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Abstract

To develop a bird-avoidance model for Naval Air Facility El Centro, California, we used a modified marine-radar system to quantify nocturnal (sunset to midnight) bird movements in the area. Previous bird-radar studies relied on visual monitoring of the radar screen for data collection. This study represents the first use of computer-aided image analysis of marine-radar bird-data. Radar images were automatically captured, analyzed, and archived with a personal computer. The image analysis eliminated ground clutter, calculated the sample area, identified bird targets, and categorized them into three relative size classes. This made data collection more uniform by eliminating observer bias. We operated the system on 34 nights between 20 Oct and 29 Nov 2000 and recorded a total of 320,703 bird targets. Calculated hazard indices ranged from a low of 0.23 to 29.48. Hazard indices $\leq$ 10.00 were classified as low, between 10.00 and 18.00 were classified as moderate, and > 18.00 were classified as high.

Introduction

Collisions between aircraft and birds (bird strikes) have been a problem since the beginning of powered flight (Blokpoel 1976, Solman 1978, Steenblik 1997). Civil and military bird-strike damage to aircraft in North America likely exceeds $500 million/year (MacKinnon 1998) and threatens human health and safety (Blokpoel 1976, Conover et al. 1995, Cleary et al. 1999). One method of reducing the number and severity of bird strikes is the development and use of bird-avoidance models (BAM), which are quantitative or qualitative assessments of the distribution of risk of a damaging-bird strike over time and space. Recent examples of BAMs include the U.S. Air Force's (USAF) US BAM, Avian Hazard Advisory System, Dare County Bombing Range BAM, and Moody Air Force Base BAM. These are all computer-based models that describe the bird-strike risk over time and space to those in charge of aircraft operations (pilots, schedulers, air traffic controllers, etc.).

Each model relies on some description of the expected distribution of birds in the area and an assessment of the hazard posed by these birds. Diurnal bird-strike risk can be assessed using visual-bird counts, but both birds and aircraft also fly at night and bird strikes do occur at night. Seventeen percent of USAF bird strikes/hour occurred at night and 34.9% occurred at dusk (Tedrow 1998). Thus, an understanding of nocturnal bird use of an air space would be useful in bird-hazard management. Additionally, a description of the disproportionate occurrence of birds at different altitudes would allow pilots to avoid altitudes with higher concentrations of birds. In this paper we use a bird-radar system to collect data for the development of a bird-avoidance model describing the nocturnal-bird hazards to aircraft at Naval Air Facility (NAF) El Centro, California. Although an avian survey was conducted at NAF El Centro in 1996, it did not describe nocturnal-bird use (Aigner and Koehler 1996).

At least two methodologies (moon watching - counting birds crossing the full moon, and ceilometers - counting birds passing through a vertical spot-light beam) have been used to quantify nocturnal-bird movements, but radar has distinct advantages over these (Blokpoel 1976). Radar was developed just prior to World War II and from the start it was able to detect birds (Eastwood 1967). In fact, birds often obscured or were mistaken for aircraft, which were the intended targets (Eastwood 1967). Much work went into masking bird targets so as to concentrate on aircraft images (Eastwood 1967). Due to its classified status, radar capabilities in general, and radar-bird detection capabilities specifically, were not revealed to the civilian sector until after the war (Brooks 1945, Lack and Varley 1945, Eastwood 1967).

Radar ornithology offers several benefits to the study of bird movements; it can sample large volumes of airspace and identify birds of all sizes, well beyond the capabilities of an observer with a spotting scope (Eastwood 1967, Blokpoel 1976). With radar, flight direction and speed of individuals or large flocks can be calculated. With radar, records of bird movements can be accumulated for indefinitely long periods. Most important to this study, birds can be counted with radar technology at night as easily as during the day. Radar does not allow the identification of bird species, nor is radar able to distinguish between radar targets caused by smaller birds flying in close proximity from those representing a single larger bird. This has been a problem since the beginning of radar ornithology because it is difficult to compare birds seen on radar with an acceptable second means of identification (Eastwood 1967, Blokpoel 1976, Cooper 1995). The use of radar for avian data collection is rather cost effective for the amount of information collected. It is the most effective nocturnal-bird-sampling method when species identifications are not needed or when only rough estimates of bird numbers are required.

The decreased cost and increased availability of radar systems to the public sector has made radar ornithology more accessible and cost effective. Currently, a marine-radar system can be found on even modest fishing and pleasure boats throughout the country. These commercially available marine-radar systems can be used, with minor adjustments, to monitor bird movements (Blokpoel 1967, Cooper 1995, Kelly et al. 1995 & 1997, Harmata et al. 1999). The proliferation of personal computers (PC) in the 1980s and 1990s, and the steady increase in their performance and power are a great benefit for bird-radar systems. Just a few years ago, bird data from a radar system had to be tallied by an observer watching the screen (Harmata et al. 1999) or by video taping the radar screen and playing back the image on a television screen (Kelly et al. 1995, 1997). Today computers make it possible to capture radar images in real-time, at virtually any interval, analyze them with much greater accuracy and precision, and archive them in digital format.

The objective of this study was to create a nocturnal bird-avoidance model for NAF El Centro using radar as the primary sampling tool. Bird hazards identified by the radar system were categorized as high, moderate, or low risk of a damaging strike. Nocturnal bird hazards were described from sunset until midnight because the Navy does not typically fly from midnight to sunrise. Curtailing flight operations during high-risk periods of heavy nocturnal bird activity can lower the bird-strike probability and corresponding damage by lowering the level of exposure to birds aloft. This is the basic premise of a BAM. On the other hand, during periods of low bird-hazard, aircraft can operate with greatly diminished risk of bird-strike damage. Flights can be concentrated at these times.

Study Area

NAF El Centro is located in Imperial County, California, approximately 193 km east of San Diego and 93 km west of Yuma, Arizona. It is 11 km north of the Mexican border and 26 km south of the Salton Sea National Wildlife Refuge (Fig. 1). The base encompasses 927.5 hectares, including the airfield and other facilities. NAF El Centro is situated in a low-lying basin of the Salton Sea Trough in the Sonoran Desert. The airfield is 13.1 meters below sea level and is surrounded by year-round, irrigated agricultural land.

NAF El Centro operates two bombing ranges (Fig. 1). These are both predominantly in a creosote bush (Larrea tridentata) scrub plant community (Costi et al. 2000). East Mesa Range is located approximately 50-km northeast of NAF El Centro. It contains two target areas, Target 68 to the south and Target 95 to the north. West Mesa Range is located approximately 15-km west of NAF El Centro. It also contains two target areas, Target 103 to the south and Target 101 to the north. Target 101 is the only target with personnel regularly on site. A range-management contractor occupies a building and control tower, and scores pilot's accuracy at Target 101. Target 95 is scored by a remote camera system, operated by the contractor at Target 101. The other two targets are not scored. All of the target areas are surrounded by public, undeveloped, and natural landscape, managed by the US Department of Interior, Bureau of Land Management.

Methods

We used Geo-Marine Inc.'s (GMI) Mobile Avian Radar System (MARS) to quantify nocturnal (sunset to midnight) bird activity at NAF El Centro from 20 Oct to 29 Nov 2000. This was a 25 kW, X-band, marine-radar system (Furuno model FR-1525). The radio frequency was 9,410 $\pm$ 10 megahertz and the wavelength was 3-cm. X-band marine-radar (2.5-4 cm wavelengths) has been used in several bird-radar studies (Cooper 1995; Kelly et al. 1995, 1997; Harmata et al. 1999).

The radar system was modified to operate in the vertical plane and was linked to a personal computer (PC). The 8-ft. antenna was turned on its side so that it rotated vertically, like a windmill, at 24 revolutions per minute (Fig. 2). The radar beam width was 20 degrees. The radar image was displayed on a 15" color monitor. The system was oriented east-west, which figuratively "cast a wide net" to sample south-migrating birds passing the site. We operated the radar at its 1,400-m range setting. The radar beam first pointed west across the surface of the ground, then rotated upward through an arc crossing vertical, and continuing through the arc until it pointed east along the surface of the ground. It then continued through the arc pointing at the ground, collecting no data until the beam rose above the ground once again to the west and continued its vertical-rotation.

MARS was located at the West Mesa Range near Target 101 (latitude 32^{o} 55' 57"/longitude 115^{o} 42' 15"). Radar images were captured, analyzed, and archived with the PC using GMI's proprietary software. The computer-aided image analysis first eliminated ground clutter (radar returns from the ground, high land formations, buildings), then measured target size and altitude, and categorized birds into relative size classes. Radar images were captured with a computer-controlled digital-video camera. A still image of the video stream was captured every 30 seconds (120 images per hour). This assured independence of samples; a bird flying at a typical speed of 50 km/hour would pass through the 90-m wide radar beam in 7 seconds. Even much slower flying birds would have cleared the sample space in less than 30 seconds. So, every 30 seconds a fresh sample of birds was recorded. The images were organized and stored on the computer's hard drive for image processing and archiving to CD-ROM.

Since bird mass is a good predictor of the relative hazard to aircraft (Tedrow 1998, Dolbeer 2000), increasing hazard was assigned to increasing size classes. To do this in a meaningful way, birds of each size were scaled using "small-bird equivalents" (SBE) to standardize birds by mass. Kelly (1995) first used the concept of SBEs in the development of the USAF's Dare County Bombing Range Bird-Avoidance Model (Kelly 1995). During fieldwork at NAF El Centro, 129-bird species were identified. Mean-body mass for each of these was estimated using Dunning (1993). For those species that showed sexual dimorphism, the mass of the larger sex was used to be conservative. Birds < 70 g were categorized as small, birds between 71 - 800 g were categorized as medium, and birds with masses > 801 g were categorized as large based on the pixel size of the bird targets on the radar screen (Kelly 1995). The median mass for each class was used as a measure of central tendency because their distributions were allokurtic (Zar 1999). We calculated the median-body mass for each class in the NAF El Centro area, then calculated the multiples of median small-bird masses in medium and large-bird masses. SBEs were the multiple of the median small-bird masses in medium and large bird masses.

The use of SBEs helps to counter the problem of unknown bird numbers per radar target. A medium target on the radar screen may be a single medium bird or a small flock of small birds. Either way it is represented in the model as the same number of SBEs. The assumption is that it is equally hazardous to strike one medium bird or a small flock of small-sized birds. A larger flock of small birds, a small flock of intermediate-sized birds, and an individual large bird would all be categorized as large-bird targets and would be recorded as the same number of SBEs. Thus, the numbers of birds per radar target, hence risk, though not completely quantifiable, is incorporated in the algorithm below.

Days of the year were categorized into 14-day biweeks originating on January first. Altitude data were categorized into altitude bands: 0-150 m, 151-300 m, 301-600 m, and >600 m. Bird hazard indices were calculated for each biweek and altitude band by iterating the following algorithm:

$H_{BA} = [(S + W_m M + W_l L)/I]/R$

- H_{BA} = hazard per biweek and altitude band
- S = count of small birds
- W_m = weight (SBEs) for hazard level of medium-sized birds (described above)
- M = count of medium birds
- W_l = weight (SBEs) for hazard level of large-sized birds (described above)
- L = count of large birds
- I = number of radar images recorded in each biweek
- R = area of radar-sampled airspace in sq. km

For each biweek and altitude band, the algorithm adds the number of small birds, the number of SBEs based on medium-sized birds, and the number of SBEs based on large birds. This yields the total number of SBEs for a specific biweek and altitude band. The mean number of SBEs per radar sample was then calculated by dividing by the number of radar images sampled per biweek. Lastly, we computed the mean SBE density using the area of airspace sampled as the divisor. The algorithm weighted birds according to a standardized relative size and calculated a mean density of birds per radar sample. GMI's proprietary image-analysis software easily calculated the area of the slice of airspace sampled by the radar by counting the number of image pixels within each altitude band and multiplying by the area of each pixel. We plotted the hazard indices in a histogram to identify break points between high, moderate, and low bird-strike hazard.

Results

Medium and large-sized birds were equal to 15 and 60 SBEs respectively (Table 1). These figures were used as the weighting values in the bird-hazard algorithm.

The MARS was operated for 34 nights, distributed across six biweeks, between 20 Oct and 29 Nov 2000. We averaged three sessions per week during the 11 weeks of operation. The radar system recorded 320,703 records, including 48,931 (15.3%) large targets, 119,678 (37.3%) medium targets, and 152,094 (47.4%) small targets. The number of birds per size class and their SBEs in each biweek and altitude band is shown in Table 2. Calculated hazard indices ranged from a low of 0.23 to 29.48 (Fig. 3). Hazard indices $\leq$ 10.00 were classified as low, between 10.00 and 18.00 were classified as moderate, and > 18.00 were classified as high. The distribution of classified-bird hazards at NAF El Centro is shown in Table 3.

Discussion

The model predicted relative bird-strike hazards throughout the six biweeks sampled. Risk levels were relative, not absolute, values. The hazard indices were highest at the very beginning of the study with a declining trend toward the end in November. We assumed that an increasing trend would have been revealed from early August to mid-September, had the radar been operational at the time. Unfortunately, funding constraints dictated our late start. This bird-hazard level closely follows the USAF bird-strike count by month (Fig. 4). The study ended as migration appeared to taper off substantially by the end of November.

Bird hazards were fairly uniform up to 600-m altitude. All three of the lower altitude bands in each biweek shared similar risk. Although the radar identified birds to 1,500-m altitude, the bird hazard above 600-m was low throughout the study period. It should be noted that birds may have been using altitudes above the sample altitude of 1,500 m. The lack of large numbers of birds between 600 m and 1500 m suggests that most birds in the study area used altitudes below 1,500 m.

Radar proved to be a valuable tool for nocturnal bird-data collection. It was advantageous to be able to collect bird-movement data at night. Radar does not provide species information but provides instead a suitable proxy for the hazard posed to aircraft. Although it is common to think of the correlation between species and the level of bird-strike damage, bird size is a primary factor in bird-strike damage to aircraft (Dolbeer et al. 2000). We based the hazard predictions on the amount of bird mass in the airspace at a particular time. Additionally, radar provided a greater degree of accuracy of the altitude distribution of birds in the airspace than is possible with visual estimates. Radar also allowed collection of a large amount of data over a short period of time.

The model was based on historical data; viz., bird-radar data from fall migration 2000 were used to predict fall migration in future years. Although the level of bird migration is relatively stable from year to year, changes in population, breeding grounds, wintering grounds, local food availability, and local land use will affect the level of bird use of the area and therefore the bird-strike risk. The model is best thought of as a historic representation of the expected distribution of bird strikes at the installation throughout the year. It should be evaluated periodically and updated as necessary. Attention to reporting of all bird strikes and maintenance of a bird-strike database will enable evaluation of the model's effectiveness and provide data for future upgrades.

Acknowledgments
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Table 1. Small-Bird Equivalents (SBE) for large and medium-sized birds based on multiples of small-bird mass at NAF El Centro, CA

			grams			
Target Size	n	Mass Range	Min	Max	Median	# SBE
Small	58	0-70	3.2	68.1	20.6	1
Medium	45	71-800	79.7	792.0	316.0	15
Large	26	801-7,000	850.0	7000.0	1233.0	60

Table 3. Nocturnal (sunset-midnight) bird-hazard categories by biweek and altitude band for fall migration at NAF El Centro, CA.

	Altitude Band			
Biweek*	0 – 150 m	150 – 300 m	300 – 600 m	> 600 m
1 (10 Sep-23 Sep)	High	High	High	Low
2 (24 Sep-7 Oct)	Medium	Medium	Medium	Low
3 (8 Oct-21 Oct)	High	High	High	Low
4 (22 Oct-4 Nov)	Medium	Medium	Low	Low
5 (5 Nov-18 Nov)	Medium	Medium	Medium	Low
6 (19 Nov-2 Dec)	Low	Low	Low	Low

* Biweeks are 14-day periods originating on 1 January.

Table 2. Nocturnal (sunset-midnight) bird-hazard indices per biweek and altitude band with number of birds per size class and number of small-bird equivalents (SBEs) at NAF El Centro, CA, 10 Sep – 2 Dec 2000.

Biweek$_a$	Altitude$_b$	Small$_c$	Medium$_c$	15M	Large$_c$	60L	SBE$_d$	Images$_e$	SBE/Image	Airspace$_f$	Hazard Index
1	1	1377	1326	19890	533	31980	53247	1322	40.278	1.683	23.930
1	2	2186	2334	35010	1133	67980	105176	1322	79.558	2.699	29.480
1	3	2452	4091	61365	2936	176160	239977	1322	181.526	6.678	27.184
1	4	1657	1160	17400	514	30840	49897	1322	37.744	11.574	3.261
2	1	3007	2941	44115	1135	68100	115222	4037	28.541	1.683	16.957
2	2	4185	4133	61995	1851	111060	177240	4037	43.904	2.699	16.268
2	3	3507	5443	81645	3578	214680	299832	4037	74.271	6.678	11.122
2	4	3008	1841	27615	996	59760	90383	4037	22.389	11.574	1.934
3	1	9663	5745	86175	1598	95880	191718	5622	34.101	1.683	20.260
3	2	11396	7245	108675	2781	166860	286931	5622	51.037	2.699	18.912
3	3	15094	15845	237675	7937	476220	728989	5622	129.667	6.678	19.418
3	4	6437	7159	107385	2985	179100	292922	5622	52.103	11.574	4.502
4	1	7477	3903	58545	892	53520	119542	4704	25.413	1.683	15.098
4	2	8691	5077	76155	1374	82440	167286	4704	35.563	2.699	13.177
4	3	7665	6691	100365	2660	159600	267630	4704	56.894	6.678	8.520
4	4	4259	3920	58800	1405	84300	147359	4704	31.326	11.574	2.707
5	1	8355	4503	67545	1218	73080	148980	6081	24.499	1.683	14.555
5	2	11684	6892	103380	2226	133560	248624	6081	40.885	2.699	15.150
5	3	14831	13867	208005	6336	380160	602996	6081	99.161	6.678	14.849
5	4	10945	10335	155025	3161	189660	355630	6081	58.482	11.574	5.053
6	1	3310	1022	15330	256	15360	34000	4436	7.665	1.683	4.554
6	2	5268	1486	22290	335	20100	47658	4436	10.743	2.699	3.981
6	3	4930	2362	35430	968	58080	98440	4436	22.191	6.678	3.323
6	4	634	310	4650	109	6540	11824	4436	2.665	11.574	0.230

a) Biweeks are 14-day periods originating on 1 Jan. Biweek 1 = 10 Sep-23 Sep, biweek 2 = 24 Sep-7 Oct, biweek 3 = 8 Oct-21 Oct, biweek 4 = 22 Oct-4 Nov, biweek 5 = 5 Nov-18 Nov, biweek 6 = 19 Nov-2 Dec. b) altitude band 1 = 0-150 m, 2 = 151-300 m, 3 = 301-600 m, 4 > 600 m. c) small-bird mass < 70 g, medium-bird mass is between 71-800 g, large-bird mass > 800 g. d) SBE = small-bird equivalents. e) number of radar images in sample. f) air space measured in square km

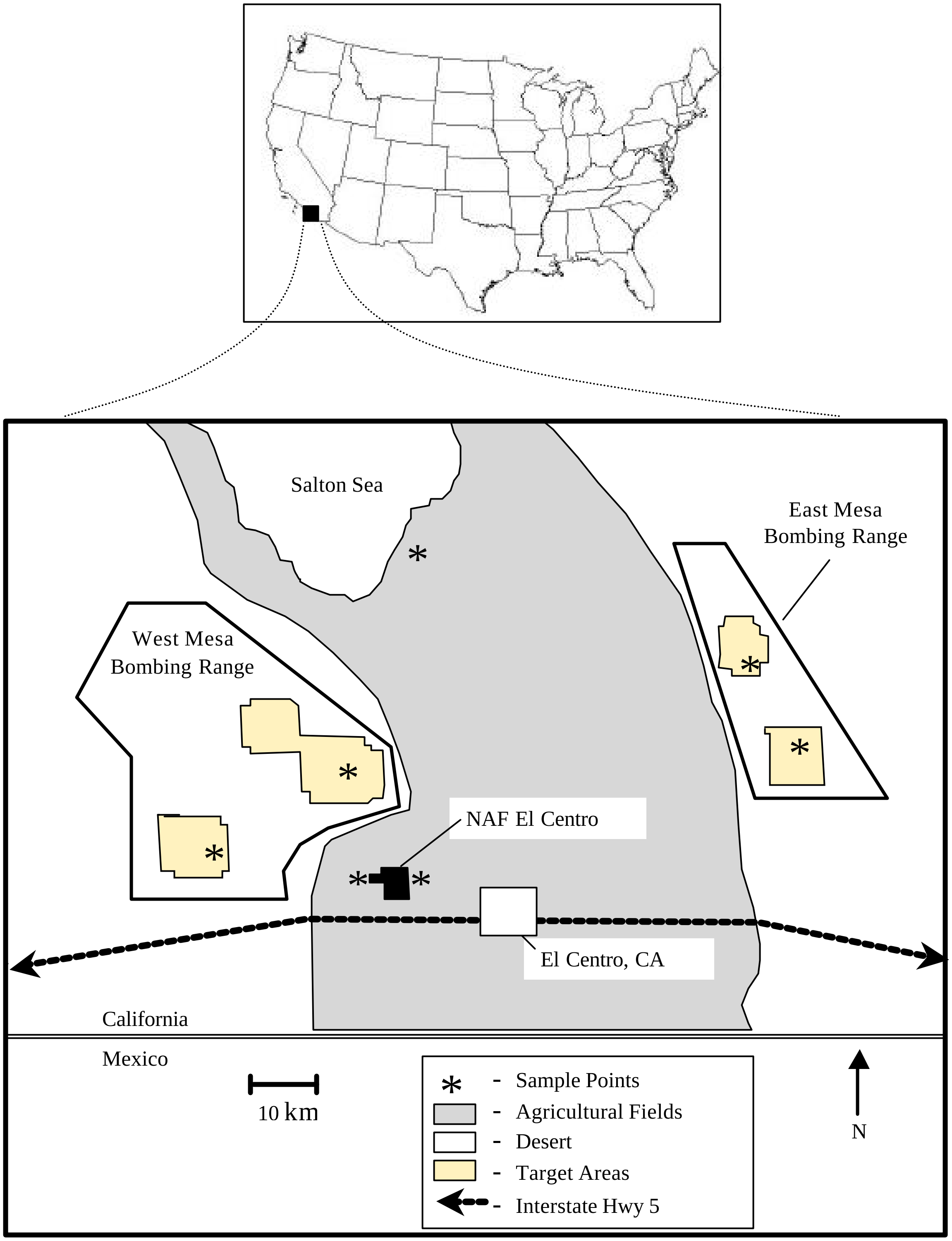

Fig. 1. Map (not to scale) of southern California showing NAF El Centro and the East and West Mesa Bombing Ranges. Inset shows location within the United States.

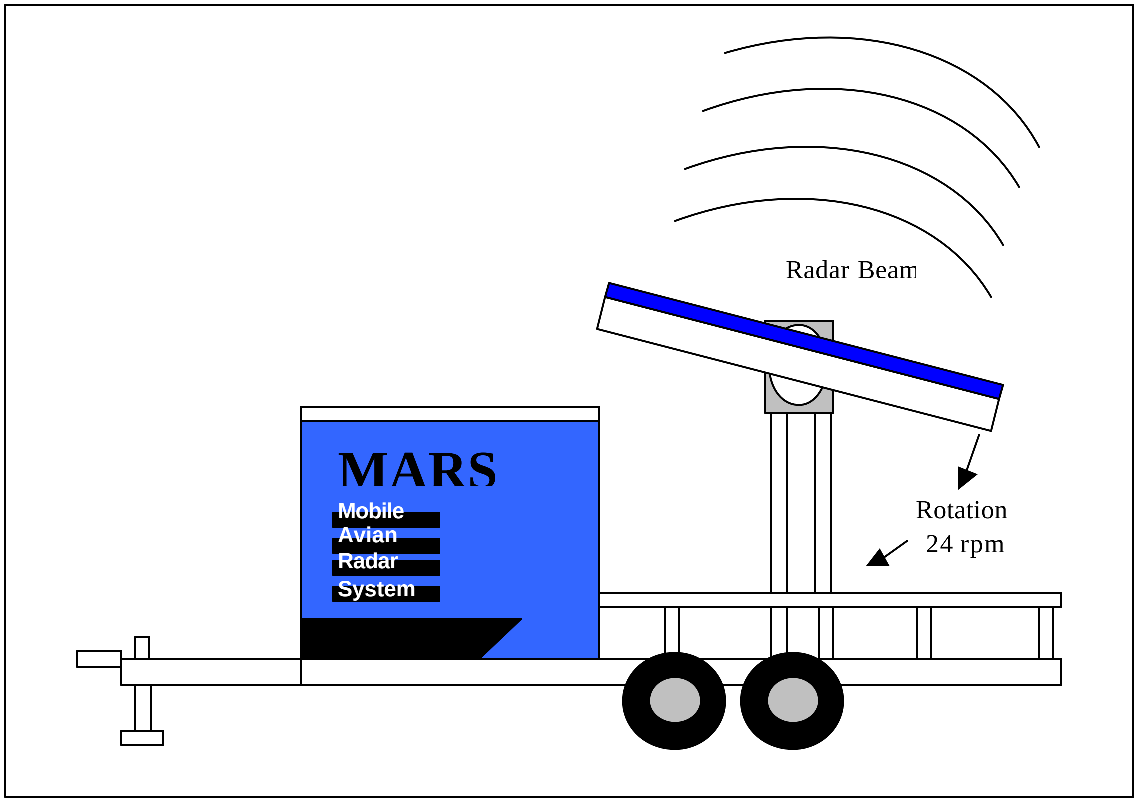

Fig. 2. Sketch of Geo-Marine Inc.'s Mobile Avian Radar System (MARS), used to collect nocturnal bird-migration data at NAF El Centro, 20 Sep – 29 Nov 2000.

a)

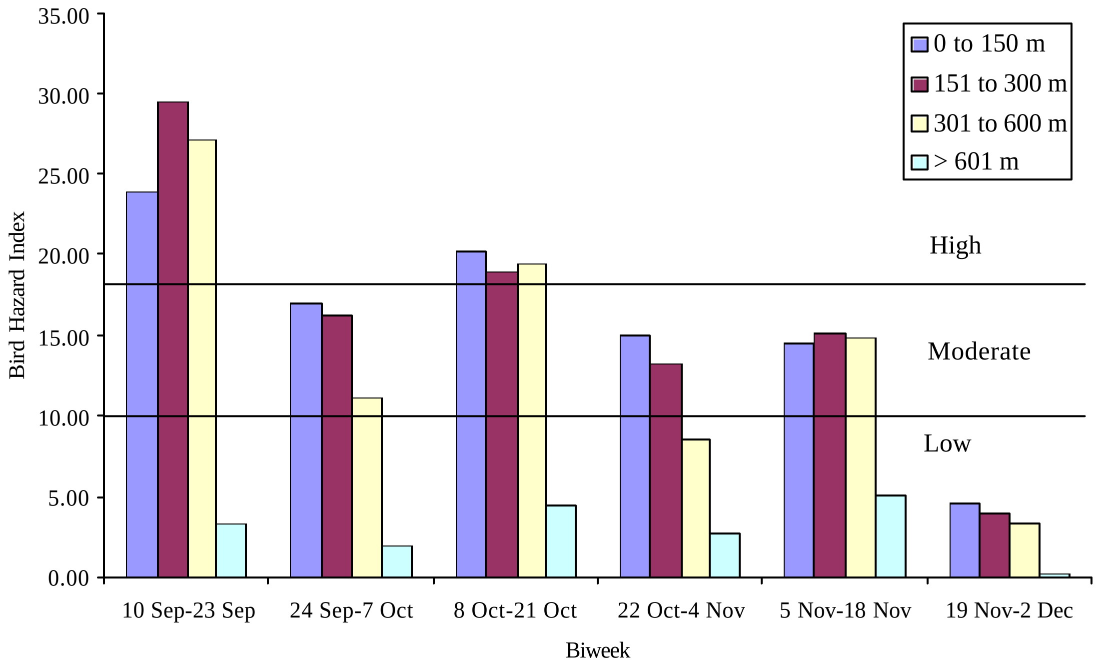

Fig. 3. Fall nocturnal bird-hazard indices by biweek and altitude band at NAF El Centro, CA. a) groups the altitude bands per biweek b) the same data with biweeks grouped per altitude band. High (18) and Moderate (10) thresholds are indicated.

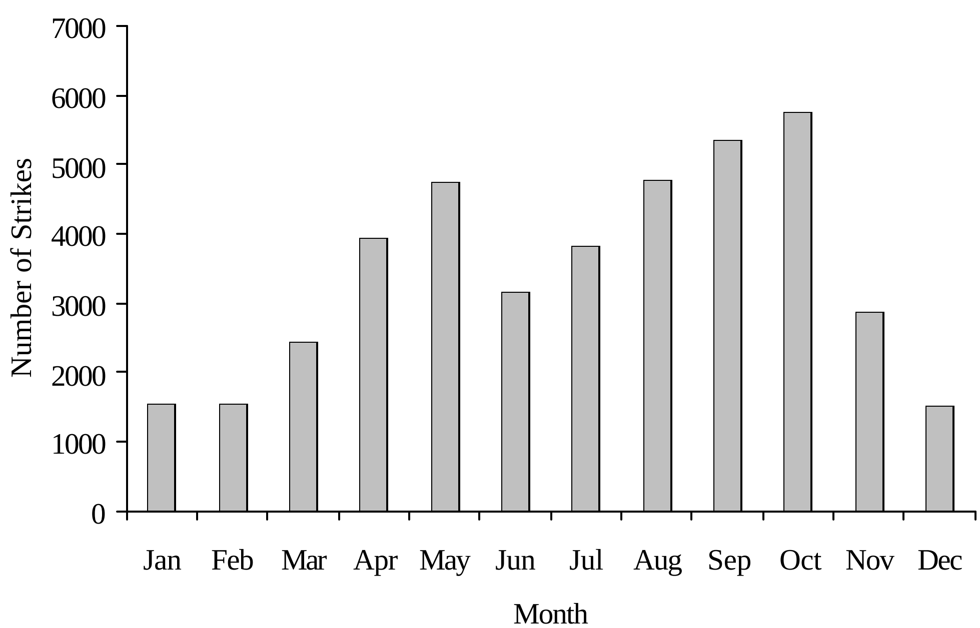

Fig. 4. US Air Force bird strikes per month, worldwide from Jan 1985 – Jun 2000 (data from the USAF BASH Team web page)