupied vs. 122 non-occupied cliffs, taking into account 15 environmental variables.	1667.9	1869.9

		Mediterranean region. Altitude range 10 to 2400m.			
Donázar (1988)	Eagle owl	Navarra (Northern Spain). Northern half of the province within Euro-Siberian region. Southern part within Mediterranean region. Altitude range 10 to 2400m.	Comparison of 29 occupied vs. 26 non-occupied cliffs in the mid and high mountains and 12 occupied and 9 non-occupied nests in the Ebro valley, taking into account 18 environmental variables.	(mountain) 12641.4 (valley) 3750	(mountain) 11619.61 (valley) 4188

Appendix 5. Full citation of papers finally selected for quantitative meta-analysis on the impact of human recreational activities on breeding birds of prey.

- Andrew, J.M. & Mosher, J.A. 1982. Bald eagle nest site selection and nesting habitat in Maryland. *Journal of Wildlife Management* 46: 383-390.
- Bisson, I.A., Ferrer, M. & Bird, D.M. 2002. Factors influencing nest-site selection by Spanish Imperial Eagles. *Journal of Field Ornithology* 73: 298-302.
- Boal, C.W. & Mannan, R.W. 1998. Nest-site selection by Cooper's hawks in an urban environment. *Journal of Wildlife Management* 62: 864-871.
- Bosch, J., Borras, A. & Freixas, J. 2005. Nesting habitat selection of booted eagle *Hieraetus pennatus* in central Catalonia. *Ardeola* 52: 225-233.
- Brambilla, M., Rubolini, D. & Guidali, F. 2006. Factors affecting habitat selection in a cliff-nesting peregrine *Falco peregrinus* population. *Journal of Ornithology* 147: 428-435.
- Ceballos, O. & Donázar, J.A. 1989. Factors influencing breeding density and nest-site selection of the Egyptian vulture (*Neophron percnopterus*). *Journal für Ornithologie* 130: S353-S359.
- Donázar, J.A. 1988. Selección del hábitat de nidificación por el buho real (*Bubo bubo*) en Navarra. *Ardeola* 35:233-245. (Provides separate information for two habitat types).
- Donázar, J.A., Hiraldo, F. & Bustamante, J. 1993. Factors influencing nest site selection, breeding density and breeding success in the bearded culture (*Gypaetus barbatus*). *Journal of Applied Ecology* 30: 504-514.
- Gangoso, L. and Donázar J.A. (unpublished data on *Buteo buteo* in Fuerteventura).
- García-Ripollés, C., López-López, P., García-López, F., Aguilar, J.M. & Verdejo, J. 2005. Modelling nesting habitat preferences of Eurasian Griffin culture *Gyps fulvus* in Eastern Iberian Peninsula. *Ardeola* 52: 287-304.
- Gil-Sánchez, J.M., Molino-Garrido, F. & Valenzuela-Serrano, G. 1996. Selección de habitat de nidificación por el águila perdicera (*Hieraetus fasciatus*) en Granada (SE de España). *Ardeola* 43: 189-197.
- González, L.M., Bustamante, J. & Hiraldo, F. 1992. Nesting habitat selection by the Spanish Imperial Eagle *Aquila adalberti*. *Biological Conservation* 59: 45-50.
- Malan, G. & Robinson, R.E. 2001. Nest-site selection in Black Sparrowhawks *Accipiter melanoleucus*: implications for managing exotic pulpwood and sawlog forests in South Africa. *Environmental Management* 28: 195-205.
- Martínez, J.E. & Calvo, J.F. 2000. Selección de hábitat de nidificación por el buho real (*Bubo bubo*) en ambientes mediterráneos semiáridos. *Ardeola* 47: 215-220.
- Martínez, J.A., Serrano, D. & Zuberogoitia, I. 2003. Predictive models of habitat preferentes for the Eurasian eagle owl *Bubo bubo*: a multiscale approach. *Ecography* 26: 21-28. (Data requested to author).
- Morán-López, R., Sánchez, J.M., Costillo, E., Corbacho, C. & Villegas, A. 2006. Nest-site selection of endangered cinereous culture (*Aegypius monachus*) populations affected by anthropogenic disturbance: present and future conservation implications. *Animal Conservation* 9: 29-37.
- Ontiveros, D. 1999. Selection of nest cliffs by Bonelli's eagle (*Hieraetus fasciatus*) in southeastern Spain. *Journal of Raptor Research* 33: 110-116.
- Penteriani, V. & Faivre, B. 1997. Breeding density and landscape-level habitat selection of common buzzards (*Buteo buteo*) in a mountain area (Abruzzo Apennines, Italy). *Journal of Raptor Research* 31: 208-212.
- Poirazidis, K., Goutner, V., Skartsis, T. & Stamou, G. 2004. Modelling nesting habitat as a conservation tool for the Eurasian black vulture (*Aegypius monachus*) in Dadia Nature Reserve, northeastern Greece. *Biological Conservation* 118: 235-248.

- Rodríguez, B., Siveiro, M., Rodríguez, A. & Siveiro, F. 2007. Density, habitat selection and breeding success of an insular population of Barbary falcon *Falco peregrinus pelegrinoides*. *Ardea* 95: 213-223.
- Sergio, F., Scandolara, C., Marchesi, L., Pedrini, P. & Penteriani, V. 2005. Effect of agro-forestry and landscape changes on common buzzards (*Buteo buteo*) in the Alps: implications for conservation. *Animal Conservation* 7: 17-25. (Provides separate information for cliff-nesting and tree-nesting common buzzards).
- Suárez, S., Balbotín, J. & Ferrer, M. 2000. Nesting habitat selection by booted eagles *Hieraetus pennatus* and implications for management. *Journal of Applied Ecology* 37: 215-223.