FACTORS AFFECTING PRAIRIE FALCON FLEDGLING PRODUCTIVITY IN THE MOJAVE DESERT, CALIFORNIA

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Abstract: Mean Mojave Desert prairie falcon fledgling productivity over a six-year period during the 1970s was below the continental mean for the species and outside the lower limit for the 95% confidence interval. Human disturbance was thought to be responsible for the low fledgling productivity. I studied human disturbance and physiographic variables at prairie falcon nesting sites from 1977 to 1979 to determine whether fledgling productivity was in any way related to these variables. Significant differences in mean values between successful nests (fledging three to five young) and unsuccessful nests (fledging zero to two young) were found for elevation of the nest, position of the nest with respect to the bottom of the nesting cliff, the amount of time required to walk to the nest from the nearest road, the number of roads near the nest, ease of which the cliff can be climbed by humans, shooting and eggshell thickness. The aforementioned variables, except for eggshell thickness, were variables that measured the degree of isolation of prairie falcon nests from man. No single human disturbance variable was responsible for lowered fledgling productivity on a desert-wide basis. Rather, a variety of impacts working in concert have lowered fledgling productivity desert-wide. The best indication of multiple impacts is that successful nests were more than a 12-minute walk from the nearest road while unsuccessful nests were less than a 12-minute walk from a road. This indicates that nests which were easily accessible to man's multiple impacts had significantly lower productivity than nests in more remote locations. Evidence of man-created chemical pollution also exists because prairie falcon eggshell thickness at unsuccessful nests was 17% thinner than pre-DDT levels.

In recent years many North American falcon populations have declined in number. Peregrine falcons were extinct as a breeding falcon east of the Rocky Mountains until 1980 (Hickey 1969, Cade and Dague 1980). Merlin numbers may be decreasing (Fox 1971) and prairie falcon populations are thought to be decimated by the same factors affecting peregrine falcons (e.g., chemical poisoning by DDE) (Fyfe et al. 1969, Enderson and Berger 1970, Garrett and Mitchell 1973).

Organochlorine pesticide (DDT and its metabolites) application over North American agricultural areas was the major underlying cause for many regional declines in falcon populations (Fyfe et al. 1976, Peakall 1976). DDE, a metabolite of DDT, is the principal agent producing lethal effects through eggshell thinning and increased rates of embryonic deaths (Ratcliffe 1967, Hickey and Anderson 1969, Enderson and Berger 1970), and sublethal effects in a variety of abnormal reproductive behaviors (Peakall 1976). Since the ban on DDT use in 1972, there are indications of diminishing DDE levels in our environment (Anderson and Hickey 1972, Risebrough et al. 1980) but some falcon populations continue to decline on a local level, including prairie falcons in California (Garrett and Mitchell 1973).

The current breeding status of prairie falcons throughout their range remains a matter of speculation. In Utah, prairie falcons show reduced occupation rates at historical nests and total extirpation in others (White 1969). Some western Montana populations may not be stable in numbers (Leedy 1972) while Idaho contains an apparently stable population (Ogden 1973). Eastern Oregon populations may be declining (Denton 1975) while in Colorado prairie falcons were breeding in good numbers in 1979, except for lowered productivity along the western slope of the Rocky Mountains (J. Enderson, pers. commun.). A declining Canadian population has shown some recovery (Fyfe and Armbruster 1977). In California, Glading (1969) reported a population decline around the periphery of the Central Valley. Garrett and Mitchell (1973) concurred with Glading's finding and also noted declines in northern and southern California and evidence of a population increase along the central coast of California.

Ten floristic regions are recognized in California (Stebbins and Major 1965) and, during the 1970s, prairie falcons were observed nesting in each region. More than 500 breeding attempts by prairie falcons may occur annually in California with greatest nesting densities found in the Mojave Desert region (Boyce et al., 1986). Although the Mojave Desert contains the greatest number of nesting prairie falcons, Garrett and Mitchell (1973) noted that numbers of nesting pairs at historical nesting sites were decreasing. High levels of human disturbance noted near historical nesting territories were thought to be responsible for the observed decline (Boyce 1977, Boyce and Garrett 1977). Concurrently, however, the central coast population, with virtually no human disturbance, was increasing (B. Walton, pers. commun.). I used a multifactorial approach to examine possible causes for the observed decline.

STUDY AREA

The Mojave Desert is located in southeastern California and lies within the Sierra Nevada Mountain Range's rain shadow. Elevations vary from -83 m near Tule Spring to above 1,500 m on interdesert mountain tops; most of the desert is above 600 m in elevation. Interdesert mountain ranges run north-south with isolated buttes being common. The climate is severe, varying annually, but predictably hot (37+ C) in summer and cold in winter (8-18 C). Average rainfall varies between 25.4 mm and 114.3 mm annually. Greatest precipitation falls from December through March and snow will fall into early April.

The Colorado River runs through a portion of the Mojave Desert near Needles, California. It marks the eastern edge of the study area and forms the state boundary with Arizona. The only other major river is the Mojave River. Originating in the San Bernardino Mountains, it flows north to northwest. Water flows underground along major sections of the river. Where the river surfaces (e.g., in Victorville), cottonwood trees (*Populus fremonti*) and screwbean mesquites (*Prosopis pubescens*) grow along the banks. No tributaries feed into the river along its entire 235-km course (Jaeger 1957). Alkali sinks are scattered along the pathway of the old Mojave River bed.

Delineation of the Mojave Desert boundaries closely parallels the outer distributional limits of the joshua tree (*Yucca brevifolia*) (Jaeger 1957). Creosote (*Larrea divaricata*) and burro bush (*Fanseria dumosa*) are also characteristic desert flora. Alkali sinks, creosote bush scrub, shadscale (*Atriplex confertivolia*) scrub, joshua tree woodland and pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) woodland form the major Mojave Desert floral communities (Munz and Keck 1959).

The Mojave Desert is principally owned by the United States government and includes marine training bases, naval ordinance test ranges, air force bases and the Bureau of Land Management (BLM) lands. The largest single land steward is the BLM controlling nearly 4.8 million hectares.

METHODS

I examined historical nesting territories from April through the beginning of June 1976-1979. Territories occupied by pairs of falcons were studied. I collected data for two *domains* of variables (physiographic domain and human disturbance domain) which might account for observed prairie falcon fledgling productivity in the desert. The terminology used generally follows that used by Garrett and Mitchell (1973). The term "territory" refers to an area 0.75 km in diameter. Within a territory, alternate nesting cliffs and nest ledges may be used by falcons from year to year. The term *nesting site* refers to a specific cliff where falcons nest within a territory. The term *nest* refers to the location on the cliff where falcon eggs are deposited. The nest may be thought of as a three-dimensional space having length, width and height. Fledgling productivity refers to the number of young (age = 36 days or more) which fledge or were expected to fledge from nests.

Physiographic Domain

Sixteen variables were selected to describe physical characteristics of nesting sites. Below, I list each variable and how it was measured.

Nest Elevation.— Nesting sites were plotted on U.S. Geological Survey (USGS) topographical maps (scale 1:62500 or 1:24000) and the nearest contour line to the nest was recorded as the elevation for that nest. Elevations were rounded off to the nearest 29 m interval.

Lowest Elevation.— A 1.6 km diameter circle was drawn around each nest site on topographical maps. The lowest elevational point within that circle was recorded to indicate altitudinal variability among nesting territories when compared with nest site elevation.

Nest Aspect.— Nest aspect was the direction a nest site faced away from the cliff face. For analytical convenience, cliff aspect was recorded in a dichotomous form; this is, a nest site either did or did not face each of 4 directional quadrants (SE, SW, NE, NW).

Temperature.— Temperature values were obtained from U.S. climatological records. Temperatures ascribed to each site were obtained from the nearest recording station. Deviation from expected averages were used to examine temperature variability at nests throughout the desert.

Precipitation.— Precipitation deviation from the expected mean was obtained from U.S. climatological records and calculated similarly to temperature, except that total precipitation values for the entire year were used instead of just for the nesting season.

Cliff Height.— Cliff height was measured as the linear distance from the cliff base to the cliff top taken on a perpendicular line running through the location of the falcon nest. I measured cliff height by marking a climbing rope at the cliff top and then again at the cliff base after the rappel.

Nest to Cliff Top.— This measurement was the distance from the nest floor to the cliff top.

Nest to Cliff Bottom.— This was measured as the distance from the nest floor to the cliff base.

Nest Type.— For each nesting attempt the nest type was recorded as: ledge, cavity, stick nest on a ledge, stick nest in a cavity, or stick nest not on a ledge or in a cavity.

Nest Opening Height.— The height was measured at the front of the nest and was the tallest point from nest floor to ceiling.

Nest Opening Width.— The opening width was measured at the widest point at the nest opening.

Nest Length.— Length was measured along the floor of the nesting space (as the greatest length) from the nest opening (front) to the rear of the nesting space.

Nest Width.— Nest width was considered the greatest width measurement made from one side of the nest to the other.

Nesting Area.— Area was calculated as the product of nest width and nest length. There was no vertical component of this measurement.

Nest Height.— Nest height was considered to be the vertical height of the nesting space measured from floor to roof or overhang.

Cliff Face Area.— Cliff face area was a two-dimensional measurement of the cliff face calculated using a compensating polarimeter calibrated to known cliff height to trace a photographic outline of the cliff's perimeter.

HUMAN DISTURBANCE DOMAIN

Each historical territory studied had some type of human disturbance present. These disturbances varied from territory to territory but centered around human recreational activities. Eight of 11 variables studied were selected to examine the relationship between human access to nests in terms of distance and time, from both Los Angeles and from the nearest interdesert city. The amount of human disturbance near nest sites and the amount of protection available to nesting falcons were also examined. The last variable, prairie falcon eggshell thickness, was measured to determine if chemical pollutants, such as DDE, might be affecting fledgling productivity.

Linear Distance to Los Angeles (L.A.).— A straight line connecting downtown L.A. and each falcon nest was plotted on a USGS topographical map (scale 1:50000) and the distance between the two points measured in centimeters.

Pavement Distance to L.A.— Pavement distance was measured as the number of paved road km from each nest to downtown L.A.

Pavement Time to L.A.— Pavement time was considered the time required to travel on paved roads from downtown L.A. at legal speeds to the end of pavement nearest the nest site.

Dirt Distance to Nest Cliff.— Dirt distance was measured as the number of km of dirt road traveled to reach the roadhead nearest the nesting cliff.

Dirt Time to Nest Cliff.— Dirt time was considered the amount of time required to travel on dirt roads to reach the roadhead nearest the nest.

Foot Distance to Nest Cliff.— Foot distance was measured using a Heuer pedometer as the distance from the nesting cliff to the roadhead.

Foot Time to Nest Cliff.— Foot time was calculated as the amount of time required to travel on foot from the roadhead to the nesting cliff.

City Distance.— Distance in km from the nearest city (via paved and dirt roads and on foot) to the nesting cliff was measured.

City Time.— The time required to travel from the nearest city to the nesting cliff was calculated.

Human Disturbance.— The types of human disturbances around each nesting cliff were categorized (Table 1). Each disturbance type was subjectively scaled into four or five levels of disturbance severity and assigned a numerical value (0-4). High values (4) denote serious disturbance. Each nest site was evaluated and a score derived for each disturbance. The scores for each type of disturbance were summed to yield a measure of overall human disturbance for each nesting attempt. In this manner, all types of human disturbance were collapsed into one variable.

Human Protection.— Human protection was measured on a scale of 1 to 5 in order of available protection (most protected = 5 pts.). The most protected level was a cliff located on private property with "no trespassing" signs posted and an armed guard present. Next was private or public property with signs posted and guarded occasionally (usually weekends). The third level was private property that was posted but had no guards. Public lands with

Table 1. Subcategories of the variable *human disturbance* with respective numerical values per level given.

Category	Sublevel definition	Numerical value
Off road vehicles (ORV)	a. major ORV use area = 10+ trails	4
	b. moderate ORV use = 5+ trails	3
	c. fair ORV use area = 2+ trails	2
	d. low ORV use area = 1 trail	1
	e. no ORV use in area = no trails	0
Established road	a. leads directly to nest site	4
	b. leads within 0.17 km of nest site	3
	c. leads within 0.33 km of nest site	2
	d. leads within 1.0 km of nest site	1
	e. road greater than 1 km away from nest	0
Buildings within 2 km of nest	a. 10+ buildings in zone	4
	b. 5+ buildings in zone	3
	c. 2+ buildings in zone	2
	d. 1 building in zone	1
	e. no buildings in zone	0
Development within 1 km	a. paved roads with housing or industry	4
	b. paved roads with scattered houses	3
	c. paved roads with mainly agriculture	2
	d. dirt roads or mining operations	1
	e. no development	0
Camping within 2 km of nest	a. large informal aggregations of humans (5+vehicles)	4
	b. small informal aggregations of humans (5+vehicles)	3
	c. small public camping facility	2
	d. very little evidence of camping	1
	e. no camping evident	0
Cliff climbability	a. easy with no special equipment needed	4
	b. fair with precautions necessary	3
	c. safety line mandatory	2
	d. very difficult even with climbing gear	1
	e. cannot climb into the nest	0
Hiking activity	a. established trails with heavy use	4
	b. trails with moderate use	3
	c. trails barely visible and rarely used	2
	d. random hiking no established trails	1
	e. no hiking signs seen	0
Shooting within .13 km of nest	a. falcons observed being shot at and 100+ spent cartridges found near nest	4
	b. 20-100 cartridges found near nest	3
	c. 10-49 cartridges foung near nest	2
	d. 1-9 cartridges found near nest	1
	e. no cartridges found near nest	0
Falconry activity	a. young falcons found missing from nest, theft suspected or confirmed	4
	b. falconers seen at nest site	3
	c. site well known to falconers	2

Table 1. (*Continued*)

Category	Sublevel definition	Numerical value
	d. site known to just a few falconers	1
	e. site presumed unknown to falconers	0
Grazing	a. 50+ animals (sheep or cattle) present	4
	b. 20+ animals present	3
	c. 5+ animals present	2
	d. 1-4 animals present	1
	e. no animals present or sign observed	0
Power lines	a. high transmission lines and house lines	4
	b. house lines only	3
	c. high transmission lines only	2
	d. no lines present	1
Scientific research	a. falcons trapped and transmitters attached	4
	b. falcons trapped but quickly released	3
	c. falcons under long-term visual study	2
	d. nest visited by scientist at least once (usually involved climb to nest)	1
	e. no other scientific research	0

posted signs was the fourth level (2 pts.). The least protected were nests located on public lands without guards or signs.

Eggshell Thickness.— I collected eggshell fragments from nests and measured them using a Federal #35 comparator thickness gauge.

Standard statistical packages (SPSS, Nie et al. 1975; BMDP, Dixon and Brown 1979) were used to calculate univariate, bivariate and multivariate statistics. In searching for correlates with variability in prairie falcon fledgling productivity, I compared physiographic and human disturbance characteristics of "successful" nests with those of "unsuccessful" nests. I defined "success" as fledging three or more young; the minimum number of fledglings needed to sustain a stable population (Platt 1981). Spearman's coefficient of correlation was used to put ordinal and interval data on a common basis so that all bivariate correlations could be examined. I used principal component analysis (PCA), with varimax rotation, to reduce the dimensionality of the data set and to provide factors which were independent; unlike the original variables which were not independent. Factor scores were calculated for each case (nesting attempt) and tested using ANOVA to determine if successful nests were significantly different from unsuccessful nests. While PCA reduces data dimensionality it does not necessarily identify the most important variables contributing to the statistical separation of successful nests from unsuccessful nests. Discriminant function analysis (DFA) was used to create a linear function of those variables which maximally separated the centroid (multivariate mean) of successful nests from unsuccessful nests.

RESULTS

Descriptive statistics are not reported here but are available elsewhere (Boyce 1982, 1987). I summarized historical Mojave Desert prairie falcon nesting territory use and productivity (fledglings produced) for six years during the 1970s (Table 2). There is a great deal of variation in Mojave Desert fledgling productivity that cannot be explained in terms of the variables I studied. I was unable to reliably predict nest success or failure by analysis of either the physiographic or human disturbance domains of variables. Either other factors are involved or my level of metrics was not satisfactory. Fledgling productivity, however, was clearly not independent of the variables studied. Eggshell thickness and human disturbance in the form of nearest roads and access time on foot to reach nests, are clearly related to fledgling productivity. It remains unclear which ultimate factor or combination of factors is responsible for nest failure.

Variables most highly correlated with fledgling productivity were human disturbance at nests and the time needed to walk to nests from a roadhead (Table 3). Nests located at higher elevation (1,084 m), on a cliff well above the cliff base (21 m), at least a 30-minute walk from the nearest

Table 2. Summary of historical Mojave Desert prairie falcon nesting territory use and productivity (fledglings produced) for six years during the 1970s. Percent values are given in parentheses.

	1970[a]	1971[a]	1972[a]	1977	1978	1979	TOTAL
Territories studied	22	28	45	35	36	25	191
Territory use	16 (73)	17 (61)	20 (44)	20 (60)	20 (56)	14 (56)	107 (56)
Vacant	6 (27)	11 (39)	25 (56)	15 (40)	16 (44)	11 (44)	84 (44)
Single birds	3 (14)	4 (14)	1 (02)	1 (03)	1 (03)	1 (04)	11 (06)
Pairs	13 (59)	13 (46)	19 (42)	19 (54)	19 (53)	13 (52)	96 (50)
Productive pairs	6 (46)	7 (54)	12 (63)	15 (79)	10 (53)	8 (62)	58 (60)
Nonproductive pairs	7 (54)	6 (46)	7 (37)	4 (21)	9 (47)	5 (38)	38 (40)
Number of young fledged	18	24	40	53	32	21	189
Mean number of fledglings/ productive pair	3.00	3.43	3.33	3.53	3.32	2.63	3.26
Mean number of fledglings/ pair studied	1.38	1.85	2.11	2.79	1.74	1.62	1.97

[a]Data from R. L. Garrett (pers. commun.)

road and having thicker eggshells (327.8 mm) have significantly higher fledgling rates than nests located low in elevation (927 m), located closer to the bottom of the nesting cliff (15.8 m), only a 12-minute walk from a road and having thinner eggshells (302.6 mm) (Table 4).

Physiographic Domain

Factor Analysis.— I selected a 9-factor model which accounted for 84% of the variation in the physiographic domain (Table 5). Only the cliff size mean factor score was significantly different between successful and unsuccessful nests ($P < 0.06$). The cliff size factor comprised 22.2% of the variation in the physiographic domain and was the first principal component of the model.

Discriminant Analysis.— Nests which were more remote by virtue of being higher in canyons, on mountain slopes or on buttes were more successful. Elevation, therefore, was a variable of nest isolation. Direct DFA produced a function which moderately separated successful and unsuccessful nests (Wilks Lambda = 0.750; approximate F-statistic = 2.828). From the squared canonical correlation it was evident that the discriminant function could only explain 16.8% of the difference between successful and unsuccessful nests (canonical correlation of 2 = 0.168). Elevation was the most highly correlated variable with the discriminant function (Table 5).

Table 3. Spearman correlation coefficients for variables correlated with productivity at $P < 0.10$ significance level ($n = 52$).

Variable	Correlation coefficient	Significance level
Nest elevation	0.23	0.05
Elevation of nest above surrounding terrain	0.23	0.05
Cavity height	0.24	0.09
Foot distance to nest	0.39	0.00
Foot time to nest	0.46	0.00
Human disturbance	-0.51	0.00
Human protection	0.33	0.01

Human Disturbance Domain

Factor Analysis.— A 5-factor model accounted for 84.5% of the variation in the domain (Table 6). Only one mean factor score, linear distance to Los Angeles and eggshell thickness factor, was significantly different between successful and unsuccessful nests ($P < 0.04$). This factor was the fifth principal component in the model and only accounted for 6.2% of the variation in the human disturbance domain.

Discriminant Analysis.— Only one variable, the amount of time spent walking to the nests, entered the stepwise DFA. Group centroid separation was significant (Wilks Lambda = 0.923; approximate F-statistic = 4.95) but much of the variation between successful and unsuccessful nests (93%) remained unexplained (canonical correlation 2 = 0.077). Direct DFA resulted in a moderate group centroid separation (Wilks Lambda = 0.482; approximate F-statistic = 1.40) and explained much of the difference between groups (canonical correlation 2 = 0.518). The pooled within-group correlations between the canonical function and human disturbance variables show that variables most highly correlated with the function are travel to the nest while on foot and eggshell thickness (Table 7). Two functions are shown in Table 7. Function I contains the variable eggshell thickness for which the sample size is only 34. Function II, which does not include the variable eggshell thickness, was created to examine the function based on a much larger sample size.

THE VARIABLE "HUMAN DISTURBANCE"

A Chi-square analysis of the scales comprising the variable revealed that successful nests and unsuccessful nests were significantly different ($P < 0.10$) in the following categories: off road vehicle use, number of roads near the nest, climbable (by humans), nature of the cliff, hiking activity near the nest, shooting near the nest, grazing and falconry activity. Although these relationships may be significant, some might not be substantial. Spearman correlation coefficients for the scales of the composite variable, human disturbance, demonstrate the level of association with fledgling productivity (Table 8). The number of

Table 4. Variables for which the mean for successful nests were significantly different from that for unsuccessful nests (t-test, $P < 0.10$).

Variable[a]	Successful nests	Unsuccessful nests	Significance level
Nest elevation	1,085 m	928 m	0.03
Nest distance to cliff base	21	16 m	0.09
Foot time to nests	32 min	12 min	0.02
Eggshell thickness	328 mm	303 mm	0.02
Human disturbance[b]	14	22	0.05
Human protection[b]	2	1	0.05

[a] $n = 52$

[b] Median value for ordinal data; Mann-Whitney test.

Table 5. Variable loadings on each factor, for a 9-factor model, in the Physiographic Domain are shown as well as the pooled within groups correlation between the canonical function and the variables. Correlations [> 0.3] from the highest loading are suppressed in each factor. Eigen values and percent contribution of each factor in the models are shown. Variables are ordered by the largest correlation with the canonical function.

Variable name	Factor[a] 1	2	3	4	5	6	7	8	9	Canonical function
Elevation of nest	—	—	—	.86	—	—	—	—	-0.64	
Lowest elevation within 1 km of nest	—	—	—	.85	—	—	—	—	—	-0.31
Southeast nest	—	—	—	—	—	.89	—	—	—	-0.31
Nest to cliff base	.63	—	—	—	—	—	—	—	—	-0.27
Variation in temperature	—	—	—	—	—	—	.77	—	—	-0.19
Cliff height	.91	—	—	—	—	—	—	—	—	-0.19
Stick nest in crevice	—	—	—	—	—	—	-.83	—	—	-0.17
Stick nest on a ledge	—	.84	—	—	—	—	—	—	—	0.17
Nest opening width	—	—	.81	—	—	—	—	—	—	0.10
Nest area	—	—	.90	—	—	—	—	—	—	0.09
Stick nest	—	.89	—	—	—	—	—	—	—	0.09
Northwest nest	—	—	—	—	—	—	—	.94	—	-0.06
Cavity nest	—	-.72	—	—	-.57	—	—	—	—	-0.06
Southwest nest	—	—	—	—	—	-.69	—	—	—	-0.06
Cliff area	.86	—	—	—	—	—	—	—	—	-0.06
Ledge nest	—	—	—	—	.82	—	—	—	—	-0.02
Stick nest in cavity	—	—	—	—	—	—	—	—	.84	-0.02
Nest to cliff top	.87	—	—	—	—	—	—	—	—	0.01
Eigen value	4.4	2.4	1.8	1.7	1.7	1.4	1.3	1.1	1.0	
Percent contribution	22.2	11.8	9.2	8.6	8.5	6.9	6.6	5.5	5.0	
Cumulative percent	22	34	43	52	60	67	74	79	84	

[a]Factor: 1 = cliff size; 2 = non-pothole stick nest; 3 = nest; 4 = elevation; 5 = ledge nest; 6 = southwest nest; 7 = temperature; 8 = northwest nest; 9 = pothole-stick nest.

Table 6. Variable loadings on each factor, for a 5-factor model, in the *human disturbance* domain. Correlations (> 0.3) from highest loading are suppressed. Eigen values and percent contribution for each factor are shown.

Variable	Factor[a] 1	2	3	4	5
Distance to L.A. from nest	—	—	—	—	-0.87
Pavement km from L.A.	0.76	—	—	—	—
Pavement time to L.A.	0.73	—	—	—	—
Km of dirt road to nest	—	—	0.85	—	—
Time on dirt road to nest	—	—	0.91	—	—
Foot distance to nest	—	0.80	—	—	—
Foot time to nest	—	0.83	—	—	—
Human protection	—	0.80	—	—	—
Time from nearest city	0.92	—	—	—	—
Km from nearest city	0.91	—	—	—	—
Human disturbance	—	—	—	-0.80	—
Eggshell thickness	—	—	—	—	0.77
Eigen value	4.6	2.5	1.3	1.0	0.7
Percent contribution	38	21	11	8	6
Cumulative percent	38	59	70	78	84

[a]Factor: 1 = city distance; 2 = foot distance; 3 = dirt distance; 4 = human disturbance; 5 = eggshell thickness and distance to L.A.

roads near the nest, climbable nature of the cliff and shooting are the most highly correlated scale values with productivity.

DISCUSSION

Platt (1981) calculated a mean continent-wide prairie falcon occupancy rate of 76.3%, the 95% confidence interval extends from 67% to 86%. Mojave Desert occupancy rates during the 1970s fell not only well below the national average, but also outside the 95% confidence interval. Mean continental fledgling productivity was 2.4 young with a 95% confidence interval of 2.1 to 2.7 young (Platt 1981). Except for 1977, Mojave Desert prairie falcon fledgling productivity was below both the continental mean and the lower limit of the 95% confidence interval.

Platt (1981), using a deterministic population modeling procedure, showed that over a five-year period, a mean prairie falcon productivity rate of 1.88 young would result in a 17% population decrease. The observed mean Mojave Desert prairie falcon productivity is below 1.88 young. If Platt's model is appropriate, by application, a population reduction of approximately 25% is underway in the Mojave Desert. Observed occupancy rates of historical Mojave Desert nesting territories are down by 19% and fledgling productivity rates are down by 23%. These data not only support the hypothesis that a population reduction is underway in the Mojave Desert, but also show that the population is approaching the level predicted by Platt's model.

Factors affecting prairie falcon productivity in the Mojave Desert are many and include: shooting, nest destruction, mining activity, chemical pollution, startling disturbances (low flying jets), hikers, photographers, collisions with man-made objects, falconers and recreational activities, to name just a few. Any one of a multitude of causes may result in failure of a specific nesting pair of falcons. No single cause appears responsible for lowered productivity regionally. The overall pattern appears to be nest site accessibility to humans. The historical nesting territories that remained vacant during this study were easily accessed by humans. Results from this study show that unsuccessful nests were easily reached by humans and that successful nests were not. An analysis of the scales in the variable "human disturbance" reveal that the number of roads near the nest, climbable (by humans), nature of the cliff and shooting are the most highly correlated items with productivity.

Prairie falcon nests located within a 12-minute walk of a road generally fail while those located further away succeed. The probability of nesting failure increases as the number of roads located near nests increases because prairie falcons have a greater chance of coming into contact with humans. Wiley (1975) found that both the red-tailed hawk and red-shouldered hawk had significantly lower fledgling productivity at nests located close to roads than at nests located more remotely (more than 0.4 km from a road). Craighead and Craighead (1956) reported that nearly half of their raptor nesting failures were attributed directly or indirectly to human destruction. White and Thurow (unpubl. data) demonstrated that there was a significant difference in fledgling productivity between ferruginous hawk nests that were subjected to experimental human disturbance and a control group of nests which were not disturbed.

What is the magnitude of human use of the desert? The results of a survey that I took in Jawbone Canyon on one weekend in late May 1977 indicate the magnitude of recreational use. I surveyed the entire canyon length (18 km) at 10:00 a.m. on a Friday morning and recorded only one vehicle present. I repeated the survey Saturday at 10:00 a.m. and recorded 283 motorcycles, 37 dune buggies, and 232 recreational vehicles (campers, etc.) totaling 552 vehicles. The canyon was used most heavily near the mouth where it is wide and the hills less steep. Vehicles were present, however, throughout the canyon. The average number of vehicles/1.6 km was 49.3 of which 25.3 were motorcycles, 3.3 dune buggies, and 20.7 recreational vehicles. The desert is used most heavily during weekends and on holidays.

Use of the Mojave Desert by recreationalists in 1977 totaled 15 million visitor-use days and 85% of those visitors live in the urban megalopolis of southern California near Los Angeles (Ruch 1980). The current human population there is estimated to be 12.5 million people and is projected to grow to 16.3 million in just 18 years. The southern California basin is essentially an island surrounded by water or desert. The desert provides a natural area for Los Angeles residents to escape to and experience solitude and open space. There are approximately 72,000 km of vehicle routes to travel in the desert. Wexler (1981) reported a 350% increase in desert use by recreationalists since 1970 and, according to the U.S. Geological Survey, more than 0.4 million hectares of land have been denuded by off road vehicle use. Ruch (1980) reports that 11% of the total recreational activity on BLM land is on the use of vehicles as an end in itself. Unfortunately the greatest influx of recreationalists occurs when young prairie falcons are just preparing to fledge at the end of May and early June.

Table 7. Pooled within-group correlations between the canonical functions and the variables in the *human disturbance* domain. Function I includes all variables in the domain while Function II does not include the variable eggshell thickness.

Variable	Function I ($n = 24$)	Function II ($n = 52$)
Eggshell thickness	-0.42	—
Foot time to nest	-0.38	0.62
Pavement time to nest	-0.35	0.42
Pavement distance to nest	-0.34	0.35
Foot distance to nest	-0.25	0.36
Distance of nearest city to nest	-0.24	0.33
Dirt road distance to nest	-0.17	0.33
Dirt road time to nest	-0.14	0.14
Linear distance to Los Angeles	0.10	0.11
Travel time from nearest city to nest	0.02	0.10

Table 8. Spearman correlation coefficients for the variable fledgling productivity with the scales of the composite variable *human disturbance*. Scales with significance levels less than $P \leq 0.10$ are suppressed ($n = 52$).

Variable	Correlation coefficient	Significance level
Off road vehicles (ORVs)	-0.29	0.02
Roads	-0.50	0.00
Climbing	-0.42	0.00
Hiking	-0.27	0.03
Shooting	-0.39	0.02
Falconers	-0.37	0.00
Grazing	-0.32	0.01

Beyond the variety of permanent and ephemeral human disturbances that impact prairie falcon nesting success, health of the prey base and health of the raven (*Corvus corax*) population may also contribute to lowered nesting success. Both the prey base and raven population are undoubtedly impacted by human disturbance, but the extent of that impact on prairie falcons remains unknown. The ultimate source of raptor nesting failure, without human disturbance, is fluctuation in prey populations (Newton 1979). The U.S. Department of the Interior (1979) presented data which correlated declines in prairie falcon nesting density in Idaho with decreased Townsend ground squirrel (*Citellus townsendi*) numbers. The Townsend ground squirrel composed a major segment of the prey base in their study. A 15% decrease in nesting prairie falcon pairs occurred in 1978 when the ground squirrel population crashed.

An accurate quantitative assessment of Mojave Desert prairie falcon prey base was beyond the means of this study. Unlike the Idaho prairie falcon population, which relies principally on the Townsend ground squirrel for food, the Mojave Desert falcons take a wide variety of prey (Boyce 1985). A major reduction in several principal Mojave Desert prey items may have to occur concurrently before a nesting population reduction, of the order observed in Idaho, would occur.

Lowered occupancy rates of prairie falcon nests may be linked to long-term fluctuations in the raven population. Prairie falcons in the Mojave Desert nest in raven nests. Half of the observed prairie falcon nesting attempts were in raven nests. If ravens declined, replacement rates of raven nests may not keep pace with natural nest destruction rates. If this were to happen, the prairie falcon population may decline due to loss of nesting habitat.

It is clear that in this study, nests with easy human access have significantly lower fledgling productivity. Such nests are close to roads, within easy walking distance, at low elevations and on small cliffs or in eyries located near the ground. Prairie falcons at these nests also have thinner eggshells. There are a variety of factors which influence eggshell thickness in birds (Romanoff and Romanoff 1949). Lincer (1975) and Ratcliffe (1981) noted that DDE will cause eggshell thinning when ingested in high levels. Fyfe et al. (1976) found that productivity of prairie falcons in Canada was related to the eggshell thickness index developed by Ratcliffe (1967). He further noted (Fyfe et al. 1976:348) that shell thickness is "closely dependent upon DDE concentrations and DDE explains most of the increase in variance of the shell thickness index." Newton (1979) noted that there was no correlation between shell-thinning and other organochlorine compounds unless they were correlated with DDE. Mean eggshell thickness for successful prairie falcon nests was significantly different than unsuccessful nests. Unsuccessful nests had a mean eggshell thickness 17% thinner than pre-DDE levels in the Mojave Desert. It is reasonable to assume that chemical pollution (DDE) may play a role in determining fledgling productivity in the Mojave Desert and that the prey base may be poisoned.

What remains uncertain is the exact relationship, if any, between thin eggshells and nests located low in elevation and close to human access. Busch et al. (1978) found that just the sight of an approaching human caused a three-fold increase in heart rate in ferruginous hawks. Whether human disturbance physiologically stresses prairie falcons to the point of producing thin eggs is unknown.

RECOMMENDATIONS

Wildlife managers may expect to witness abandonment of nests, lowered productivity or nesting failure at nest locations easily accessible to man. What can be done? In the future I would recommend that placement of new roads be carefully considered. For the present, the possibility of changing locations of dirt roads away from nesting sites is an option. A general rule of thumb would be to place roads at least a 15-minute walk from a nest; preferably a 30-minute walk. Seasonal closure of habitat near nests is a possibility. Closure success depends on enforcement capability. The BLM tried two such closures in the Mojave Desert but violations of the closure area were common.

The difficult question faced by managers is where to draw the battle line. Do we accept the loss of nests within easy access to humans and try to defend encroachment on nests located in more remote areas? Do we enter into a vigorous educational campaign to increase public awareness in the management unit? Do we try to save the most visible nests in an attempt to save all nests? Do we accept substantial loss in one region thinking that, across the entire prairie falcon range, the population is not threatened and production in other areas can compensate for losses in our area? What losses are acceptable? Ten percent this decade, 10% next decade and so on and so on until managers 100 years from now have only a fraction of the nests that exist today?

The single most important factor for the wildlife manager is to know the location of raptor nests within a management unit. Prairie falcons, for example, exhibit annual attachment to specific nesting territories (Platt 1981). Knowledge of breeding territory locations not only facilitates finding nesting falcons from year to year, but also allows for development of historical nesting territory profiles. Through time these profiles form an invaluable data base for studying regional variation in rates of nesting territory occupancy, fledgling productivity, eggshell thickness and trends in human disturbance. From such a data base come informed management decisions vital to the continued health of the falcon population.

In the Mojave Desert, prairie falcon fledgling productivity may continue to decline at all but the most inaccessible sites. Prairie falcons from other regions may immigrate and supplement the Mojave Desert population and account for falcons returning year after year to nests which annually fail. Prairie falcons may continue to return every year until the habitat itself is no longer capable of supporting their nutritive requirements. The destructive process may proceed slowly for a prolonged period and, if no consideration is given to the prairie falcon population then, as Dean Amadon states (1969:502): "for species that are subjected to all sorts of adverse influences, the population may get along after a fashion, but then a culmination of various things increasing their mortality in one way or another just subtly reaches a point of no return, and the populations disappear even though the situation in some cases may not have deteriorated in any obviously new manner." Or, as Stanley A. Temple phrases it, "a death of a thousand cuts."