Radar Monitoring of Vernal Bird Migration in Central Montana

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Abstract

Marine surveillance radar was configured to determine distance from radar and height of birds within a 5600-m long east-west transect near the town of Judith Gap in spring 2002. Located in a physiographic gap between two mountain ranges, data were intended as control for impact studies related to proposed wind power development in the vicinity. A single echo or target displayed on the radar screen was considered an event and consisted of a single bird or many birds of one or several species. Highest event rate recorded was 716/hour on the night of 18 May and was the larger and second of two prominent peaks evident during the season. Detectability of events was a function of proximity to radar. Event rate was adjusted for radar detectability and defined as activity rate. Mean activity rate at night was over 2.5 times that of daylight. Daylight activity rates/100-m segment of transect were inversely correlated with topographical relief. Median height of night events (278 m) was 1.5 times higher than daylight events ($P < 0.001$). Median heights of daylight events/100-m segment of transect were inversely correlated with topographical relief ($P < 0.001$). A larger ($P < 0.001$) proportion (29.3%) of events in daylight were at or below maximum height of rotor swept area (105 m) of wind turbines proposed in the vicinity than night events (18.5%). Although an estimated 2 million birds may have passed over the radar transect in spring 2002, as many as 6.7 million may have passed through the Gap. Event rate may be an appropriate metric for impact analysis of future wind resource development.

Key Words: activity rate, birds, central Montana, height, radar, vernal migration

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Introduction

Development of wind power resources in the western United States is increasing and additional sites are proposed or under consideration (National Renewable Energy Laboratory 2001). Considerable avian mortality induced by older wind energy developments, e.g., early stages of Altamont, California (Orloff and Flannery 1992), has increased scrutiny and review of proposed projects with respect to impacts on wildlife. Recent studies have recorded additional mortality of birds and bats associated with wind turbines in the United States (Erickson et al. 2002) and the contribution to cumulative impacts to bird populations may be cause for concern (Johnson et al. 2002). The USDI Fish and Wildlife Service and the wind power industry now recommend pre- and post-development monitoring of proposed wind resource areas to identify and manage impacts to natural resources, especially birds and bats (Anderson et al. 1999, USDI Fish and Wildlife Service 2002). Further, they recommend monitoring regimes be consistent with a Before–After, Control–Impact (BACI) study design (Green 1979).

Proposed wind power development in central Montana stimulated evaluation of avian activity in the vicinity of Judith Gap. Because many birds migrate at night (Evans and Mellinger 1999), radar (**RA**dio **D**etection **A**nd **R**anging) monitoring is a useful technique to study bird movements and assess impacts of resource development (Harmata et al. 1999). Therefore, a marine surveillance radar (MSR) monitoring system was employed to obtain a more complete picture of avian activity near Judith Gap in spring 2002. Study objectives were to (1) determine profiles of avian activity during spring migration, and (2) develop metrics of avian activity useful in impact assessment of any future wind power development in the Judith Gap area.

Study Area

A site 6.4 km east and 0.4 km north of the town of Judith Gap, Wheatland County, in northcentral Montana (UTM = 602427E - 5170648N) was chosen for monitoring. Dominant wind directions are 196° (SSW) and between 350° and 15° (NNW to NNE). Sustained wind velocities ≥96 kph (60 mph) are common. Mean elevation of the area is 1490 m (4900 ft). Monitoring site was located between two east-west running mountain ranges, an assumed "migration focal point" (Kerlinger 1989). The monitoring site was on a small hill on a bluff in the approximate geographic center of the physiographic gap between the Snowy Mountains to the east and the Little Belt Mountains to the west. Land use within the gap was livestock grazing of native Northern shortgrass prairie and dryland crop production and was devoid of forest cover. The site permitted unimpeded radar scanning for at least 3 km due east and west of the site.

Methods

Equipment

An X-band, 10-kilowatt Raytheon™ 1210XX MSR described by Harmata et al. (1999) was used for monitoring bird activity. The radar system was mounted on a vehicle and configured to determine height of birds above and respective horizontal distance from the radar (Harmata et al. 2003). This configuration created a vertical "curtain" of radar waves that radiated the length of the area scanned and expanded in width as it traveled at an angle of 25°. Objects penetrating the radar beam created a signature on the screen (Fig. 1) that permitted measurement of distance up to 133 km left, right, and above the radar antenna.

Harmata et al. (1998) found that data obtained at range setting 1.5 nm (2.8 km) best represented avian activity. This setting permitted monitoring of a 5.6-km east-west transect and height of 5.5 km above the radar. Range discrimination of the Raytheon 1210 XX MSR is < 20 m with a bearing accuracy of ± 1° at maximum surveillance range (Raytheon Marine Company 1995). Maximum error of height above radar calculation would be ± 40 m, but error probably was much less at a surveillance range of 2.8 km.

Data Recording and Management

Monitoring periods usually occurred between 2300 and 0300 hr nightly and 1100 and 1500 hr daily because avian activity rates at Norris Hill Wind Resource Area (NHWRA) in southwestern Montana were highest during these hours (Harmata et al. 1999). Attempts were made to make each monitoring period 90 min to minimize observer fatigue.

Number of monitoring periods/week varied between 0 and 3 to accommodate logistics, accidents, and weather while attempting to provide as close to an even distribution of effort over the season as possible. At the beginning of a monitoring period, observers oriented the vehicle so area scanned was perpendicular to the suspected direction of migrant bird flight, i.e., north. Heading data were obtained from an Electronic Heading Sensor, an accessory of the radar system, and assured the vehicle was positioned to obtain consistent coverage. The radar vehicle left the site after each monitoring period.

An individual target (echo, signature) displayed on the radar screen was considered an *event* (Fig. 1). As events appeared on the radar screen, observers positioned the cursor (a cross that appears on screen in "CURSOR" mode) on the event and recorded time, distance, and bearing from the radar displayed for the cursor position. Bearings usually fell between 0-90° and 270-359°. Events below the radar often were detected because

Figure 1. Screen of radar (center of concentric rings) in vertical mode displaying an event signature, probably a flock of Canada geese, moving from right (east) to left (west). Height of flock is approximately 470 m above radar. Horizontal irregular blob is ground level.

scanning arc extended to areas of elevation lower than the radar site. Each event and associated data were afforded a record line on the data sheet. If the event progressed across the screen (e.g., Fig. 1), position data at the lowest point were recorded.

Distance and bearing data in Microsoft® Excel 2000 files were imported to and analyzed in various modules of STATISTICA '99™ (StatSoft 1999). Distance and bearing were converted to horizontal distance from radar and height (above radar) by solution of right triangles. Formula for horizontal distance (left or right) from radar was (cosine (bearing-270))*d, where d = distance from radar to events. Height above radar level was calculated by (sine(bearing-270))*d.

Number of events detected overall, i.e., in daylight, at night, or by 100-m segment, were divided by respective hours of monitoring time expended and expressed as *event rate*.

Estimating Spatio-temporal Bird Numbers

Adjusting Event Numbers.—The probability of an observer detecting a target on screen was not evaluated but most likely was unaffected by position or rate of events. However, previous radar study (Harmata et al. 1998) indicated raw number of events displayed by radar did not reflect actual number or spatial distribution of events. The likelihood of events being detected by the radar decreased with increasing horizontal distance from the radar. Capacity of birds to reflect radar waves probably was more a function of configuration rather than mass, e.g., a B-117 stealth bomber probably has less reflective capacity than a White Pelican (*Pelecanus erythrorhynchos*) and a Prairie Falcon (*Falco mexicanus*) less than an American Crow (*Corvus brachyrhyncos*).

Event numbers adjusted for a decline in detection capability of the radar more accurately depicted numbers and spatial relationships. The radar was treated as an observer moving south along a transect parallel to assumed south-to-north travel direction of vernal migrant birds. Distances to events detected to the left or right (and above) were assigned to 1 of 50 horizontal 100-m segments emanating to the west (0 to -2500) and east (0 to +2500) of the radar site. Line transect analysis (Burnham et al. 1980) and program DISTANCE (Laake et al. 1993) were used to generate detection probabilities (Harmata et al. 1999). Observed frequencies of events for each category (daylight, night, or combined) on either side and above the radar were corrected for detectability by dividing the observed number in each segment by the respective detectability of that segment. Frequency of events/100-m segment/unit time was adjusted for detectability and defined as *activity rate*.

Profile of Vernal Migration.— In an effort to detect associations of activity rates with topography, the highest point of elevation in each 100-m distance interval of the scanning transect was determined from contour lines on 7.5-in topographical maps of the study area. This elevation was considered ground level in each 100-m distance interval because migrating birds would likely fly over local topography rather than around.

Magnitude of avian migration within radar range between 11 April and 2 June 2002 was crudely calculated by two estimation techniques. One estimator (N_e) was designed for comparison with other impact assessment categories (i.e., Before-Impact, etc.) and included only mean event rate/100-m segment/hour of monitoring. Resultant expression was $N_e = r_e*56*h$, where r_e = mean event rate, 56 = number of segments in scanned transect, and h = number of hours in the estimate period (703 for night; 994 for daylight; 1704 for the season). The other estimator (N_p) was an attempt to estimate avian vernal migrant populations passing through the gap. It included multipliers for detectability, i.e., activity rate) and mean/event flock size (3.5) determined at NHWRA in southwestern Montana (Harmata et al. 1998), but transect length was reduced to 50 segments. Resultant expression was $N_p = r_a* 50*h*f$, where r_a = activity rate, 50 = number of segments in scanned transect and f = average number of birds/ event (3.5).

Height of Bird Flights

Detectability adjustments were not incorporated in any analysis involving event height. Height of an event was categorized into 3 levels relative to configuration of wind turbines proposed for siting within Wheatland County (Leib, L., AMERESCO Energy Services, pers. comm.). Rotor swept area of these machines extends between 25 and 105 m above ground level and a collision "risk" may be presented to birds flying between these heights (Anderson et al. 1999). Height of events also was displayed relative to ground level in each 100-m distance interval of the scanning transect.

If any analysis indicated data were not normally distributed, nonparametric tests were employed. Tests used for specific data sets are indicated in Results. A difference was considered statistically significant if $P \leq 0.05$.

Results

Radar Detections

Radar monitoring consumed a total of 31.7 hours between 11 April and 2 June 2002. Radar detected 3537 events during 23.2 hrs of 19 night monitoring sessions and 478 events during 8.6 hrs of 10 daylight monitoring sessions (Fig. 2).

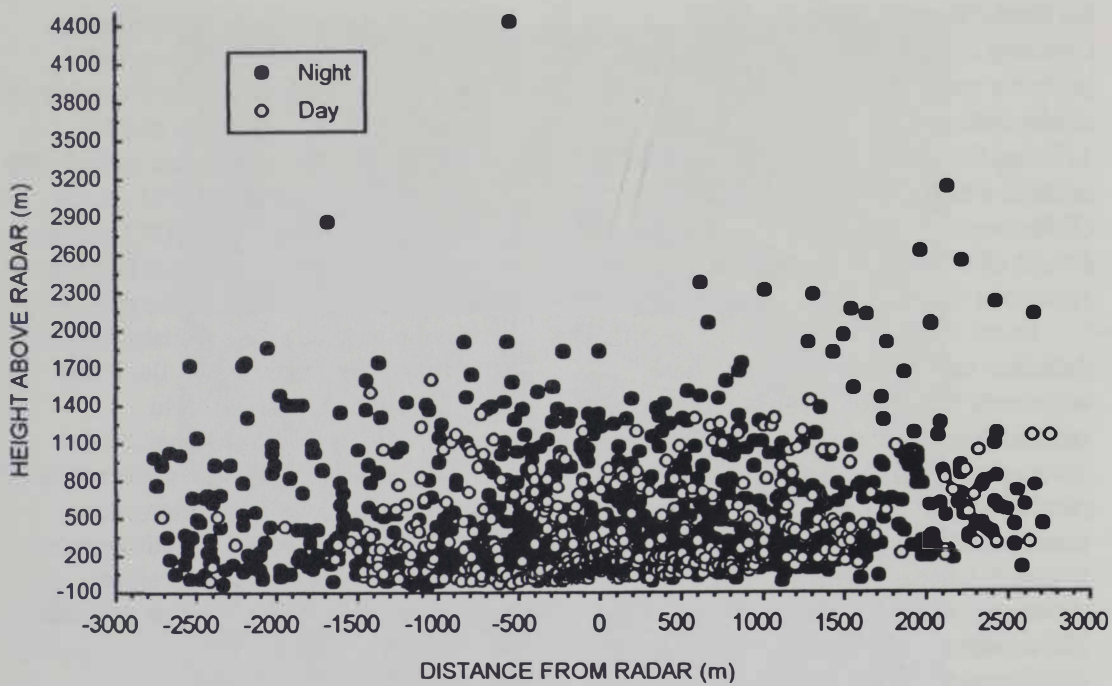

Figure 2. Events detected during radar monitoring of a 5600 m transect, 6.4 km east of Judith Gap, Wheatland Co., Montana, spring 2002. Open circles are daylight events, closed dots are night events. Radar site was located at distance 0. Right (+) is east, left (-) is west.

All events detected were assumed to be birds. No signatures displayed could be attributed to insects (Larkin 1991) and monitoring ceased before many bats returned to Montana or emerged from hibernacula (Flath, D. pers. comm.).

An event may have consisted of a single bird or many birds of one or several species, grouped tightly enough to present one signature on the display screen per antenna rotation (Harmata et al. 1999). Aircraft were easily distinguishable. Composition of night events, i.e., biological Class, Order, Family, species, could not be determined visually for obvious reasons and was beyond the scope of this study. However, characteristics of events confirmed visually in daylight suggested at least biological Class or group (waterfowl, passerine) of some events detected at night.

Rates of Vernal Migration

Event rates were higher at night (median = 121.8/hr, quartile range = 94.13) than in daylight (median = 50.8/hr, quartile range = 14.09) (Mann-Whitney $U = 17.00$, $P < 0.001$). Highest event rate for the season was 716 events/hr on the night of 18 May, the larger of two dramatic peaks evident during the season (Fig. 3). Respective night and daylight event rates by date were not correlated (Spearman's *Rho* = 0.10, $P = 0.873$). However, lack of daylight sampling (due to weather and logistics) in late April and mid May could have missed temporally correlative high event rates evident at night (Fig. 3).

Probability of event detection decreased as ground level distance from radar increased (Fig. 4). Mean night activity rate/100-m distance segment was > 2.5 times that of daylight (Mann-Whitney $U = 80.00$, $P < 0.001$) (Table 1). No correlation between night and daylight activity rates/100-m segment of the 5-km transect was found (Spearman's *Rho* = 0.7, $P < 0.62$). Daylight activity rates/100-m segment were inversely correlated with topographical relief (Spearman's *Rho* = -0.32, $P < 0.03$) but night rates were not (Fig. 5).

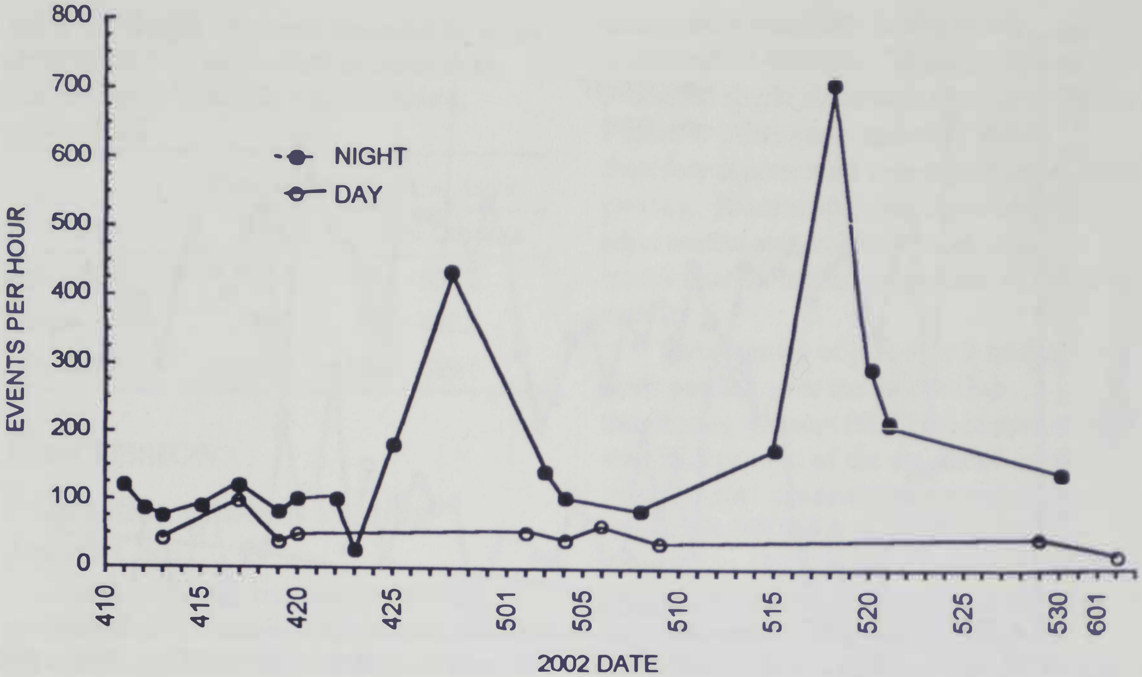

Figure 3. Seasonal night and daylight event rates recorded during radar monitoring near Judith Gap, Wheatland County, Montana, spring 2002

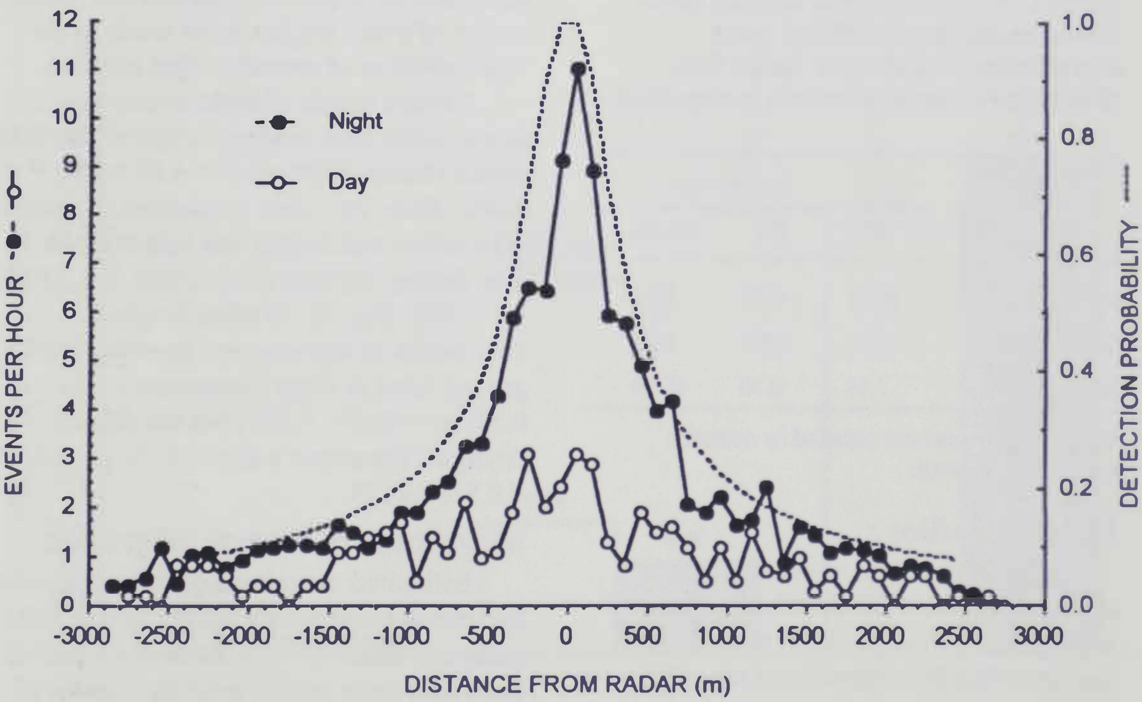

Figure 4. Event rates and detection probability (dotted line) at increasing distance from marine surveillance radar in vertical monitoring mode during night (closed circle) and daylight (open circle) monitoring near Judith Gap, Wheatland County, Montana, spring 2002. Right (+) is east, left (-) is west.

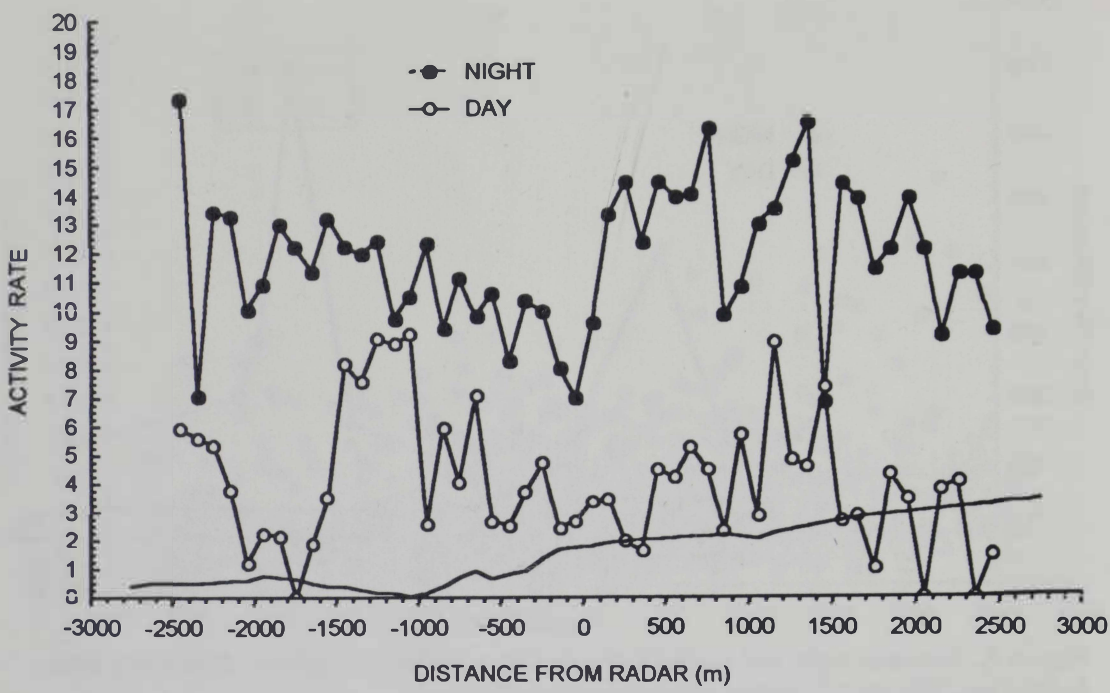

Figure 5. Night and daylight activity rates/100-m segment of a radar transect relative to ground level (irregular horizontal line) near Judith Gap, Wheatland County, Montana, spring 2002. Radar site was located at distance 0. Right (+) is east, left (-) is west.

Table 1. Avian migration activity rates/100-m segment of a 5000-m radar surveillance transect near Judith Gap, Wheatland County, Montana, spring 2002.

Diel (n)	Activity Rate[1] $\bar{x}$	SE	Range
Night (50)	10.25	0.33	9.14
Daylight (50)	4.04	0.34	9.20
Total (110)	7.14	0.38	15.09

[1]Number of events/hour adjusted by detection probability (see text).

Height Profiles

Maximum height of events recorded above radar was 4420 m (19,400 ft msl) at night and 1604 m (10,100 ft msl) during daylight (Fig. 2); neither were aircraft. Heights of night and daylight events were not normally distributed (Shapiro-Wilk's $W > 0.79$, $P < 0.001$). Mean heights in some 100-m segments were skewed by a few very high events (e.g., Fig. 2). Therefore, analysis and display of medians and quartile ranges of event heights were much more representative of overall height profiles.

Median height of night events was 1.5 times higher than median height of daylight events (Mann-Whitney $U = 5.81 \times 10^5$, $P < 0.001$; Table 2). Also, proportion of events at or below risk height was less at night than during daylight (Bonferroni $Z = 2.933$, $P = 0.001$; Fig. 6). Median height of events/100-m segment was correlated with ground level at night (Spearman's $Rho = 0.52$, $n = 55$, $P < 0.001$) but not during daylight (Spearman's $Rho = 0.11$, $n = 37$, $P = 0.51$; Fig. 7).

Magnitude of Vernal Migration

Estimated magnitude of migration over the monitoring transect during spring 2002 exceeded 2 million (N_p, Table 3). Up to 423 birds may have passed over each meter of transect during the season and the majority (> 60%) at night. Number of birds estimated by event rate (N_e) averaged only 12.5 percent ($n = 3$, SD = 4.5) N_p (Table 3).

Table 2. Height of events detected by radar along a 5600-m east - west transect near Judith Gap, Wheatland Co., Montana, spring 2002.

Diel (*n*)	Event Height (m) Above Radar	
	Median	75% Quartiles
Night (3537)	278.8	135.2 - 534.8
Daylight (478)	186.0	90.2 - 480.2
Both (4015)	270.7	125.6 - 529.1

DISCUSSION

Population of Birds Passing Judith Gap

Calculating the migrant population passing over the monitoring transect (5600 m) with event rates (N_e, Table 3) resulted in an estimate of just over 200,000 events occurring between 11 April and 2 June. Clearly, single events often were composed of large numbers birds. One flock of Snow Geese (*Chen caerulescens*) observed over Judith Gap was composed of ≥ 300 birds and flocks of Canada Geese (*Branta canadensis*) observed farther south contained 20-60 birds. These events produced single signatures similar to that in Figure 1. Absolute number of events therefore represented only a portion of birds passing. Rates employing detectability adjustments are probably much more representative of true magnitude of avian activity.

The estimate of just over 2 million birds passing over the Judith Gap monitoring transect (5000 m) in spring 2002 was 58.8 percent of the estimated vernal migrants that passed over a comparable transect in NHWRA in southwestern Montana in 1995-96 (Harmata et al. 1998). Magnitude difference between study sites may be a result of the proximity of the NHWRA radar site to Ennis Lake, a strong ecological magnet and a historical migration stopover site for many species of birds. NHWRA was less than 4 km due north of Ennis Lake and many birds leaving the lake to continue northward flew directly over the radar site. Judith Gap is in a physiographic gap, but the actual portal is a

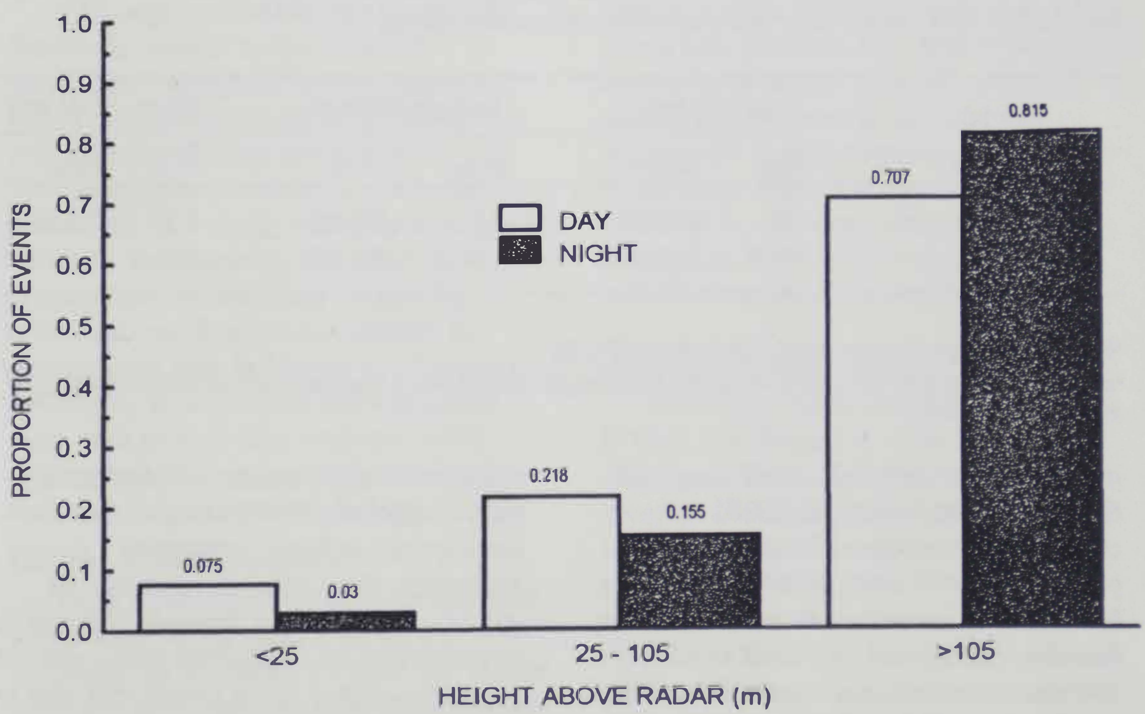

Figure 6. Height of events above radar during monitoring near Judith Gap, Wheatland County, Montana, spring 2002. Categories are relative to rotor swept area (25 – 105 m) of wind turbines proposed in the vicinity.

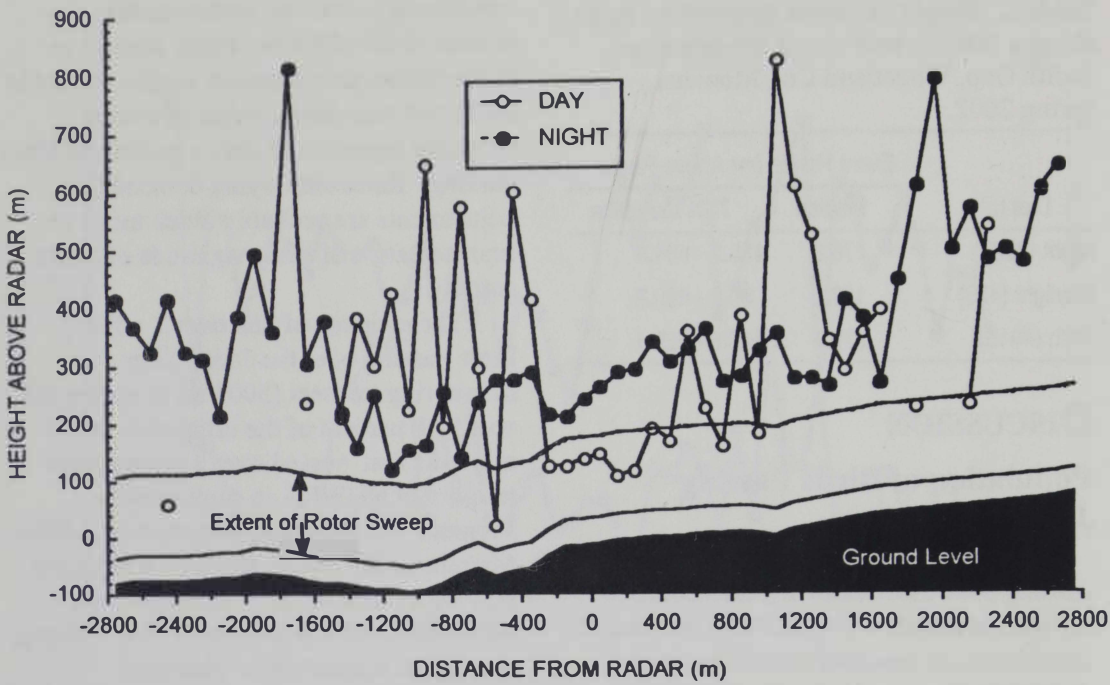

Figure 7. Median height of night and daylight events above radar and relative to ground level and rotor swept area of proposed wind turbines along a 5.6-km transect, near Judith Gap, Wheatland County, Montana, spring 2002 during. Perspective is from an observer south of the site, facing due north. Radar site is at distance and height 0. Turbines are not proposed for the site but for other sites in Wheatland County.

Table 3. Two estimators of numbers of birds flying over an east - west transect during radar monitoring near Judith Gap, Wheatland Co., Montana, spring 2002.

	Night (703 hrs)		Daylight (994 hrs)		Season (1704 hrs)	
Estimator	Rate	Birds	Rate	Birds	Rate	Birds
N_e[1]	2.8	110,230	2.2	122,460	2.5	238,560
N_p[2]	10.25	1,261,006	4.04	702,758	7.1	2,117,220

[1]Estimator uses event rate over a 5.6 km transect (Fig. 3).
[2]Estimator uses activity rate (event rate/radar detection probability) over a 5 km transect and a mean flock size multiplier (3.5/event).

minimum of 16 km wide. Birds may pass through the Gap widely dispersed or concentrated over the radar site or other portions, e.g., the foothills of the Snowy Mountains to the east, to disperse again on the other (north) side. If vernal avian movement were dispersed over the width of the Gap, as many as 6.7 million birds may pass through.

Although waterfowl were observed migrating over Judith Gap, behavior and signature of night events indicated many were composed of either single birds or small groups of birds, suggesting passerines, shorebirds, or other smaller species. Magnitude differences between the two sites may be a reflection of the relative population size of avian groups that tend to pass over them (i.e., waterfowl vs. passerines).

Interpretation of event composition may confound population estimates. It is unlikely multiple night events at high altitude in spring were composed of individual birds or flocks reversing direction or circling, passing through the radar beam several times. Such phenomena would over-estimate actual numbers. Many daylight events, however, were probably composed of multiple detections of a single bird and may have resulted in an over-estimate of daylight populations. Flock size multipliers used here also may be unrepresentative. Passerine flocks may consist of many more individuals than waterfowl flocks. Conversely, more events detected at Judith Gap may have consisted of single birds than those detected at NHWRA.

Timing of Migration

Peaks in night activity rates were evident in late April and mid May (Fig. 3). Radar monitoring 6 km farther south in Wheatland County in 2003 also showed temporally identical peaks in late April and mid May (Harmata 2003). Remarkably, timing and number of peaks in Wheatland County were nearly identical for vernal migrant birds at NHWRA.

Although movement may be episodic from influences of meteorological phenomena throughout spring, pulses in vernal migration of birds were clearly evident at Judith Gap and NHWRA. Movement may therefore be relatively predictable (± 1 week) each year throughout the state. Predictability has important implications for designing monitoring regimes to verify migration activity at development sites in Montana. Minimizing monitoring time to a few dates spanning these peak periods may produce results representative of seasonal migration and eliminate the need for season long effort.

Height Considerations

Only 3 percent of events were detected within 25 m above radar level during total darkness (Fig. 6). Many of these low events may have been Lark Buntings (*Calamospiza melanocorys*) because of similarity of signature behavior to their courtship flights. Most diurnal birds are not known to forage at night. Aside from courting, there seems to be little reason to be aerial at night other than to migrate. Additional height would facilitate avoidance of structures (trees, towers, topography) and migrating in darkness would facilitate avoidance of diurnally active predators. This and the dramatic difference in median height and activity rates between night and daylight events (Table 3) suggest most night events were indeed composed of migrant birds. Also, correlation of night heights with topographical relief suggests nocturnal migrant birds may fly at minimum height above ground level.

Impact Analysis Potential

Impact of resource development should be evaluated with adequate data on all aspects of a BACI study. Data generated for Judith Gap can well serve as "Before-Control" avian-activity data for proposed wind-power development. Determining values comparable to those presented here for proposed wind resource areas pre-construction (Before-Impact) may assist in evaluating impacts of development post-construction, if proposed sites are not too distant in space (> 50 km) or time (> 5 yrs). Event rates (Table 3, Fig. 4) may be used in comparisons instead of activity rates, eliminating the need for detectability adjustments in post-construction monitoring. Effect or impact may be indicated by statistical changes in these values (i.e., $P \leq 0.05$) or other biological criteria when considered with controls.

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