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# FORAGING HABITAT USE AND SELECTION OF WESTERN MARSH-HARRIERS (*CIRCUS AERUGINOSUS*) IN INTENSIVE AGRICULTURAL LANDSCAPES

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Abstract.—We studied foraging habitat use and selection of the Western Marsh-Harrier (*Circus aeruginosus*) in agricultural areas, by radio-tracking seven individuals in the Ebro Basin (northern Iberian Peninsula). Generalized Linear Mixed Models indicated that the probability that a certain point within the study area was used by harriers was influenced by both distance to the nesting site and habitat. Probability of occurrence decreased with the distance to the nesting site and increased in wetlands and herbaceous crops (both those with high-intensity agricultural practices and those with low-intensity agriculture). In areas dominated by high-intensity herbaceous crops (irrigated maize, cereal, and alfalfa), marsh-harriers ($n = 2$) did not use all crop types equally throughout the year; they selected different crops in relation to the crop stage (growing, fallow, and stubble) and to particular agricultural practices (irrigated, unirrigated).

Key Words: *Western Marsh-Harrier*; Circus aeruginosus; *agriculture*; *habitat use*; *habitat selection*; *radiotelemetry.*

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USO Y SELECCIÓN DEL HABITAT DE FORRAJEO DE *CIRCUS AERUGINOSUS* EN PAISAJES DE AGRICULTURA INTENSIVA

Resumen.—Estudiamos la selección y el uso del hábitat del aguilucho *Circus aeruginosus* en áreas agrícolas, mediante el uso de radio-telemetría en 7 individuos en la depresión del Ebro (en el norte de la Península Ibérica). La aplicación de Modelos Lineales Generalizados Mixtos mostró que la probabilidad de uso de un punto dentro del área de estudio dependía tanto de la distancia a la zona de cría como del hábitat. La probabilidad de ocurrencia disminuyó con la distancia al nido y aumentó en zonas húmedas y cultivos herbáceos (tanto en campos de uso poco intensivos de secano como en campos de uso muy intensivos de regadío). En zonas dominadas por cultivos herbáceos intensivos (maíz, cereal y alfalfa), los aguilucho ($n =$ 2) no utilizaron todos los cultivos por igual a lo largo del año. Además seleccionaron diferentes cultivos en función de su estadio (crecimiento, sembrado, rastrojo) y de determinadas prácticas agrícolas (con y sin riego).

[Traducción del equipo editorial]

Food supply is one of the main limiting factors for raptors (Newton 1979). Breeding densities and breeding success can vary in relation to food availability (Salamolard et al. 2000, Redpath et al. 2002). Land-use change from extensive dry agriculture into intensive farmlands has been described as a major cause leading to impoverished food resources and reduction or degradation of foraging habitats for many open-habitat birds occupying farmlands (Tella et al. 1998, Newton 2004). However, agricultural intensification has not affected all species in the same way, and some species can still take advantage of such modified environments (Siriwardena et al. 1998).

The Western Marsh–Harrier (*Circus aeruginosus*) is a medium-sized raptor that occurs within a wide range of open habitats, including agricultural landscapes. During recent decades, the species has undergone a moderate increase (<10% in Europe; BirdLife International 2004). In some areas, such as the Iberian Peninsula, the increase and spread of the Western Marsh-Harrier population has been noticeable in some agricultural regions (Molina and Martínez 2008). There the species seems to be benefiting from both artificial irrigation ponds and reservoirs for nesting habitat and from the intensive herbaceous crops in their surroundings for hunting (Cardador et al. 2011). However, little is known

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about foraging habitat use and selection of the Western Marsh-Harrier in agricultural areas (Kitowski 2007, Luo et al. 2010). Because male harriers provide most of the food during the nesting period (Simmons 2000), we investigated the foraging habitat use and selection of male marsh-harriers in an agricultural region within the Iberian Peninsula in relation to habitat type and distance to the breeding site.

## METHODS

**Study Area.** The study area was located in the Catalan Ebro Basin, in the northeastern portion of the Iberian Peninsula. The landscape is mostly low-lying and flat, broken by discrete ranges of small hills (0–400 m asl), and has a semiarid Mediterranean climate. During the twentieth century, agriculture in this area underwent several changes, including the replacement of traditionally cultivated cereals (i.e., spring-sown wheat and barley) with a variety of alternative crops (e.g., winter-sown wheat and barley, alfalfa, maize, or fruit trees), the establishment of irrigation systems, the increase in the use of fertilizers and pesticides, and the reduction or disappearance of fallow systems and field margins (Tella et al. 1998). However, the degree of intensification was not homogeneous in the study area, which is now composed of a mixture of high-intensity herbaceous crops (mainly irrigated alfalfa, irrigated winter-sown wheat and barley, and some irrigated maize crops), high-intensity orchards (mainly irrigated peach, pear, and apple trees), low-intensity herbaceous crops (mainly dry winter-sown wheat and barley) and low-intensity orchards (mainly dry almond and olive trees; Aldomà 2004).

We captured harriers and tracked them at two sites, 30 km apart from each other: the ''intensive farmland'' (41°43′N, 0°23′E), which was dominated by high-intensity herbaceous crops and had scattered small ponds where one, or occasionally two, harrier nests were found (Fig. 1); and the ''mixed farmland'' (41°29′N, 0°30′E), which was a more heterogeneous area, centered on Utxesa, a 280-ha reservoir that harbors a colony of 14–16 breeding pairs (Fig. 1).

**Capture and Radiotelemetry.** During the breeding periods (May–June) 2000–03, we captured and tagged two male harriers in the intensive farmland and five in the mixed farmland. Marsh-harriers were captured in the breeding areas using bal-chatri traps ($n = 6$) or bow nets ($n = 1$). Each harrier was fitted with a backpack transmitter: 12-g AYAMA-Segutel (Mataró, Barcelona, Spain) transmitters or Biotrack (Wareham, Dorset, U.K.) transmitters. Tracking of the birds was conducted from a car. We began each tracking session near the breeding site (<1000 m), and we then followed the signals until the bird was located (i.e., when we knew the position of the bird to within 100 m by visual contact or radio-signal proximity). We used AYAMA or TELEVIT-900 receivers and a three-element Yagi antenna. Tracking sessions lasted on average 6 ± 2 hr ($n = 283$ tracking sessions). Birds were located at all hours between sunrise and sunset. Tagged harriers in the mixed farmland were tracked following a rotational scheme; once one harrier was located, we searched for the next one. Tagged harriers in the intensive farmland could be tracked continuously. We noted the habitat (low intensive herbaceous crops, low intensive fruit trees, high intensive herbaceous crops, high intensive fruit trees, and wetlands; classified in the field by the observer), and plotted each location on 1:25 000 aerial photographs. To avoid autocorrelation, the minimum interval between successive locations of a single bird was 2.5 hr in both the intensive and mixed farmlands and, on average, 2.31 ± 1.02 relocations per harrier per tracking day ($n = 340$ tracking days) were obtained. In cases when several locations were obtained within one 2.5-hr period, the earliest location was selected for inclusion in the dataset. In the intensive farmland (where harriers were tracked continuously), we noted the total time harriers were observed searching for food in fields with different herbaceous crops (alfalfa, cereal and maize), crop stages (growing, fallow and stubble) and agricultural practices (whether the crops were being irrigated or not) during the entire tracking session. We also recorded hunting attempts when witnessed. Harriers were monitored during periods ranging from 1 to 15 mo and were located 1.7 ± 1.4 d/wk ($n = 197$ weeks). We did not expect biases associated with differences in tracking years or periods because marsh-harriers showed high site-fidelity to foraging areas both between and within years in the study area (Cardador et al. 2009).

**Habitat Selection.** We used a generalized linear mixed model (GLMM; binomial error distribution; logit-link function), to describe mathematically the probability that a certain point within the study area was used by birds in relation to its habitat characteristics (included as a categorical variable with five levels: low intensive herbaceous crops, low intensive fruit trees, high intensive herbaceous crops, high

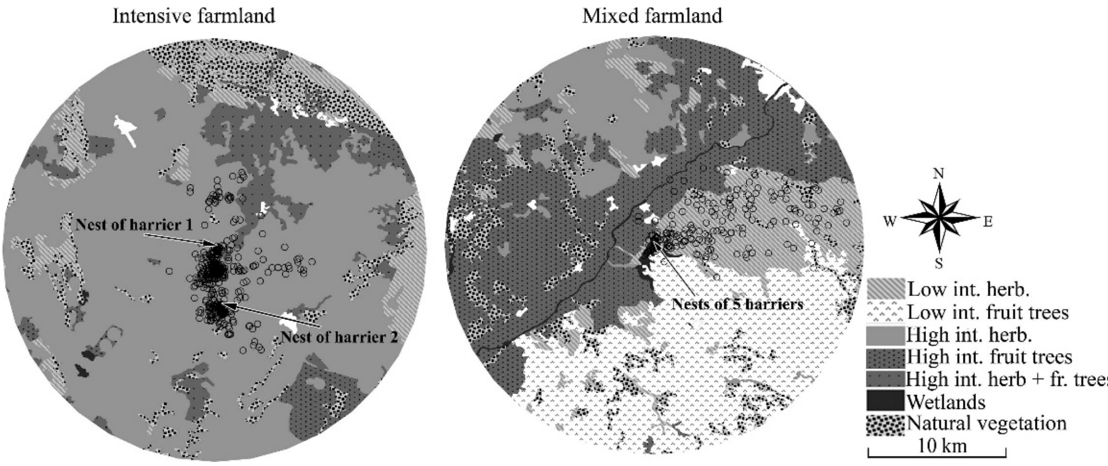


Figure 1. Study area and radio-locations of the seven tagged Western Marsh-Harriers in intensive and mixed farmlands, Catalan Ebro Basin, Spain, May 2000–April 2004. Nest position and available habitats are shown.

intensive fruit trees, and wetlands) and its distance to the nesting site. The dataset included radio-locations of individuals (value 1) and an equal number of randomly selected points not used (value 0) but included within the available study area (Carrete and Donázar 2005). We considered that the total study area was a circle of 15-km radius (the maximum distance from the study site recorded during the study period) focused on the nesting sites. Random points were obtained as independent *x,y* random coordinates within the uniformly sampled study area by using the Animal Movement extension of ArcView 3.2. Habitat types at those points were obtained from a 1:50 000 digital land-use map (Departament de Medi Ambient i Habitatge de la Generalitat de Catalunya, year 1997). In the construction of the model, we included ''individual'' and ''farmland'' as a nested random factor (individual within farmland) in the model to control for the potential nonindependence of data associated with repeated measures of the same individual and farmland.

In the intensive farmland, where harriers ($n = 2$) could be tracked continuously, we also analyzed habitat selection in relation to different herbaceous crops (alfalfa, cereal, and maize), crop stages (growing, fallow, and stubble) and agricultural practices (whether the crops were being irrigated or not). Following Ursúa et al. (2005), habitat selection was analyzed using the Savage selectivity index $w_i = U_i/p_i$, where $U_i$ is the proportion of hunting attempts recorded in a given habitat and $p_i$ is the proportion of total foraging time harriers spent searching for food in that habitat. This index varies

Table 1. Results of GLMM to analyze foraging habitat use of seven male Western Marsh-Harriers relative to habitat and distance to the nesting site (Ebro Basin, 2000–04).

| PARAMETER[1] | ESTIMATE | SE | *t*-VALUE | *P* |
|---|---|---|---|---|
| Intercept | 1.5 | 0.5 | 3.3 | 0.017 |
| Distance | −0.0005 | 0.00003 | −19.3 | <0.001 |
| Habitat | | | | |
| Wetlands | 2.1 | 0.6 | 3.4 | <0.001 |
| Low int. herb. | 3.5 | 0.5 | 7.6 | <0.001 |
| High. int. herb. | 1.5 | 0.4 | 3.4 | <0.001 |
| Low int. fruit trees | −0.25 | 0.9 | −0.3 | 0.78 |
| High int. fruit trees | – | – | – | – |

[1] These results were obtained while controlling for the potential effect of individual and farmland fitted as a nested random term (individual within farmland) in the model ($P = 0.35$). Deviance explained by the model: 53.7%; df = 1259.

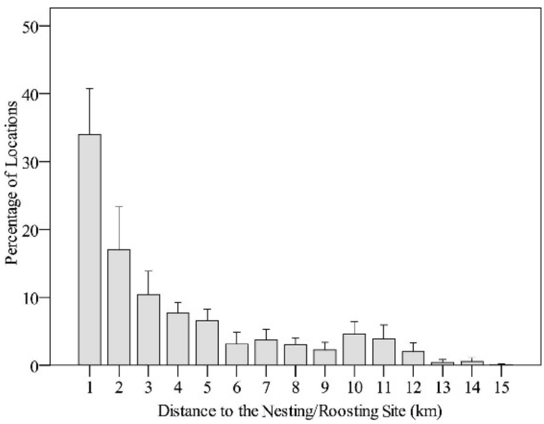


Figure 2. Distribution of distances to the nesting/roosting sites of seven radio-tagged male Western Marsh-Harriers (mean ± SE), relative to distances to the nesting/roosting sites, Catalan Ebro Basin, Spain, May 2000–April 2004.

from 0 (maximum negative selection) to ∞ (maximum positive selection), 1 indicating no selection. The statistical significance of this index was obtained by comparing the statistic $(w_i - 1)^2/\mathrm{se}(w_i)^2$ with the corresponding critical value of a $\chi^2$ distribution with one degree of freedom. The standard error of the index $[\mathrm{se}(w_i)]$ was calculated by $[(1 - p_i)/u_+ * p_i)]^{1/2}$ where $u_+$ was the total number of hunting attempts sampled.

## RESULTS

Seven male harriers were captured and radio-tagged during the study period: five in the mixed farmland (three in 2000 and two in 2001) and two in the intensive farmland (one in 2002 and one in 2003). In total, 678 radio-locations were obtained. The GLMM analysis indicated that the probability that a certain point within the study area was used by harriers was influenced by both distance to the nesting site ($F_{1,1259} = 373$, $P < 0.001$) and habitat ($F_{4,1259} = 22$, $P < 0.001$). Probability of occurrence decreased with the distance to the nesting site and increased in wetlands and herbaceous crops, both high intensive and low intensive (Table 1, Fig. 2).

Radio-tagged harriers in the intensive farmland ($n = 2$) were observed searching for food a total of 227 hr. They principally used alfalfa, maize, and cereal fields (94 ± 2% of total time, $n = 2$). They used alfalfa all year round. Maize use increased during autumn and winter, and cereal use increased during winter and spring (Fig. 3). In total, we observed 455 hunting attempts during this time. Hunting attempts were not distributed at random over the herbaceous crops prospected by harriers. On the contrary, harriers selected different crops relative to habitat type, crop stage, and irrigation (Fig. 4).

## DISCUSSION

Raptors are highly mobile predators, which typically have large home ranges, and which often use more than one type of habitat to satisfy their ecological requirements (Newton 1979). As expected, habitat use of marsh-harriers was mainly delineated by two different habitat types: wetlands (which coincided with the breeding/roosting sites and represented <2% of total available habitat), and the herbaceous crops around wetlands (Schipper 1977, Altenburg et al. 1982, Luo et al. 2010), which may offer an adequate vegetation structure for hunting (Preston 1990). Relative to farming practices, marsh-harriers used both low intensive and high intensive herbaceous crops. Proximity to the nesting site also influenced the probability that an area was used for foraging. Although male harriers can hunt far from the nest (up to 14–15 km), most hunting locations were within 3 km of the bird's nest (62 ± 21%, $n = 7$, Fig. 2). Indeed, differences in crop distribution around breeding sites may explain why marsh-harriers in the intensive farmland mainly foraged in high intensive herbaceous crops while those in the mixed farmland mainly foraged in low intensive herbaceous crops (Fig. 1). As in other central-place foragers, the foraging-habitat selection pattern of marsh-harrier may result from a trade-off between the quality of the different patches and the distance at which they were located from the nesting/roosting sites (Carrete and Donázar 2005, Cardador et al. 2009).

Within intensive irrigated farmlands, Western Marsh-Harriers ($n = 2$) mainly foraged in alfalfa fields (81 ± 2% of total foraging time), followed by cereal (9 ± 2%) and maize fields (4 ± 2%). These percentages differed from those estimated from 1:5 000 aerial photographs (Institut Cartogràfic de Catalunya) ground-truthed in the field in 2003 over an area of approximately 90 km$^2$ (alfalfa: 50%; cereals: 25%; maize: 15%), suggesting that harriers did not prospect all crops at random. Maize fields, which are sown in April–May, were scarcely used before September, probably because their green cover is too dense and high (0.6–2 m) for hunting and were used primarily during autumn and winter when fields are either covered with stub-

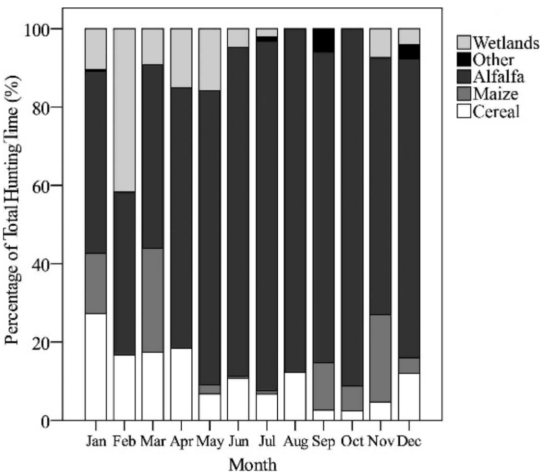


Figure 3. Proportion of hunting time in different crop types by two radio-tagged marsh-harriers in the intensive farmland throughout the year. Mean values for the two harriers are shown. Total observed time = 227 hr.

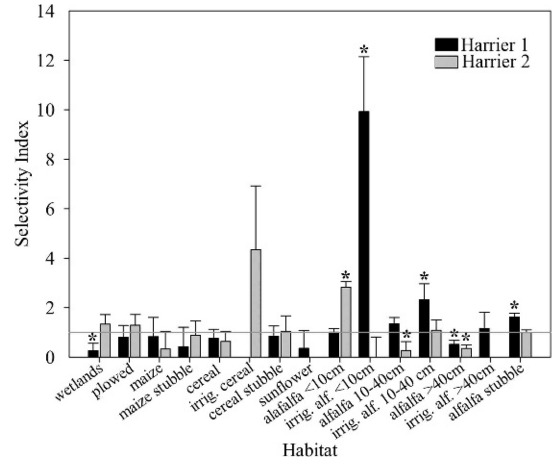


Figure 4. Savage selectivity index (±SE) for each habitat for the two radio-tagged marsh-harriers in the intensive farmland (Catalan Ebro Basin, 2002–04). The horizontal line shows the index value (=1) indicating no habitat selection. Asterisks indicate significant positive/negative selection.

ble or plowed (Ursúa et al. 2005). When harriers used them, hunting attempts were distributed as expected based on the amount of foraging time spent in such crops. Wheat and barley fields were used primarily during winter and spring, during their growing period (before reaching maximum vegetative cover) and harriers did not preferentially use them for foraging. In contrast, Western Marsh-Harriers took advantage of the presence of regularly mown fields (intensively managed alfalfa), which may offer an adequate vegetation structure for hunting during most of the year, especially when crops are <10 cm in height or when stubble is present (Ursúa et al. 2005, Kitowski 2007), and hunting attempts were more frequent than expected based on foraging time spent in these habitats. Interestingly, one of the harriers also increased the number of foraging attempts per hunting-flight time in some fields (alfalfa <10 cm and alfalfa of 10–40 cm) during irrigation. Our observations at the site suggested that the irrigation of such fields may increase the accessibility of small mammals to harriers. The small sample size in our study prevented further analysis of habitat selection and precluded extrapolation of the results outside the studied population.

Although intensification has been considered a major threat for this and other open-habitat bird species occupying farmlands (Benton et al. 2003), our results agreed with previous findings, and showed that intensive agriculture still may offer adequate foraging habitats for some species, at least when food availability is not compromised (Ursúa et al. 2005, Balbontín et al. 2008). Like other generalist predators, Western Marsh-Harriers may be able to exploit transient resources in intensive agricultural habitats, and may be less sensitive to habitat degradation than other more specialized species (Siriwardena et al. 1998).

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