



HABITAT USE BY FEMALE PEREGRINE FALCONS (*FALCO PEREGRINUS*) IN AN AGRICULTURAL LANDSCAPE

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ABSTRACT.—Intensive agriculture, as is typical of corn and soybean production, may be responsible for declines in the abundance and diversity of farmland birds. In Quebec, the transition to intensive crops is evidenced by marked increases of corn and soybean fields. From 2008 to 2010, we used satellite telemetry to study use of corn (*Zea mays*) and soybean (*Glycine max*) fields, other farmlands, wetlands, urban areas, and other habitats by 10 female Peregrine Falcons (*Falco peregrinus*) of the *anatum-tundrius* complex, a taxon of “special concern” in Canada. We monitored females during the nesting season, from hatching of eggs to independence of young, but before the young dispersed away from the nest site. Adult females were less likely to use corn and soybean fields than the “other farmlands” and “other habitats” categories during the nestling stage and the first month after young fledged. Once young fledged, other farmlands and urban areas were more likely to be used than the “other habitats” category when females were hunting in the areas that were farthest from the nest. The expansion of corn and soybean fields in the Quebec agricultural landscape has occurred to the detriment of other crops and may contribute to the decline in quality of hunting habitat of Peregrine Falcons and other avian top predators. Received 14 August 2012, accepted 11 February 2013.

Key words: corn, *Falco peregrinus*, habitat use, intensive crop, Peregrine Falcon, reproductive success, satellite telemetry, soybean.

Utilisation de l'habitat par les femelles de *Falco peregrinus* dans un paysage agricole

RÉSUMÉ.—Les cultures intensives, comme les productions de *Zea mays* et de *Glycine max*, peuvent être responsables du déclin de l'abondance et de la diversité des oiseaux en milieu agricole. Au Québec, l'augmentation marquée des cultures de *Zea mays* et de *Glycine max* témoigne de la transition vers l'agriculture intensive. De 2008 à 2010, nous avons eu recours à la télémétrie satellitaire pour étudier l'utilisation des cultures de *Zea mays* et de *Glycine max*, des autres milieux agricoles, des milieux humides, des milieux urbains et des autres habitats par 10 femelles de *Falco peregrinus* appartenant au complexe *anatum-tundrius*, un taxon désigné « préoccupant » au Canada. Nous avons suivi ces femelles en période de nidification, depuis l'éclosion jusqu'à l'indépendance des fauconneaux en regard des parents, mais avant leur dispersion. Les femelles avaient moins de chances d'utiliser les cultures de *Zea mays* et de *Glycine max* que les autres milieux agricoles et que la catégorie des autres habitats, pendant que les fauconneaux étaient au nid et le premier mois après leur envol. Après l'envol des fauconneaux, les femelles avaient plus de chances d'utiliser les autres milieux agricoles et les milieux urbains que la catégorie des autres habitats, lorsqu'elles chassaient dans les endroits les plus éloignés du nid. L'expansion des cultures de *Zea mays* et de *Glycine max* dans le paysage agricole du Québec, qui se produit au détriment d'autres cultures, peut contribuer au déclin de la qualité des habitats de chasse du Faucon pèlerin et d'autres oiseaux de proie.

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THE ANATUM–TUNDRIUS COMPLEX of the Peregrine Falcon (*Falco peregrinus*; hereafter “peregrine”) is ranked as of “special concern” in Canada (Committee on the Status of Endangered Wildlife in Canada 2007), and the subspecies *F. p. anatum* is ranked as “vulnerable” in Quebec (Gazette officielle du Québec 2003). Despite this status, most of the Canadian populations of *F. p. anatum* have been increasing since the end of mass hacks of captive-raised young in 1996 (Holroyd and Banasch 2012); where populations have been declining, low productivity because of a lack of prey species is suspected (Holroyd and Banasch 2012). The peregrine can feed on a wide range of bird species and is often recognized as a generalist predator (Redpath and Thirgood 1999). However, it can also specialize on a more restricted range of prey (White et al. 2002, Dawson et al. 2011). Although the species occurs in many habitats, it prefers hunting in open environments (Cade 1982), such as agricultural landscapes, where potential prey are abundant (Carter et al. 2003, Sergio et al. 2004).

Since the past century, agricultural landscapes of Europe and North America have been progressively transformed with the conversion of extensive crops into intensive crops (Best et al. 1995, Chamberlain et al. 2000). Intensive cropping has been cited as the principal reason for massive increases in global agricultural production since the mid-20th century (Food and Agriculture Organization 2007). This method of crop production is implemented to maximize yield through the heavy use of pesticides and fertilizers (Jobin et al. 2003, Le Roux et al. 2008, Meehan et al. 2010) and features deep and repetitive tillage (Le Roux et al. 2008). Intensive cropping has often been suggested as the main culprit responsible for declines in species abundance and diversity (Le Roux et al. 2008) among plants (Billeter et al. 2008, Liira et al. 2008), insects (Cherrill 2010), mammals (Aschwanden et al. 2007), amphibians (Sparling and Fellers 2009), and birds (Boatman et al. 2004, Billeter et al. 2008).

Direct effects of pesticides on birds are well known (Newton 1995). In addition, many pesticides are now believed to have broad indirect effects propagated through food webs (Newton 1995), and many studies have implicated pesticide and fertilizer use in intensive cropping as the cause of declining bird species abundance and diversity in agricultural areas of Europe and North America (e.g., Best et al. 1995, Stoate et al. 2001). Decreases in plant diversity because of herbicide use can reduce host plant numbers, which in turn diminishes the abundance of the invertebrates associated with these host plants (Campbell and Cooke 1997), which then reduces the availability of seeds and invertebrates that serve as the food supply for birds during the nesting season (Campbell and Cooke 1997). In Quebec, the conversion from extensive to intensive agriculture has occurred at an impressive rate (Jobin et al. 2004). For example, the surface area occupied by soybeans (*Glycine max*) increased sixfold between 1991 and 2006, while that of corn (*Zea mays*) increased by 38% during the same period (Statistics Canada 2009). According to Best et al. (1995), few bird species utilize corn and soybean fields. Moreover, the replacement of extensive crops with intensive crops such as corn and soybeans on marginal lands has reduced the number of bird species in the American Upper Midwest (Meehan et al. 2010).

Along with other apex predatory bird species (Sánchez-Zapata and Calvo 1999, Cardador and Mañosa 2011), the peregrine is likely to be affected by intensive cropping. A decrease in the availability of high-quality prey in areas of intensive cropping, particularly in areas of corn and soybean production, could have consequences for peregrine hunting success and, ultimately, reproductive success.

The main objective of our study was to quantify and compare the use of intensive corn and soybean fields by female peregrines in their home range during the nesting season when other habitats were available. Given that prey are less abundant in intensive crops (Best et al. 1995, Stoate et al. 2001), we predicted that corn and soybean fields would be utilized to a lesser degree than the “other farmlands” and “other habitats” categories. Moreover, because peregrines are central-place foragers during the nesting season, we also predicted that the probability of patch use would decline with increasing distance of the patch from the nest (the central place; Rosenberg and McKelvey 1999). Also, because the food needs of the brood increase as the young peregrines grow, we predicted that female home-range size would increase between the nestling period and the first month after fledging.

METHODS

Study area.—Our study area is mainly located in southern Quebec (Fig. 1) and extends over the St. Lawrence Lowlands, the Appalachians, and the Abitibi and James Bay Lowlands (Li and Ducruc 1999). In the St. Lawrence Lowlands, agriculture covers >50% of the territory (Li and Ducruc 1999), with corn and soybeans as the main crops (La Financière agricole du Québec [FADQ] 2010a). Agriculture in the Appalachians is practiced in the less hilly terrain and in the southern parts of this region, occupying ~15% of the territory (Li and Ducruc 1999). The main crops are hay, corn, oats (*Avena sativa*), barley (*Hordeum vulgare*), and soybeans (FADQ 2010a). In the southern part of the Abitibi and James Bay Lowlands, agricultural production does not dominate the landscape and consists mainly of hay fields (FADQ 2010a). The study area encroaches upon a small part of the Champlain Lowlands (U.S. Environmental Protection Agency 2011) in New York and Vermont, where hay and corn are the main crops (U.S. Department of Agriculture [USDA] 2009a, b).

Capture, manipulation, and telemetry.—From 2008 to 2010, we banded and fitted 30-g PTT transmitters on 10 breeding females, using a backpack harness made of Teflon. We captured birds at the beginning of the nesting season (i.e., end of March to mid-May). They were captured either using the dho-gaza method (Bloom et al. 1992) with a live or lure owl or using a TR-170 trap (Northwoods Falconry, Rainier, Washington) with a live Rock Dove (*Columba livia*) as lure. The transmitters of the 10 females that were monitored during the study were programmed to indicate the bird’s location once every hour during the species’ activity period (0500 and 1900 hours EST).

Periods sampled during the nesting season.—Telemetry fixes of adult birds were classified into two periods: (1) the nestling stage and (2) the first month after fledging. The nestling stage was defined by the period when the chicks were unable to take flight. The start and end of these periods were generally estimated through back calculation ($n = 7$), by establishing nestling ages during subsequent visits to the nesting site (Canadian Peregrine Foundation 2010). The 30 days estimated for the period after fledging represented the average duration of young peregrines’ dependence on their parents, before they disperse away from the nest site (Weir 1978).

In nearly half the cases ($n = 6$), no data were available for the ages of young peregrines, and therefore hatching date was based on telemetric data (i.e., by taking the first day in a sequence of several days, during which no or very few telemetry fixes were transmitted). We considered this method reliable because the females are bound to be present at the nest during the first 14 days after

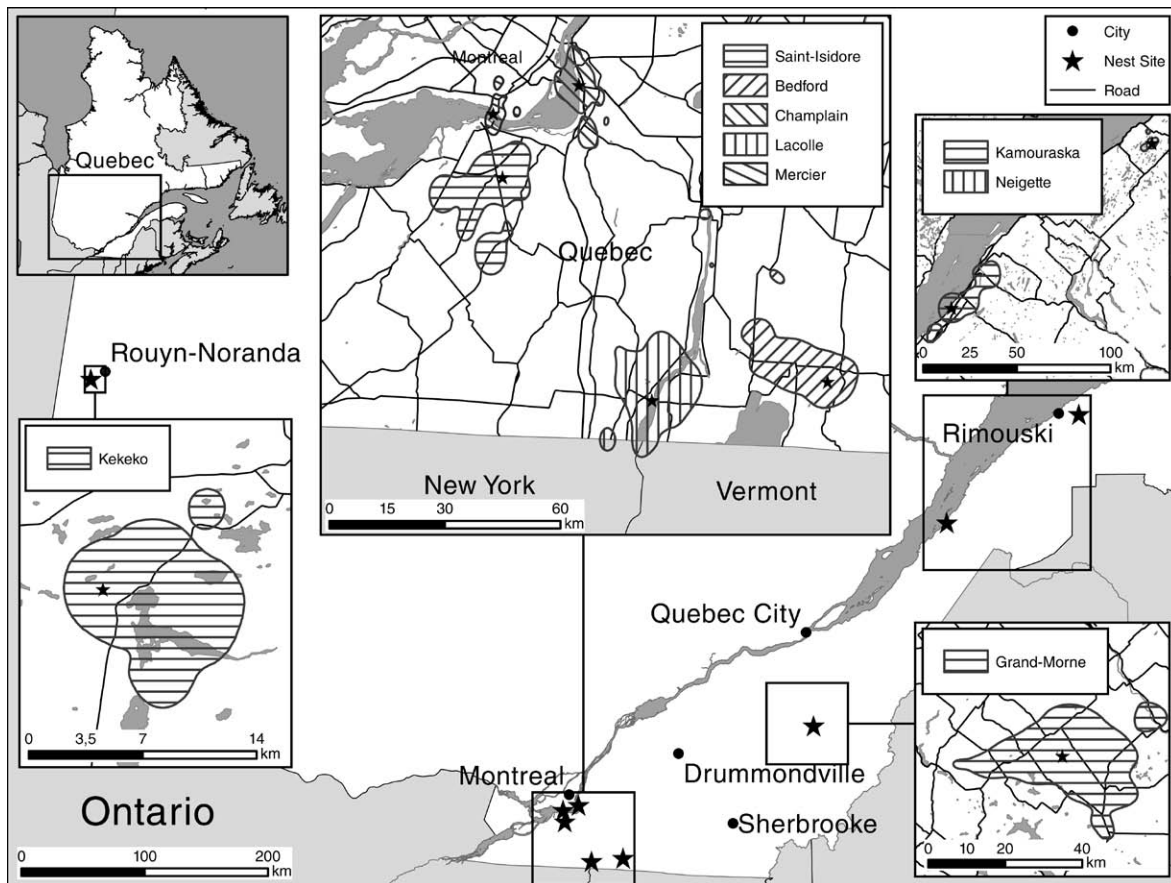


FIG. 1. Map of the study area in southern Quebec. Inserts show the location of Peregrine Falcon nest sites and the delimitation of home ranges during the first month after fledging.

hatching (Harrison 1984), thereby rendering communication between transmitters and satellites more difficult. In some cases, more than one period with few or no data was identified. To retain the period most likely relevant to hatching, the units were compared with dates derived from back calculations.

Habitat categories.—Available habitats were classified into five categories: corn and soybean fields, other farmlands, wetlands, urban areas, and other habitats (habitats not belonging to any other category). The map layer for the wetlands was obtained from digital maps at the scale of 1:20,000 from the third or fourth ecoforest inventory that was conducted by the Province of Quebec (Ministère des Ressources naturelles et de la Faune 2009, 2011).

Our choice of habitats belonging to wetlands was based on research performed by Lemelin et al. (2010), who studied the selection of these environments by waterfowl species that are potential prey of the peregrine. This resulted in the retention of lakes, rivers, ponds, and islands with surface area <20 ha, as well as wetlands with tree cover <25%, shrub swamps, and flooded zones. Brooks were also added to this category of habitat. To account for the precision of our telemetry fixes (± 18 m), a buffer strip of 30 m was applied around these polygons and brooks. We considered that wetlands might not have any perches and that peregrines would be forced to perch at the perimeter of these to search for prey.

Urban areas, including rural agglomerations, were obtained by combining two map sources to produce the most accurate representation possible. We combined the agglomeration map layer at a scale of 1:50,000 from the National Cartography Database (Government of Canada 2004) with the urban polygons that were depicted on digital maps of Quebec's third or fourth ecoforest inventory.

The cartography of the agricultural areas was based mainly on the insured-crops database of FADQ, using the following categories: wheat (*Triticum aestivum*), canola (*Brassica napus*), hay, corn, barley, oats, soybean, other seeds, market gardening, and small fruits (FADQ 2008, 2009, 2010a). Because of crop rotation, we used the digital layers corresponding to each year of our study. Because each of these layers alone did not represent all ($\geq 90\%$) of the cultivated territory of Quebec (FADQ 2010b), we combined these with the agricultural and agroforestry polygon layer derived from the third or fourth ecoforest inventory mentioned above. Telemetry fixes that were located at distances ≤ 30 m from an agricultural area and outside of a wetland or an urban area were linked with the agricultural category to which they were the closest. This method was used because of the possible absence of perches within the agricultural areas, as is the case with wetlands.

We obtained some 30 telemetry fixes in the states of Vermont and New York for one individual in the sample. In this case, we used maps provided by the USDA (2009a, b) to delineate the

habitat that had been used. All geomatic manipulations were performed in ARCGIS, version 10 (ESRI, Redlands, California).

Statistical analyses.—We used 95% fixed-kernel density estimates to demarcate the home ranges of each female per year and period. The smoothing factor of the density function, which is a critical component of the fixed-kernel method (Worton 1995), was estimated using the biased cross-validation (BCV) method. The BCV method is more appropriate for large samples (Wartmann et al. 2010). To improve the accuracy of home-range estimates and to avoid losing useful biological information, we did not eliminate spatial and temporal autocorrelation by subsampling the data (De Solla et al. 1999). Between study periods, the average surface areas of the home ranges were compared using a paired *t*-test.

We used logistic regression with random effects to estimate probabilities of use for each habitat category (Zuur et al. 2009). We estimated parameters in the models using the Laplace approximation to the likelihood (Raudenbush et al. 2000). We treated individual peregrines and years of the sample as random effects to account for the correlations between the observations of the same individual in a given year. To obtain the probability function of resource selection (Manly et al. 2002), we compared separate samples of telemetry fixes that were used versus random unused ones. This type of case-control sampling provides a biased estimate of the probability of use, because model intercepts are different from those of conventional models (Keating and Cherry 2004). Therefore, we presented the probabilities of use as odds ratios, which allowed us to make approximately unbiased quantitative analyses (Keating and Cherry 2004). The 95% confidence intervals of the odds ratios were calculated using the delta method (Oehlert 1992).

We tested our hypotheses regarding the probability of habitat use by comparing eight candidate models (Table 1). The distance variable was integrated into several candidate models to reduce the bias generated by the selection of habitats close to the nest (Rosenberg and McKelvey 1999). Euclidean distance was natural log-transformed and centered to simplify calculations and linearize relationships. We used Akaike's information criterion, corrected for small sample size (AIC_c), to compare the candidate models with one another and to identify the most parsimonious

one (Burnham and Anderson 2002). Models with a $\Delta AIC_c \leq 2$ were considered to be most plausible (Burnham and Anderson 2002).

Our statistical inference was based on only 10 individuals, which constituted the main limitation of our analyses, despite having between 135 and 1,761 telemetry fixes for each individual. Our small sample size and the heterogeneity of the landscapes surrounding the nesting sites that were inhabited by these individuals justified verification of the stability of the model that we retained. To do so, we conducted a sensitivity analysis by redoing model selection after having removed, in turn, a different individual from the sample, and by recalculating the estimates of the parameters of the top-ranked model.

Home ranges were estimated within R, version 2.13.1 (R Development Core Team 2011), and the packages ADEHABITAT, version 1.8.6 (Calenge 2006), and KS, version 1.8.2 (Duong 2011). The manipulations regarding the selection of random points and the association of habitat attributes with used and random telemetry fixes were performed with GEOSPATIAL MODELLING ENVIRONMENT, version 0.5.3 Beta (Beyer 2011), which uses R as well as the ARCGIS environment. The models were adjusted and compared in R, with the packages LME4, version 0.999375-41 (Bates et al. 2011), and AICCMODAVG, version 1.17 (Mazerolle 2011).

RESULTS

Between 2008 and 2010, 10 females provided a total of 8,825 telemetry fixes during the nesting season. These data excluded fixes in years when some females were not breeding ($n = 2$). On average, the date of hatching was 18 May (27 April–14 June) and the end of the nestling stage (or the date of fledging) was 1 July (19 June–16 July). The end of the first month after fledging was, on average, 2 August (19 July–15 August). After estimating the home-range sizes, only the telemetry fixes that were included within those home ranges were retained for subsequent analyses. Thus, a total of 8,356 telemetry fixes were retained; 4,588 (54.9%) during the nestling stage and 3,768 (45.1%) during the first month after fledging.

Home ranges and distances from the nest.—Areas of home ranges of the adult females that provided data over entire periods were quite variable, averaging 83.9 km² (range: 0.3–392.5 km²; SD = ± 120.7 km²; $n = 12$) during the nestling period and 201.9 km² (range: 10.0–811.1 km²; SD = ± 261.1 km²; $n = 10$) during the first month after fledging. The average home-range area of females during the first month after fledging was significantly larger than during the nestling period ($t = -4.23$, $df = 9$, $P < 0.05$). Some 95% of the telemetry fixes were located within an 8.7-km radius (maximum distance = 25.2 km) of the nest during the nestling period, compared with a 16.1-km radius (maximum distance = 33.0 km) during the first month after fledging—all were within the defined home ranges.

Habitat use.—Our data suggest that corn and soybean fields were underutilized at almost every distance class from the nest location (Fig. 2). By contrast, the most heavily used habitat category ≤ 5 km from the nest was the “other habitats” category. Most of the nest sites were located in or beside this catchall habitat category. Breeding females often perched or fed their brood on the nest ledge or in its vicinity, and this probably contributed to an overestimate of the use of the “other habitats” category inside of 5 km from the nest.

With an Akaike weight (w_i) of 1, the global model was clearly the most parsimonious among the models that were compared (Table 1). Nest distance was included in all top-ranking candidate models

TABLE 1. Model selection according to Akaike's information criterion, corrected for small sample size (ΔAIC_c ; w_i = Akaike weight), of eight logistic regression models with random effects explaining the probability of habitat patch use by 10 female Peregrine Falcons in southern Quebec, 2008–2010.

Model ^a	K^b	ΔAIC_c	w_i
Model 7: Period + Habitat + Distance + Period * Habitat + Habitat * Distance + Period * Distance ^c	18	0.00	1
Model 5: Period + Distance + Period * Distance	6	657.31	0
Model 4: Habitat + Distance + Habitat * Distance	12	1,049.23	0
Model 3: Habitat + Distance	8	1,552.65	0
Model 2: Distance	4	1,800.05	0
Model 6: Period + Habitat + Period * Habitat	12	4,771.40	0
Model 1: Habitat	7	5,072.25	0
Model 8: Intercept only (null model)	3	6,967.13	0

^a Variables: Period = the nestling period and the first month after fledging; Habitat = corn and soybean fields, other farmlands, wetlands, urban areas, other habitats; and Distance = $\log(\text{Distance}) - \text{average}[\log(\text{Distance})]$.

^b Number of parameters including the intercept and the variance.

^c Global model.

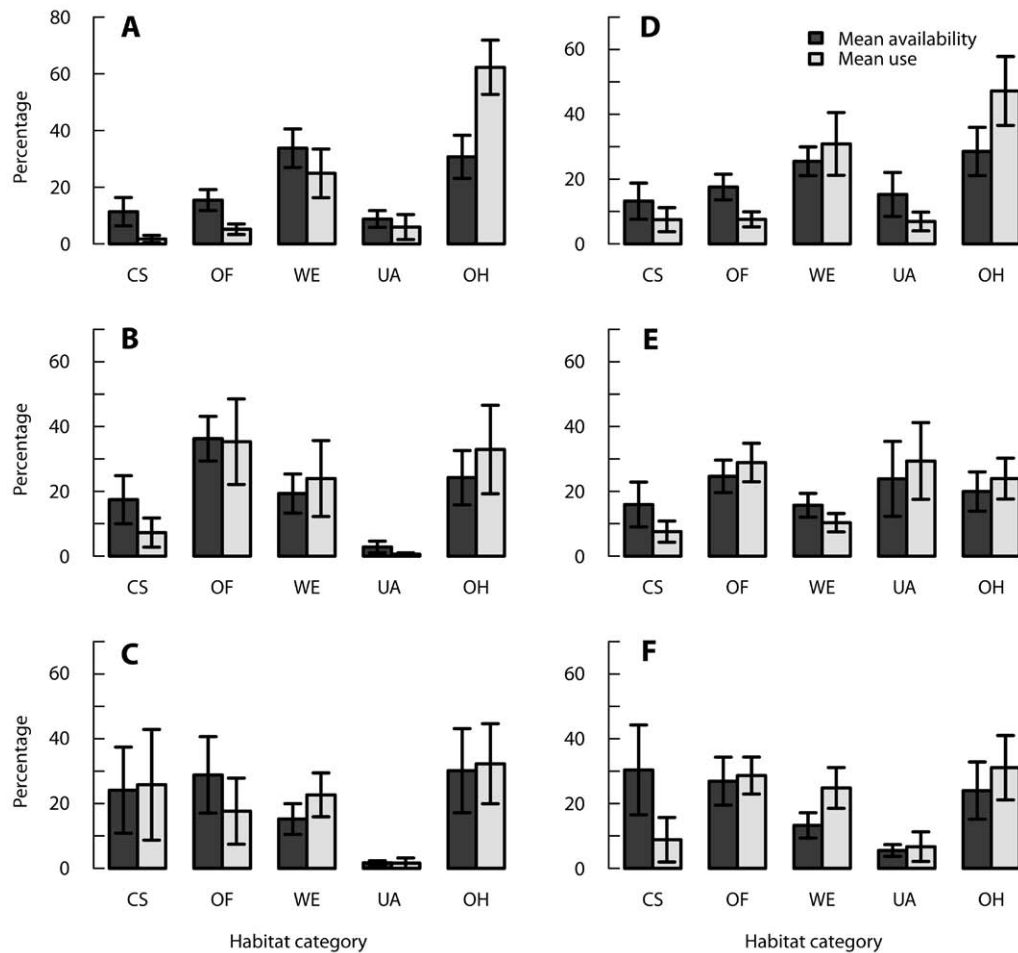


FIG. 2. Comparison of mean habitat availability and mean habitat use by 10 female Peregrine Falcons during the nestling period in southern Quebec: (A) ≤5 km, (B) >5 to ≤10 km, and (C) >10 km; and during the first month after fledging: (D) ≤5 km, (E) >5 to ≤10 km, and (F) >10 km. Abbreviations: CS = corn and soybean fields, OF = other farmlands, WE = wetlands, UA = urban areas, and OH = other habitats.

according to the ΔAIC_c and had a major effect on the probability of use of a habitat patch (Table 1). According to the global model, the probability of habitat patch use by a breeding female decreased with increasing distance from the nest, even though the effect of distance depended on habitat category and period (Table 2). The effect of distance was stronger in the wetlands and weaker in the corn and soybean fields and “other farmlands” habitat categories (interaction between distance and habitat category). Moreover, the effect of distance on habitat patch selection was greater during the nestling period than during the first month after fledging (interaction between distance and period). Also, the effect of the nestling period on habitat patch selection was stronger in the wetlands than in the “other farmlands” category (interaction between period and habitat category).

Within the range of distances represented in the figures (including >98% of the telemetry fixes), “other farmlands” (odds ratio $\pm 1.96^*SE$: 0.41 ± 0.10 to 1.51 ± 0.37) and “urban areas” (0.65 ± 0.13 to 0.89 ± 0.07) categories were less likely to be used than the “other habitats” category within the first 8 km from the nest during the nestling period (Fig. 3A, B). Beyond this distance, “urban areas” had as great a probability of being used as did the “other habitats” category. The “other farmlands” category was more likely

to be used than the “other habitats” category when located >15 km from the nest. During the first month after fledging, the use of “other farmlands” (0.61 ± 0.12 to 1.62 ± 0.26) by adult females was comparable to the preceding period, with their probability of using this habitat being greater than the “other habitats” category beyond a distance of 10 km from the nest (Fig. 3C). “Urban areas” (0.97 ± 0.05 to 1.55 ± 0.39) were more likely to be used than “other habitats” except within the first kilometers from the nest, where they had as great a probability of being used as did the “other habitats” category (Fig. 3D).

Corn and soybean fields (0.22 ± 0.10 to 0.78 ± 0.38), together with wetlands (0.31 ± 0.09 to 1.00 ± 0.01), were less likely to be used than “other habitats” at most distances from the nest during the nestling period (Fig. 3A, B). During the first month after fledging, corn and soybean fields (0.50 ± 0.14 to 1.03 ± 0.21) were less likely to be used than “other habitats” up to 9 km from the nest (Fig. 3C). Furthermore, these crops were not used more than 13 km from the nest position. During this period, wetlands (0.70 ± 0.13 to 1.05 ± 0.04) were less likely to be used than “other habitats” except in the first kilometers from the nest, where they had as great a probability of being used as “other habitats” (Fig. 3D).

TABLE 2. Summary of the top-ranked model explaining the probability of habitat patch use by 10 female Peregrine Falcons in southern Quebec, 2008–2010.

Parameter (β)	Estimate	SE	95% CI	
			Lower bound	Upper bound
Intercept ^a	0.93	0.29	0.36	1.50
Period _{Nestling}	-0.92	0.08	-1.07	-0.79
Habitat _{Other farmlands}	-1.15	0.10	-1.34	-0.96
Habitat _{Corn and soybean}	-1.49	0.14	-1.76	-1.22
Habitat _{Wetlands}	0.17	0.09	-0.00	0.34
Habitat _{Urban areas}	-0.03	0.12	-0.26	0.21
Distance	-0.99	0.03	-1.05	-0.92
Habitat _{Other farmlands} * Distance	0.64	0.04	0.56	0.72
Habitat _{Corn and soybean} * Distance	0.66	0.08	0.51	0.81
Habitat _{Wetlands} * Distance	-0.21	0.04	-0.29	-0.13
Habitat _{Urban areas} * Distance	0.21	0.06	0.08	0.34
Period _{Nestling} * Distance	-0.16	0.03	-0.23	-0.10
Period _{Nestling} * Habitat _{Other farmlands}	-0.16	0.12	-0.39	0.08
Period _{Nestling} * Habitat _{Corn and soybean}	-0.58	0.15	-0.88	-0.27
Period _{Nestling} * Habitat _{Wetlands}	-0.79	0.11	-1.02	-0.57
Period _{Nestling} * Habitat _{Urban areas}	-0.68	0.18	-1.03	-0.33

^a Corresponds to the period of the first month after fledging and to the “other habitats” category.

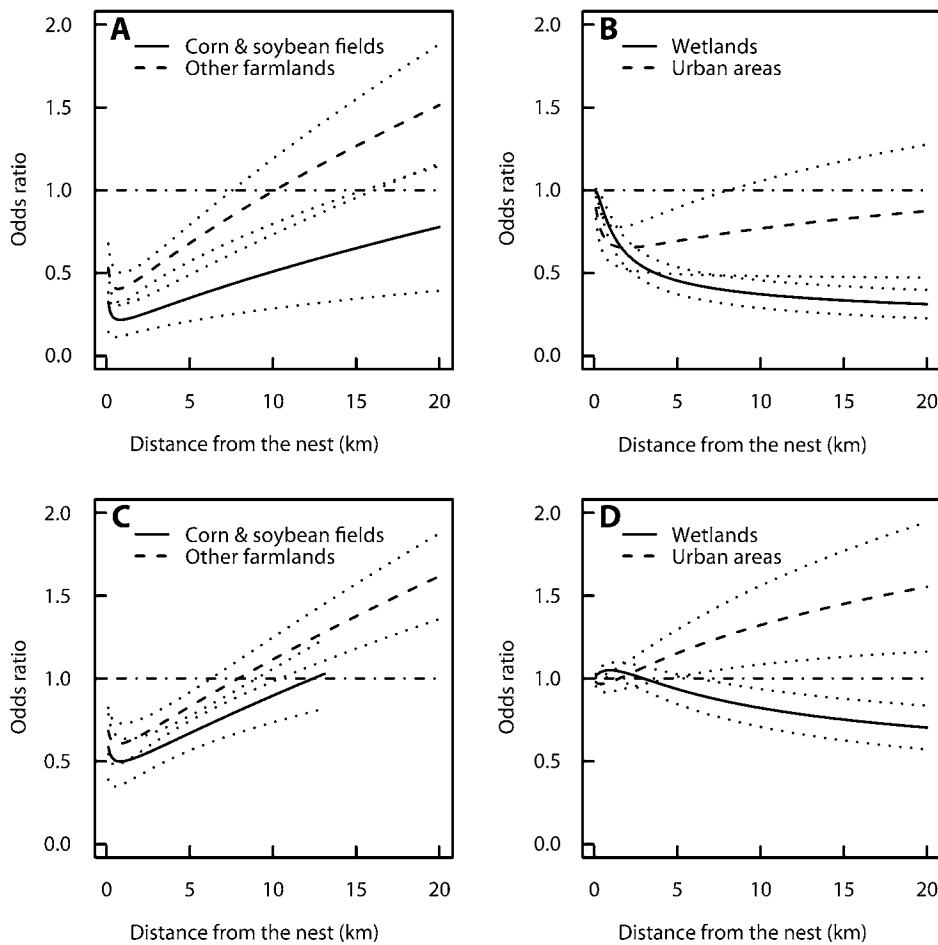


FIG. 3. Probability of habitat use by 10 female Peregrine Falcons in southern Quebec, compared with the “other habitats” category, on the basis of nest distance during the nestling period: (A) corn and soybean fields and other farmlands, and (B) wetlands and urban areas; and during the first month after fledging: (C) corn and soybean fields and other farmlands, and (D) wetlands and urban areas. Dotted lines represent 95% confidence intervals, and dotted-and-dashed lines the “other habitats” category.

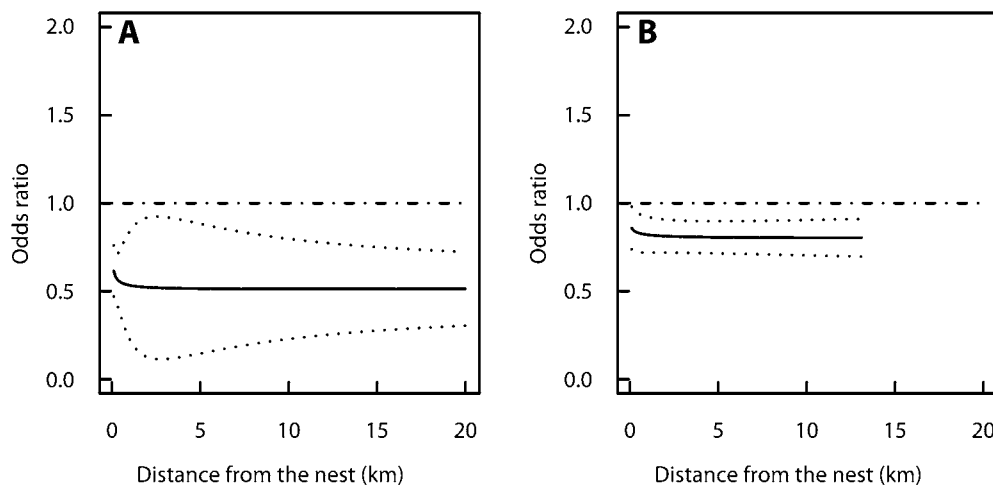


FIG. 4. Probability of use of corn and soybean fields by 10 female Peregrine Falcons in southern Quebec, compared with other farmlands, on the basis of distance from the nest during (A) the nestling period and (B) the first month after fledging. Solid lines represent corn and soybean fields, and dotted-and-dashed lines represent the “other farmlands” category. Dotted lines represent 95% confidence intervals.

Corn and soybean fields (Fig. 4A, B) were less likely to be used than “other farmlands” by adult females during the nestling period (0.51 ± 0.21 to 0.62 ± 0.14) and during the first month after fledging (0.80 ± 0.11 to 0.86 ± 0.12). In each of these periods, the odds ratio between corn and soybean fields and “other farmlands” was maintained at about the same value, except in proximity to the nest (nestling period: 0.5; first month after fledging: 0.8).

The sensitivity analysis showed that model selection was robust to exclusion of any individual from the analysis, in that the global model was always the top-ranked model, regardless of which individual was excluded from the analysis. The effects of most variables and their interactions also remained unchanged when individual peregrines were removed from the sample, especially in the case of agricultural areas. Our top-ranked model contained an interaction between nest distance and habitat category. To minimize bias in the parameter estimate for this interaction, a habitat category must be represented with similar proportions in all nest-distance categories. For some individuals, this criterion was violated. We verified the stability of our model in relation to our conclusions for agricultural areas during the period after fledging (home ranges were generally larger during this period). Here, we recalculated parameter estimates by retaining only those individuals for which the home range exhibited a homogeneous proportion of cover across all distance classes for the two agricultural categories (corn and soybean fields and “other farmlands”). The effects of the agricultural variables and their interactions with other variables remained unchanged, justifying our retention of the interaction between nest distance and habitat category. Conclusions were less robust concerning wetlands and urban areas, although the model we presented seems realistic for the majority of the individuals in our sample.

DISCUSSION

For most birds of prey, both the shape and size of the home range frequently expands toward the end of the nesting period (Newton 1979). These changes may be attributed to different distribution of prey, a change in food needs, and the fact that adults no longer need to defend a territory or tend closely to the brood (Newton 1979). Our

results are consistent with the initial predictions concerning the effect of the period, because the probability of habitat patch use by adult females at a given distance was weaker during the nestling period than in the first month after fledging, according to our model.

The marginal value theorem and optimal foraging theory are based on the assumption that a foraging animal attempts to maximize energy intake (MacArthur and Pianka 1966, Charnov 1976, Nonacs 2001). These theoretical models assume that the distribution of very mobile predators such as birds of prey is not random, in that their hunting activity takes place mainly in habitat patches where the largest energy intake can be procured (Stephens and Krebs 1986). Energy intake can be influenced by the abundance and vulnerability of prey in different habitats (Thirgood et al. 2003). Viewed in the context of the marginal value theorem, our results suggest that period and distance from nest had considerable effects that varied with habitat category. These results suggest potential differences in the respective quality of these habitats with regard to the search for prey.

Many studies highlighted the quality of agricultural landscapes (Sergio et al. 2004) and urban areas (Brambilla et al. 2006, Gahbauer 2008) as hunting sites for the peregrine because of apparent high prey availability. Rock Doves, a major prey item of peregrines in continental temperate regions (Cade and Bird 1990, White et al. 2002, Carter et al. 2003), along with other columbids (White et al. 2002) and European Starlings (*Sturnus vulgaris*; Carter et al. 2003), are common. In temperate continental latitudes, pigeons and doves may be not only the most frequently taken prey, but also the most important in terms of biomass (White et al. 2002). In our study, the “other farmlands” category was more likely to be used than the remaining habitat categories, with the exception of “urban areas,” at a distance of more than 10–15 km from the nest. After fledging, “urban areas” were also more likely to be used than “other habitats” by adult females when they traveled such distances. These results suggest that the peregrine may find sufficient large prey in “other farmlands” and “urban areas” to make it worth the effort to carry them to the nest. The abundance of Rock Doves in both types of habitat could explain why they were more likely to be used than the remaining habitats at a distance more than 10–15 km from the

nest; theory predicts that predators will take prey at great distances from nests only if the energy value is sufficient to compensate for the transport costs (Orians and Pearson 1979). Hunter et al. (1988) studied prey selection by adult peregrines over the nestling stage along the Yukon River in Alaska and found that prey captured at great distances from the nest had greater average mass than prey captured close to the nest.

In accordance with our predictions, our results suggest that corn and soybean fields were underutilized compared with “other farmlands” during the nesting season. Indeed, during the nestling period, corn and soybean fields were about half as likely to be used as “other farmlands.” After fledging of the young, but while they were still dependent on their parents, corn and soybean fields were up to 1.2× less likely to be used than “other farmlands,” and up to half as likely to be used compared with the “other habitats” category. Much research suggests that intensive cropping, especially of corn and soybean, is the potential cause of the decline in abundance and diversity of many bird species within agricultural areas (Best et al. 1995, Meehan et al. 2010). Peregrines prey upon many of these species, and thus our results suggest that corn and soybean fields may not have provided sufficient prey for peregrines during the reproductive period.

After tame hay, fields of corn and soybean dominate the agricultural landscape of Quebec (Institut de la statistique du Québec 2012a). An increase in these crops is anticipated with the increasing popularity of biofuel ethanol production based on corn and crop residues, together with the planned increase in soybean production that is related to climate change (Brassard and Singh 2007). In fact, the surface area of corn and soybean fields in Quebec increased 10% between 2010 and 2012: from 6,820 km² to 7,520 km² (Institut de la statistique du Québec 2011, 2012a, b). This represents an area equivalent to two peregrine home ranges per year (where the home range of a female peregrine during the first month after the fledging of her brood averaged 202 km²). According to our results, an increase in the land area allocated to corn and soybeans could mean a decrease in the quality of hunting habitats for peregrines. On the basis of the supplementation theory, a species may respond to decreased quality of its habitat by using habitat patches of the same type or of inferior quality that are located in proximity to the preferred type (Dunning et al. 1992). Therefore, the anticipated expansion of intensive crops could lead to an increase in home-range size, as a consequence of decreasing prey abundance. However, if travel costs increase too drastically, the model developed by Bernstein et al. (1991) predicts that predators will be less inclined to leave a habitat patch, even if energy intake there is lower than what they could obtain elsewhere. Consequently, an expansion of these crops could translate into a decrease in peregrine reproductive success because of declines in the availability of prey necessary to bring larger broods to the fledging stage (Dawson et al. 2011). Monitoring of breeding peregrines' pair productivity in relation to the level of agricultural intensification is needed to test this hypothesis.

Surprisingly, females made little use of wetlands compared with “other farmlands” and “other habitats.” Ducks and shorebirds are frequently cited as prey of peregrines (White et al. 2002) and are readily available in wetlands (Cade 1951, Dawson et al. 2011). In our study area, few shorebird species are present during the nesting season (Gauthier and Aubry 1996). Moreover, from the time that females again start to hunt during the nestling stage, until the date of fledging, the overall density of the most abundant and widespread duck species

was relatively low in our study area (U.S. Fish and Wildlife Service 2008, 2009, 2010a, b). During the first month after fledging, which is a period that extends until the beginning of August, American Black Ducks (*Anas rubripes*) and Mallards (*A. platyrhynchos*) became more abundant, together with some shorebirds (Bird Studies Canada 2011). This increased quantity of available prey could explain a greater use of wetlands by peregrines during this period.

In conclusion, the peregrine's underutilization of corn and soybean fields is a possible signal that intensive agriculture may affect other top avian predators in agricultural landscapes. For example, declines in American Kestrel (*Falco sparverius*) populations remain unclear to date, but habitat loss and degradation can be considered important factors (Smallwood et al. 2009). Although potential prey of peregrines (Icteridae and Anseriformes) may concentrate foraging activity on waste grain in corn and soybean fields in the fall (White et al. 1985, Foster et al. 2010, Sherfy et al. 2011) and, thus, provide forage for peregrines, our results suggest that expansion of corn and soybean fields could lead to decreases in the reproductive success of the peregrine, a species of special concern in Canada.

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