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HOME-RANGE CHANGES IN RAPTORS EXPOSED TO INCREASED HUMAN ACTIVITY LEVELS IN SOUTHEASTERN COLORADO

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There is considerable interest in the impact of human disturbance on wildlife populations. Increased human activity has altered the behavior of elk (*Cervus elaphus*) (Ward 1985, Kuck et al. 1985, Edge et al. 1985), mule deer (*Odocoileus hemionus*) (Ward 1985), waterfowl (Korschgen et al. 1985), bald eagles (*Haliaeetus leucocephalus*) (Stalmaster and Newman 1978, Knight and Knight 1984), coyotes (*Canis latrans*) (Gese et al. 1989), and red-tailed hawks (*Buteo jamaicensis*) (Andersen et al. 1986). In birds of prey, some short-term impacts of human disturbance have been documented, including nesting failures (Boeker and Ray 1971), lowered nesting success (Wiley 1975, White and Thurow 1985), displacement (Andersen et al. 1986), and changes in wintering distribution and behavior (Stalmaster and Newman 1978). It is conceivable that these short-term responses can lead to long-term community changes, such as changes in breeding density and species composition (Voous 1977, Craighead and Mindell 1981).

Change in characteristics of an animal's home range has received little attention (Andersen 1988, Andersen et al. 1988, Gese et al. 1989). Changes in behavior in response to human disturbance might alter an animal's spatial and temporal use of its home range (Andersen et al. 1986). In this paper, we use harmonic-mean measures of animal activity areas (Dixon and Chapman 1980), and minimum convex polygon (MCP) (Mohr 1947,

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Table 1. Raptors radio-tracked on the Piñon Canyon Maneuver Site, Colorado, during July and August 1983–1985.

Group[a] Species	Identification no.	Sex	Year	Status[c]	No. of days tracked: July	No. of days tracked: August	Total locations: July	Total locations: August	Schoener ratio[b]: July	Schoener ratio[b]: August
Control										
Red-tailed hawk	19	F	1983	S	3	4	14	41	1.09	0.84
	9	F	1984	S	3	2	25	20	1.49[d]	1.47[d]
	42	F	1984	S	3	2	29	22	0.92	0.61
	2	M	1984	S	3	2	27	21	2.14[d]	1.55[d]
	32	F	1984	S	3	2	27	22	1.52[d]	0.46
	22	M	1984	U	3	2	24	21	1.26	1.04
	17M	M	1984	S	3	2	28	21	1.23	0.77
	17F	F	1984	S	3	2	27	20	1.29	0.69
	42	F	1985	S	3	4	26	37	0.71	1.17
Swainson's hawk	8	F	1985	S	3	5	23	40	1.32	0.72
	17	M	1985	S	3	4	34	33	1.18	1.15
	18	M	1985	S	3	4	25	37	1.46	1.36
Golden eagle	9	M	1983	U	2	4	13	57	1.68[d]	0.17
Experimental										
Red-tailed hawk	9	F	1985	S	4	3	30	26	1.19	0.99
	55	F	1985	S	6	3	52	26	0.61	1.87[d]
	56	F	1985	S	5	5	35	46	0.31	0.42
Swainson's hawk	10	F	1985	S	3	1[e]	24	7	1.12	—
Ferruginous hawk	13	M	1985	S	4	3	34	30	0.70	0.61
	11	M	1985	S	4	1[e]	37	4	1.41	—
Golden eagle	3	F	1985	S	5	4	47	36	0.42	0.83

[a] Birds were placed in control and experimental groups on the basis of occurrence of military training activity (see text).
[b] Schoener ratios after Schoener (1981) and Swihart and Slade (1985*b*).
[c] S = successfully fledged at least 1 young, U = attempted breeding unsuccessfully.
[d] Schoener ratio does not differ significantly from 2 ($P > 0.05$) indicating effective independence between successive locations.
[e] Birds that abandoned the study area when military training occurred in 1985.

Southwood 1966) and 95% ellipse (Jennrich and Turner 1969) estimates of home range to assess the response of raptors to increased human activity levels in southeastern Colorado.

STUDY AREA AND METHODS

We conducted this study on the 1,040-km² Piñon Canyon Maneuver Site (PCMS), located in Las Animas County in southeastern Colorado along the northwest rim of the Purgatoire River Canyon. Elevation ranged from 1,300 to approximately 1,800 m and topography consisted of broad, moderately sloping uplands bordered by the Purgatoire River Canyon on the east, limestone hills on the west, and a basalt hogback on the south. Vegetation was dominated by shortgrass prairie and pinyon (*Pinus edulis*)-juniper (*Juniperus monosperma*) woodland (Costello 1954, Kendeigh 1961). The pinyon-juniper plant association was concentrated along the Purgatoire River Canyon and its associated side canyons, in the limestone hills, and on parts of the basalt hogback in the south.

The PCMS was acquired by the U.S. Dep. of the Army in 1983. Prior to Army acquisition, the PCMS had supported large grazing operations and low human densities since it was first settled in the 1870's (Friedman 1985). Beginning in August 1985, the PCMS has been used on a periodic basis for military training of the 4th Infantry Division (Mechanized).

Capture and Telemetry

From March 1983 through July 1985, we captured raptors that were members of resident, breeding pairs in dho-gaza nets baited with a live great horned owl (*Bubo virginianus*) (Hamerstrom 1963), bal-chatri traps (Berger and Mueller 1959), a cannon net, and by hand. Captured birds were sexed on the basis of relative size and subsequent behavior near the nest. Ten red-tailed hawks, 4 Swainson's hawks (*Buteo swainsoni*), 2 ferruginous hawks (*B. regalis*), and 2 golden eagles (*Aquila chrysaetos*) were captured and fitted with radio transmitters. All raptors captured were members of breeding pairs and all but 2 (Table 1) successfully fledged

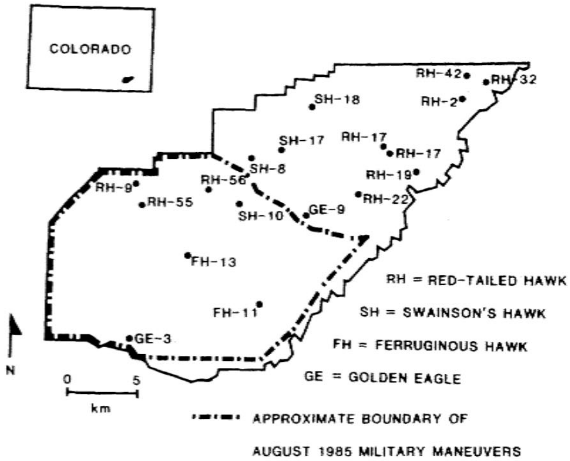

Fig. 1. Approximate locations of radio-marked birds of prey studied to assess the impact of initiation of military training activity on home range characteristics on the Piñon Canyon Maneuver Site, Colorado from 1983–1985.

young in the year that they were radio-marked and subsequently tracked.

Lithium-battery powered (2) and NiCad-battery powered, solar-assisted (16) radio transmitters (Advanced Telemetry Systems, Inc., Isanti, Minn. and Telemetry Systems, Inc., Mequon, Wis.; use of company names does not imply endorsement by the U.S. Fish and Wildlife Service or the University of Wisconsin) were attached to captured hawks with a crisscross backpack-type harness (Smith and Gilbert 1981, Andersen et al. 1986) made of woven teflon ribbon (Bally Ribbon Mills, Bally, Pa.). Complete transmitter packages weighed 18 to 25 g. Similar transmitters (20–35 g) were attached to the rachis of tail feathers of golden eagles. Radio-marked birds were followed by 1 observer with a hand-held Yagi antenna and a portable receiver, from a vehicle or on foot. Every 5–10 days during the study, each bird was tracked for a 3–5 hour period. Individuals were tracked systematically during the study on a rotating basis (see Andersen and Rongstad 1989). At 0.5-hour intervals, the location of the bird (to the nearest 100 m grid intersection) was recorded on 1:24,000 U.S. Geological Survey topographic maps using the Universal Transverse Mercator grid system. When possible, visual observations were obtained (40.0% of 1,149 total locations) or estimated locations were plotted with reference to a location where the bird was observed previously (20.0%) (e.g., monitoring of telemetry signals indicated that the bird did not leave its perch). Otherwise, standard triangulation procedures (Mech 1983) were used to estimate locations and the observer verified those locations with subsequent visual observation. Thus, all locations were based on direct observation, and the primary source of error associated with them would result from plotting error.

Experimental Design and Analysis

Radio-equipped birds were divided into 2 groups: control and experimental. Birds in the control group were located in areas where military training activity did not occur, or were followed in years before military training activity began. Birds in the experimental group were followed during July 1985 prior to the initiation of military training activity on the PCMS, and in August 1985 during the first period of military training activity. To make results comparable between control and experimental groups, we used only telemetry locations obtained in July and August to calculate home ranges of birds in the control group. One red-tailed hawk (no. 9) was included in the control group during 1984 and in the experimental group during 1985, when military training activity occurred in its home range. Another red-tailed hawk (no. 42) was included in the control group in both 1984 and 1985 as it was not located in an area used in 1985 for military training.

The first military training exercises occurred on the PCMS during August 1985. During a 3-week period, approximately 2,700 personnel and 1,000 vehicles used the southern $\frac{3}{5}$ of the study area (T. L. Warren, Fort Carson Environment, Energy, and Natural Resources Div., pers. commun.; Fig. 1). Training activity included helicopter overflights, simulation of heavy weapons firing, military traffic and maneuvers, and encampments. Encampments consisted of temporary (generally <3–5 days) tent camps established to support up to several hundred personnel. The type of activity occurring in an area was recorded during a radio-tracking period, but presence or absence of activity within the bird's July (no military) MCP was used as the basis for categorizing telemetry data. On the PCMS, nestlings of red-tailed and ferruginous hawks and golden eagles fledged in late June or early July. Swainson's hawk nestlings fledged in late July or early August (D. E. Andersen, unpubl. data). Thus, in July and August, raptors that successfully bred on the PCMS were still providing food to dependent young.

We used MCP's (Mohr 1947, Southwood 1966, Jennrich and Turner 1969) to represent the boundary of a bird's home range. However, because this approach assumes a uniform utilization distribution (Samuel and Garton 1985) with no center of activity within the home range, we also used 95% ellipses (Jennrich and Turner 1969) and 50% harmonic-mean activity areas (Dixon and Chapman 1980) to estimate the boundary of a bird's home range and to identify areas of intensive use within the home range. We believed that 50% harmonic-mean activity areas were a reasonable estimate of high use or core areas (see Anderson 1982, Samuel et al. 1985*a*). Harmonic-mean activity areas, MCP's, and 95% ellipses were calculated for each bird for both time periods (July and August, Table 1) that it was tracked with computer program DC80 (J. R. Cary, University of Wisconsin) (see Fig. 2 for an example). We selected harmonic-mean grid densities for each species based on the algorithm suggested by Sam-

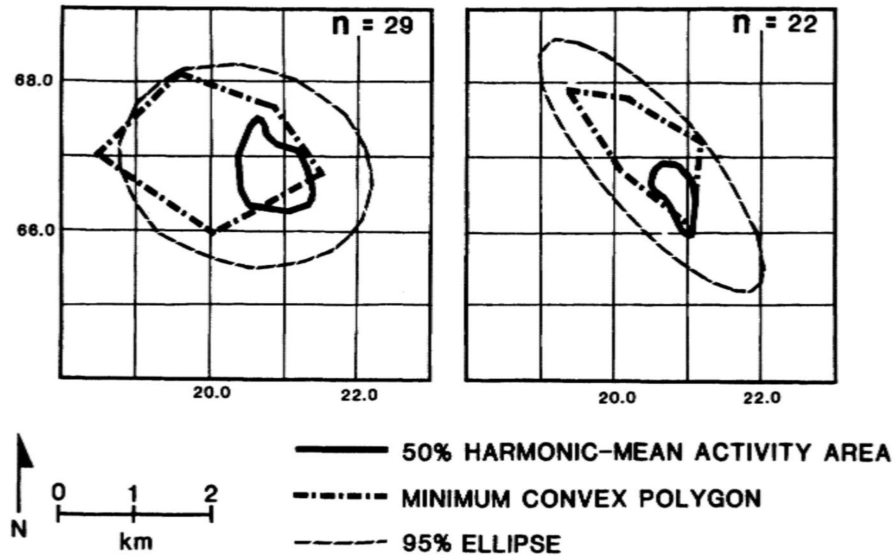

Fig. 2. Fifty percent harmonic-mean activity areas, minimum convex polygons, and 95% ellipse estimates of home range for an adult female red-tailed hawk (no. 42) on the Piñon Canyon Maneuver Site, Colorado during July (left) and August (right) 1984. Sample sizes (n) refer to the total number of locations obtained each month.

uel et al. (1985*b*). To test for independence between successive telemetry locations, we also calculated Schoener ratios (Schoener 1981, Swihart and Slade 1985*b*) for each bird in each month that it was followed (Table 1).

To assess the impact of human activity on home range characteristics, we tested whether birds in the experimental group shifted the center of their home range or activity area farther than control group birds by measuring the change in the geometric center of the distribution of data points and the center of 50% activity areas between July (no military) and August (military). To control for individual and interspecific variation in home range size, we used the ratio between MCP's in July and August to assess the change in size of home ranges between those 2 periods. Similar ratios between July and August 50% harmonic-mean activity areas were also used to test for changes in core area size. We also tested whether experimental group birds were more likely to make "extra-home range" movements than control group birds. We operationally defined an extra-home range movement as a movement during August (military) in which the bird moved beyond the area defined by the July (no military) MCP by at least 75% of the longest axis of the July MCP (Fig. 3). All statistical tests were based on ratios between home-range characteristics in July and August for an individual bird, and thus minimized the influence of any error associated with obtaining location data. Statistical procedures follow those outlined by Gibbons (1985) and Snedecor and Cochran (1980). Tests for increased home-range size based on July/August area ratios are 1-tailed.

RESULTS

Red-tailed hawks exposed to periods of military training activity ($n = 3$) shifted the geometric center of their home ranges (Mann-Whitney-Wilcoxon test, $T = 31$, $P = 0.036$) and the geometric center of 50% harmonic-mean

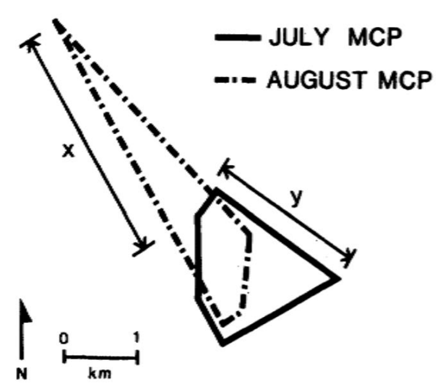

Fig. 3. Minimum convex polygons (MCP) for an adult female red-tailed hawk (no. 32) on the Piñon Canyon Maneuver Site, Colorado during July and August 1984. We calculated an index to the occurrence of extra home-range movements by comparing the farthest distance a bird travelled in August outside of the July MCP (x) and scaling that distance to the longest axis of the July MCP (y).

Table 2. Distance between geometric centers of the distribution of telemetry locations and 50% harmonic-mean activity areas, ratio of areas of minimum convex polygons (MCP), 95% ellipses, and 50% harmonic-mean activity areas, and extra-home range movement ratios from July and August radio tracking of raptors on the Piñon Canyon Maneuver Site, Colorado, from 1983–1985.

		Shifts in geometric centers[a]		Area ratios[b]			
Group Species	Identification no.	All telemetry locations	50% harmonic-mean activity area	MCP	95% ellipse	50% harmonic-mean activity area	Index of extra-home range movement[c]
Control							
Red-tailed hawk	19	0.48	0.50	0.55	1.11	1.78	40.4
	9	0.90	0.95	1.09	0.92	0.63	25.0
	42	0.05	0.10	2.60	1.52	2.29	16.7
	2	0.39	0.33	1.83	1.60	2.47	47.7
	32	0.56	0.20	0.87	0.40	1.58	142.5
	22	0.82	0.25	0.61	0.38	0.68	62.5
	17M	0.17	0.10	0.82	0.56	0.72	50.0
	17F	0.36	0.60	1.38	0.93	1.23	32.2
	42	0.16	0.50	0.39	0.75	0.33	60.0
Swainson's hawk	8	0.23	0.65	2.45	3.55	0.86	4.5
	17	0.48	0.10	0.56	0.57	0.55	27.3
	18	0.43	0.39	0.27	0.45	0.37	76.2
Golden eagle	9	2.10	0.50	0.46	0.70	6.96	35.0
Experimental							
Red-tailed hawk	9	0.93	2.09	1.24	1.18	0.76	25.4
	55	0.57	1.20	0.44	0.38	0.56	178.6
	56	2.96	3.55	0.50	0.82	0.26	75.0
Swainson's hawk	10	—[d]	—	—	—	—	—
Ferruginous hawk	13	5.15	9.39	0.61	0.44	2.49	77.7
	11	—[d]	—	—	—	—	—
Golden eagle	3	1.66	1.90	1.35	1.17	1.08	6.6

[a] Distance (km) between centers of July and August telemetry locations and 50% harmonic-mean activity areas.
[b] Ratio of the area of indicated July and August home-range estimates.
[c] Index of extra-home range movement = August movement/July axis × 100 (Fig. 3).
[d] Birds that abandoned the study area during military maneuvers in August 1985.

activity areas ($T = 33$, $P = 0.01$) significantly greater distances than did red-tailed hawks in the control group ($n = 9$) (Table 2). Due to small sample sizes, data from Swainson's hawks ($n = 4$), ferruginous hawks ($n = 2$), and golden eagles ($n = 2$) were pooled to conduct statistical tests. Because 2 of these birds abandoned the area altogether (Swainson's hawk [no. 10] and ferruginous hawk [no. 13]; Table 1), each was treated as an extreme observation in nonparametric analyses. Again, compared to control group birds ($n = 4$), birds in the experimental group ($n = 4$) exhibited a greater shift in the geometric center of their home range ($T = 11$, $P = 0.058$) and the center of 50% ($T = 10$, $P = 0.028$) harmonic-mean activity areas (Table 2).

To test whether military activity increased the size of a raptor's home range, we compared July/August area ratios between experimental and control groups. The 2 hawks that abandoned the study area were treated as extreme observations. Experimental group birds (species pooled) exhibited larger August (military) MCP's than control group birds ($T = 56.5$, $P = 0.096$; Table 2). Likewise, experimental group birds exhibited larger August 95% ellipses ($T = 57.5$, $P = 0.109$; Table 2) and 50% harmonic-mean measures of activity areas ($T = 56$, $P = 0.088$; Table 2).

Experimental group birds made extra-home range movements more frequently than birds in the control group ($\chi^2 = 6.28$, 1 df, $0.010 < P < 0.025$; Table 2). The 2 hawks that left the study area were considered to have made extra-home range movements. Birds exposed to military activity also moved farther in August in relation to July MCP boundaries than control group birds ($T = 105$, $P = 0.039$).

Schoener ratios calculated for each bird in each month it was tracked ranged from 0.17 (golden eagle [no. 9], August 1983) to 2.14 (red-tailed hawk [no. 2], July 1984) (Table 1). Low ratios indicate a high degree of autocorrelation between successive locations and effectively reduce the number of data points used to calculate a home range or activity area. Only 7 of 38 Schoener ratios we calculated indicated that locations could be considered independent for statistical purposes.

DISCUSSION

The first military training rotation began on the PCMS in August 1985 and lasted approximately 3 weeks with a dramatic increase in human activity levels. During this period, resident birds of prey located in the area where military training occurred shifted the center of their home range and activity areas, made movements outside of the areas in which they had previously been confined, and increased the size of the area they used. Birds located in areas that were not exposed to this training and birds that were followed in years prior to the initiation of training did not exhibit these changes in home range use to the same extent as experimental group birds.

In general, birds appeared to increase the size of their home ranges during periods of military activity (Table 2). An alternative response to disturbance might have been to seek out areas within the home range that were isolated from the disturbance. We did not have sample sizes large enough to test for this response, but several experimental group birds seemed to remain in isolated areas within their home range when military activity was ongoing.

None of the 3 red-tailed hawks nor 1 golden eagle exposed to military training activity moved completely out of its former home range. However, 1 of 2 ferruginous hawks and the only Swainson's hawk located in areas where military training activity occurred left the study area. Neither of these birds was located again until the following spring when they returned to the same nesting territories with functioning transmitters. Species-specific responses to human activity have been noted in cervids (Ward 1985), where elk were less tolerant of human activity than mule deer. If raptor species respond differentially to increased human activity, long-term changes in species composition (Voous 1977, Craighead and Mindell 1981) might result with birds less tolerant of disturbance becoming less abundant over time. Differences in response to human activity among individuals within a species may also occur with some individuals tolerating or habituating to higher levels of human activity than others (Andersen et al. 1989). On the PCMS, resident birds of prey had not previously been exposed to the levels of human activity present as military training activity began in 1985.

Our assessment of behavioral responses of raptors to military training activity is based on analysis of radiotelemetry data. The use of radiolocation data to calculate home ranges and activity areas presents several methodological problems (Swihart and Slade 1985*a,b*; Andersen and Rongstad 1989). First, a moderate number of locations is required to adequately describe a bird's home range. Due to the time required to repeatedly locate individuals and the fact that military activity did not occur continuously in any given area, we chose to track individual birds for 3–5 hour periods ("bursts," Dunn and Gipson 1977, Samuel and Garton 1987) rather than randomly locate individual birds throughout the study. This sampling strategy can result in underestimation of home-range size due to nonindependence between successive locations (Swihart and Slade 1985*a*). Tests for independence (Table 1) indicated that most data sets exhibited significant autocorrelation. However, because we used comparisons between 2 independent estimates of home range for an individual bird, we do not believe that a moderate degree of autocorrelation between successive locations severely biases our results. Andersen and Rongstad (1989) demonstrated that red-tailed hawk telemetry locations gathered in bursts and resulting in significant autocorrelation did not appear to significantly bias home-range area estimates and indices.

Second, estimates of home-range size tend to increase with the number of locations used to estimate the home range (Jennrich and Turner 1969). The ratio between comparable areas in July and August (used to test for increased home-range size) could potentially be biased by this relationship. We examined the relationship between sample size and MCP area graphically and could find no apparent systematic bias. All area–sample size curves appeared to reach an asymptote. If the number of locations used to estimate a home range determined its size, we would expect the ratio of the number of locations obtained in July to the number obtained in August to be correlated with the July/August area ratios. However, there were no significant correlations between the ratio of the number of locations and the ratio of areas between months (all P's > 0.10; Tables 1, 2).

Abandonment and shifts in home range in response to increased human activity have several important implications and potential impacts include all of Pomerantz et al.'s (1988) categories except direct mortality. First, repeated or prolonged disturbance might influence an individual's energy budget. Increased energy costs would be incurred as flying time increased. Second, if changes in home range occur during reproduction, productivity might be decreased with subsequent impacts at the population level. We did not determine whether observed changes in home-range characteristics in our study resulted in decreased prey delivery rates to dependent (fledged) young. Third, responses that vary among species might eventually result in changes in community composition, with less tolerant species becoming less abundant through time. Finally, human activity occurring at the end of or after the breeding season influenced behavior in raptors, and this should be considered when managing for birds of prey.

SUMMARY

From 1983 to 1985, we radio-tracked 10 red-tailed hawks, 4 Swainson's hawks, 2 ferruginous hawks, and 2 golden eagles on their nesting grounds in southeastern Colorado. We used harmonic-mean measurements of activity areas, MCP's and 95% ellipses to assess the changes that occurred in home range characteristics of these birds to initiation of military training activity in the area. Raptors were assigned to 1 of 2 groups based on the presence or absence of military training activity in the bird's home range. Experimental group birds were followed during July 1985 prior to military activity and in August 1985, during military training. Control group birds were located in areas that did not experience military training activity, or were followed in years prior to the beginning of military training on the PCMS (1983 and 1984). Birds in the experimental group shifted the center of their home range and activity areas farther, increased the size of the area they used, and made extra-home range movements more frequently than control group birds. Our results document behavioral responses of birds of prey to increased levels of human activity and we outline methodology to test for changes in home-range characteristics in free-ranging raptors.

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EFFECTS OF HAY-CROPPING ON EASTERN POPULATIONS OF THE BOBOLINK

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Populations of bobolinks (*Dolichonyx oryzivorus*) in the eastern United States have declined since the early 1900's (Bent 1958:28, Bull 1974:523, Leck 1984:171). Explanations for this include the decline of hayfield area (Bent 1958:29, Laughlin and Kibbe 1985:14, Andrle and Carroll 1988:466), earlier and more frequent hay-cropping (Bent 1958:29, Andrle and Carroll 1988:466), and the shift from timothy (*Phleum pratense*) and clover (*Trifolium* spp.) to alfalfa (*Medicago sativa*) (Campbell 1968:260). Agricultural practices were initially responsible, however, for range expansions of most grassland bird species in the eastern United States (Hurley and Franks 1976, Andrle and Carroll 1988:466) because they keep land open and free of woody vegetation (Griscom and Snyder 1955:214, Laughlin and Kibbe 1985:14).

Bobolinks might be affected by hay-cropping because they are late nesters (Wiens 1969: 44, Stewart and Kantrud 1972) and breed ex-

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