

## SHORT COMMUNICATIONS

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### AGGREGATIONS AND DIETARY CHANGES OF SHORT-TOED SNAKE-EAGLES: A NEW PHENOMENON ASSOCIATED WITH MODERN AGRICULTURE

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Temporary or unexpected patchiness in food distribution can give rise to behavioral changes in many animals, including changes in their characteristic social behavior. The type of food distribution over an area shaped territorial behavior and anti-intruder aggression in juvenile *Anolis aeneus* lizards (Stamps and Tanaka 1981). White Wagtails (*Motacilla alba*) wintering in Israel changed their flocking behavior to territorial behavior when food was distributed in distinct, rich patches that could be defended (Zahavi 1971). In a study on a community of songbirds (Great Tits [*Parus major*], Eurasian Blue Tits [*Cyanistes caeruleus*], Marsh Tits [*Poecile palustris*], Coal Tits [*Parus ater*], and Eurasian Nuthatches [*Sitta europaea*]), Firth and Sheldon (2015) demonstrated that external factors (artificially imposing specified rules controlling individual access to feeding stations) could shape social structure, and that behavioral changes were carried over into other aspects of social structure. The changes were abandoned, however, following cessation of the perturbation, thus indicating a flexible social network.

In raptors, Bald Eagles (*Haliaeetus leucocephalus*) are territorial during the breeding season, but congregate by the hundreds to exploit a seasonally concentrated food resource—spawning salmon—on migration (Restani et al. 2000). Zuberogitia et al. (2010) demonstrated that

Griffon Vultures (*Gyps fulvus*) alter their behavior relative to predation risk depending on food availability and their hunger level, ranging from a cautious approach to more tolerant, fearless behavior when hunger is acute. The Black Kite (*Milvus migrans*) sometimes nests solitarily, but unusually large nesting aggregations occurred in southern Spain where the population of rabbits (*Oryctolagus cuniculus*), a primary prey species, was large (Viñuela et al. 1994). In contrast, when the availability of profitable prey decreased, Red Kites (*Milvus milvus*) in southern Spain increased their food diversity, overall foraging activity, the amount of time spent searching in less favorable habitats, and use of energy-saving flight patterns (Blanco et al. 1990).

Especially for field crops, agricultural cultivation typically involves a system of rapid seasonal changes, thus constituting a highly dynamic ecosystem. The changing availability of food, in terms of its quantity and distribution, is a perpetual challenge for the wildlife within and around agricultural fields, and new agri-technical innovations may pose further challenges but may also represent new opportunities for the associated flora and fauna.

The Short-toed Snake-Eagle (*Circaetus gallicus*) is a medium-sized raptor that forages primarily in open country, generally on the wing and often hovering (Cramp and Simmons 1980). Prey typically consists almost exclusively of reptiles, mainly snakes; however, only a few studies have presented detailed quantitative analyses of the species' diet. In the Dadia Forest of northeastern Greece, the diet included eight species of lizards and 10 species of snakes (Bakaloudis et al. 1998). In southeastern Spain, primarily three species of snakes constituted 95% of the diet, in both frequency and biomass (Gil and Pleguezuelos 2001). During autumn migration through the Straits of Gibraltar,

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however, young Short-toed Snake-Eagles prey on invertebrates, possibly to avoid competition with more experienced adults for other prey resources (Yáñez et al. 2013).

Short-toed Snake-Eagles mostly migrate in small flocks (Panuccio et al. 2012), but much larger flocks can accumulate before a sea barrier (Agostini et al. 2009). Muñoz et al. (2010) reported a communal roost of this species during spring migration at the Strait of Gibraltar. Premuda (2010) also reported observing groups of up to 12 individuals (mostly immature birds) over a 10-yr period at a summer roost site in northern Italy; however, the Short-toed Snake-Eagle is typically not gregarious during the breeding season (Cramp and Simmons 1980). More recently in Israel, however, dozens of Short-toed Snake-Eagles were observed aggregating during summer in crop fields that were being cultivated. The objectives of our study were to quantify and understand the reasons for these aggregations, examine the eagles' diets during this practice, and evaluate the implications of this phenomenon for management of agricultural and natural resources in Israel.

## METHODS

**Study Area.** The study area comprised crop fields in two adjacent villages located in the Judean Foothills of Israel: Kibbutz Gal'on (31°38'N, 34°51'E) and Kibbutz Beit Nir (31°39'N, 34°52'E). The total cultivated area was approximately 1500 ha, divided into 49 plots. The main crops were wheat, oats, watermelons, sunflowers, cotton, and legumes, with some yearly rotations. The study area contained a high density of Short-toed Snake-Eagles; Hadad (2006) documented 133 pairs using 68 nests in a 30 × 20-km area.

**Field Surveys.** SD surveyed 154 fields (1–105 ha in size) on a total of 92 d during the summers of 2006 and 2007. Most surveys occurred when fields were being cultivated. Ten fields were surveyed both 3 d before and during cultivation, and 48 fields were surveyed both during cultivation and again a day later. The surveys produced estimates of the number of Short-toed Snake-Eagles in each field and provided information about the eagles' foraging activity (i.e., frequency of hovering and diving, capture success, prey types, and positions relative to working machinery, usually a tractor) and the characteristics of each field (i.e., area, crop type, and deep or shallow cultivation). We gathered information on prey types sporadically during summer 2008.

In 2007, we also assessed the density of rodents in 41 wheat fields just before cultivation occurred. In each field, we counted the number of active burrows in four randomly placed 2 × 50-m belt transects, and we used the mean burrow count per transect to estimate the density of rodents per 100 m<sup>2</sup> of field.

**Age and Physiological Condition of Eagles.** During the study, we captured 103 Short-toed Snake-Eagles using bal-chatri traps baited with rodents exposed during field

cultivation. We captured 56 eagles while they were aggregating in fields, and 47 eagles while they were foraging solitarily. We assessed the age (adult or immature) and measured the wing chord (mm) and mass (g) of each eagle. We calculated the ratio of wing length to body mass as a measure of physiological condition (Gosler 2004). We also outfitted each eagle with an alphanumeric aluminum leg band prior to release.

**Statistical Analyses.** We used Fisher's exact test to compare proportions, independent *t*-tests to compare means, and paired *t*-tests to compare pre-cultivation versus cultivation and post-cultivation versus cultivation counts of Short-toed Snake-Eagles in relevant fields. All *P* values are for a two-tailed alternative, and we performed parametric tests only after checking for normality.

We used linear regression to evaluate how the density of eagles in fields varied by crop type (wheat or not), the type of cultivation (shallow or deep), the number of fields under simultaneous cultivation, and the density of rodents in the field. Dividing the number of eagles observed by the square root of the transect area produced a linear density estimate (eagles per meter) that was independent of transect area. We considered the linear density of eagles in fields as the dependent variable in the linear regression analyses.

## RESULTS

**Aggregation Size.** The number of Short-toed Snake-Eagles aggregating in fields under cultivation varied from 0 to 89 individuals per field or 0 to 10 eagles per ha (mean ± SE: 0.75 ± 0.08 eagles/ha). We observed no eagles in 10 fields surveyed pre-cultivation, but an average of 18 eagles in the same fields surveyed on the day of cultivation ( $t_9 = 3.19$ ,  $P = 0.01$ ). Similarly, in 48 fields, we counted an average of 23 eagles per field on the day of cultivation, but an average of only 0.5 eagles per field the day after cultivation ( $t_{47} = 9.11$ ,  $P < 0.001$ ).

For the 88 observations from 2006, we tested which field characteristics were associated with eagle presence during active cultivation. Not surprisingly, the number of eagles in the field under cultivation was positively correlated with field area; however, the density of eagles in individual fields was negatively correlated with field area. We also found that the density of Short-toed Snake-Eagles was higher in wheat fields than in other crop types (linear density increased by 2.25 eagles/100 m,  $P < 0.001$ ), was higher in deeply cultivated fields than in shallowly cultivated fields (increased by 1.72 eagles/100 m,  $P = 0.039$ ), and declined as the number of fields under simultaneous cultivation increased (each additional field decreased linear density by 0.70 eagles/100 m,  $P = 0.008$ ).

In 41 wheat fields that underwent deep cultivation in 2007, the linear density of eagles was positively correlated with the estimated density of rodents (Pearson's correlation coefficient: adjusted  $R^2 = 0.49$ ,  $P < 0.001$ ; Fig. 1), but

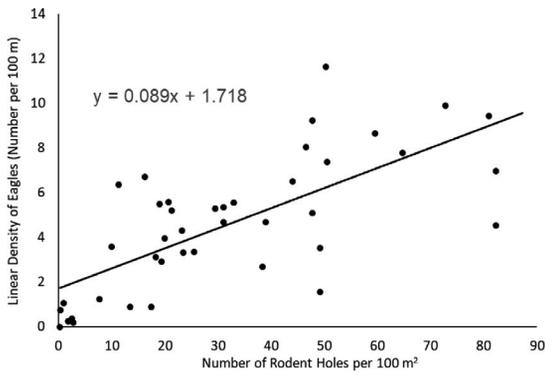


Figure 1. The linear density of Short-toed Snake-Eagles (mean number of eagles per 100 m) in Israel in post-harvest wheat fields during cultivation in relation to the estimated density of rodent holes (holes per 100 m<sup>2</sup>) in the fields just prior to cultivation.

was not influenced by the number of simultaneous cultivations.

**Prey Capture.** Short-toed Snake-Eagles foraged almost exclusively in areas that had just been tilled. During nine surveys of deeply cultivated fields, 89 (65%) of 137 prey capture attempts by eagles were successful. Of 338 confirmed prey items, 328 (97%) were rodents and 10 (3%) were snakes. Of 73 rodents that could be classified to species, 58 (79%) were Günther's voles (*Microtus guentheri*), 12 (16%) were Tristram's jirds (*Meriones tristrami*), and 3 (4%) were house mice (*Mus musculus*).

**Age and Physiological Condition of Eagles.** The percentage of immatures among the 56 eagles caught while aggregating in fields (54%) did not differ significantly from the percentage among 47 eagles caught while foraging solitarily (43%; Fisher's exact test,  $P = 0.36$ ). We detected no difference in the mean wing chord to body mass ratio for eagles caught while aggregating in fields ( $2.90 \pm 0.26$  [SD]) and eagles caught while foraging solitarily ( $2.93 \pm 0.24$ ;  $t_{101} = 0.60$ ,  $P = 0.55$ ).

## DISCUSSION

Deep, post-harvest plowing has given rise to behavioral and social changes in the foraging habits of the Short-toed Snake-Eagle in parts of Israel. Such plowing prepares the field for the next sowing and exposes rodents that accumulated in the field during the growing season. Deep plowing is recommended to reduce rodent populations in agricultural crops by exposing them to desiccation and predation and by destroying their burrows (e.g., de Villafañe et al. 1988 [Argentina]; Jug et al. 2008 [Croatia]; Bonnet et al. 2013 [France]; Jacob et al. 2014 [Germany]; Rodríguez-Pastor et al. 2016 [Spain]). In Israel, the exposed prey attracts and concentrates Short-toed Snake-

Eagles, which generally are territorial raptors. We observed up to 89 eagles in individual, mostly wheat, fields that were being plowed. The aggregating eagles, which normally feed almost exclusively on reptiles (mainly snakes), readily consumed the exposed rodents. Rodents constituted 60% of the prey items brought to a nest in the study area (Y. Eshbol pers. comm.), which was higher than reported in other studies (Bakaloudis et al. 1998, Gil and Pleguezuelos 2001). Although other, non-specialist raptor species—such as the Black Kite (Panuccio et al. 2014)—show plasticity in feeding behavior while exploiting peaks of food sources, such plasticity has not been reported previously for the Short-toed Snake-Eagle.

What remains unclear is why these aggregations mostly appeared only during the last decade, despite postharvest plowing having been practiced in the area for several decades. It could be that the use of more powerful modern machinery has accelerated the process of field conditioning. This process previously extended into the beginning of winter, but may now be more concentrated in summer when Short-toed Snake-Eagles nest in Israel.

Behavioral changes resulting from changes in agricultural methods are common among raptors. Less frequent are cases in which such changes enhance feeding or nesting success for raptors. Reintroducing individuals of the threatened New Zealand Falcon (*Falco novaeseelandiae*) into vineyards—a highly modified agricultural habitat—increased the feeding rates of breeding falcons and related breeding behavior such as nest attendance and brooding rate (Kross et al. 2012). Breeding success of the Western Marsh-Harrier (*Circus aeruginosus*) was enhanced in a mosaic agricultural landscape in northern Spain (Cardador et al. 2011), where habitat around artificial ponds was used for breeding and surrounding crops were used for foraging. The Black-winged Kite (*Elanus caeruleus*) in southwestern Spain may have taken advantage of the gradual increase of cultivated *dehesas* (Mediterranean agro-silvo-pastoral systems) during the second half of the 20th century to expand its range in Europe (Balbontín et al. 2008). The relevant *dehesas*, planted in cereal with a low density of trees, are structurally similar to the African savannahs where the kites thrive, and may offer a higher density of rodents than traditional *dehesas* that contain primarily livestock pasture. However, García et al. (2006) emphasized the importance of maintaining traditional Spanish cultivation practices (*barbechos*) to improve habitat for Lesser Kestrels (*Falco naumanni*) in agricultural areas of Spain.

The phenomenon described in our study has important implications for nature conservation in Israel. The results demonstrate that Short-toed Snake-Eagles can assist agriculture by providing biological control of rodents. Conversely, a shift to foraging on rodents in crop fields exposes the eagles to new hazards in the form of agricultural poisons. The Short-toed Snake-Eagle was one of the few species unaffected by the vast poisoning of raptors that occurred in Israel during the 1960s, mainly because of its

diet (mostly reptiles) and because pesticides were used mostly during the winter before the eagles arrived (Meir 1986). A shift to foraging in intensively cultivated fields would be cause for concern if the birds were increasingly exposed to pesticides (Bakaloudis et al. 1998). Further investigation of this possibility is warranted.

AGREGACIONES Y CAMBIOS EN LA DIETA DE *CIRCAETUS GALLICUS*: UN NUEVO FENÓMENO ASOCIADO CON LA AGRICULTURA MODERNA

RESUMEN.—Recientemente en Israel, docenas de individuos de *Circaetus gallicus*, especie considerada típicamente como no gregaria durante la época reproductiva, han sido observados agrupándose durante el verano en campos agrícolas siendo cultivados. Estos trabajos incluyen el arado profundo, que expone un gran número de roedores. Esta nueva fuente de alimentos ha alterado los hábitos sociales y tróficos de *C. gallicus*, que usualmente es una rapaz territorial, cuya dieta principal son reptiles, especialmente las serpientes. Las águilas se agrupan en estos campos en grandes números y se alimentan de los roedores. Nuestras observaciones mostraron que este fenómeno ocurre principalmente en campos de trigo y que la densidad de *C. gallicus* en estos campos está positivamente correlacionada con la densidad de roedores. Este nuevo fenómeno tiene implicaciones importantes para la conservación de rapaces y demuestra el servicio ecológico que *C. gallicus* proporciona en el control biológico de roedores. Por el contrario, coloca a las águilas en una nueva situación de peligro, debido al riesgo de envenenamiento.

[Traducción del equipo editorial]

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