Time-of-day bias in diurnal raptor abundance and richness estimated by road surveys

Pablo Vergara

Road surveys are the most commonly used method for estimating the abundances of raptors, although biases may occur in relation to the time-of-day that surveys are conducted. However, very few studies have addressed the impact of time-of-day bias on the accuracy of survey results. In the present work, several raptor species were surveyed over the course of a year at different times of day. In six of the 11 studied species, the time of day (hours after sunrise) affected the number of detected individuals and the estimation of species richness. Even slight differences in the time-of-day (e.g. two hours) had a significant impact on results. Furthermore, when detected the time-of-day variation was specific for each species: Hen Harrier *Circus cyaneus*, Montagu's Harrier *C. pygargus*, Common Buzzard *Buteo buteo* and Common Kestrel *Falco tinnunculus* were detected more often around sunrise, whereas Griffon Vulture *Gyps fulvus* and Short-toed Eagle *Circaetus gallicus* were most commonly detected later in the morning (at least two hours after sunrise). No interactions between the time-of-day and season (breeding vs. non-breeding) were found for the studied raptor species. The present study highlights the need to control for time-of-day bias when applying road survey methodology to raptor populations.

Key words: census methods, detectability, flight requirements, management, prey availability, species richness.

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Road surveys are often used to estimate abundances of raptor species (Fuller & Mosher 1981, Ellis *et al.* 1990, Marin & Schmitt 1996, Eakle 1997, Cardiel 2006, Palomino 2006). The technique of counting birds from a car moving at low speed is relatively easy and cost-effective and provides accurate population estimates (Bibby *et al.* 1992, Viñuela 1997). In addition, if conducted using standardized protocols road surveys are a practical tool in the study of seasonal changes in population sizes, habitat selection and comparisons between different regions and/or habitats (Wauer & Wunderle 1992, Sorley & Andersen 1994, Thiollay 1999, Viñuela *et al.* 1999, Dean & Milton 2003, Bustamante & Seoane 2004, Ursua *et al.* 2005), and are potentially of use in decisions regarding land use and management (Leptich 1994, Sanchez-Zapata *et al.* 2003). However, potential biases when using road surveys do exist and include weather conditions, observer, habitat, time of year and time of day (Millsap & Lefranc 1988, Bunn *et al.* 1995, Anthony *et al.* 1999).

It is widely believed that time of day (e.g. morning vs. afternoon) has an effect on raptor activity and thus on their detectability (see Bunn *et al.* 1995). However, despite the widespread use of road surveys to estimate raptor abundances, very few studies have ever addressed the impact of this bias on the accuracy of the method. As well, previous studies have found that the time of day affects each raptor species differently, thus suggesting that it is not possible to establish a single generalized road survey protocol for all raptors (Bunn *et al.* 1995). These results highlight the need for more species-specific studies on the potential effect that time of day may have on raptor abundances estimated by road surveys.

The aim of this work was to explore time-of-day bias in the number of individuals detected of several raptor species and in overall raptor species-richness. The study was conducted in an area of high raptor species-richness during both the breeding and non-breeding periods (see below), thereby ensuring that the effect of the time of day on a great number of raptor species could be studied throughout the year. In addition, other potential biases in raptor abundances such as season (breeding vs. non-breeding) were controlled for; the possible interaction between season and time of day was also explored to test whether the posited time-of-day bias in raptor abundances varies throughout the year and/or between seasons. The ultimate aim of this study was to provide valuable information for improving survey methods in a number of threatened species (see Tucker & Heath, 1994, Madroño *et al.* 2004), of great importance for conservation and management.

Methods

Study area

The study was conducted in an agricultural region in central Segovia province, central Spain (41° 02' 21" N 4° 08' 57" W, altitude 950 m). The study area consists of a mosaic of extensively cultivated cereal fields, ploughed and fallow land, stubbles and patches of pines and poplars. Irrigated land is present but scarce. This area is used by many raptor species during breeding and non-breeding periods (i.e. wintering individuals) (Sanz-Zuasti & Velasco 2005). During the breeding period some species of eagles and vultures use the study area as, respectively, hunting and foraging territories rather than as a breeding area since there is a greater availability of potential nest-sites (e.g. tall trees in the case of eagles or cliffs for vultures) in surrounding areas (Sanz-Zuasti & Velasco 2005).

Survey design

Road surveys were conducted along two linear parallel routes running north-south, which were approximately 10 km apart. Each route was about 25 km long. Surveys were conducted from May 2007 to April 2008 at different times of day. The time of day was categorized in three levels: 1) early morning = from sunrise to 2 hours after sunrise; 2) late morning = 2-4 hours after sunrise; and 3) afternoon = 4-8 hours after sunrise. Two surveys per day, one survey per route, were conducted, except in one case, in which only one route could be surveyed. In total, 89 road surveys were conducted, 17, 18 and 9 for time-of-day categories 1, 2, and 3, respectively, along one route, and 17, 11 and 17 along the other. The average time elapsing between surveys was 8.3 days (range 4-20). Each day the direction of travel and the order of routes surveyed were randomly selected. After the first road survey of the day, at least two hours elapsed before beginning the second road survey (on the other route). All surveys were conducted from the same car travelling at 40-50 km/h. Surveys were also carried out Saturdays and Sundays to avoid any possible weekend bias (Baustista *et al.* 2004). Both routes followed minor roads through farmland with very little traffic. No surveys were conducted on days with rain, mist or high winds. All raptors observed by eye (flying or perching) within 500 m of the road were recorded. Whenever necessary, the car was stopped and binoculars (8x30) or a telescope (20x30-60) were used to identify the species. Other individuals detected during these pauses were not included in the analyses. Flying and perched individuals were not distinguished, as the objective of the present study was to explore differences in the number of detected individuals, rather than differences in behaviour (see Discussion).

Raptor species in the study area

The 'relative raptor-species richness' was calculated as the number of species identified during each survey divided by the total number of species that should be present in a typical year in the study area on that date. Relative species-richness (hereafter 'species richness') rather than absolute richness was used to avoid potential season-related effects. From previous studies (Díaz *et al.* 1996, Sanz-Zuasti & Velasco 2005) the phenology (month) of arrival and departure dates for migratory species are known (see Table 1). This information was used to calculate the

Table 1. Species surveyed, periods in which they were present, total number of detected individuals and range of detected individuals per day and route (see methods for details).
Espècies estudiades, períodes en els quals estan presents, nombre total d'individus detectats i distribució dels individus detectats per dia i itinerari (per a més detalls vegeu mètodes).

Specie	Status	Number of individuals	Range
Griffon Vulture *Gyps fulvus*	Resident	738	0-52
Cinereous Vulture *Aegypius monachus*	Resident	50	0-5
Egyptian Vulture *Neophron percnopterus*	Breeding (March to September)	4	0-1
Golden Eagle *Aquila chrysaetos*	Resident	5	0-1
Imperial Spanish Eagle *Aquila adalberti*	Resident	25	0-2
Short-toed Eagle *Circaetus gallicus*	Breeding (March to September)	10	0-1
Booted Eagle *Hieraaetus pennatus*	Breeding (March to September)	104	0-7
Red Kite *Milvus milvus*	Resident + Non-breeding (October to February)	446	0-27
Black Kite *Milvus migrans*	Breeding (February to September)	749	0-47
Western Marsh Harrier *Circus aeruginosus*	Resident	9	0-2
Hen Harrier *Circus cyaneus*	Non-breeding (October to February)	7	0-2
Montagu's Harrier *Circus pygargus*	Breeding (March to September)	8	0-2
Common Buzzard *Buteo buteo*	Resident + Non-breeding (October to February)	304	0-15
Common Kestrel *Falco tinnunculus*	Resident + Non-breeding (October to February)	410	0-18
Peregrine Falcon *Falco peregrinus*	Non-breeding (October to February)	5	0-1

potential number of species present in the study area during each survey. For resident species, 'season-period' was considered as a binary variable with two categories: 1 = non-breeding and 2 = breeding. In the case of Griffon Vulture *Gyps fulvus*, Cinereous Vulture *Aegypius monachus*, Golden Eagle *Aquila chrysaetos* and Spanish Imperial Eagle *A. adalberti*, 'non-breeding' was taken as the months from September to January and 'breeding' from February to August. In the rest of the studied species present in the study area during the year (see Table 1), 'non-breeding' was designated as the period from September to February and 'breeding' from March to August (Díaz *et al.* 1996, Sanz-Zuasti & Velasco 2005). To calculate species richness, 'non-breeding' was taken as the months from September to February and 'breeding' from March to August since this is the categorization that is best suited to the greatest number of studied species (Díaz *et al.* 1996, Sanz-Zuasti & Velasco 2005). Sample sizes (number of road-surveys) for times of day 1, 2 and 3 were 15, 13 and 8 for breeding, and 19, 16 and 18 for the non-breeding period, respectively.

Statistical procedures

The variation in the number or frequencies of individuals and the raptor species-richness detected during surveys (included as response variables) was analysed among time-of-day periods (included as a three-level fixed factor) with SAS 9.0 statistical software (SAS 1989-96 Institute Inc., Cary, NC, USA). Species with normal distributions for individuals detected during the surveys, raw data (Red Kite *Milvus milvus*) or after log-transformations (Black Kite *Milvus migrans*, Common Buzzard *Buteo buteo* and Common Kestrel *Falco tinnunculus*) were analysed using General Linear Models (GLM) with normal error and identity functions. The Short-toed Eagle *Circaetus gallicus* showed a binary distribution (i.e. '0' = no individuals, '1'= 1 individual per survey) and was analysed using a GENMOD procedure with binomial error distribution and logit function. Species with low numbers of detected individuals per survey were also considered as binaries (i.e. '0' = no individuals, '1'= 1 or more individuals, see

Table 1) and analysed by GENMOD procedures with binomial error distribution and logit function. The number of Griffon Vultures detected during road surveys was high (8.3 individuals per survey), but showed no normal (even after transformations), Poisson or negative binomial distribution. Thus, the abundance of this species was also considered as a binary variable ('0' = no individuals, '1'= 1 or more individuals). According to previous studies, the potential numbers of Egyptian Vulture *Neophron percnopterus*, Golden Eagle, Spanish Imperial Eagle and Peregrine Falcon *Falco peregrinus* in the study area is very low (less than 4-6 individuals, see Martí *et al.* 2003). The present study confirmed these low numbers (see Table 1) and to avoid patterns associated with the presence of only a few individuals, these species were not analyzed independently, but were included as part of the analyses of species richness. In the case of species present in the study area during the whole year (Table 1), 'season-period' was included as a fixed factor, and its interaction with time of day was also tested for. In addition, 'route' was included as a two-level fixed factor in models (to control for potential differences in habitat composition between routes), but was removed when it was not statistically significant. 'Day of the week' (included as a two-level fixed factor, 'weekend' or 'not weekend') did not affect the number of individuals or the species detected (all $P>0.2$) and thus was not included in the final models.

Results

Resident species

Neither time of day, season-period, nor the interaction time of day × season-period significantly affected variation in the number of Cinereous Vultures (all $P>0.16$) or Western Marsh Harriers *Circus aeruginosus* (all $P>0.21$). However, time of day did significantly explain Griffon Vulture numbers ($\chi^2_2 = 6.76$, $P=0.034$, Fig. 1), but season-period ($P=0.10$) and time-of-day × season-period interaction ($P=0.75$) did not. Fewer Griffon Vultures were detected during road surveys conducted in the early morning than in the late morning ($\chi^2_1 = 5.99$, $P = 0.014$) or afternoon (although not significantly so, $\chi^2_1 = 3.34$, $P=0.067$); however, no differences were found between late morning and afternoon surveys ($P=0.58$).

Resident-Wintering species

Variation in the number of Common Kestrels was significantly explained by time of day ($F_{2,84}=5.41$, $P=0.006$, Figure 1), season-period ($F_{1,84}=45.72$, $P<0.001$, more kestrels during the non-breeding period) and route ($F_{1,84}=22.99$, $P<0.001$), but not by the time-of-day × season-period interaction ($P=0.58$). Controlling for season-period and route (both $P<0.01$ in all cases), significant differences were found between early and late morning ($F_{1,59}=6.21$, $P=0.015$), and between early morning and afternoon ($F_{1,56}=7.53$, $P=0.008$), but not between late morning and afternoon surveys ($P=0.58$). More kestrels were recorded during early morning surveys than during the rest of the day, and this trend was similar for both breeding and non-breeding kestrels. The number of Common Buzzards detected was also significantly explained by time of day ($F_{2,85}=8.84$, $P<0.001$, Figure 1) and season-period ($F_{1,85}=34.96$, $P<0.001$, more individuals during the non-breeding season), but not by the time-of-day × season-period interaction ($P=0.81$). Like the Common Kestrel, more individuals were detected early in the morning than during the rest of the day: early morning vs. late morning ($F_{1,60}=14.09$, $P<0.001$) or early morning vs. afternoon ($F_{1,57}=12.27$, $P<0.001$), the season-period being $P<0.001$ in both cases; no differences were found between late morning and afternoon ($P=0.82$). However, variation in the number of Red Kites was affected by season-period ($F_{1,87}=66.91$, $P<0.001$, more kites during the non-breeding season), but not by time of day or by the interaction time-of-day × season-period (both $P>0.25$).

Wintering species

Time of day affected variation in the frequency of road surveys detecting Hen Harriers *Circus cyaneus* (although not significantly so, $\chi^2_2 = 4.62$, $P = 0.099$, Figure 1). More individuals were detected during surveys in the early morning than in the afternoon ($\chi^2_1 = 4.53$, $P = 0.033$), although no differences were found between the other two time-of-day comparisons (both $P>0.15$).

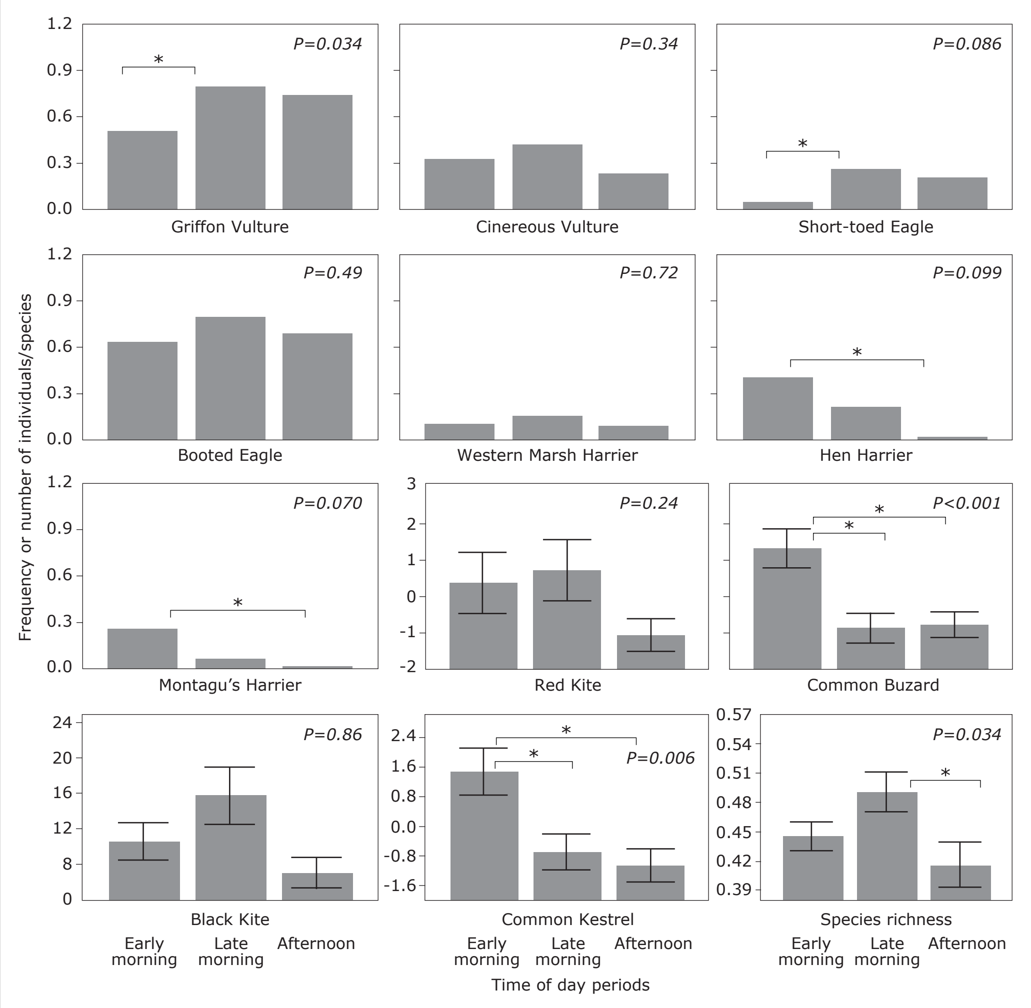

Figure 1. Differences between time-of-day periods in the frequency of detection of individuals and in the number of individuals found during road surveys in the studied species. Bottom-right panel shows the overall species richness (more details in text). Bars represent means and whiskers show SE only for species with normal distributions. Note the differences in the y-axis scale between species. Significant between-period differences ($P < 0.05$) are marked with *. Values of Red Kite, Common Buzzard and Common Kestrel are corrected by season-period.
*Diferències en la freqüència de les enquestes per carretera en la detecció d'individus o en el nombre d'individus censats en les enquestes per carretera entre diversos períodes de temps del dia en les espècies estudiades i riquesa d'espècies (més detalls en el text). Les barres representen la mitjana i les barres d'error el SE només per a les espècies que mostren distribucions normals. Tingueu en compte les diferències d'escala de l'eix y i entre les espècies. Les diferències significatives entre períodes (P <0,05) estan marcades amb *. Els valors del Milà Reial, Aligot Comú i Xoriguer Comú s'han corregit per estació-període.*

Breeding species

The frequency of Black Kites (P=0.86) and Booted Eagles *Hieraaetus pennatus* (P =0.49) found during road surveys was not affected by time of day. However, the frequencies of observed individuals relative to the time-of-day periods were marginally different in Short-toed Eagles (χ^2_2 = 4.90, P = 0.086, Figure 1) and in Montagu's Harriers *Circus pygargus* (χ^2_2 = 5.32, P = 0.070, Figure 1). In Short-toed Eagles fewer individuals were detected in early morning than in late morning (χ^2_1 = 4.54, P = 0.033) or afternoon surveys (although not significantly so, χ^2_1 = 2.83, P = 0.092), although no differences were found between late morning and afternoon surveys (P = 0.63). By contrast, more Montagu's Harriers were detected during early morning surveys than during late morning (but only marginally, χ^2_1 =3.38, P = 0.066) and afternoon surveys (χ^2_1 = 8.06, P = 0.005), although no differences were found between late morning and afternoon surveys (P=0.22).

Raptor species richness

Species richness was significantly explained by time of day ($F_{2,86}$=3.53, P=0.034; Figure 1), but not by season-period (P=0.38) or by the time-of-day × season-period interaction (P=0.52). More species were detected during road surveys conducted in late morning than in early morning (although not significantly so, $F_{1,61}$=3.31, P=0.074) and afternoon ($F_{1,53}$=5.71, P=0.021). In addition, more raptor species were found during early morning than in afternoon surveys, although this difference was not significant ($F_{1,61}$=2.86, P=0.096).

Discussion

Raptor richness and abundance detected during road surveys was affected by the time of day (hours after sunrise), as has been reported in previous studies (e.g. Bunn *et al.* 1995). In addition, the effect of the time of day differed depending on the species: some species showed no variation at all while others were more detectable early in the morning, late in the morning (at least two hours after sunrise) or in the afternoon. In fact, nearly all possible combinations of bias resulting from the time-of-day periods were detected: surveys in the early morning reported the highest number of Common Kestrel, Common Buzzard and Hen and Montagu's Harriers, but also the fewest Griffon Vultures and Short-Toed Eagles. In the case of species richness, late-morning surveys were the most species-rich. These species-specific results agree with previous studies (Bunn *et al.* 1995) that have reported that the highest abundance may vary between species. Similarly, patterns of time-of-day bias differed between species in this study.

Assuming that detectability is linked to activity, one possibility explaining differences within and between species may be the fact that hunting activity varies over the course of the day, possibly as a result of changes in prey availability (Bunn *et al.* 1995). For example, raptors that mainly hunt small mammals are probably more active in the early morning than in the late morning or afternoon since small mammal activity peaks around sunrise (Halle 1995). This agrees with the observed results for kestrels, buzzards and harriers since small mammals such as voles and shrews are important prey items of these species in the study area (Arroyo & García 2004, Fargallo *et al.* 2009). The same idea may explain the time-of-day bias in Short-toed Eagles, which mainly hunt reptiles (e.g. lizards) that have a delayed activity period in comparison with small mammals (Gómez *et al.* 1987, Ellis *et al.* 2007). However, similar explanations are unlikely to be true in the case of the Griffon Vulture whose main food items are livestock carcasses (Donázar 1993), mainly found in *muladares* (dumps of livestock carcasses, see Blanco *et al.* 2007, Lemus *et al.* 2008) in the study area. Therefore, in this species, prey availability is unlikely to be time-of-day dependent. The number of detected individuals of this vulture is probably a consequence of differences in flying requirements and hunting strategies, which are associated with the time of day rather than prey availability. The Griffon Vulture is a large heavy bird that requires thermals and updrafts to soar (Fuller & Mosher 1981); vultures therefore experience difficulty in flying very early in the morning and their peak activity as a result does not occur around sunrise. In addition, differences in hunting strategies between species including hunting by active flight (e.g. kestrels) or by gliding (e.g. kites) - also associated with the presence of thermals and updrafts - may explain time-of-day differences in activity. No time-of-day bias was found for the rest of the studied species, possibly due to a lack of noticeable differences in their activity during the day or to a methodological constraint caused by low sample sizes in some of these species (e.g. Cinereous Vulture, Western Marsh Harrier, see Table 1.).

All of the factors discussed above that link activity and time-of-day bias also help to explain the observed daily pattern of raptor species-richness. The time of day with the highest number of species was late morning, followed by early morning and then by afternoon. This pattern may be a response to the high number of species with temperature-related flight requirements (vultures, large eagles) within the studied raptor group. In addition, the lower number of species detected in the afternoon agrees with this same tendency in most of the studied species (although not significantly in some cases, see Figure 1), and concurs with the idea that - in general - raptors decrease their activity as the day progresses (Bunn *et al.* 1995).

Finally, no significant results for the time-of-day × season-period interaction were found for any of the studied species. This suggests that the studied species behaved similarly during both breeding and non-breeding periods *vis-à-vis* the time of day or, at least, the behaviour patterns that influence detectability were similar in these two periods. In addition, no differences were found between periods, even in species whose numbers increased during the non-breeding period, e.g. Common Kestrel and Red Kite, thereby highlighting the importance of the study area for wintering populations of both these species (see Blanco *et al.* 2007) and indicating that resident and non-resident birds behave in a similar fashion. Therefore, in terms of the road survey methodology, these results seem to imply that it is not necessary to control for the time of day at which road surveys are conducted in order to standardize breeding and non-breeding periods in the studied species.

The present study constitutes a further step toward understanding the effect of time of day on the abundance of raptor species detected by road surveys since small differences in the time of day (e.g. two hours) were shown to affect the number of birds detected. Previous work has shown differences between morning and afternoon surveys, but our study shows that even within 'morning surveys', the time of day might have an effect on the number of raptors detected. This knowledge could be important if the study area is small or if the road survey is short (e.g. less than 100 km). In these cases, road surveys will probably not exceed one or two hours and hence the estimates they obtain are more likely to be affected by a time-of-day bias.

In conclusion, the present study reveals the existence of a time-of-day bias in the numbers of six of the 11 raptor species studied, as well as in the raptor species-richness measured during the road surveys. The fact that time-of-day biases are species-specific may invalidate the use of this methodology for all raptors. In addition, small differences in the time of day that road surveys were conducted (e.g. two hours) may have a significant impact on results.

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Resum

Biaixos en l'hora del dia en l'abundància i riquesa de rapinyaires diürnes estimades mitjançant censos per carretera

Els censos per carretera són el mètode més utilitzat per estimar abundàncies de rapinyaires, tot i que pot mostrar biaixos en funció de l'hora del dia en què es realitzen els censos. No obstant això, molt pocs estudis han analitzat l'impacte dels biaixos en l'hora en la precisió dels resultats dels censos. En el present treball es van censar diverses espècies de rapinyaires durant un any en diferents hores del dia. En sis de les 11 espècies estudiades, l'hora del dia (hores des de l'alba) va afectar el nombre d'individus detectats i a l'estimació de la riquesa d'espècies. Petites diferències en l'hora del dia en què es van realitzar els censos (ex. dues hores) van tenir un impacte significatiu en els resultats. A més, quan es va trobar, aquesta variació en l'hora del dia va ser específica per a cada espècie: Arpella pàl·lida *Circus cyaneus*, Esparver cendrós *Circus pygargus*, Aligot Comú *Buteo buteo* i Xoriguer Comú *Falco tinnunculus* es van detectar principalment al voltant del alba, mentre que el Voltor Comú *Gyps fulvus* i l'Àguila Marcenca *Circaetus gallicus* es van detectar principalment segons avançava el matí (almenys dues hores després de l'alba). No es van trobar interaccions entre l'hora del dia i l'estació (reproductora vs. no reproductora) per a les espècies estudiades. Aquest treball posa de manifest la necessitat de controlar pels biaixos en l'hora del dia quan s'apliquen els censos per carretera a poblacions de rapinyaires.

Resumen

Sesgos en la hora del día en la abundancia y riqueza de rapaces diurnas estimadas mediante censos por carretera

Los censos por carretera son el método más utilizado para estimar abundancias de rapaces, aunque puede mostrar sesgos dependiendo de la hora del día en que se realicen los censos. Sin embargo, muy pocos estudios han analizado el impacto de los sesgos en la hora del día en la precisión de los resultados de los censos. En el presente trabajo se censaron varias especies de rapaces durante un año a diferentes horas del día. En seis de las 11 especies estudiadas, la hora del día (horas desde el amanecer) afectó al número de individuos detectados y a la estimación de la riqueza de especies. Pequeñas diferencias en la hora del día en la que se realizaron los censos (ej. dos horas) tuvieron un impacto significativo en los resultados. Además, cuando se encontró, esta variación en la hora del día fue específica para cada especie: Aguilucho Pálido *Circus cyaneus*, Aguilucho Cenizo *Circus pygargus*, Ratonero Común *Buteo buteo* y Cernícalo Común *Falco tinnunculus* se detectaron principalmente en torno al amanecer, mientras que el Buitre Leonado *Gyps fulvus* y el Águila Culebrera *Circaetus gallicus* se detectaron mayormente según avanzaba la mañana (al menos dos horas después del amanecer). No se encontraron interacciones entre la hora del día y la estación (reproductora vs. no reproductora) para las especies estudiadas. El presente trabajo pone de manifiesto la necesidad de controlar por los sesgos en la hora del día cuando se aplican los censos por carretera a poblaciones de rapaces.

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