Final Report

Development of a Bird-Avoidance Model for Naval Air Facility El Centro, California

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PREFACE

Bird-strikes (collisions between birds and aircraft) pose a significant threat to aviation safety. Naval Air Facility El Centro, CA lost an F-18 jet to a bird strike in October 1995. To help combat this threat we developed a bird-avoidance model as a risk-management tool to help the Navy plan training flights in areas and during times of low bird activity at the installation. The calculated bird-strike risks were published as a web page to be maintained on the installation's internet server for easy access by flight crews, flight-safety officers, airfield managers, natural resource managers, and other Navy personnel.

Bird hazards during daylight hours were quantified using daily bird counts throughout the year 2000. These were combined with a bird-hazard index for different species groups developed using U.S. Air Force (USAF) bird-strike records.

Nighttime bird hazards were quantified in the fall of 2000 using a bird-radar system to count birds in three relative size classes. Counts were combined with a size-class hazard index known as *small-bird equivalents*, which scaled the three size classes by the extent of damage done to USAF aircraft. Small-bird equivalents were calculated using an avian-species list for the study area. Calculated small-bird equivalents were 1 for small birds (< 70 g), 15 for medium-sized birds (between 70-800 g) and 60 for large birds (> 800 g). Thus, a large bird is 60 times as hazardous, and a medium bird is 15 times as hazardous as a small bird. The bird-strike hazard at Naval Air facility El Centro was highest on nights in late April-May and September-early October.

In this study, many references are made to USAF and Federal Aviation Administration (FAA) studies, reports, and data. The USAF and FAA have a long history of supporting bird-hazard management and research and their information is complete and well documented. We encourage the Navy to take a more prominent lead in the field of bird-hazards to aircraft.

BIRD STRIKE BACKGROUND

Less than eight years after the Wright Brothers' first flight in Kitty Hawk, North Carolina, Cal Rogers became the first person to fly across the continental United States. Five months later he collided with a gull while flying over Long Beach, CA. He became the first bird-strike fatality on April 3, 1912. The problem has grown since.

BIRD HAZARDS TO AIRCRAFT

Collisions between aircraft and birds (bird strikes) have been a problem since the beginning of powered flight (Blokpoel 1976, Solman 1978, Steenblik 1997) and will likely increase in number and severity in the future (Steenblik 1997, Tedrow 1998, Dolbeer 2000). The risk of a damaging bird strike greatly increased when jet engines replaced piston engines in the 1950's (Solman 1973, 1978; Blokpoel 1976). Both the numbers of aircraft (Langley 1970, Tedrow 1998, Dolbeer 2000) and the numbers of many species of birds (Steenblik 1997, Tedrow 1998, Dolbeer 2000) have increased dramatically over the last century. From 1980 to 1998 civil air passenger enplanements increased 110%, a mean annual rate of 4.2%, and are expected to continue at current levels through 2005 (Cleary et al. 2000, Dolbeer 2000). The number of civil wildlife-strikes reported to the Federal Aviation Administration (FAA) has risen 280% from 1,739 in 1990 to 4,878 in 1999 (Cleary et al. 2000). This rise is due to both increased aircraft movements and increased bird populations. Military aircraft rely heavily upon the tactic of low-level, high-speed flight. Their bird-strike risk may be similar to civil aircraft when flying near airfields, but they additionally strike many birds during low-level training flights.

Changes in land use and successful wildlife management by resource agencies and environmental organizations (e.g., pesticide regulation, expansion of the refuge system) have resulted in increased populations of several bird species known to be hazardous to aircraft (Dolbeer 2000). Resident Canada goose populations have increased at an annual rate of 13.1% from 1966 to 1998 (Cleary et al. 2000, Dolbeer 2000). In the same period ring-billed gull populations increased 5.9% per year (Cleary et al. 2000, Dolbeer 2000). Turkey vulture and red-tailed hawk populations increased 1.0% and 3.1% per year respectively over this period (Cleary et al. 2000, Dolbeer 2000).

Generally, the risk of a bird strike is greatest at low altitudes, where birds are most abundant. Thus, risk for most aircraft is generally highest near airfields (Solman 1971, 1973). Seventy-five to ninety percent of birdstrikes involving civil aircraft occurred near airports, primarily during take off and landing (Blokpoel 1976, Cleary et al. 2000). Although most bird strikes occur near airfields, military aircraft have additional exposure to bird strikes because of their emphasis on low altitude, high speed, training flights (Solman 1973, Tedrow 1998). Over 20% of U.S. Air Force (USAF) bird strikes occur during low-level training (Tedrow 1998). From 1986 to 1996, bird-strikes resulted in nearly $500 million damage to USAF aircraft and the loss of 33 airmen (Lovell and Dolbeer 1997a). During maneuvers military aircraft usually operate at altitudes from 50 to 300 m above ground, and at 450 to 1,100 km/h during low-level flight (DeFusco 1993). Low-level flight increases the probability of a strike because larger numbers of birds are found at lower altitudes. Also, if a serious bird strike occurs at low altitude there is much less time or space for the pilot to maneuver while dealing with complications resulting from the strike.

The Navy began its mandatory bird-strike-reporting program in 1981 (Walker and Bennett 1985). Eighty percent or more of bird strikes go unreported to USAF and FAA databases (Cleary et al. 1996, 1997, 1998; Dolbeer et al. 1995; Linnel et al. 1999; Barras and Dolbeer 2000). The Navy reporting rate is unknown but is likely less than USAF and the FAA reporting rates. Navy BASH support seems to be improving as evidenced by their 1st BASH Symposium in October 2000. Despite the low reporting rate, Naval Air Facility (NAF) El Centro in southern California has recorded 53 bird strikes from 1981 to 1998. The most damaging strike resulted in the loss of an F-18 jet to a “large bird” on 5 October 1995, at a replacement cost of $30 million, suggesting the need to establish a prevention protocol. The aircrew of the F-18 safely ejected, although this is not always possible when serious damage is done to the aircraft. One week prior to the crash at NAF El Centro, the USAF lost an E-3 Sentry, Airborne Warning And Control System (AWACS) aircraft at Elmendorf Air Force Base, AK. The modified Boeing 707 reportedly struck in excess of 30 Canada geese on take-off, lost power in two of its four engines, and crashed destroying the $300 million aircraft and killing all 24 crew members on board (Combat Edge 1998).

In addition to the loss of aircraft and personnel, several million dollars are spent each year on repairs to aircraft damaged by bird strikes. For example, the Navy bird-strike database describes an incident where an F-18 jet aborted takeoff after hitting a "large owl" at NAF El Centro on 11 January 1993. Though the aircraft was not destroyed, post-flight inspection revealed major damage to both fan and compressor sections of the right engine (repair cost unknown). The USAF bird-strike data shows, on average, the USAF loses one aircraft per year, loses at least one life every other year, and experiences over $38 million damage per year because of bird strikes. Clearly, efforts to manage the bird-strike hazard are warranted for both safety and fiscal reasons.

BIRD AIRCRAFT STRIKE HAZARD MANAGEMENT

Comprehensive Bird-Aircraft Strike Hazard (BASH) Management incorporates several components to reduce the risk of bird strikes. Minimization of risk (lowering the bird-strike rate) is dependent on the successful integration of all these components. They include: collecting and analyzing bird-strike data, designing bird-resistant aircraft components, managing birds at airfields, and reducing bird attractants near airfields. A final component, the development and use of bird-avoidance models, is the subject of this study and is described in detail in the next section.

Bird Strike Database Management

In the United States, the Navy, USAF, and FAA all maintain wildlife-strike databases. Data collection for the Navy's wildlife-strike database began in 1981 (Walker and Bennett 1985), and contains over 12,000 records with a mean of 750 per year 1981-1997 (Lovell 1997). The USAF Bird-Strike Database contains over 41,000 records, beginning in 1985, with a mean of over 2,700 records per year for the period 1985 to 1998. The FAA maintains their National Wildlife Strike Database for civil aircraft that contains 28,114 records for the period 1990 to 1998 with a mean of 2,800 records per year (Cleary et al. 2000). Analysis of these data is necessary to understand the magnitude of the problem, search for possible solutions, and measure their effectiveness.

A key component of bird-strike data is the identification of the bird species involved. Unfortunately, the identification of the species of birds struck by aircraft is difficult to determine and hence is often missing from the reports. Both the FAA and the USAF BASH Team have arrangements with the Smithsonian Institution, National Museum of Natural History in Washington D.C. to identify the remains of birds struck by aircraft (Dove 1999). Ornithologists use microscopic-feather characteristics and comparisons with museum specimens to identify birds, even with only feather fragments as evidence (Dove 1999 & 2000). The Navy does not have a similar arrangement with the Smithsonian at this time.

Engineering Solutions

Aircraft are innately susceptible to bird-strike damage. Aircraft, especially jet aircraft, fly at speeds that render evasive action, by either the aircraft or the birds, nearly impossible (Defusco and Turner 1998). Aircraft fly at such high speeds that birds become essentially stationary objects (Solman 1981). At 925 kilometers/hour, typical fighter aircraft airspeed, a bird must be detected more than 1.6 kilometers away in order for a pilot to avoid collision with it (DeFusco and Turner 1998). Pilots do not see most birds until after a strike or near miss.

Though aircraft engines and other components are designed and constructed with lightweight materials, they are engineered to withstand much of the high-impact pressure resulting from a bird strike. For example, fighter-aircraft windscreens are designed to withstand a strike with a 1.8-kg bird at 740 kilometers/hour. This equates to over eight tons of force on a 300-sq. cm area. The next generation of windscreens will be able to sustain the same bird impact at 1065 kilometers/hour or about 17 tons on the same 300-sq. cm area (Rolphsen 2000). Still, large birds have penetrated aircraft windscreens resulting in destroyed aircraft and loss of life. The required flight characteristics of military aircraft (i.e., high speeds, low-level flight, lightweight and non-radar reflective materials) limit the possible engineering solutions to bird-proofing aircraft (Kelly 1993).

Although they are designed to be as bird resistant as possible, jet engines contain relatively delicate components that are completely exposed through large frontal-air intakes. The main components of a jet engine are a series of high-speed compressor fans leading to a combustion chamber and exhaust nozzle. The problem of a bird strike is exacerbated when the bird breaks one or more pieces of the first fan blade. This starts a chain reaction with the broken pieces striking the next fan, breaking more pieces, and sending more debris into each successive fan leading to complete disintegration of the engine (Blokpoel 1976, Cleary et al. 2000). The greater the mass of the bird, the greater the damage, but the force of even a medium-sized bird strike is extremely high. For example, 1.8-kg bird (e.g., large duck or gull) struck by an aircraft flying at 480 km/h exerts a force of approximately 15 tons to a 15-cm diameter impact point on the aircraft (Solman 1973). If the speed of the aircraft doubles, the impact force quadruples (Solman 1973). Currently no jet engine can ingest a large bird (e.g., Canada goose, tundra swan, turkey vulture) and continue to operate (Eschenfelder 2000).

Airfield-Bird Management

Between 75-90% of all bird strikes occur at or near airfields, primarily during take-off and landing operations (Blokpoel 1976). Near airfields, aircraft are flying at low altitudes where the density of birds typically is greatest (Tedrow 1998). The high bird-strike rate at airfields also is related to the attractiveness of airfields to birds and other wildlife (Tedrow 1998).

Airfield-management personnel play a major role in bird-hazard management (Blokpoel 1976, Solman 1981, Barker 1998, Janca 2000). Airfields often use both passive and active bird-management techniques. Passive methods make airfields less attractive to birds by reducing or eliminating the basic necessities of life: food, water, and shelter. These include but are not limited to bird-proofing hangers, long-grass management to discourage birds from feeding on the airfield, and draining standing water from the airfield (Blokpoel 1976, Jarmen 1993, Barker 1998). Some active airfield-bird management methods include the use of propane cannons, pyrotechnics, border collies, and falcons to scare birds from the airfield (Blokpoel 1976, Jarmen 1993).

The Airfield In Context - Adjacent Land Uses

The noise from aircraft operations has resulted in management decisions to locate many airfields in more rural areas away from urbanized areas, and often airfields are surrounded by agricultural crop fields, wetlands or water bodies, and landfills. These land uses are generally unaffected by aircraft operations but attract many birds and can lead to potentially dangerous situations for flight safety. Adjacent land uses must be considered when assessing bird hazards to aircraft (Cleary et al. 1999, Lahser 2000). There may be opportunities to manage them to be less attractive to birds. For example, landfills and agricultural operations attract large numbers of birds. It is unwise to construct new landfills near airfields. Management of existing landfills near airfields is possible. Those that do not accept putrescible waste do not attract birds. Those that do can maintain a clean operation and insure that waste is kept covered at all times. Landfills that do attract hazardous numbers of birds can use active control measures as described above. Agricultural fields adjacent to airfields are often a seasonal-bird attractant (Morrison et al. 1992). Crops may be grown that are less attractive to birds, excessive flood irrigation can be controlled to be less attractive to birds, or active bird dispersal may be warranted. In all cases pilots and other personnel in charge of flight should be aware of the potential bird hazard in the immediate area.

BIRD-AVOIDANCE MODELS

The final approach to BASH management is the development and use of bird-avoidance models. A bird-avoidance model (BAM) is a quantitative or qualitative assessment of the distribution of risk of a damaging-bird strike over time and space. They generally consist of a measure of bird use of an area and an assessment of the hazard posed by different birds. Although it is impossible to predict the exact location of an individual bird at a specific time, over larger spatial and temporal scales, the distribution and movement of birds is predictable. Birds make daily movements to and from feeding and roosting sites. They make seasonal migrations at nearly the same time and to the same area each year (Thompson 1964, Blokpoel 1976, Weidensaul 1999). Except for the timing of weather favorable for migration each year, timing of migration is remarkably consistent from year to year (Thompson 1964, Blokpoel 1976, Weidensaul 1999).

Assessments of the hazard posed by different birds have used indices based on differences in body mass or species classifications. BAMs based on radar data, with no species identification, assign different risk levels to birds based on body mass (Kelly et al. 1995, 1997). Other models have assigned different levels of risk to species based on some qualification of known hazard by species (Defucso 1993, 1998; Lovell 1997a; Burney 1999). BAMs are generally disseminated as a computer program with visual graphics to help those in charge of aircraft operations (pilots, schedulers, air traffic controllers) to visualize the risk for planning and risk management purposes.

Concentrations of hazardous species or sizes of birds across the landscape or through time represent a high risk to aircraft. The assessment of bird-strike risk can therefore be incorporated into the scheduling of range time, use of the local airspace, and use of the airfield environment. By avoiding these high-risk periods pilots lower their exposure and thereby lower the potential for damaging-bird strikes over time. A BAM will also lower risk by showing airfield managers where and when to expect an increased need for bird-control measures. If the BAM identifies an increased risk on the airfield due to large numbers of horned larks every February, then measures can be planned each year to actively patrol the area and employ scare techniques to mitigate the problem.

BAMs have been developed on two different geographical scales. The USAF's US BAM and Avian Hazard Advisory System (AHAS) were developed at the nationwide scale. The US BAM was created to evaluate low-level military-training routes throughout the contiguous United States (Defucso 1993, 1998; Lovell 1997a; Burney 1999). It uses a geographical information system (GIS) to correlate bird numbers from the annual Breeding Bird Surveys and Christmas Bird Counts with multiple geographical features across the conterminous U.S. (Defucso 1993). From these data, predictions are generated regarding the presence of birds across the U.S. and throughout the year (Defucso 1993). AHAS combines the predictions of the US BAM, with bird-migration forecasts, and near-real-time bird-migration monitoring on a nationwide scale (Kelly 1999a & 2000, Kelly et al. 2000). Migration is monitored with the National Weather Service's NexRad Weather Radar System (Kelly 1999a & 2000, Kelly et al. 2000). The US BAM is based on historical data while AHAS compliments it with ever-current data. Because of the large extent of these nationwide models they are low resolution with little detail. They are best suited for assessing the extent and timing of large-scale migrations of birds.

The original US BAM was developed for use by pilots in 1982 and updated in 1987. It did not have a user-friendly interface and ran on a mainframe computer system

(Lovell 1997). This affected its utility because a squadron (the intended user) could not afford the expensive computer equipment needed to run the model and the model itself was difficult to learn and use. Eventually the USAF BASH Team hired a specialist to run the model upon request from the end users (Lovell 1997).

The current US BAM, completed in 1998, was developed in a GIS format. The interface was an easily readable, color-coded risk map. It could be run on existing personal computers in each squadron but required the purchase of and training in the use of GIS software. In 2000 the results of the model were published as a web page (http://ahas.com/bam) accessible to all end users with existing computers, software, and user capabilities.

One of the main concerns of pilots and schedulers in using BAMs is the low temporal resolution of the models. An area may be considered high risk for several weeks on end when in fact the risk is due to a heavy migration expected over only 2 or 3 days during that period. Many days in that period may be low risk but the model does not show enough temporal detail to separate which days are high and which are low. AHAS starts with the predictions of the US BAM, checks the current state of migration, evaluates weather variables, make predictions on migration level in the next 24 hours, and monitors large-scale migration in near-real time. The migration monitoring uses the national weather-radar system and is very similar to national weather monitoring. In essence, it increases the temporal resolution of the US BAM to identify times of actual migration instead of historically predicted migration. AHAS does require recurrent funding for operation of the system while historical models, those predicting future risk based on past bird activity, require funding only for development and occasional updates.

The USAF evaluated the level of bird hazard at its installations and selected two with high bird-strike risk (Dare County Bombing Range, NC and Moody Air Force Base, GA) for installation-specific BAMs (Kelly et al. 1995, 1997). Both of these studies used radar, radio telemetry, satellite telemetry, and visual observations to quantify the movement and distribution of birds at the installations over a 2- to 3-year period (Kelly et al. 1995, 1997). The extent of these models (a single installation as opposed to the entire U.S.) was much smaller, so the detail was greater. Where nationwide models are best suited to monitor large-scale migrations, installation-specific models assess the risk of daily hazards at the site. These models demonstrated the lesson learned regarding ease of use and operation on existing computer equipment. They were both designed as multimedia programs similar to current web pages. They were run from a CD-ROM or a local hard drive. They were based on historical data and need to be updated periodically time to account for changes in bird patterns due to population changes or changes in local land-use patterns.

BASH Management at NAF El Centro

A BASH Plan for NAF El Centro and the Target Ranges was completed in August 2000 (U.S. Navy 2000). This document outlines the problem, recommends management actions, and provides supplementary information. It identifies, for example, nearby areas (Salton Sea National Wildlife Refuge, surrounding irrigated agriculture) that attract many birds to the area.

Currently almost no actual BASH management occurs on the base (U.S. Navy 2000), and operations personnel on the base have confirmed this. The natural resources office on base has been developing tools [e.g., BASH Management Plan (U.S. Navy 2000), an ornithological survey (Aigner and Koehler 1996), a study of the relationship between birds and agricultural fields (Morrison et al. 1992)] to manage the bird-strike hazard. The 2001 NAF El Centro Integrated Natural Resources Management Plan (INRMP) includes the implementation of the 2000 BASH Plan. This will coordinate efforts and improve BASH Management on the installation.

Objective

The objective of this study is to develop a bird-avoidance model for NAF El Centro. The model will reduce the probability of damaging bird strikes by helping pilots and other Navy personnel to identify areas and times with high bird activity. Decisions regarding flight can then be made based on risk of a bird strike. We designed the model to assess the risk of a damaging-bird strike throughout the year at the airfield as well as at the West and East Mesa Bombing Ranges. It is a pragmatic, management-oriented model. It is intended as a problem-solving tool and not as an analysis of the various factors involved in bird-strike damage to aircraft (Starfield and Bleloch 1991, Starfield 1997).

The intent of the model is to help Navy personnel visualize risk and make decisions regarding flight scheduling.

STUDY AREA

NAF El Centro is located in Imperial County, California. It is 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 and the Salton Sea National Wildlife Refuge (Fig.1). NAF El Centro lies within the Pacific Flyway for bird migration.

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 m below sea level and is surrounded by year-round, irrigated agricultural land (Fig.2.).

NAF El Centro has no permanently stationed aircraft. All flight operations are transient resulting in a variety of aircraft types using the airfield and airspace. NAF El Centro is the winter training base for the Blue Angles, the Navy's flight demonstration squadron. Virtually all Navy and Marine Corps aircraft types may use the installation. Training uses include FCLP, touch-and-goes, air-combat maneuvering, close air support, high- and low-level ordinance delivery training, parachute drops, and air defense exercises (U.S. Navy. 2000).

NAF El Centro operates two bombing ranges. These are both predominantly in a creosote bush (*Larrea tridentata*) scrub plant community (Costi et al. 2000). East Mesa Range is located approximately 4-km northeast of NAF El Centro (Fig.3.). It contains two target areas, Target 68 to the south and Target 95 to the north. West Mesa Range is located approximately 1.5-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 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 U.S. Department of Interior, Bureau of Land Management.

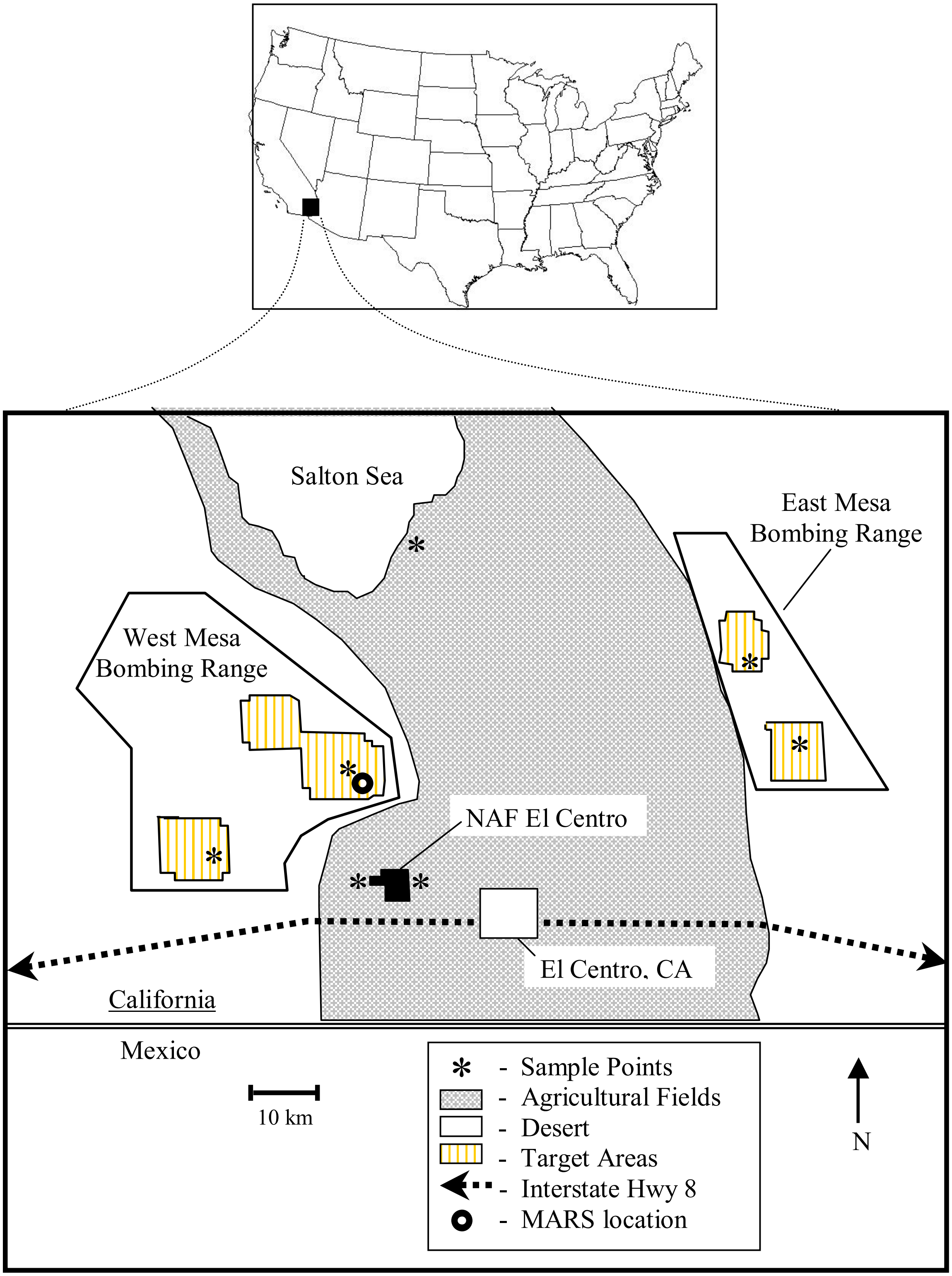


Fig. 1. Map (not to scale) of southern California showing NAF El Centro and the East and West Mesa Bombing Ranges. Inset shows location within the United States.

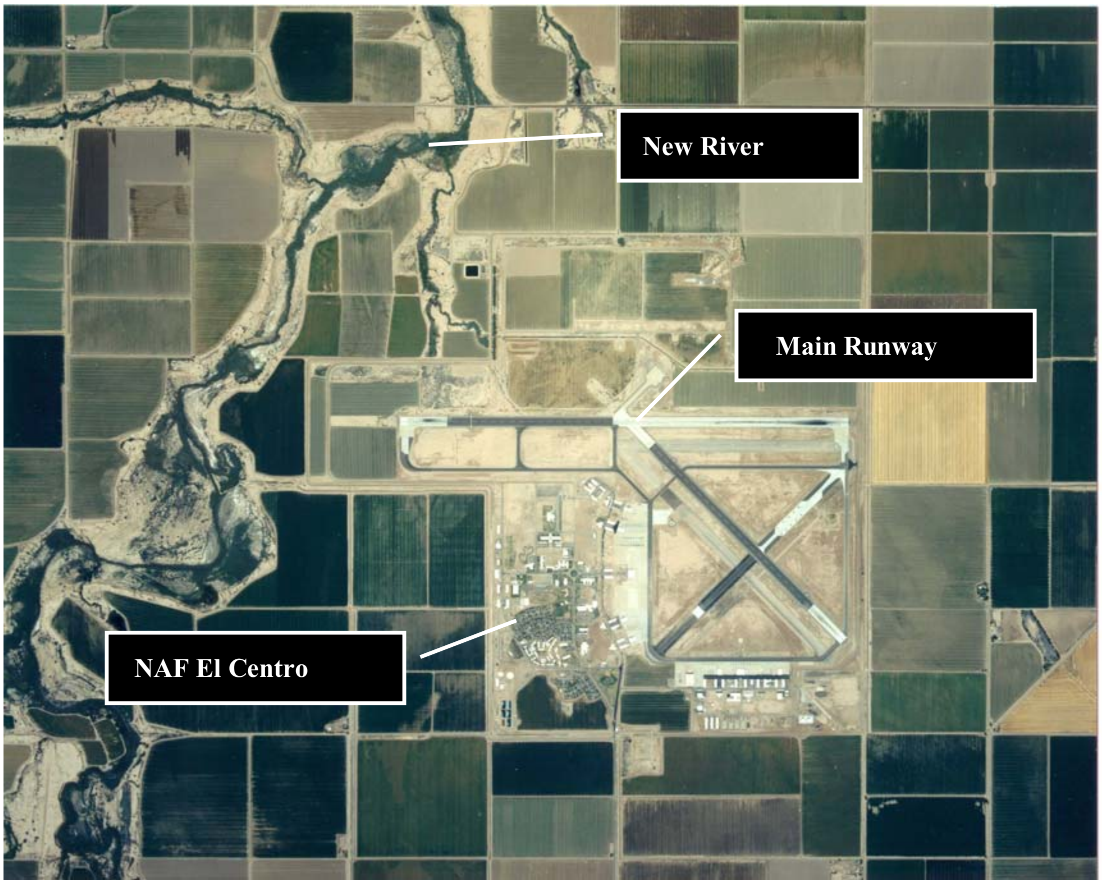


Fig. 2. Aerial photo of NAF El Centro, New River, and adjacent local agriculture.


Fig. 3. Creosote bush at the Ease Mesa Bombing Range.

METHODS

The BAM is comprised of two sub-models: one for diurnal bird-strike risk and one for nocturnal bird-strike risk. The models differ in the methods used to assess bird activity in the area. The main parameters of each model are a description of bird use of the area and a description of the level of hazard posed by different individual birds. Diurnal bird use was sampled using visual-bird counts conducted throughout a one-year period. The hazard posed by different species was analyzed using data in the USAF Bird-Strike Database. The species that were involved in over 5,000 strikes were ranked by 3-damage levels. From these rankings a composite-hazard index was computed. We used these species-hazard indices to scale the hazard of the bird species recorded in the visual surveys at NAF El Centro.

DIURNAL BIRD HAZARDS

Diurnal bird hazards were estimated using an algorithm that combines the number of birds expected to be in the area (estimated using visual bird counts) and the relative hazard level that different bird species pose to aircraft (estimated using USAF bird-strike data).

Species Groups

We lumped bird species into "species groups". Species groups were based on taxonomy, behavior, size, and bird-strike history. This simplified the analysis when assessing the USAF data and for the visual counts at NAF El Centro. Grouping species decreased the number of bird categories and allowed the use of partly identified species (e.g., unknown gull species).

Class A and B Weights

Damage to USAF aircraft is classified by factors such as cost (Table 1). Class-C strikes are most numerous but cause the least amount of damage. They are not adjusted in

Table 1. U.S. Air Force aviation-damage categories (Air Force Instruction 91-202).

Damage Class	Description
Class A	>$1,000,000 damage, loss of aircraft, loss of life, or permanent total disability
Class B	$200,001-$1,000,000 damage, permanent partial disability, or inpatient hospitalization of three or more personnel
Class C	$10,000-$200,000 damage, an injury resulting in a lost workday

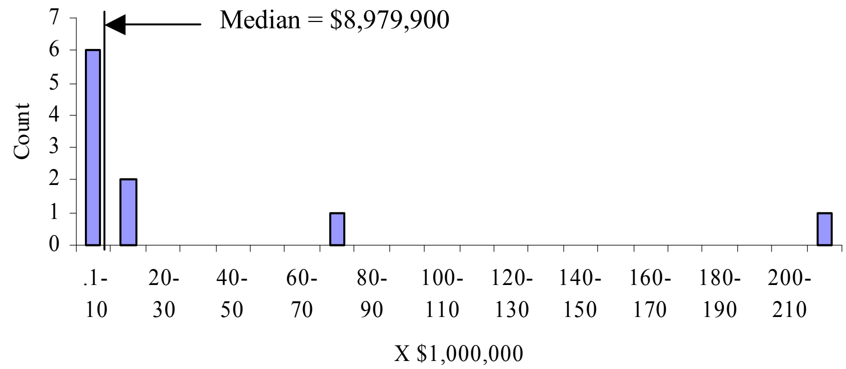
the diurnal-hazard algorithm. Class-B strikes are less numerous but more serious. They are multiplied by a constant to adjust for the increased severity of damage. Class-A strikes are most serious but rarely occur. They are weighted in the algorithm by a higher constant.

We developed the weighting constants for Class A and B damage based on the reported cost/class in the USAF bird-strike database. Because the distributions of reported class A, B, and C damage costs were each allokurtic or skewed (Fig. 4), we used their medians as measures of central tendency. The weighting constants were the multiples of median Class-C cost within median Class A and B costs. In this way, the damage level was empirically based on both the USAF's own damage categories and on their records of past damage costs.

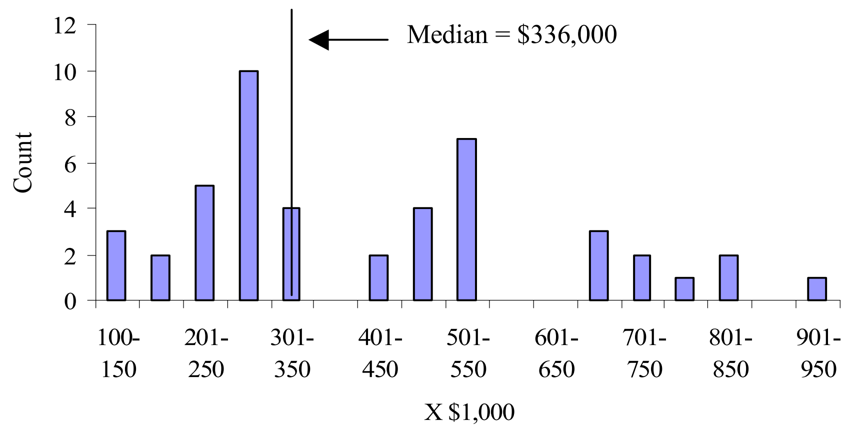
Species Hazard Indices

For each species group the relative hazard to military aircraft was estimated using USAF bird-strike data. We developed a relative species-hazard index (SHI) using 5,204 records of species identified as causing USAF bird-strikes from 1985-1998. We assessed the hazard level of each species group by the number of bird strikes it caused in three damage categories (Table 1). This assessment accounted for both the number and severity of strikes caused by each species group. The species groups were ranked in ascending order most to least hazardous based on these hazard indices.

a) USAF Class A bird-strike costs.



b) USAF Class B bird-strike costs.



c) USAF Class C bird-strike costs.

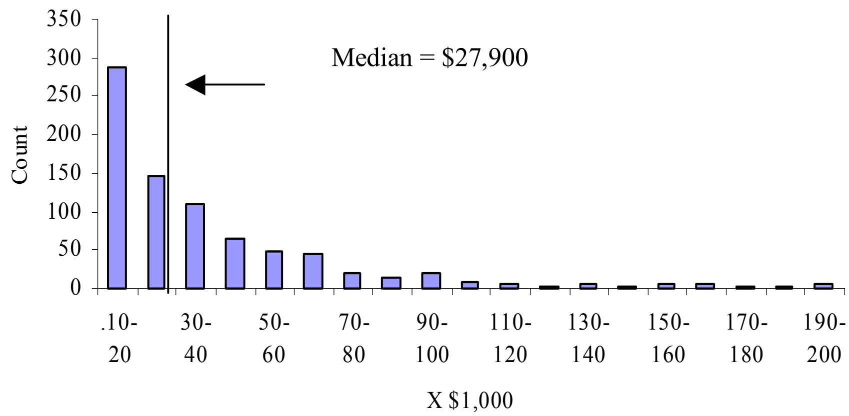


Fig. 4. Distribution of a) Class A, b) Class B, and c) Class C bird-strike costs, with median indicated, from the U.S. Air Force bird-strike database, 1985-1998.

We selected those species groups that caused damage to USAF aircraft in the U.S. For each species group, we summarized the mean number of damaging strikes per year. We then developed the following algorithm to calculate a Species Hazard Index for each species group:

$H_S = (C_S) + (B_S * W_B) + (A_S * W_A)$

Where: - H_S = hazard index per species group

- C_S = the number of Class-C strikes per species group per year
- B_S = the number of Class-B strikes per species group per year
- A_S = the number of Class-A strikes per species group per year
- W_A and W_B are weighting constants to adjust for the increased severity of Class A and Class-B strikes (described above).

Visual Bird Counts

An understanding of the bird use of an area throughout the year is necessary to effectively manage bird hazards to aircraft. Additionally, a description of the altitudes used by birds in the area is necessary. This data is usually lacking in a typical avian survey. The purpose of this study was to develop a bird-avoidance model for NAF El Centro and the East and West Mesa Bombing Ranges. For the purposes of this study, bird strikes are presumed to be a function of the number of birds in the airspace adjusted for the hazard level of a particular species. Birds were counted at Naval Air Facility (NAF) El Centro in 1996, but this was not a year-round study (Aigner and Koehler 1996). To sample the number and species of birds present we conducted a yearlong visual count of the birds in the area.

The number of records of species groups across time periods, altitude bands, and sites was required for this study. This data was collected by simple point counts without distance estimation (Verner 1985). We established 7 fixed, 300-m., circular-plots for conducting modified-point counts (Reynolds et al. 1980, Verner 1985, Ralph et al. 1993). Two points were located at the airfield (Fig. 1); one at the east end of the main runway and one at the west end (Table 2). Two points were located at the East Mesa Range; one near Target 68 and one near Target 95. Two points were located at the West Mesa Range; one near Loom Lobby Target and one near Shade Tree Target. The last point was located at the Salton Sea NWR. This was considered as a worst-case scenario for bird hazards to aircraft.

Birds were observed and counted at all points for an entire year (10 Jan 2000 to 9 Jan 2001) during daylight hours (half-hour before sunrise to half-hour after sunset). Counts were one-hour long to sample the birds present and moving through the area over time. We recorded date, time, species, number, and altitude of birds (individuals or in flocks). Species were categorized into the species groups discussed above. Grouping species decreased the number of bird categories, allowed the use of partly identified species (e.g., unknown gull species). We assumed that species groups were equally detectable. This is a reasonable assumption in the open habitats surveyed (Verner 1985). We summarized the data in 26-biweekly periods throughout the year.

Table 2. UTM coordinates of survey points for visual- and radar-bird counts at NAF El Centro, CA, 10 Jan 2000 – 9 Jan 2001.

Survey Point	Meters East	Meters North
Airfield West	622432.1	3633162.2
Airfield East	625837.5	3633266.5
Target 68	665397.6	3647188.8
Target 95	664280.6	3651852.9
Target 101	616607.2	3646335.9
Target 103	605864.0	3635896.8
Salton Sea	628429.1	3671679.7
Radar Site	621150.4	3644357.9

Diurnal Bird-Hazard Algorithm

The bird-count data was categorized into 26 biweeks (14-day periods of the year), four-daily time periods (sunrise-9 am, 9 am-noon, noon-3 pm, 3 pm-sunset, and sunset-midnight), and 4 altitude bands (surface-500’, 501-1000’, 1001-2000’, and >2000’).

We multiplied the number of records of each species group per biweek, time period, and altitude band by its Species Hazard Index to calculate the relative hazard posed by the presence of a particular bird in the area. Given the number of birds of various species present at the site, this is the relative risk of striking a bird and sustaining damage. We plotted the resulting bird-hazard indices on a histogram and categorized them as either a high, moderate, or low bird-strike hazard. Diurnal bird hazards were calculated using the following algorithm:

$$R_{AT} = \Sigma(C_S / h * H_S)$$

- R = bird-strike risk
- A = area (site and altitude band)
- T = time (biweek and daily time period)
- C_S = count of each species group
- h = hours surveyed
- H_S = hazard index for each species (described above)

FALL NOCTURNAL BIRD HAZARDS

Fall nocturnal bird hazards were estimated using counts of night-migrating birds collected using a bird-radar system. Birds were classified by size as small, medium, or large. Birds of different size were weighted differently in the bird-hazard algorithm.

Mobile Avian Radar System

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. Visiblelight wavelengths range from about 0.4 μm (violet) to 0.7 μm (red). Infrared light is a slightly longer wavelength than our eyes can sense. Beyond infrared waves are microwaves, which are commonly used in both microwave cooking and radar. Longer still are radio waves used for communication, radio, and television. The frequencies used for radar are partitioned for convenience into frequency bands. 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 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. 5). 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 (Fig. 1). 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. As a result a fresh sample of birds was recorded every 30 seconds. The images were organized and stored on the computer's hard drive for image processing and archiving to CD-ROM.

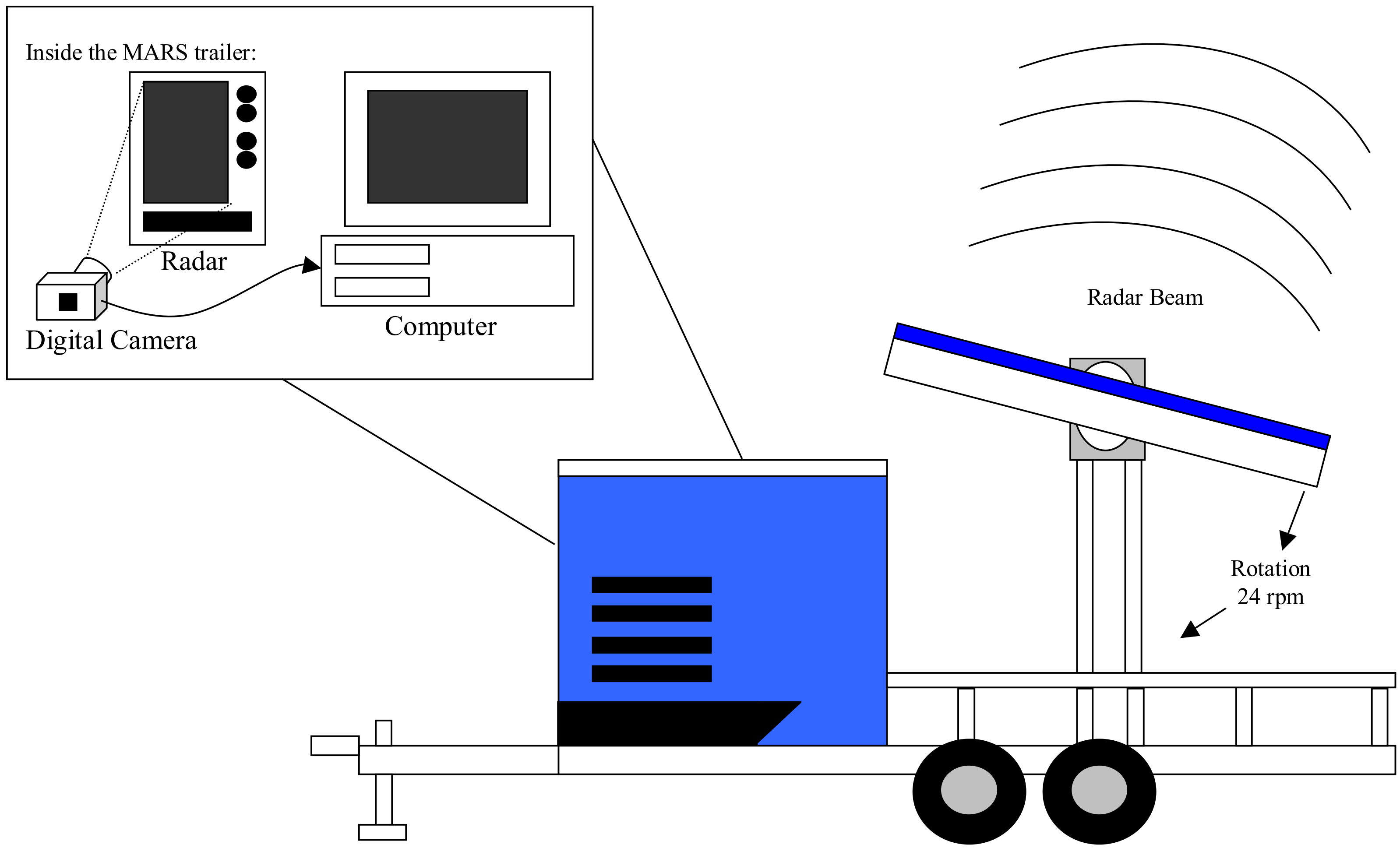


Fig. 5. Sketch of Geo-Marine Inc.'s Mobile Avian Radar System (MARS), used to collect nocturnal bird-migration data at NAF El Centro, 20 Sep – 29 Nov 2000. Inset shows the radar monitor and computer equipment within the trailer's office space.

We operated MARS to quantify nocturnal-bird migration in the area, 20 Oct to 29 Nov 2000. The bird-radar system recorded the relative size of birds but could not differentiate between species. The density of medium and large birds in the radar sample was used as an index of the hazard to aircraft. The radar-count analyses were summarized into 26-biweek time periods throughout the year and four-altitude bands (0-150 m, 150-300 m, 300-600 m, and > 600 m) at each site. The results were categorized into high, moderate, and low bird-strike risk.

Small Bird Equivalents

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, NC 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 (Kelly 1995). The median body mass for small bird species was used to normalize values for medium and large-sized birds found in the El Centro area. SBEs were these normalized values.

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 intermediate-sized 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 intermediate-sized 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 birds per radar target, hence risk, though not completely quantifiable, is incorporated in the algorithm.

Fall Nocturnal Bird Hazard Algorithm

Fall nocturnal bird hazards were evaluated from September through November. Days of the year were categorized into 26 14-day biweeks originating on 1 January. Altitude data was 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
- M = count of medium birds
- W_l = weight (SBEs) for hazard level of large-sized birds
- 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 for medium-sized birds, and the number of SBEs for 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. Counting the number of image pixels within each altitude band and multiplying by the area of each pixel calculated the area of the slice of airspace sampled by the radar. We plotted the hazard indices in a histogram to identify break points between high, moderate, and low bird-strike hazard.

Non-Fall Nocturnal Bird Hazards

Nocturnal bird hazards from December through August were estimated by assessing the USAF bird-strike data. The mean numbers of USAF bird strikes per month from 1985-2000 were plotted on a histogram to identify times of high bird-strike risk based on high bird strike numbers.

Web Page Application

Being a practical model, it was essential that the results of the BAM were disseminated to the end users. The objective of the study was to reduce the probability of damaging bird-strikes by identifying and avoiding flying in areas or during times with high bird activity. The methods thus far identify the hazards. This fulfills only half of that objective. The other half involves making the results available to flight crews, air traffic controllers, airfield managers, and natural resource managers at the installation.

The results of the BAM were compiled and published as a web page to be maintained on NAF El Centro's internet server and on the USGS, Utah Cooperative Fish and Wildlife Research Unit internet server. Areas and times of high, moderate, and low bird-strike risk were color-coded red, yellow, and green respectively and displayed in a graphical format. This allows personnel to quickly reference the bird-strike risk. The hazard of bird strikes is described to make Navy personnel aware of the problem. The most common hazardous species in the area were described. As well, management options and recommendations were given where appropriate. All personnel on base responsible for safe flight operations and natural resource management have access to the BAM to help visualize bird-strike risk for management and planning purposes.

RESULTS

DIURNAL BIRD HAZARDS

Species Groups

Bird species identified in the USAF bird-strike database were sorted into 53 species groups. Forty-six of these species groups caused class A, B, or C damage to USAF aircraft (Appendix A). Data from visual bird counts compiled 36 species groups containing between 0-16 species (Appendix B).

Class A and B Weights

USAF Class-A, -B, and -C distributions were each allokurtic (Fig. 4). The Class-A weighting factor equaled 320 and the Class-B weighting factor equaled 12 (Table 3). Thus, Class-A bird-strike damage was 320 times more costly than Class-C damage, and Class-B damage was 12 times more costly than Class-C damage. These weights were used in the Species Hazard Index algorithm below.

Species Hazard Indices

The USAF Bird Strike Database contained 25,519 records of wildlife strikes in the United States. Of these, 20.4% (5,204) indicated the species or species group involved. These were sorted into 53 species groups, 46 of which caused Class A, B, or C damage to USAF aircraft. Only 10 of the 53-species groups had sample sizes ≥10 (Table 4).

Table 3. Weighting factors for Class A, B, and C damage to U.S. Air Force aircraft, 1985-1998. Median Class-A and B costs as multiples of median Class-C cost.

Class	n	Median	Weight
A	10	$8,979,934.50	320
B	47	$336,561.50	12
C	807	$27,958.00	1

Table 4. Ten species groups in the U.S. Air Force bird-strike database (1985-1998) with sample sizes > 10.

Sample Size	Species Group
119	Vulture
70	Buteo
41	Duck
34	Goose
27	Gull
19	Horned Lark
13	Mourning Dove
11	Thrush
11	Swallow
10	Meadowlark

Vultures were ranked by far the most hazardous species group to USAF aircraft (Table 5). They were followed by geese and pelicans, which were only 60% and 36% as hazardous as vultures, respectively. The seven species groups (coyote, small mammal, woodcock, sky lark, dove, woodpecker, and flycatcher), which struck aircraft, but did no damage, all received hazard indices of zero and were ranked last (23rd). There were a high number of tied hazard indices and ranks (Rank 17th – 23rd in Table 5). These were all bird species groups that caused low numbers of Class-C strikes and no Class A or B strikes.

Visual Bird Counts

From 10 Jan 2000 to 9 Jan 2001, 637 1-hour surveys were conducted (Table 6). No birds were observed during five of the surveys at the East Mesa Range and 57 of the surveys at the West Mesa Range. No surveys were conducted in midday during the hot summer months. Few birds were active during 40^{o}- 50^{o} C temperatures.

We recorded 90,948 individual birds in 5,260 records and 145 species in 36 species groups across all sites (Table 7). A record is a count of a single bird or a flock of birds. The average record consisted of 17.3 birds/flock (90,948/5,260). At the airfield we recorded 59,639 birds, 2,838 records, and 91 species in 33 species groups (Table 8). The average flock size at the airfield was 21.0 birds/flock. At the East Mesa Range we tallied 1,909 birds, 594 records, and 43 species in 19 species groups. The East Mesa Range

Table 5. Hazard Index and ranking of hazardous species groups* to USAF aircraft in the US, 1985-1998.

Species Group	C/Yx1	B/Y	B/Yx12	A/Y	A/Yx320	Hazard Index	Rank
Vulture	7.714	0.429	5.148	0.357	114.240	127.888	1
Goose	1.786	0.429	5.148	0.214	68.480	76.057	2
Pelican		0.071	0.852	0.143	45.760	46.826	3
Blackbird/Starling	0.357			0.143	45.760	46.260	4
Buteo	4.714	0.214	2.568	0.071	22.720	30.287	5
Horned Lark	1.214	0.071	0.852	0.071	22.720	24.928	6
Swallow	0.643			0.071	22.720	23.434	7
Gull	1.500	0.429	5.148			7.077	8
Duck	2.714	0.214	2.568			5.496	9
Crane	0.286	0.143	1.716			2.145	10
Thrush	0.714	0.071	0.852			1.637	11
Meadowlark	0.643	0.071	0.852			1.566	12
Rock Dove	0.500	0.071	0.852			1.423	13
Egret/Heron	0.357	0.071	0.852			1.280	14
Owl	0.143	0.071	0.852			1.066	15
Mourning Dove	0.929					0.929	16
Eagle	0.500					0.500	17
Rail	0.500					0.500	17
Sparrow	0.357					0.357	18
Accipiter	0.357					0.357	18
Osprey	0.357					0.357	18
Deer	0.357					0.357	18
Cattle Egret	0.357					0.357	18
Cormorant	0.286					0.286	19
Killdeer	0.214					0.214	20
Nighthawk	0.214					0.214	20
Crow	0.214					0.214	20
Ibis	0.214					0.214	20
Kestrel	0.214					0.214	20
Grackle	0.143					0.143	21
Bat	0.143					0.143	21
Kite	0.143					0.143	21
Thrasher	0.143					0.143	21
Grebe	0.143					0.143	21
Small Shorebird	0.143					0.143	21
Large Shorebird	0.143					0.143	21
Other	0.071					0.071	22
Pheasant	0.071					0.071	22
Warbler	0.071					0.071	22
Tern	0.071					0.071	22
Stork	0.071					0.071	22
Sea Bird	0.071					0.071	22
Loon	0.071					0.071	22
Quail	0.071					0.071	22
Waxwing	0.071					0.071	22
Falcon	0.071					0.071	22

* Seven additional species groups (coyote, small mammal, woodcock, sky lark, dove, woodpecker, and flycatcher), have been struck by USAF aircraft but have never caused damage. These are all tied and ranked 23rd.

Table 6. Number of one-hour, visual bird surveys per time period and biweek at each site.

		Airfield				East Mesa Range				West Mesa Range				Salton Sea			
Dates	Biweek	TP 1*	TP 2	TP 3	TP 4	TP 1	TP 2	TP 3	TP 4	TP 1	TP 2	TP 3	TP 4	TP 1	TP 2	TP 3	TP 4
1 Jan - 14 Jan	1	3	4	6	3	6	1	5	3	3	5	2	3	0	2	0	0
15 Jan - 28 Jan	2	4	4	3	1	3	3	2	1	2	3	0	2	0	0	0	1
29 Jan - 11 Feb	3	4	4	1	3	1	1	2	4	1	1	1	1	1	0	1	0
12 Feb - 25 Feb	4	0	1	8	3	2	4	0	0	0	1	2	3	1	0	0	1
26 Feb - 11 Mar	5	3	4	3	0	2	2	4	0	2	1	0	3	0	0	1	1
12 Mar - 25 Mar	6	4	4	1	3	0	2	2	4	0	1	2	1	0	0	0	1
26 Mar - 8 Apr	7	2	2	4	4	4	0	2	4	4	2	2	0	0	1	2	0
9 Apr - 22 Apr	8	1	4	0	0	0	0	4	0	0	0	2	4	1	1	0	0
23 Apr - 6 May	9	6	3	4	6	5	5	0	0	1	1	3	3	1	1	0	0
7 May - 20 May	10	3	1	0	4	3	1	0	2	1	2	0	1	0	0	0	1
21 May - 3 Jun	11	6	4	0	7	3	1	0	2	2	0	0	5	2	0	0	1
4 Jun - 17 Jun	12	7	1	0	1	5	1	0	1	3	1	0	0	0	0	0	1
18 Jun - 1 Jul	13	8	2	0	4	6	2	0	1	2	2	0	3	0	1	0	1
2 Jul - 15 Jul	14	2	0	0	2	3	1	0	1	1	0	0	2	1	0	0	0
16 Jul - 29 Jul	15	6	2	0	4	3	1	0	2	5	3	0	2	2	0	0	0
30 Jul - 12 Aug	16	6	2	0	1	2	2	0	0	1	1	0	2	0	1	0	1
13 Aug - 26 Aug	17	6	2	0	4	5	1	0	2	4	0	0	4	2	0	0	0
27 Aug - 9 Sep	18	6	4	0	2	2	4	0	6	3	4	0	0	0	1	0	0
10 Sep - 23 Sep	19	0	0	3	2	2	2	0	2	0	0	0	4	1	1	0	1
24 Sep - 7 Oct	20	0	2	1	3	0	0	3	0	0	0	3	0	0	0	0	1
8 Oct - 21 Oct	21	1	1	2	2	0	2	0	2	0	1	0	2	0	0	2	0
22 Oct - 4 Nov	22	3	2	1	0	2	0	0	2	0	0	2	1	2	0	0	0
5 Nov - 18 Nov	23	0	0	4	2	1	3	1	0	1	1	1	1	0	1	0	1
19 Nov - 2 Dec	24	2	2	2	0	2	1	1	0	3	0	0	0	0	1	1	0
3 Dec - 16 Dec	25	4	4	3	1	0	4	2	2	0	3	1	2	1	1	0	0
17 Dec - 31 Dec	26	7	3	1	1	0	1	3	0	1	1	1	0	0	0	1	0
Totals	-	94	62	47	63	62	45	31	41	40	34	22	49	15	12	8	12

* TP = Time Period: 1 = sunrise to 9 am, 2 = 9 am to Noon, 3 = Noon to 3 pm, 4 = 3 pm to sunset

Table 7. Number of records per species group at each site* at NAF El Centro, CA, 10-Jan-2000 to 9-Jan-2001.

Species Group	Airfield	East Mesa	West Mesa	Salton Sea
Accipiter	33	1	0	13
Blackbird/Starling	196	69	41	67
Buteo	24	6	1	6
Cattle Egret	146	0	0	32
Crow	45	7	17	0
Duck	30	0	0	221
Egret/Heron	18	0	0	127
Falcon	2	0	0	0
Flycatcher	158	22	16	58
Goose	15	0	0	59
Grackle	17	0	0	20
Gull	72	0	0	169
Horned Lark	99	15	59	6
Ibis	77	0	0	10
Kestrel	148	15	4	23
Killdeer	120	0	0	39
Large Shorebird	121	0	0	110
Meadowlark	260	0	0	4
Mourning Dove	175	68	3	26
Nighthawk	35	26	12	2
Other	228	67	28	148
Dove	8	16	0	17
Owl	118	0	0	0
Pelican	0	0	0	68
Roadrunner	16	1	0	7
Quail	50	1	0	15
Rail	1	0	0	48
Small Shorebird	32	0	0	27
Sparrow	103	7	10	43
Stork	0	0	0	2
Swallow	143	33	17	41
Tern	0	0	0	60
Thrasher	6	5	2	1
Thrush	25	5	1	0
Vulture	51	10	0	5
Warbler	266	220	44	99
Totals	2838	594	255	1573

- Survey effort was not equal at among sites.

Table 8. Number of birds, records, species, and species groups recorded at NAF El Centro, CA, 10-Jan-2000 to 9-Jan-2001.

Site	Birds[a]	Records[b]	Species	Species groups	Mean Flock Size
Airfield	59,639	2,838	91	33	21.0
East Mesa	1,909	594	43	19	3.2
West Mesa	888	255	30	14	3.5
Salton Sea	44,137	1,573	115	32	28.1
Total	90,948	5,260	145[c]	36[c]	17.3[c]

[a] count of individuals
[b] count of flocks
[c] not a column sum

averaged only 3.2 birds/flock. At the West Mesa Range we recorded 888 birds, 255 records, and 30 species in 14 species groups. The West Mesa Range averaged only 3.5 birds/flock. At the Salton Sea site we tallied 44,137 birds, 1,573 records, and 115 species 32 species groups. The Salton Sea site had the highest average flock size with 28.1 birds/flock.

Most birds were observed below 150 m (n=5,188). An additional 68 birds were recorded between 150 and 300 m. Only three records (Canada geese, white-faced ibis, and an unknown gull species) were observed in the third altitude band (300-600 m) and one record (a flock of unknown gull species) was observed in the fourth altitude band (>600 m). No birds were observed above 150 m at either of the desert bombing ranges.

Warblers (n=266) and meadowlarks (n=260) were the most common species groups recorded at the airfield (Table 9). Warblers (n=220) were by far the most commonly observed species group at the East Mesa Range. Horned larks (n=59), warblers (n=44), and blackbirds/starlings (n=41) were the most common species recorded at the West Mesa Range. Ducks (n=221) and gulls (n=169) were the most common species groups recorded at Salton Sea.

Table 9. Three most common species groups at each site during NAF El Centro, CA bird counts, 10-Jan-2000 to 9-Jan-2001.

Site	Most common	2nd most common	3rd most common
Airfield	Warblers n=266	Meadowlarks n=260	Blackbird/Starling n=196
East Mesa	Warblers n=220	Blackbird/Starling n=69	Mourning Dove n=68
West Mesa	Horned Lark n=59	Warblers n=44	Blackbird/Starling n=41
Salton Sea	Ducks n=221	Gulls n=169	Egret/Heron n=127

Diurnal Hazard Calculations

All calculated bird-hazard indices (across all sites, biweeks, daily time periods, and altitude bands) were between 0-500 [(no units) (Fig. 6)]. Because most hazard indices at the Salton Sea National Wildlife Refuge were > 150, this was considered the threshold for high bird-strike hazard (Figs. 7 & 8). The data do not indicate a threshold to distinguish between low and moderate bird-strike hazard. To be conservative, we chose $1/3^{rd}$ of the interval between zero (no hazard) and 150 (high hazard). Hazard indices < 50 were classified as low hazard. Hazard indices >50 and < 150 were classified as moderate hazard. The hazard indices and risk categories per hour, biweek, time period, altitude band, and site are shown in Appendices C-E.

FALL NOCTURNAL BIRD HAZARDS

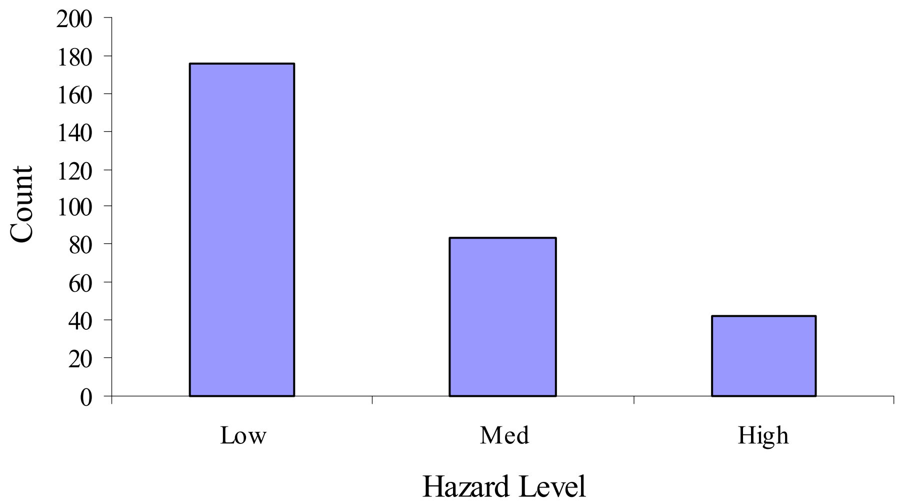
Mobile Avian Radar System

The MARS was operated for 34 nights, distributed across six biweeks, between 20 Oct and 29 Nov 2000 (Table 10). 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 11.

Small Bird Equivalents

A species list of the birds identified on NAF El Centro, the East and West Mesa Bombing Ranges, and the Salton Sea National Wildlife Refuge, their mean body masses (Dunning 1993), and their size classes are shown in Appendix F. The distributions of small, medium, and large-bird masses are all allokurtic (Fig. 9) thus, the median of each distribution was used as a measure of central tendency. Medium and large-sized birds were equal to 15 and 60 SBEs respectively. The median mass and the number of SBEs for each size class are shown in Table 12.

a)



b)

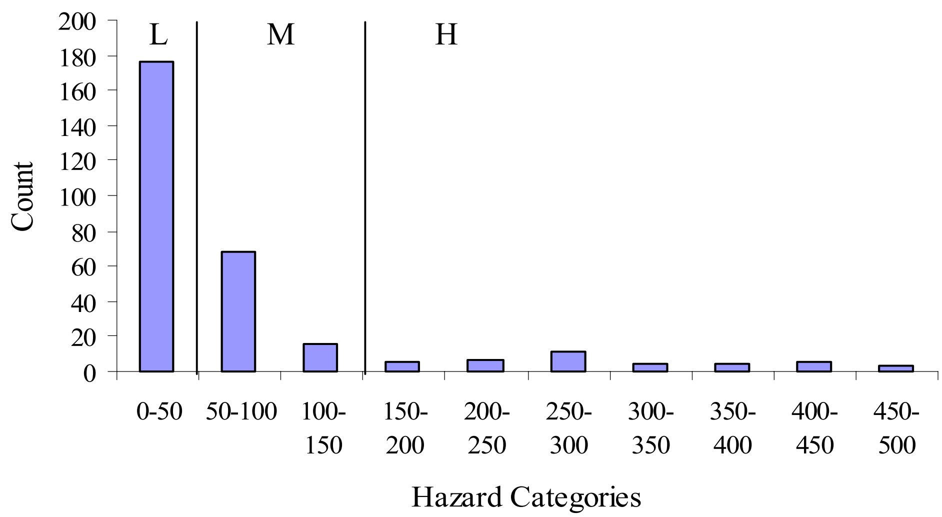
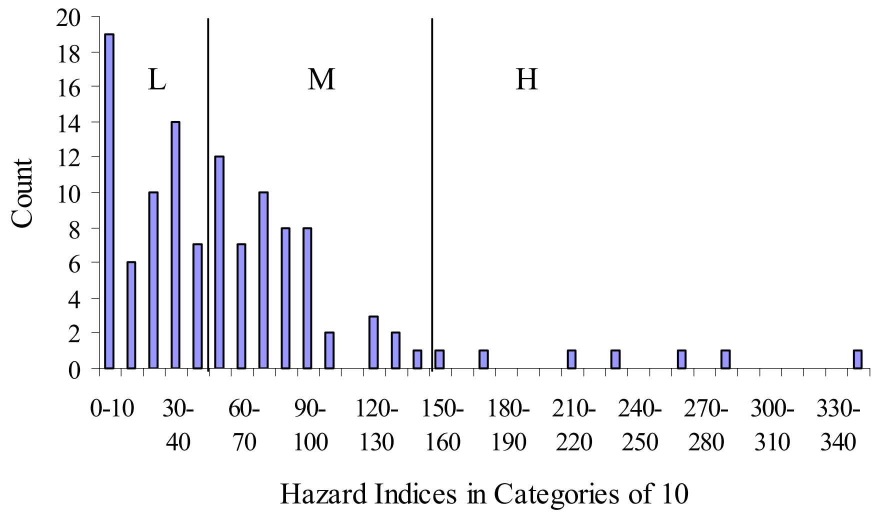


Fig. 6. All calculated Hazard Indices (across all sites, biweeks, time periods, and altitude bands) at NAF El Centro a) frequency histogram in classes of 50 (no units) and b) the number of indices in each bird-strike-risk category [(Low (L), Moderate (M) and High (H)].

a) Airfield bird-hazard indices.



b) Salton Sea bird-hazard indices.

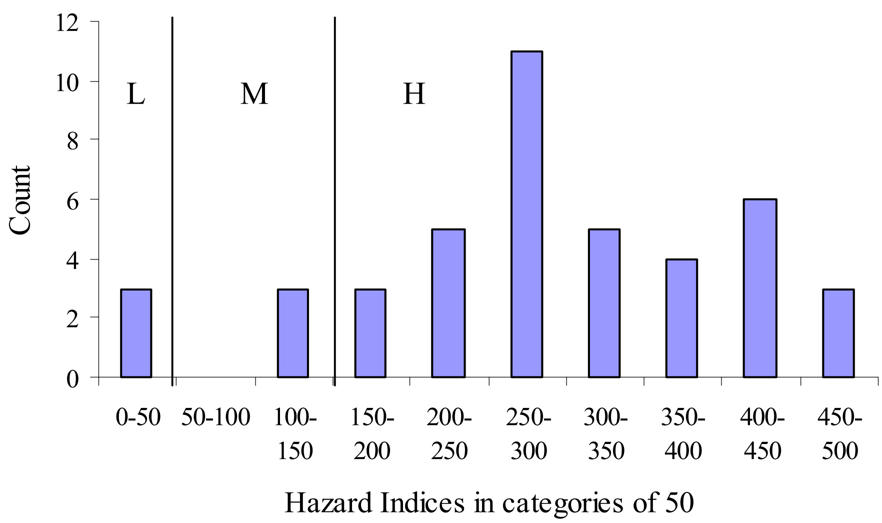
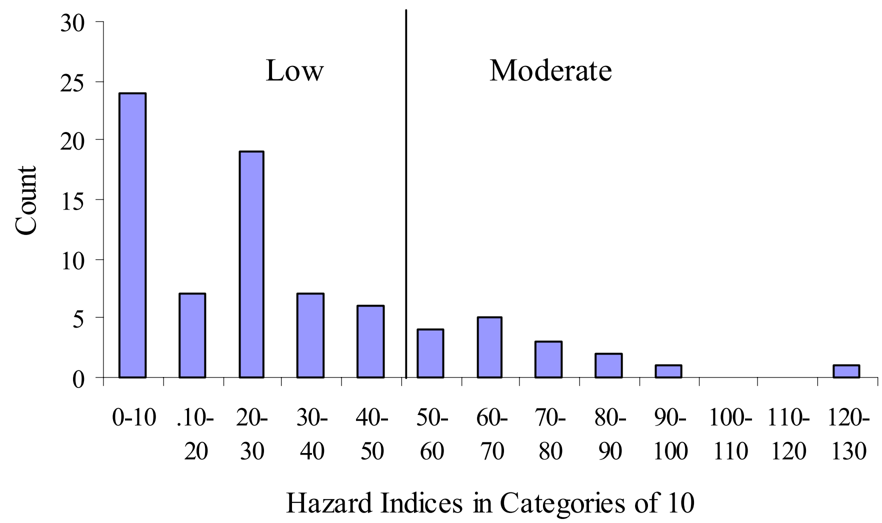


Fig 7. All calculated Hazard Indices at each site (biweeks, time periods, and altitude bands) with Low (L), Moderate (M), & High (H) risk thresholds shown. a) NAF El Centro b) Salton Sea. The Salton Sea site was considered to be a high bird-strike hazard. The high-risk threshold was set below most of the Salton Sea hazard levels.

a) East Mesa Range bird-hazard indices.



b) West Mesa Range bird-hazard indices.

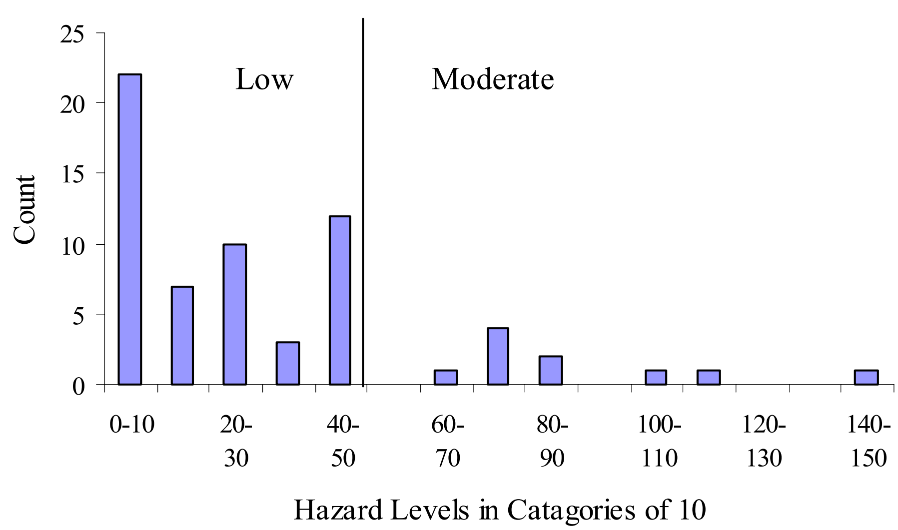


Fig. 8. All calculated Hazard Indices at each site (biweeks, time periods, and altitude bands) with Low and Moderate risk thresholds shown. a) East Mesa Range b) West Mesa Range.

Table 10. Date of operation within each biweek (14-day periods originating on January 1st) for the 34-radar sessions for monitoring nocturnal (sunset-midnight) avian migration at NAF El Centro, CA.

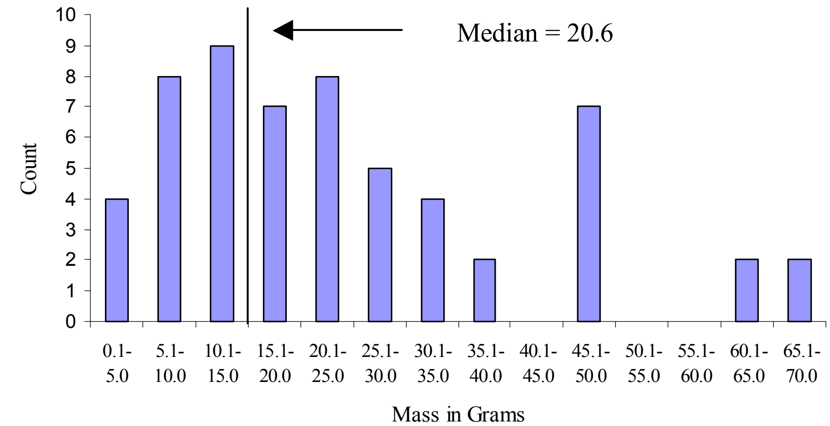
Radar Session	Date	Biweek
1	20-Sep-00	1
2	21-Sep-00	1
3	23-Sep-00	2
4	24-Sep-00	2
5	25-Sep-00	2
6	27-Sep-00	2
7	29-Sep-00	2
8	30-Sep-00	2
9	7-Oct-00	3
10	10-Oct-00	3
11	11-Oct-00	3
12	12-Oct-00	3
13	13-Oct-00	3
14	17-Oct-00	3
15	18-Oct-00	3
16	19-Oct-00	3
17	21-Oct-00	4
18	23-Oct-00	4
19	24-Oct-00	4
20	26-Oct-00	4
21	30-Oct-00	4
22	1-Nov-00	4
23	4-Nov-00	5
24	6-Nov-00	5
25	7-Nov-00	5
26	9-Nov-00	5
27	14-Nov-00	5
28	16-Nov-00	5
29	17-Nov-00	5
30	20-Nov-00	6
31	23-Nov-00	6
32	25-Nov-00	6
33	28-Nov-00	6
34	29-Nov-00	6

Table 11. 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.

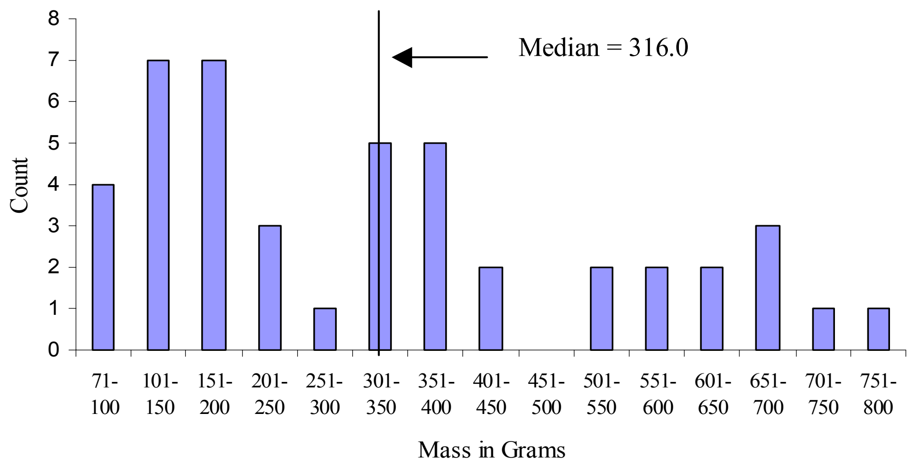
Biweek$_a$	Altitude$_b$	Small$_c$	Medium$_c$	15M	Large$_c$	60L	SBE$_d$	Images$_e$	SBE/Image	Airspace$_f$	Hazard Index
1	1	1377	1326	19890	533	31980	53247	1322	40.278	1.683	23.930
1	2	2186	2334	35010	1133	67980	105176	1322	79.558	2.699	29.480
1	3	2452	4091	61365	2936	176160	239977	1322	181.526	6.678	27.184
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

(a) Small (<70 g) bird masses in 5-g categories



(b) Medium (between 71-800 g) bird masses in 50-g categories.



(c) Large (>800 g) bird masses in 1,000-g categories.

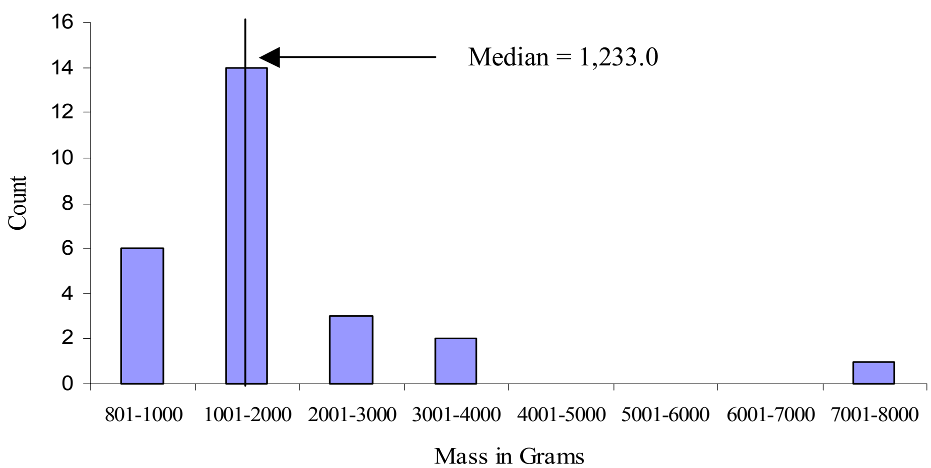


Fig. 9. Distributions of (a) small, (b) medium, and (c) large birds by mean body mass at NAF El Centro.

Table 12. 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

Fall Nocturnal Bird Hazards

Calculated hazard indices ranged from a low of 0.23 to 29.48 (Table 11 & Fig. 10). Hazard indices ≤ 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 13.

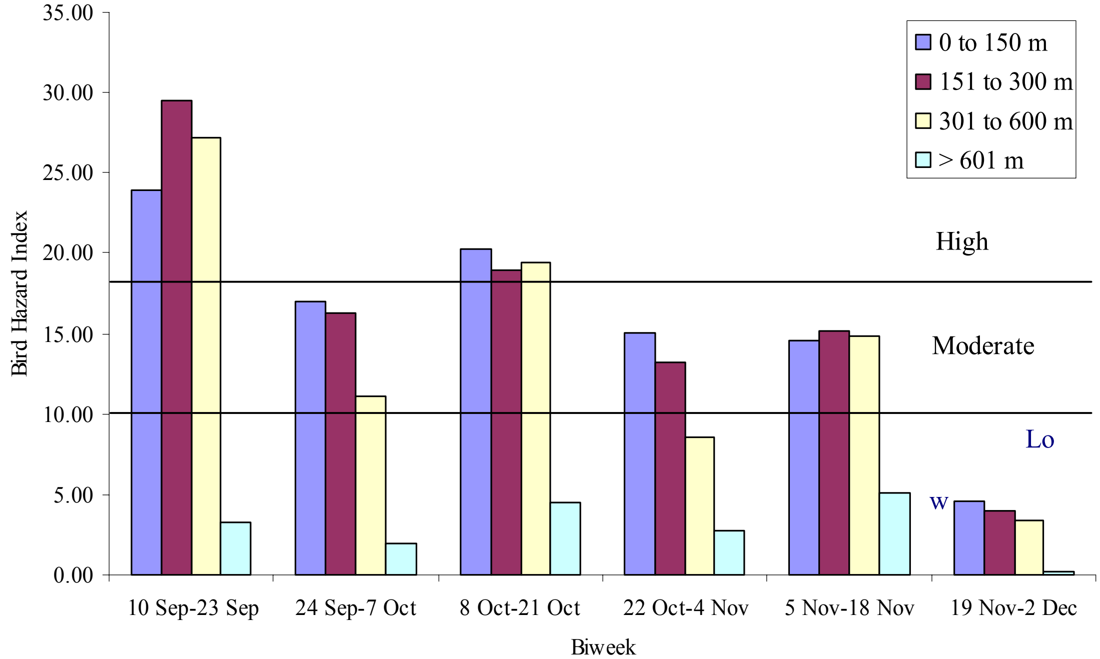
NON-FALL NOCTURNAL BIRD HAZARDS

The USAF monthly bird-strikes, 1985-2000, showed a bimodal distribution with peaks in April-May and September-October (Fig. 11). The peaks correspond with spring and fall migration. The fall nocturnal migration bird-radar study revealed correlated with the fall bird-strike peak. The spring peak was considered a high bird-strike risk for spring nocturnal migration.

NAF EL CENTRO BAM WEB PAGE

One copy of the web page was installed on the NAF El Centro web server. A second copy was installed on the USGS, Utah Cooperative Fish and Wildlife Research Unit's web server at Utah State University, College of Natural Resources. From these sites all interested parties have ready access to the information as needed. The NAF El Centro BAM web page can be viewed using a web browser by opening the file *index.htm* on the accompanying CD-ROM or by accessing the following web sites:

a)



b)

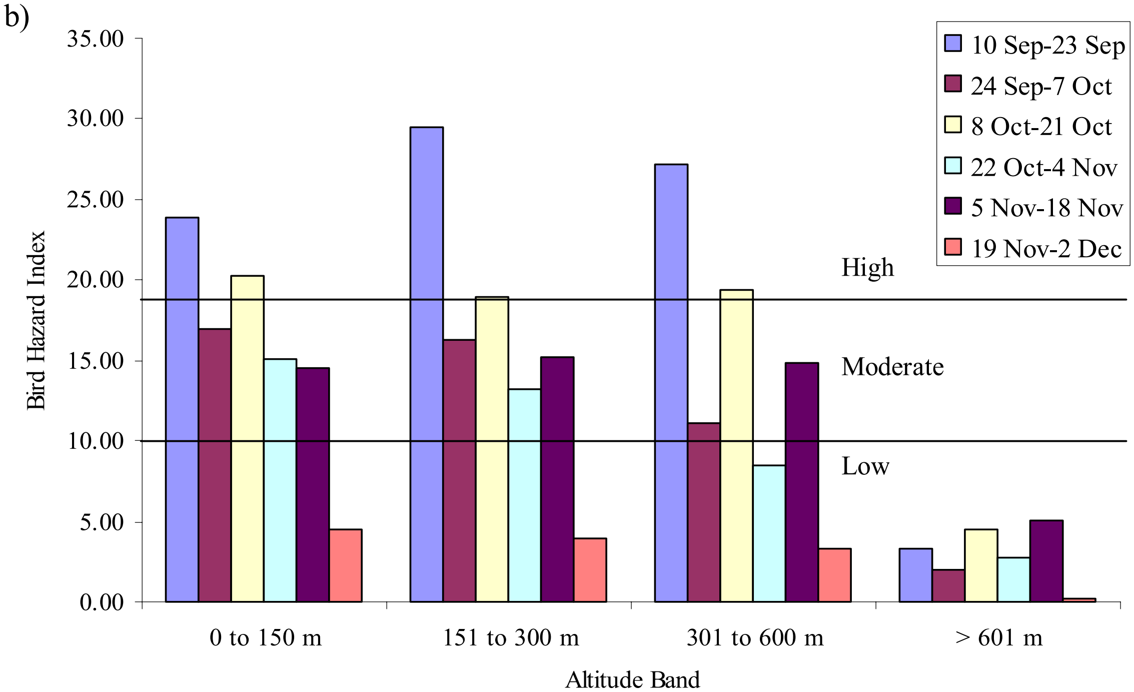


Fig. 10. Fall nocturnal bird-hazard indices by biweek and altitude band at NAF El Centro, CA. a) groups the altitude bands per biweek b) the same data with biweeks grouped per altitude band. High (18) and Moderate (10) thresholds are indicated.

Table 13. 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.

- http://www.nafec.navy.mil/
- http://ella.nr.usu.edu/~utcoop/

The home page introduces the BAM and provides links to the various pages. The "Bird-Avoidance Model" button links to selection pages for the risk graphs. A selection is first made of the area: the airfield, the East Mesa Range (R-2512), or the West Mesa Range (R-2510). The bird-strike hazards evaluated at the Salton Sea National Wildlife Refuge are not included. They were only calculated as a reference for high bird-strike hazards. Next is a selection of the 26 biweeks. This selection links to the risk graphs, the main component of the BAM.

The risk graphs describe the relative bird-strike risk in a simple, color-coded graph (Fig 12). The 5 daily time periods (sunrise-9 am, 9 am-Noon, Noon-3 pm, 3 pm-sunset, sunset-midnight) are delimited along x-axis. The four altitude bands (0-500 ft., 501-1000 ft., 1001-2000 ft., and >2000) are delimited along the y-axis. The intersection of altitude and time is colored red for high risk, yellow for moderate risk, and green on low risk.

Twenty-five species or species groups both hazardous to aircraft and common in the area are described from the "El Centro Birds" button (Table 14). These pages describe the species, its distribution in the area, the risk level, and the management options. There are links to other web sites that show pictures of the birds and have additional information.

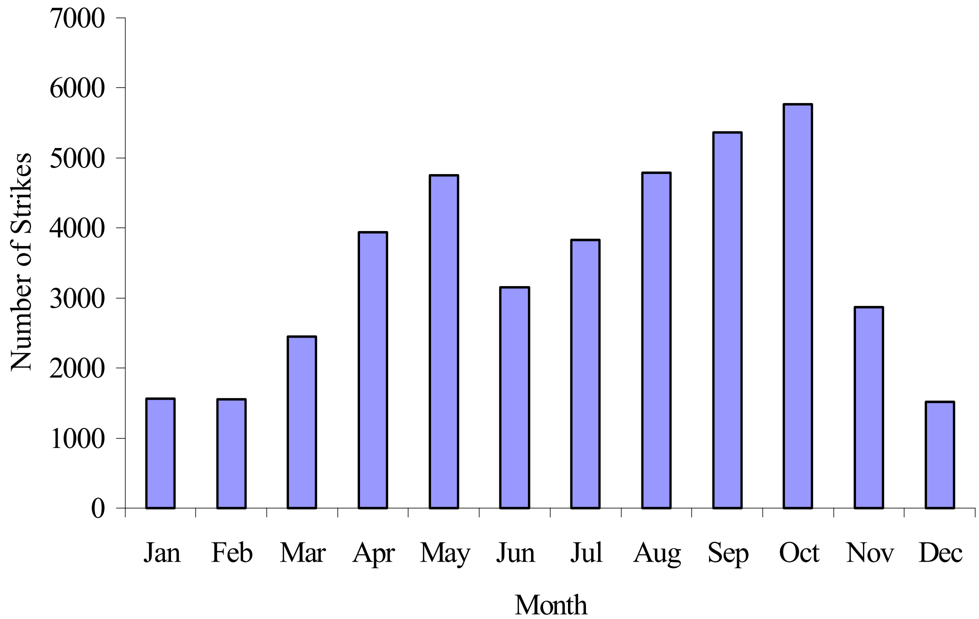


Fig. 11. US Air Force bird strikes per month, worldwide from Jan 1985 – Jun 2000 (data from the USAF BASH Team web page).

Fig. 12. NAF El Centro BAM risk graph for biweek 20 (September 24 – October 7).

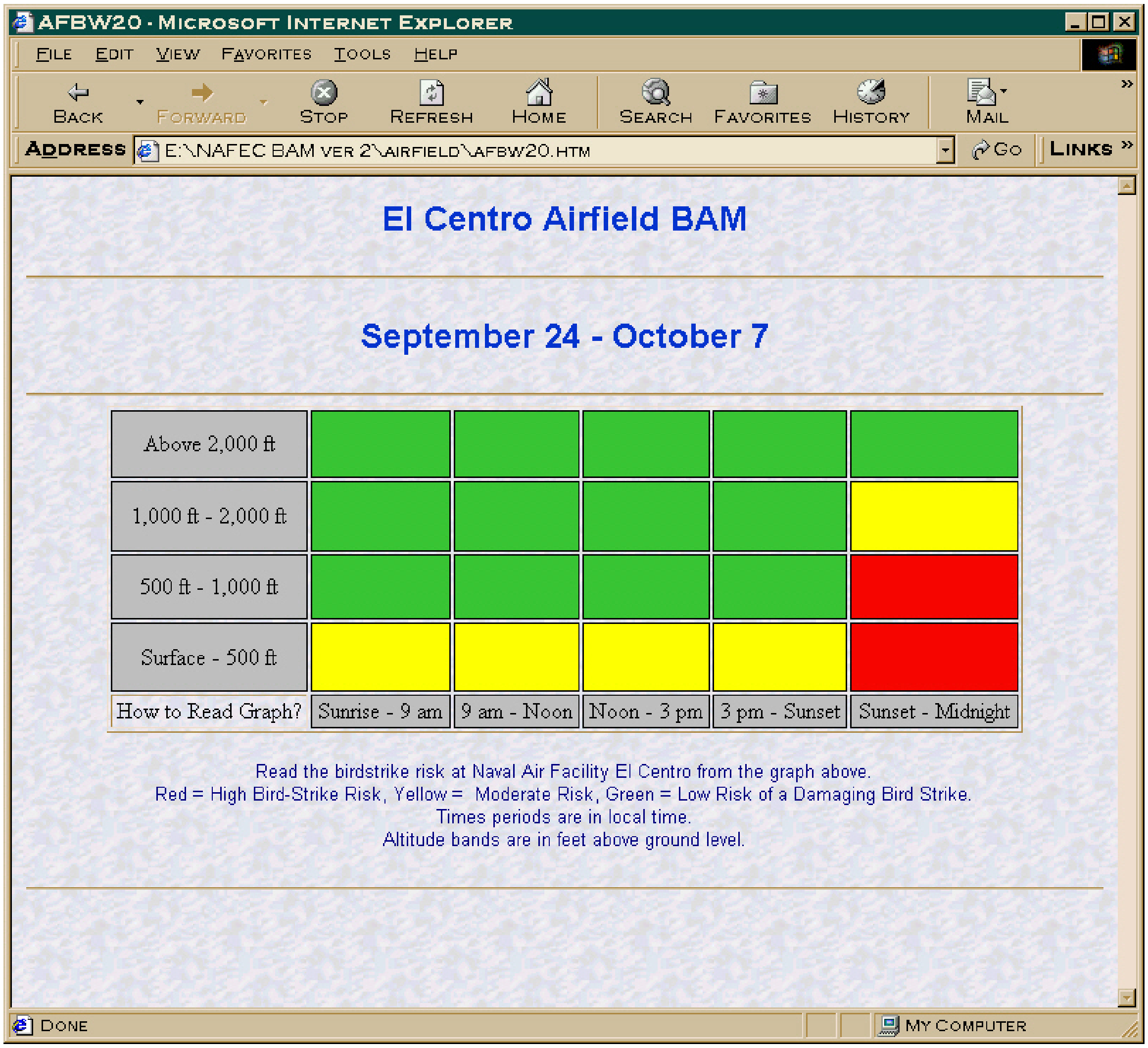


Table 14. Twenty-five species or species groups described on the NAF El Centro web page.

Ibis	Cattle Egrets
Shorebirds	Egrets & Herons
Burrowing Owls	American Kestrel
Horned Lark	Loggerhead Shrike
Meadowlark	Killdeer
Doves & Pigeons	Greater Roadrunner
Blackbirds & Starlings	Gulls
Swifts & Swallows	Lesser Nighthawk
Turkey Vulture	Red-tailed Hawk
Northern Harrier	Common Raven
Ducks	Pelicans
Geese	Cranes
Coyote	

DISCUSSION

The bombing ranges, as expected, had lower bird-strike risk than the airfield. Eighty-four percent of the calculated indices for daytime bird hazards at the West Mesa Range were low, 16% were moderate, and none were high. Its sparse creosote-bush vegetation supports fewer avian species than the airfield. Most of the species found there are relatively small and occur alone or in small flocks.

The most hazardous species are swallows, lesser nighthawks, horned larks, common ravens, and European starlings. The starlings and horned larks are found in low numbers and are unlikely to fly in altitudes that would conflict with aircraft using the range. The ravens are definitely large enough to cause significant damage if struck. They are not very common on the range since they tend to be associated with human populations. They few ravens that are seen on the range may soar on thermals and conflict with aircraft occasionally. The swallows (especially tree and cliff swallows) and lesser nighthawks are more of a concern than the other species. They are small and do not fly in tight flocks but they commonly fly at altitudes that conflict with aircraft using the range.

Eighty percent of the calculated indices for daytime bird hazards at the East Mesa Range were low, 20% were moderate, and none were high. Its dense creosote-bush vegetation supports fewer avian species than the airfield. Most of the species found at the East Mesa Range are relatively small and occur alone or in small flocks. A couple of very hazardous species (red-tailed hawk and turkey vulture) were recorded, but in very low numbers. Similar to the West Mesa Range, the species of most concern at the East Mesa Range are tree and cliff swallows and lesser nighthawks. Again, they are small and do not fly in tight flocks but they commonly fly at altitudes that conflict with aircraft using the range.

Four percent of the calculated bird-strike risks were categorized as high. Low and moderate bird-strike risks were equally represented at 48% of the calculated risks. The airfield was more hazardous because it had a great many more species using the area, many more individual birds, and many of those species occurred in large flocks. Eighteen hazardous species around the airfield might be loosely separated into three categories: airfield species, agricultural species, and species that are attracted to both areas. Six species may be considered hazardous airfield species (horned larks, American kestrels, killdeer, meadowlarks, mourning doves, and burrowing owls). Seven species (or species groups) may be considered agricultural species (blackbirds, European starlings, cattle egrets, common ravens, gulls, white-faced ibis, and shorebirds). The ibis and cattle egrets are of particular concern. Their size, large numbers, and common occurrence at the ends of the runways is an accident waiting to happen. Eliminating the agricultural fields off the ends of the runways can help to reduce the risk of striking these species. These species will still be a hazard locally since there are many agricultural fields, but at least they birds will not be encouraged to congregate at the end of the runway, one of the most hazardous areas for bird strikes. Five species (or species groups) may be attracted to both the airfield and the agricultural fields (northern harriers, red-tailed hawks, lesser nighthawks, swallows, and turkey vultures). The hawks are primarily attracted to small mammals in brushy, overgrown areas on the base. Vultures are attracted to carcasses on which to feed and thermals for soaring flight. The swallows and nighthawks are hawking flying insects and are difficult to manage in an effective way. As with the bombing ranges, at least they are small and fly in dispersed flocks.

Nocturnal migration was assumed to be uniform across the entire area. The radar site was situated at the West Mesa Range along the edge of the agricultural area and almost due north of the airfield. Fall nocturnal bird-strike risk peaked in October, which corresponded with the peak in USAF bird strikes. The nocturnal bird-strike risk through the rest of the year was based on the USAF data. This showed a peak in bird-strike risk in April and May, which we considered high risk.

It should be noted that the many nights categorized as high-bird-strike risk in the spring and fall will not be hazardous every night. This hazard is caused by night-migrating birds, which are active during favorable migration weather. Favorable weather is light to moderate winds out of the south (southwest to southeast) during the spring and out of the north (northwest to northeast) during the fall. This is a very general rule of thumb, but risk is likely to be highest on nights in April with a breeze out of the south or on nights in October with a good breeze out of the north. With the wind opposing the migratory direction, fewer birds will migrate and the risk will be reduced.

Visual bird counts most likely underrepresented birds at higher altitudes. Except for large, flocking, and vocal species (i.e. Canada geese) it can be very difficult to spot birds at altitudes beyond 300 m (1,000 ft) agl - with binoculars or without. This may lead the diurnal model (based on visual observation data) to under-represent the bird hazard at higher altitudes. Avian radar systems are not so limited in their ability to detect birds at altitude. The highest bird detected during this study was at 1,600m (5, 281 ft) agl. This should be considered an advantage for using radar to survey birds in future studies.

No bird strikes were reported to the Naval Safety Center from NAF El Centro during the time period covered by the study (the year 2000). The author, however, has personal knowledge that a burrowing owl, a cattle egret, and an unknown flock of small birds were struck on the airfield during one week in January 2000. The small birds caused 2 dents in the engine cowling of the aircraft, but there is no record of the strike in the database. There is no way to know, but the Navy bird strike database is most likely under-represents the bird-strike threat at NAF El Centro. One of the first priorities must be to quantify the problem, and this requires reporting of bird strikes by all involved in aircraft operations at NAF El Centro.

NAVY BASH RECOMMENDATIONS

1. Although it is beyond the direct influence of personnel at NAF El Centro, we recommend a serious and committed effort to improve the Navy-wide BASH program. The BASH office at the Naval Safety Center was not able to provide adequate assistance or data for this project. Instead we relied on USAF and FAA information and data. BASH must be managed at the base level, but will never be fully integrated without support and assistance from higher up the chain of command. The NAF El Centro Bird Hazard Working Group (BHWG) should encourage the formation of a strong Navy BASH office at the Naval Safety Center.

2. There is a great need to improve the Navy bird-strike-reporting rate. This must include improved pilot reporting, maintenance crew reporting, and runway-carcass reporting. An understanding of the Navy's exposure to bird-strikes is necessary for projects like this one. NAF El Centro has a particular concern with this issue. Since aircraft from many sources use the base and its ranges, bird-strikes may be reported at home bases though the strikes occurred at El Centro. The squadrons may wish to study their exposure to bird-strikes regardless of where they fly. The bird-strike database must be able to be queried for the location of the strike regardless of the home base of the aircraft involved. Increased bird-strike reporting will need to be promoted by the NAF El Centro BHWG and the Navy BASH office.

3. Neither this BAM nor the BASH Plan can have any effect on the damaging bird-strike rate if they are not actively and regularly used for the guidance they were designed convey. Promotion of these and other bird-strike risk-management tools will be the responsibility of the NAF El Centro BHWG.

4. Form an active Bird Hazard Working Group (BHWG) as directed in the NAF El Centro Bird Aircraft Strike Hazard (BASH) Plan (U. S. Navy 2000). BASH management is not a one-person job. It involves the cooperation and organization of several parties (natural resources management, grounds maintenance, ATC, airfield management, aircrews, aircraft-maintenance crews, cooperative farmers, etc.). The BHWG is the organizing body of those stakeholders. Without an effective BHWG, BASH management will remain a non-issue until the next serious mishap occurs. The goal of the BHWG is to prevent that mishap from occurring through proactive risk management. As described in the introduction of this report, bird-strikes will result in expensive repair costs, loss of aircraft, and loss of life. This is a safety and fiscal issue worth pursuing because there are steps that can be taken to reduce the risk.

5. We recommend a continuous bird-monitoring program at the base. This will be helpful in monitoring the effectiveness of management actions, in evaluating the BAM in the future, and monitoring bird-hazard conditions. As well the bird surveys should include environmental factors likely to attract the birds. This should include monitoring water levels in irrigated fields and other attractants that can be identified and management actions taken.

6. The BHWG must identify, implement, and evaluate both passive and active bird-hazard-management strategies at the base. For example, rock doves (pigeons) should be eliminated from aircraft hangars, American kestrels and burrowing owls should be eliminated from the airfield in some way, and the agricultural fields off the ends of the runways should be eliminated or altered to reduce their attractiveness to white-faced ibis, cattle egrets, and other birds. The importance of human motivation in managing bird hazards to aircraft cannot be understated (Solman 1970 & 1981). "Unless the work is always done well, bird strikes will continue and human lives and aircraft will be lost" (Solman 1981). The BHWG and personnel directly involved in bird-hazard management must be interested and motivated to work creatively toward the goal of identifying and solving bird-hazard problems.

7. Lastly, we recommend that this BAM be evaluated in the future for its effectiveness. The bird-strike reports and bird surveys will assist with this effort.

LITERATURE CITED

Aigner, P. A., and C. E. Koehler. 1996. Final Report: Ornithological Survey, Natural Resource Management Plan, Naval Air Facility, El Centro. Naval Air Facility Cl Centro, El Centro, California, USA.

Barker, R. L. 1998. Civil engineering's role in BASH. The Combat Edge 6:19-20.

Barras, S. C., and R. A. Dolbeer. 2000. Reporting bias in birdstrikes at John F. Kennedy international airport, New York, 1979/1998. Proceedings of the International Bird Strike Committee Meeting 25:99-112.

Blokpoel, H. 1976. Bird hazards to aircraft. Clarke, Irwin and Company, Ottawa, Ontario, Canada.

Burney, C. 1999. BAM (Bird Avoidance Model) 101. Flying Safety 55:12-15.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer. 1996. Wildlife strikes to civilian aircraft in the United States 1993-1995. Federal Aviation Administration, Office of Airport Safety and Standards, Washington D.C., USA.

_____, _____, and _____. 1997. Wildlife strikes to civil aircraft in the United States 1992-1996. Federal Aviation Administration, Office of Airport Safety and Standards, Washington D.C., USA.

_____, _____, and _____. 1998. Wildlife strikes to civil aircraft in the United States 1991-1997. Federal Aviation Administration, Office of Airport Safety and Standards, Washington D.C., USA.

_____, _____, and _____. 1999. Wildlife strikes to civil aircraft in the United States 1990-1998. Federal Aviation Administration, Office of Airport Safety and Standards, Washington D.C., USA.

_____, _____, and _____. 2000. Wildlife strikes to civil aircraft in the United States 1990-1999. Federal Aviation Administration, Office of Airport Safety and Standards, Washington D.C., USA.

DeFusco, R. P. 1993. Modeling bird hazards to aircraft: A GIS application study. Photogrammetric Engineering and Remote Sensing 59:1481-1487.

_____, and R. A. Turner. 1998. Dodging feathered bullets. The Combat Edge 6:19-20.

Dolbeer, R. A. 2000. Birds and aircraft: fighting for airspace in crowded skies. Proceedings of the Vertebrate Pest Conference 19:37-43.

_____, S. E. Wright, and E. C. Cleary. 1995. Bird and other wildlife strikes to civilian aircraft in the United States, 1994. Federal Aviation Administration, FAA Technical Center, Atlantic City, New Jersey, USA.

Dove, C. J. 1999. Feather identification and a new electronic system for reporting U.S. Air Force bird strikes. Proceedings of the Joint Meeting of Bird Strike Committee-USA/Canada 1:225-229.

_____. 2000. A descriptive and phylogenetic analysis of plumulaceous feather characters in Charadriformes. Ornithological Monographs. 51:1-163.

Eschenfelder, P. 2000. Jet engine certification standards. Proceedings of the International Bird Strike Committee Meeting. 25:535-540.

Janca, M. 2000. Take control of your BASH program. Flying Safety 56:4-9.

Jarmen, P. 1993. A manual of airfield bird control. Birdcheck, Bedford, England.

Kelly, T. A. 1993. An investigation of bird avoidance model methodology using records of bird aircraft strikes with two North American raptor species: turkey vultures (*Cathartes aura*) and red-tailed hawks (*Buteo jamaicensis*). Thesis, University of Kent, Canterbury, England, United Kingdom.

_____, A. G. Smith, and E. J. Zakrajsek. 1995. Dare County Range Bird Avoidance Model. Unpublished proceedings of Bird Strike Committee USA Meeting 5.

_____, _____, and _____. 1997. Moody AFB/Grand Bay Weapons Range Bird Avoidance Model. Unpublished proceedings of Bird Strike Committee USA Meeting 7.

_____. 1999. The Avian Hazard Advisory System (AHAS). Flying Safety 55:8-11.

_____. 2000. AHAS update. Flying Safety 56:14-17.

_____, R. L. Merritt, R. White, A. G. Smith, and M. Howera. 2000. The Avian Hazard Advisory System (AHAS): operational use of weather radar for reducing bird strike risk in North America. Proceedings of the International Bird Strike Committee Meeting 25:1-7.

Langley, M. 1970. The birdstrike problem. Science Journal 6:55-60.

Lahser, C. 2000. Look over the fence. Flying Safety 56:22.

Linnel, M.A., M. R. Conover, and T. J. Ohashi. 1999. Biases in bird strike statistics based on pilot reports. Journal of Wildlife Management 63:997-1003.

Lovell, C. D. 1997. The U.S. Air Force bird avoidance model for low-level training flights. Great Plains Wildlife Damage Control Workshop 13:162-170.

_____, and R. A. Dolbeer. 1999. Validation of the U.S. Air Force Bird Avoidance Model. Wildlife Society Bulletin. 27:167-171.

Morrison, M. L., A. J. Kuenzi, and L. Ellison. 1992. Avian-agricultural field relationships on selected Naval and Marine Corps installations with aircraft operations. Naval Facilities Engineering Command, San Diego, California, USA.

Robbe, A. 1998. Tragedy at Elmendorf. Combat Edge 6:26:30.

Solman, V. E. F. 1970. Current work on bird hazards to aircraft. Proceedings of the Vertebrate Pest Conference 4:184-187.

_____. 1973. Birds and aircraft. Biological Conservation 5:79-86.

_____. 1978. Gulls and aircraft. Environmental Conservation 5:277-280.

_____. 1981. Birds and aviation. Environmental Conservation 8:45-51.

Starfield, A. M. 1997. A pragmatic approach to modeling for wildlife management. Journal of Wildlife Management 61:261-270.

_____, and A. L. Bleloch. 1991. Building models for conservation and wildlife management. Burgess International Group, Inc., Edina, Minnesota, USA.

Steenblik, J. W. 1997. Wildlife hazards to aircraft. Air Line Pilot 66:30-33, 62.

Tedrow, C. A. 1998. Bird strike risk assessment for United States Air Force airfields and aircraft. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

Thompson, A. L. 1964. A new dictionary of birds. T. Nelson Ltd. London, United Kingdom.

U.S. Navy. 2000. Bird Air Strike Hazard Plan: Naval Air Facility, El Centro and Target Ranges 2510 and 2512. Naval Air Facility El Centro, El Centro, California, USA.

Walker, T. C., and C. W, Bennett. 1985. Apparent efficacy of bird aircraft strike hazard programs at four naval stations. Proceedings of the Eastern Wildlife damage Control Conference 2:115-121.

Weidensaul, S. 1999. Living on the wind: across the hemisphere with migratory birds. North Point Press, New York, New York, USA.

APPENDIX A

Species in each USAF Species Group

SPECIES IN EACH USAF SPECIES GROUP

Below are lists of the species recorded in each of the 53 species groups compiled from the U.S. Air Force Bird-Strike Database (1985-1998). These data come from 5204 USAF bird-strike records that indicated the species involved. The species groups were assembled to simplify the analysis of the hazard posed by the 399 “species” recorded in the USAF bird-strike database. We place species in quotes here because sometimes only “goose” or “gull” was listed in the database and not a complete species name. Species groups allow placing these loosely categorized species correctly into usable categories. The simplification also limits the number of species groups to 53, and raises the sample size within groups. For example, only five California gulls were recorded. When grouped with all of the other gull species, however, the sample size raises to 229.

ACCIPITER		BAT	
Cooper's Hawk	*Accipiter cooperii*	Brazilian Free-tailed Bat	*Tadarida brasiliensis*
Northern Goshawk	*Accipiter gentilis*	Evening Bat	*Nycticerius humeralis*
Northern Harrier	*Circus cyaneus*	Hoary Bat	*Lasiurus cinereus*
Sharp-shinned Hawk	*Accipiter striatus*	Big Brown Bat	*Eptesicus ruscus*
		Little Brown Bat	*Myotis lucifugus*
		Long-legged Bat	*Macrophyllum macrophyllum*
		Mexican Free-tailed Bat	*Tadarida brasiliensis*
		Pale Big-eared Bat	*Plecotus townsendii pallescens*
		Red Bat	*Lasiurus borealis*
		Silver-haired Bat	*Lasionycteris noctivagans*

BLACKBIRD/STARLING		BUTEO	
Brewer's Blackbird	*Euphagus cyanocephalus*	Broad-winged Hawk	*Buteo platypterus*
European Starling	*Sturnus vulgaris*	Ferruginous Hawk	*Buteo regalis*
Red-winged Blackbird	*Agelaius phoeniceus*	Harris Hawk	*Parabuteo unicinctus*
Rusty Blackbird	*Euphagus carolinus*	Red-shouldered Hawk	*Buteo lineatus*
Tricolored Blackbird	*Agelaius tricolor*	Red-tailed Hawk	*Buteo jamaicensis*
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	Rough-legged Hawk	*Buteo lagopus*
		Swainson's Hawk	*Buteo swainsoni*

CATTLE EGRET		CORMORANT	
Cattle Egret	*Bubulcus ibis*	Double-crested Cormorant	*Phalacrocorax carbo*

COYOTE		CRANE	
Coyote	*Canis latrans*	Sandhill Crane	*Grus canadensis*

CROW		DEER	
American Crow	*Corvus brachyrhynchos*	White-tail Deer	*Odocoileus virginianus*
Fish Crow	*Corvus ossifragus*		
Yellow-billed Magpie	*Pica nuttalli*		
Common Raven	*Corvus cryptoleucus*		

DOVE		DUCK	
Barred Ground Dove	*Geopelia striata*	American Wigeon	*Anas americana*
Collared Dove	*Streptopelia decaoto*	Black Duck	*Anas rubripes*
Inca Dove	*Columbina inca*	Blue-winged Teal	*Anas discors*
Ruddy Turtle Dove	*Streptopelia orientalis*	Bufflehead	*Bucephala albeola*
White-winged Dove	*Zenaida asiatica*	Canvasback	*Aythya valisineria*
		Cinnamon Teal	*Anas cyanoptera*
		Gadwall	*Anas strepera*
		Greater Scaup	*Aythya marila*
		Green-winged Teal	*Anas crecca*
		Hooded Merganser	*Lophodytes cucullatus*
		Lesser Scaup	*Aythya affinis*
		Mallard	*Anas platyrhynchos*
		Northern Pintail	*Anas acuta*
		Redhead	*Aythya americana*
		Ring-necked Duck	*Aythya collaris*
		Wood Duck	*Aix sponsa*

EAGLE		EGRET/HERON	
Bald Eagle	*Haliaeetus leucocephalus*	Black-crowned Night Heron	*Nycticorax nycticorax*
Golden Eagle	*Aquila chrysaetos*	Great Blue Heron	*Ardea herodias*
		Great Egret	*Casmerodius alba*
		Green Heron	*Butorides virescens*
		Little Blue Heron	*Egretta caerulea*
		Snowy Egret	*Egretta thula*

FALCON - LARGE	FLYCATCHER
Peregrine Falcon *Falco peregrinus*	Acadian Flycatcher *Empidonax virescens*
Prairie Falcon *Falco mexicanus*	Eastern Kingbird *Tyrannus tyrannus*
	Gray Kingbird *Tyrannus dominicensis*
	Great-crested Flycatcher *Myiarchus crinitus*
	Least Flycatcher *Empidonax minimus*
	Say's Phoebe *Sayornis saya*
	Scissor-tailed Flycatcher *Tyrannus forficatus*
	Vermilion Flycatcher *Pyrocephalus rubinus*
	Western Kingbird *Tyrannus verticalis*

GOOSE	GRACKLE
Canada Goose *Branta canadensis*	Common Grackle *Quiscalus quiscula*
Snow Goose *Chen caerulescens*	Boat-tailed Grackle *Quiscalus major*

GREBE	GULL
Pied-billed Grebe *Podilymbus podiceps*	Black-headed Gull *Larus ridibundus*
Western Grebe *Aechmophorus occidentalis*	California Gull *Larus californicus*
	Franklin's Gull *Larus pipixcan*
	Glaucous Gull *Larus hyperboreus*
	Glaucous-winged Gull *Larus glaucescens*
	Great Black-backed Gull *Larus marinus*
	Herring Gull *Larus argentatus*
	Laughing Gull *Larus atricilla*
	Lesser Black-backed Gull *Larus fuscus*
	Mew Gull *Larus canus*
	Ring-billed Gull *Larus delawarensis*
	Western Gull *Larus occidentalis*

HORNED LARK	IBIS
Horned Lark *Eremophila alpestris*	Glossy Ibis *Pelegradis falcinellus*
	White Ibis *Eudocimus albus*

FALCON - SMALL	KILLDEER
American Kestrel *Falco sparverius*	Killdeer *Charadrius vociferus*
Merlin *Falco columbarius*	

KITE	**SHOREBIRD - LARGE (>100 g)**
Mississippi Kite *Ictinia mississippiensis*	American Avocet *Recurvirostra americana*
	Bar-tailed Godwit *Limosa haemastica*
	Lesser Yellowlegs *Tringa flavipes*
	Long-billed Dowitcher *Limnodromus scolopaceus*
	Oystercatcher *Haematopus palliatus*
	Short-billed Dowitcher *Limnodromus griseus*
	Upland Sandpiper *Bratramia longicauda*
	Whimbrel *Numenius phaeopus*
	Willet *Catoptrophorus semipalmatus*

LOON	**MEADOWLARK**
Common Loon *Gavia immer*	Eastern Meadowlark *Sturnella magna*
	Western Maedowlark *Sturnella neglecta*

MOURNING DOVE	**NIGHTHAWK**
Mourning Dove *Zenaida macroura*	Common Nighthawk *Chordeiles minor*
	Lesser Nighthawk *Chordeiles acutipennis*

OSPREY	**OTHER**
Osprey *Pandion haliaetus*	Anna's Hummingbird *Calypte anna*
	Belted Kingfisher *Ceryle alcyon*
	Blue Grosbeak *Guiraca caerulea*
	Blue Jay *Cyanocitta cristata*
	Brown-headed Cowbird *Molothrus ater*
	Carolina Wren *Thryothorus ludovicianus*
	Gray Jay *Perisoreus canadensis*
	House Wren *Troglodytes aedon*
	Loggerhead Shrike *Lanius ludovicianus*
	Northern Oriole *Icterus galbula*
	Pine Grosbeak *Pinicola enucleator*
	Rock Wren *Salpinctes obsoletus*
	Rose-breasted Grosbeak *Pheucticus ludovicianus*
	Ruby-throated Hummingbird *Achilochus colubris*
	Rufus-sided Towhee *Pipilo erythrophthalmus*
	Scarlet Tanager *Piranga olivacea*
	Summer Tanager *Piranga rubra*
	Western Tanager *Piranga ludoviciana*
	Winter Wren *Troglodytes troglodytes*

OWL	PELICAN
Barn Owl *Tyto alba*	American White Pelican *Pelecanus erythrorhynchos*
Burrowing Owl *Athene cunicularia*	Brown Pelican *Pelecanus occidentalis*
Great-horned Owl *Bubo virginianus*	
Long-eared Owl *Asio otus*	
Screech Owl *Otus asio*	
Short-eared Owl *Asio flammeus*	
Snowy Owl *Nyctea scandiaca*	

QUAIL	RAIL
Bobwhite Quail *Colinus virginianus*	American Coot *Fulica americana*
Gray Partridge *Perdix perdix*	Common Galinule *Porphyrula martinica*
Prairie Chicken *Tympanuchus cupido*	Common Moorhen *Gallinula chloropus*
Sage Grouse *Centrocercus urophasianus*	Sora Rail *Porzana carolina*
	Virginia Rail *Rallus limicola*
	Yellow Rail *Coturnicops noveboracensis*

ROADRUNNER	ROCK DOVE
Greater Roadrunner *Geococcyx californianus*	Rock Dove *Columba livia*

SEA BIRD	SKY LARK
Black Noddy *Anous minutus*	Sky Lark *Alauda arvensis*
Black-legged Kittiwake *Rissa tridactyla*	
Laysan AlbatrossS *Diomedea immutabilis*	
Masked Booby *Sula dactylatra*	
Northern Gannet *Morus bassanus*	

MAMMAL - SMALL	
Black-tailed Jackrabbit	*Lepus californicus*
Chipmunk	*Tamias striatus*
Domestic Cat	*Felis domesticus*
Domestic Dog	*Canis domesticus*
Rabbit	*Sylvilagus spp.*
Bacoon	*Procyon lotor*

SHOREBIRD - SMALL (<100 g)	
American Golden Plover	*Pluvialis dominicus*
Baird's Sandpiper	*Calidris bairdii*
Black-bellied Plover	*Pluvialis squatarola*
Buff-breasted Sandpiper	*Tryngites subruficollis*
Common Snipe	*Gallinago gallinaga*
Dunlin	*Calidris alpina*
Least Sandpiper	*Calidris minutilla*
Pacific Golden Plover	*Pluvialis fulva*
Pectoral Sandpiper	*Calidris melanotos*
Ruddy Turnstone	*Arenaria interpres*
Sanderling	*Calirdis alba*
Semipalmated Plover	*Charadrius semipalmatus*
Semipalmated Sandpiper	*Calirdis pusilla*
Spotted Plover	*Actitis macularia*
Whire-rumped Sandpiper	*Calidris fuscicollis*

STORK	
Wood Stork	*Mycteria americana*

SWALLOW	
Bank Swallow	*Riparia riparia*
Barn Swallow	*Hirundo rustica*
Black Swift	*Cypseloides niger*
Chimney Swift	*Chaetura pelagica*
Cliff Swallow	*Hirundo pyrrhonota*
Purple Martin	*Progne subis*
Rough-winged Swallow	*Stelgidopteryx serripennis*
Tree Swallow	*Tachycineta bicolor*
Violet-green Swallow	*Tachycineta thalassina*
White-throated Swallow	*Aeronautes saxatalis*

VULTURE	
Black Vulture	*Coragyps atratus*
Turkey Vulture	*Cathartes aura*

SPARROW	
American Goldfinch	*Carduelis tristis*
Bachman's Sparrow	*Aimophila aestivalis*
Bobolink	*Dolichonyx oryzivorus*
Cassin's Finch	*Carpodacus cassinii*
Chestnut-collared Longspur	*Calcarius ornatus*
Chipping Sparrow	*Spizella passerina*
Clay-colored Sparrow	*Spizella pallida*
Dark-eyed Junco	*Junco hyemalis*
Fox Sparrow	*Passerella iliaca*
Grasshopper Sparrow	*Ammodramus savannarum*
House Finch	*Carpodacus mexicanus*
House Sparrow	*Passer domesticus*
Indigo Bunting	*Passerina cyanea*
Lapland Longspur	*Calcarius lapponicus*
Lark Bunting	*Calamospiza melanocorys*
Lark Sparrow	*Chondestes grammacus*
Leconte's Sparrow	*Ammodramus leconteii*
Lincoln's Sparrow	*Melospiza lincolnii*
McCown's Longspur	*Calcarius mccownii*
Purple Finch	*Carpodacus purpureus*
Savanah Sparrow	*Passerculus sandwichensis*
Smith's Longspur	*Calcarius pictus*
Snow Bunting	*Plectrophenax nivalis*
Song Sparrow	*Melospiza melodia*
Tree Sparrow	*Spizella arborea*
Vesper Sparrow	*Pooecetes gramineus*
White-crowned Sparrow	*Zonotrichia leucophrys*
White-throated Sparrow	*Zonotrichia albicollis*
White-winged Crossbill	*Loxia leucoptera*

APPENDIX B

SPECIES IN EACH NAF EL CENTRO SPECIES GROUP

SPECIES IN EACH NAF EL CENTRO SPECIES GROUP

Below are lists of the species recorded in each of the 36-species groups identified at NAF El Centro, CA, 10-Jan-2000 to 9-Jan-2001. The species groups were assembled to simplify the analysis of the hazard posed by the 145 species recorded in the area. Species groups limits the number of species groups to 36, and raises the sample size within groups. For example, only seven flocks of northern pintails were recorded during the year. When grouped with all of the other species of ducks, however, the sample size raises to 251 flocks.

ACCIPITER		**BLACKBIRD/STARLING**	
Cooper's Hawk	*Accipiter cooperii*	European Starling	*Sturnus vulgaris*
Northern Harrier	*Circus cyaneus*	Red-winged Blackbird	*Agelaius phoeniceus*
Sharp-shinned Hawk	*Accipiter striatus*	Tricolored Blackbird	*Agelaius tricolor*
		Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*

BUTEO		**CATTLE EGRET**	
Red-tailed Hawk	*Buteo jamaicensis*	Cattle Egret	*Bubulcus ibis*

CROW		**DUCK**	
Common Raven	*Corvus corax*	American Wigeon	*Anas americana*
		Cinnamon Teal	*Anas cyanoptera*
		Common Goldeneye	*Bucephala clangula*
		Common Merganser	*Mergus merganser*
		Eared Grebe	*Podiceps nigricollis*
		Gadwall	*Anas strepera*
		Greater Scaup	*Aythya marila*
		Green-winged Teal	*Anas crecca*
		Lesser Scaup	*Aythya affinis*
		Mallard	*Anas platyrhynchos*
		Northern Pintail	*Anas acuta*
		Northern Shovler	*Anas clypeata*
		Redhead	*Aythya americana*
		Ruddy Duck	*Oxyura jamaicensis*
		Western Grebe	*Aechmophorus occidentalis*

EGRET/HERON		FALCON - LARGE	
Black-crowned Night-Heron	*Nycticorax nycticorax*	Prairie Falcon	*Falco mexicanus*
Great Blue Heron	*Ardea herodias*		
Great Egret	*Casmerodius alba*		
Green Heron	*Butorides virescens*		
Snowy Egret	*Egretta thula*		

FLYCATCHER		GOOSE	
Ash-throated Flycatcher	*Myiarchus cinerascens*	Canada Goose	*Branta canadensis*
Black Phoebe	*Sayornis nigricans*	Double-crested Cormorant	*Phalacrocorax auritus*
Cordilleran Flycatcher	*Empidonax occidentalis*	Ross's Goose	*Chen rossii*
Say's Phoebe	*Sayornis saya*	Snow Goose	*Chen caerulescens*
Western Kingbird	*Tyrannus verticalis*		
Willow Flycatcher	*Empidonax traillii*		

GRACKLE		GULL	
Great-tailed Grackle	*Quiscalus mexicanus*	Black Skimmer	*Rhynchops niger*
		Bonapart's Gull	*Larus philadelphia*
		California Gull	*Larus californicus*
		Herring Gull	*Larus argentatus*
		Ring-Billed Gull	*Larus delawarensis*
		Western Gull	*Larus occidentalis*
		Yellow-footed Gull	*Larus livens*

HORNED LARK		IBIS	
Horned Lark	*Eremophila alpestris*	White-faced Ibis	*Plegadis chihi*

FALCON - SMALL		KILLDEER	
American Kestrel	*Falco sparverius*	Killdeer	*Charadrius vociferus*

SHOREBIRD - LARGE		MEADOWLARK	
American Avocet	*Recurvirostra americana*	Western Meadowlark	*Sturnella neglecta*
Black-necked Stilt	*Himantopus mexicanus*		
Lesser Yellowlegs	*Tringa flavipes*		
Long-billed Curlew	*Numenius americanus*		
Long-billed Dowitcher	*Limnodromus scolopaceus*		
Marbled Godwit	*Limosa fedoa*		
Willet	*Catoptrophorus semipalmatus*		
Wilson's Phalarope	*Phalaropus tricolor*		

MOURNING DOVE		NIGHTHAWK	
Mourning Dove	*Zenaida macroura*	Lesser Nighthawk	*Chordeiles acutipennis*

OTHER		DOVE	
Abert's Towhee	*Pipilo alberti*	Common Ground Dove	*Columbina passerina*
Anna's Hummingbird	*Calypte anna*	Rock Dove	*Columba livia*
Belted Kingfisher	*Ceryle alcyon*	White-winged Dove	*Zenaida asiatica*
Bewick's Wren	*Thryomanes bewickii*		
Black-chinned Hummingbird	*Archilochus alexandri*		
Brown-headed Cowbird	*Molothrus ater*		
Buff-collared Nightjar	*Caprimulgus ridgwayi*		
Cactus Wren	*Campylorhynchus brunneicapillus*		
Costa's Hummingbird	*Calypte costae*		
Evening Grosbeak	*Coccothraustes vespertinus*		
Loggerhead Shrike	*Lanius ludovicianus*		
Marsh Wren	*Cistothorus palustris*		
Rock Wren	*Salpinctes obsoletus*		
Rufous Hummingbird	*Selasphorus rufus*		
Western Tanager	*Piranga ludoviciana*		
White-tailed Kite	*Elanus caerules*		

OWL		PELICAN	
Burrowing Owl	*Athene cunicularia*	American White Pelican	*Pelecanus erythrorhynchos*
		Brown Pelican	*Pelecanus occidentalis*

ROADRUNNER		QUAIL	
Greater Roadrunner	*Geococcyx californianus*	Gambrel's Quail	*Callipepla gambelii*

RAIL		SHOREBIRD - SMALL	
American Coot	*Fulica americana*	Least Sandpiper	*Calidris minutilla*
Clapper Rail	*Rallus longirostris*	Pacific Golden Plover	*Pluvialis fulva*
Common Moorhen	*Gallinula chloropus*	Pectoral Sandpiper	*Calidris melanotos*
		Red-necked Phalarop	*Phalaropus lobatus*
		Spotted Sandpiper	*Actitis macularia*
		Western Sandpiper	*Calidris mauri*

SPARROW		STORK	
Black-throated Sparrow	*Amphispiza bilineata*	Wood Stork	*Mycteria americana*
Chipping Sparrow	*Spizella passerina*		
House Finch	*Carpodacus mexicanus*		
Lazuli Bunting	*Passerina amoena*		
Sage Sparrow	*Amphispiza belli*		
Savannah Sparrow	*Passerculus sandwichensis*		
Song Sparrow	*Melospiza melodia*		
White-crowned Sparrow	*Zonotrichia leucophrys*		

SWALLOW		TERN	
Bank Swallow	*Riparia riparia*	Black Tern	*Chlidonias niger*
Barn Swallow	*Hirundo rustica*	Caspian Tern	*Sterna caspia*
Cliff Swallow	*Hirundo pyrrhonota*	Forster's Tern	*Sterna forsteri*
N. Rough-winged Swallow	*Stelgidopteryx serripennis*	Gull-billed Tern	*Sterna nilotica*
Tree Swallow	*Tachycineta bicolor*		
Vaux's Swift	*Chaetura vauxi*		
Violet-green Swallow	*Tachycineta thalassina*		
White-throated Swift	*Aeronautes saxatalis*		

THRASHER		THRUSH	
LeConte's Thrasher	*Toxostoma lecontei*	American Pipit	*Anthus rubescens*
Nothern Mockingbird	*Mimus polyglottos*	Mountain Bluebird	*Sialia currucoides*
Sage Thrasher	*Oreoscoptes montanus*		

VULTURE		WARBLER	
Turkey Vulture	*Cathartes aura*	Black-tailed Gnatcatcher	*Polioptila melanura*
		Common Yellowthroat	*Geothlypis trichas*
		Nashville Warbler	*Vermivora ruficapilla*
		Orange-crowned Warbler	*Vermivora celata*
		Townsend's Warbler	*Dendroica townsendi*
		Verdin	*Auriparus flaviceps*
		Wilson's Warbler	*Wilsonia pusilla*
		Yellow Warbler	*Dendroica petechia*
		Yellow-rumped Warbler	*Dendroica coronata*

APPENDIX C

Hazard indices and risk categories by biweek, time period, and altitude band at NAF El Centro's airfield.

Hazard indices and risk categories by biweek, time period, and altitude band at NAF El Centro's airfield.

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
1	1	1	57.056	Moderate
1	2	1	48.535	Low
1	2	2	33.741	Low
1	3	1	52.964	Moderate
1	3	2	26.363	Low
1	4	1	74.109	Moderate
2	1	1	2.333	Low
2	2	1	55.520	Moderate
2	2	2	0.054	Low
2	3	1	97.869	Moderate
2	3	2	42.629	Low
2	4	1	34.770	Low
3	1	1	40.242	Low
3	1	2	0.054	Low
3	2	1	38.410	Low
3	2	2	1.769	Low
3	3	1	33.847	Low
3	4	1	16.254	Low
3	4	2	33.164	Low
4	1	1	0.000	Unknown
4	2	1	2.635	Low
4	3	1	50.936	Moderate
4	3	2	31.972	Low
4	4	1	29.688	Low
4	4	2	20.412	Low
5	1	1	55.261	Moderate
5	1	2	0.119	Low
5	2	1	80.939	Moderate
5	2	4	1.769	Low
5	3	1	105.871	Moderate
5	4	1	0.000	Unknown
6	1	1	71.562	Moderate
6	1	2	19.014	Low
6	2	1	71.527	Moderate
6	3	1	27.280	Low
6	4	1	99.341	Moderate
6	4	2	7.811	Low
7	1	1	88.440	Moderate
7	2	1	86.222	Moderate
7	3	1	93.529	Moderate
7	4	1	144.092	Moderate
7	4	3	138.971	Moderate

Hazard Indices at Airfield continued

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
8	1	1	215.468	High
8	2	1	89.524	Moderate
8	2	2	0.089	Low
8	3	1	0.000	Unknown
8	4	1	0.000	Unknown
9	1	1	70.293	Moderate
9	1	2	2.345	Low
9	2	1	42.642	Low
9	2	2	20.191	Low
9	3	1	62.058	Moderate
9	4	1	94.767	Moderate
9	4	2	5.072	Low
9	4	3	0.036	Low
10	1	1	94.322	Moderate
10	2	1	51.000	Moderate
10	3	1	0.000	Unknown
10	4	1	63.949	Moderate
11	1	1	75.062	Moderate
11	1	2	74.046	Moderate
11	2	1	39.033	Low
11	3	1	0.000	Unknown
11	4	1	65.723	Moderate
12	1	1	86.725	Moderate
12	2	1	52.137	Moderate
12	2	2	178.745	High
12	3	1	0.000	Unknown
12	4	1	53.778	Moderate
13	1	1	34.787	Low
13	1	2	0.054	Low
13	2	1	103.227	Moderate
13	2	2	64.051	Moderate
13	3	1	0.000	Unknown
13	4	1	78.266	Moderate
13	4	2	5.859	Low
14	1	1	63.287	Moderate
14	1	2	38.100	Low
14	2	1	0.000	Unknown
14	3	1	0.000	Unknown
14	4	1	79.246	Moderate
15	1	1	45.231	Low
15	1	2	0.178	Low
15	2	1	26.713	Low
15	3	1	0.000	Unknown
15	4	1	44.140	Low

Hazard Indices at Airfield continued

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
16	1	1	50.942	Moderate
16	1	2	1.251	Low
16	2	1	91.084	Moderate
16	3	1	0.000	Unknown
16	4	1	76.856	Moderate
17	1	1	37.717	Low
17	2	1	81.197	Moderate
17	3	1	0.000	Unknown
17	4	1	17.879	Low
17	4	2	5.912	Low
18	1	1	67.496	Moderate
18	2	1	134.046	Moderate
18	2	2	140.159	Moderate
18	3	1	0.000	Unknown
18	4	1	65.085	Moderate
19	1	1	0.000	Unknown
19	2	1	0.000	Unknown
19	3	1	96.974	Moderate
19	4	1	43.821	Low
19	4	2	11.717	Low
20	1	1	0.000	Unknown
20	2	1	91.440	Moderate
20	3	1	153.386	High
20	4	1	35.876	Low
21	1	1	76.779	Moderate
21	2	1	234.177	High
21	3	1	89.941	Moderate
21	4	1	27.922	Low
22	1	1	19.117	Low
22	2	1	129.337	Moderate
22	3	1	27.563	Low
22	4	1	0.000	Unknown
23	1	1	0.000	Unknown
23	2	1	0.000	Unknown
23	3	1	39.353	Low
23	4	1	54.851	Moderate
23	4	2	3.610	Low
24	1	1	133.430	Moderate
24	1	2	38.029	Low
24	2	1	172.304	High
24	3	1	39.848	Low
24	4	1	0.000	Unknown

Hazard Indices at Airfield continued

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
25	1	1	28.544	Low
25	2	1	86.420	Moderate
25	2	2	7.572	Low
25	3	1	122.758	Moderate
25	4	1	59.202	Moderate
26	1	1	19.114	Low
26	2	1	126.664	Moderate
26	3	1	54.206	Moderate
26	4	1	29.131	Low

APPENDIX D

Hazard indices and risk categories by biweek, time period, and altitude band at NAF El Centro’s East Mesa Range.

Hazard indices and risk categories by biweek, time period, and altitude band at NAF El Centro's East Mesa Range.

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
1	1	1	20.168	Low
1	2	1	0.571	Low
1	3	1	14.650	Low
1	4	1	16.132	Low
2	1	1	30.982	Low
2	2	1	0.095	Low
2	3	1	0.071	Low
2	4	1	46.331	Low
3	1	1	0.071	Low
3	2	1	0.285	Low
3	2	2	30.287	Low
3	3	1	0.107	Low
3	4	1	23.308	Low
4	1	1	0.392	Low
4	2	1	13.751	Low
4	3	1	0.000	Unknown
4	4	1	0.000	Unknown
5	1	1	23.807	Low
5	2	1	87.287	Moderate
5	3	1	17.672	Low
5	4	1	0.000	Unknown
6	1	1	0.000	Unknown
6	2	1	58.566	Moderate
6	3	1	0.142	Low
6	4	1	23.344	Low
7	1	1	52.466	Moderate
7	2	1	0.000	Unknown
7	3	1	75.839	Moderate
7	3	2	63.944	Moderate
7	4	1	23.415	Low
8	1	1	0.000	Unknown
8	2	1	0.000	Unknown
8	3	1	23.666	Low
8	3	2	7.572	Low
8	4	1	0.000	Unknown
9	1	1	51.632	Moderate
9	2	1	73.751	Moderate
9	3	1	0.000	Unknown
9	4	1	0.000	Unknown
10	1	1	95.793	Moderate
10	2	1	47.153	Low
10	3	2	0.000	Unknown
10	4	1	35.668	Low
10	4	2	0.465	Low

Hazard Indices at East Mesa Range continued

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
11	1	1	16.182	Low
11	2	1	0.929	Low
11	3	1	0.000	Unknown
11	4	1	25.093	Low
12	1	1	33.684	Low
12	2	1	1.071	Low
12	3	1	0.000	Unknown
12	4	1	48.545	Low
13	1	1	42.854	Low
13	2	1	64.980	Moderate
13	3	1	0.000	Unknown
13	4	1	1.499	Low
14	1	1	32.114	Low
14	2	1	1.000	Low
14	3	1	0.000	Unknown
14	4	1	1.285	Low
15	1	1	31.423	Low
15	2	1	23.576	Low
15	3	1	0.000	Unknown
15	4	1	3.035	Low
16	1	1	24.130	Low
16	2	1	23.666	Low
16	2	2	63.944	Moderate
16	3	1	0.000	Unknown
16	4	1	0.000	Unknown
17	1	1	14.196	Low
17	2	2	0.071	Low
17	2	2	127.888	Moderate
17	3	1	0.000	Unknown
17	4	1	46.867	Low
18	1	1	59.760	Moderate
18	2	1	64.480	Moderate
18	3	1	0.000	Unknown
18	4	1	8.841	Low
19	1	1	23.201	Low
19	2	1	64.015	Moderate
19	3	1	0.000	Unknown
19	4	1	23.272	Low
20	1	1	0.000	Unknown
20	2	1	0.000	Unknown
20	3	1	0.047	Low
20	4	1	0.000	Unknown
21	1	1	0.000	Unknown
21	2	1	24.502	Low
21	3	1	0.000	Unknown
21	4	1	82.533	Moderate

Hazard Indices at East Mesa Range continued

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
22	1	1	75.132	Moderate
22	2	1	0.000	Unknown
22	3	1	0.000	Unknown
22	4	1	35.701	Low
23	1	1	25.070	Low
23	2	1	16.903	Low
23	3	1	24.999	Low
23	4	1	0.000	Unknown
24	1	1	23.201	Low
24	2	1	24.999	Low
24	3	1	0.142	Low
24	4	1	0.000	Low
25	1	1	0.000	Low
25	2	1	11.654	Low
25	3	1	24.020	Low
25	4	1	24.055	Low
26	1	1	0.000	Unknown
26	2	1	0.000	Low
26	3	1	0.118	Low
26	4	1	0.000	Unknown

APPENDIX E

Hazard indices and risk categories by biweek, time period, and altitude band at NAF El Centro's West Mesa Range.

Hazard indices and risk categories by biweek, time period, and altitude band at NAF El Centro's West Mesa Range.

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
1	1	1	0.024	Low
1	2	1	0.043	Low
1	3	1	12.606	Low
1	4	1	32.229	Low
2	1	1	46.438	Low
2	2	1	0.071	Low
2	3	1	0.000	Unknown
2	4	1	46.331	Low
3	1	1	25.427	Low
3	2	1	0.357	Low
3	3	1	0.357	Low
3	3	1	0.285	Low
3	4	1	46.474	Low
4	1	1	0.000	Unknown
4	2	1	48.860	Low
4	3	1	0.036	Low
4	4	1	32.181	Low
5	1	1	36.183	Low
5	2	1	0.071	Low
5	3	1	0.000	Unknown
5	4	1	16.833	Low
6	1	1	0.000	Unknown
6	2	1	46.260	Low
6	3	1	0.000	Unknown
6	4	1	71.259	Moderate
7	1	1	76.541	Moderate
7	2	1	142.075	Moderate
7	3	1	24.928	Low
7	4	1	0.000	Unknown
8	1	1	0.000	Unknown
8	2	1	0.000	Unknown
8	3	1	0.000	Low
8	4	1	24.154	Low
9	1	1	71.545	Moderate
9	2	1	0.000	Unknown
9	3	1	30.864	Low
9	4	1	23.872	Low
10	1	1	71.473	Moderate
10	2	1	0.107	Low
10	3	1	0.000	Unknown
10	4	1	46.474	Low
11	1	1	81.890	Moderate
11	2	1	0.000	Unknown
11	3	1	0.000	Unknown
11	4	1	14.971	Low

Hazard Indices at West Mesa Range continued

Biweek	Time Period	Altitude band	Hazard Index	Risk Category
12	1	1	16.737	Low
12	2	1	71.188	Moderate
12	3	1	0.000	Unknown
12	4	1	0.000	Unknown
13	1	1	83.956	Moderate
13	2	1	0.000	Low
13	3	1	0.000	Unknown
13	4	1	0.095	Low
14	1	1	0.000	Low
14	2	1	0.000	Unknown
14	3	1	0.000	Unknown
14	4	1	24.860	Low
15	1	1	0.000	Unknown
15	2	1	0.024	Low
15	3	1	0.000	Unknown
15	4	1	0.036	Low
16	1	1	0.071	Low
16	2	1	0.000	Unknown
16	3	1	0.000	Unknown
16	4	1	0.000	Low
17	1	1	11.565	Low
17	2	1	0.000	Unknown
17	3	1	0.000	Unknown
17	4	1	0.000	Unknown
18	1	1	64.494	Moderate
18	2	1	7.607	Low
18	3	1	0.000	Unknown
18	4	1	0.000	Unknown
19	1	1	0.000	Unknown
19	2	1	0.000	Unknown
19	3	1	0.000	Unknown
19	4	1	6.357	Low
20	1	1	0.000	Unknown
20	2	1	0.000	Unknown
20	3	1	8.452	Low
20	4	1	0.000	Unknown
21	1	1	0.000	Unknown
21	2	1	118.056	Moderate
21	3	1	0.000	Unknown
21	4	1	12.464	Low
22	1	1	0.000	Unknown
22	2	1	0.000	Unknown
22	3	1	49.145	Low
22	4	1	48.362	Low

Hazard Indices at West Mesa Range continued

Biweek	Time Period	Altitude Band	Hazard Index	Risk Category
23	1	1	24.928	Low
23	2	1	25.356	Low
23	3	1	24.928	Low
23	4	1	46.617	Low
24	1	1	0.000	Low
24	2	1	0.000	Unknown
24	3	1	0.000	Unknown
24	4	1	0.000	Unknown
25	1	1	0.000	Unknown
25	2	1	15.444	Low
25	3	1	49.927	Low
25	4	1	25.782	Low
26	1	1	0.428	Low
26	2	1	0.000	Low
26	3	1	0.000	Low
26	4	1	0.000	Unknown

APPENDIX F

Species list, Mean Mass (Dunning 1993), and Size Class of birds identified at NAF El Centro, East Mesa Bombing Range, West Mesa Bombing Range, and Salton Sea National Wildlife Refuge, 10 Jan 2000 to 9 Jan 2001.

Species list, Mean Mass (Dunning 1993), and Size Class of birds identified at NAF El Centro, East Mesa Bombing Range, West Mesa Bombing Range, and Salton Sea National Wildlife Refuge, 10 Jan 2000 to 9 Jan 2001.

Common name	*Scientific Name*	Mass (g)	Size Class*
American white pelican	*Pelecanus erythrorhynchos*	7000.0	L
Canada goose	*Branta canadensis*	3814.0	L
Brown pelican	*Pelecanus occidentalis*	3702.0	L
Snow goose	*Chen caerulescens*	2744.0	L
Wood stork	*Mycteria americana*	2702.0	L
Great blue heron	*Ardea herodias*	2576.0	L
Double-crested cormorant	*Phalacrocorax auritus*	1808.0	L
Common merganser	*Mergus merganser*	1709.0	L
Ross's goose	*Chen rossii*	1679.0	L
Western grebe	*Aechmophorus occidentalis*	1477.0	L
Turkey vulture	*Cathartes aura*	1467.0	L
Yellow-footed gull	*Larus livens*	1322.0	L
Common raven	*Corvus corax*	1240.0	L
Herring gull	*Larus argentatus*	1226.0	L
Red-tailed hawk	*Buteo jamaicensis*	1224.0	L
Redhead	*Aythya americana*	1100.0	L
Mallard	*Anas platyrhynchos*	1082.0	L
Northern pintail	*Anas acuta*	1035.0	L
Western gull	*Larus occidentalis*	1011.0	L
Common goldeneye	*Bucephala clangula*	1000.0	L
Gadwall	*Anas strepera*	990.0	L
Greater scaup	*Aythya marila*	957.0	L
Great egret	*Casmerodius alba*	935.0	L
Black-crowned night-heron	*Nycticorax nycticorax*	883.0	L
Prairie falcon	*Falco mexicanus*	863.0	L
Lesser scaup	*Aythya affinis*	850.0	L
American wigeon	*Anas americana*	792.0	M
American coot	*Fulica americana*	724.0	M
White-faced ibis	*Plegadis chihi*	697.0	M
California gull	*Larus californicus*	657.0	M
Caspian tern	*Sterna caspia*	655.0	M
Long-billed curlew	*Numenius americanus*	642.0	M
Northern shoveler	*Anas clypeata*	636.0	M
Ruddy duck	*Oxyura jamaicensis*	590.0	M
Ring-billed gull	*Larus delawarensis*	566.0	M
Cooper's hawk	*Accipiter cooperii*	529.0	M
Northern harrier	*Circus cyaneus*	513.0	M
Marbled godwit	*Limosa fedoa*	421.0	M
Cinnamon teal	*Anas cyanoptera*	405.0	M
Greater roadrunner	*Geococcyx californianus*	376.0	M
Snowy egret	*Egretta thula*	371.0	M

* L ≥ 801 g, M = between 71-800 g, S ≤ 70 g.

Common name	Scientific Name	Mass (g)	Size Class*
Rock dove	*Columba livia*	369.0	M
Green-winged teal	*Anas crecca*	364.0	M
White-tailed kite	*Elanus caerules*	350.0	M
Black skimmer	*Rhynchops niger*	349.0	M
Common moorhen	*Gallinula chloropus*	340.0	M
Cattle egret	*Bubulcus ibis*	338.0	M
Clapper rail	*Rallus longirostris*	323.0	M
American avocet	*Recurvirostra americana*	316.0	M
Eared grebe	*Podiceps nigricollis*	292.0	M
Gull-billed tern	*Sterna nilotica*	233.0	M
Willet	*Catoptrophorus semipalmatus*	215.0	M
Bonaparte's gull	*Larus philadelphia*	212.0	M
Great-tailed grackle	*Quiscalus mexicanus*	191.0	M
Sharp-shinned hawk	*Accipiter striatus*	174.0	M
Black-necked stilt	*Himantopus mexicanus*	166.0	M
Burrowing owl	*Athene cunicularia*	159.0	M
Forster's tern	*Sterna forsteri*	158.0	M
White-winged dove	*Zenaida asiatica*	153.0	M
Pacific golden plover	*Pluvialis fulva*	153.0	M
Belted kingfisher	*Ceryle alcyon*	148.0	M
Gambel's quail	*Callipepla gambelii*	145.0	M
Mourning dove	*Zenaida macroura*	123.0	M
American kestrel	*Falco sparverius*	120.0	M
Western meadowlark	*Sturnella neglecta*	112.0	M
Long-billed dowitcher	*Limnodromus scolopaceus*	109.0	M
Killdeer	*Charadrius vociferus*	101.0	M
Pectoral sandpiper	*Calidris melanotos*	97.8	M
European starling	*Sturnus vulgaris*	84.7	M
Lesser yellowlegs	*Tringa flavipes*	81.0	M
Yellow-head. blackbird	*Xanthocephalus xanthocephalus*	79.7	M
Wilson's phalarope	*Phalaropus tricolor*	68.1	S
Black tern	*Chlidonias niger*	65.3	S
Red-winged blackbird	*Agelaius phoeniceus*	63.6	S
Le Conte's thrasher	*Toxostoma lecontei*	61.9	S
Lesser nighthawk	*Chordeiles acutipennis*	49.9	S
Brown-headed cowbird	*Molothrus ater*	49.0	S
Northern mockingbird	*Mimus polyglottos*	48.5	S
Buff-collared nightjar	*Caprimulgus ridgwayi*	48.0	S
Loggerhead shrike	*Lanius ludovicianus*	47.4	S
Albert's Towhee	*Pipilo alberti*	47.1	S

* L ≥ 801 g, M = between 71-800 g, S ≤ 70 g.

Common Name	Scientific Name	Mass (g)	Size Class*
Sage thrasher	*Oreoscoptes montanus*	45.5	S
Western kingbird	*Tyrannus verticalis*	39.6	S
Cactus wren	*Campylorhynchus brunneicapillus*	38.9	S
Red-necked phalarope	*Phalaropus lobatus*	34.9	S
White-throated swift	*Aeronautes saxatalis*	32.1	S
Horned lark	*Eremophila alpestris*	31.9	S
Common ground-dove	*Columbina passerina*	30.1	S
Mountain bluebird	*Sialia currucoides*	29.6	S
White-crowned sparrow	*Zonotrichia leucophrys*	29.4	S
Western tanager	*Piranga ludoviciana*	28.1	S
Ash-throated flycatcher	*Myiarchus cinerascens*	27.2	S
Savannah sparrow	*Passerculus sandwichensis*	26.0	S
Western sandpiper	*Calidris mauri*	23.3	S
Least sandpiper	*Calidris minutilla*	23.2	S
American pipit	*Anthus rubescens*	21.6	S
Cliff swallow	*Hirundo pyrrhonota*	21.6	S
House finch	*Carpodacus mexicanus*	21.4	S
Say's phoebe	*Sayornis saya*	21.2	S
Song sparrow	*Melospiza melodia*	21.0	S
Tree swallow	*Tachycineta bicolor*	20.1	S
Black phoebe	*Sayornis nigricans*	19.5	S
Sage sparrow	*Amphispiza belli*	19.3	S
Barn swallow	*Hirundo rustica*	18.2	S
Vaux's swift	*Chaetura vauxi*	17.1	S
Rock wren	*Salpinctes obsoletus*	16.5	S
Lazuli bunting	*Passerina amoena*	16.0	S
N. Rough-winged swallow	*Stelgidopteryx serripennis*	15.9	S
Bank swallow	*Riparia riparia*	14.6	S
Violet-green swallow	*Tachycineta thalassina*	14.4	S
Willow flycatcher	*Empidonax traillii*	13.7	S
Black-throated sparrow	*Amphispiza bilineata*	13.5	S
Yellow-rumped warbler	*Dendroica coronata*	12.3	S
Chipping sparrow	*Spizella passerina*	12.3	S
Marsh wren	*Cistothorus palustris*	11.9	S
Cordilleran flycatcher	*Empidonax occidentalis*	11.4	S
Common yellowthroat	*Geothlypis trichas*	10.3	S
Bewick's wren	*Thryomanes bewickii*	9.9	S
Yellow warbler	*Dendroica petechia*	9.8	S
Townsend's warbler	*Dendroica townsendi*	9.1	S
Orange-crowned warbler	*Vermivora celata*	9.0	S
Nashville warbler	*Vermivora ruficapilla*	8.9	S

* L ≥ 801 g, M = between 71-800 g, S ≤ 70 g.

Common Name	*Scientific Name*	Mass (g)	Size Class*
Wilson's warbler	*Wilsonia pusilla*	7.7	S
Verdin	*Auriparus flaviceps*	6.8	S
Black-tailed gnatcatcher	*Polioptila melanura*	5.1	S
Anna's hummingbird	*Calypte anna*	4.4	S
Black-chinned hummingbird	*Archilochus alexandri*	3.6	S
Rufous hummingbird	*Selasphorus rufus*	3.5	S
Costa's hummingbird	*Calypte costae*	3.2	S

* L ≥ 801 g, M = between 71-800 g, S ≤ 70 g.