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

Edward J. Zakrajsek
Utah State University

DEVELOPMENT OF A BIRD-AVOIDANCE MODEL FOR NAVAL AIR FACILITY EL CENTRO, CALIFORNIA

by

Edward J. Zakrajsek

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Wildlife Biology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

2001

ABSTRACT

Development of a Bird-Avoidance Model for

Naval Air Facility El Centro, California

by

Edward J. Zakrajsek, Master of Science

Utah State University, 2001

Major Professor: John A. Bissonette
Department: Fisheries and Wildlife

Bird strikes (collisions between birds and aircraft) pose a significant threat to aviation safety. For example, Naval Air Facility El Centro, California, lost an F-18 jet to a bird strike in October 1995. To help combat the bird-strike threat at Naval Air Facility El Centro, I developed a bird-avoidance model as a risk-management tool for the installation. It can be used to schedule flights at NAF El Centro and its two associated practice-bombing ranges during times of low-bird activity. I calculated bird-strike risks and published them in web-page format on both the installation's server and the USGS/Utah State University, College of Natural Resources' 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 through the year 2000. These were combined with a bird-hazard index for various species, developed using U.S. Air Force bird-strike records. Nocturnal bird hazards were quantified in the fall of 2000 using a bird-radar system to count birds in three relative size classes. Large- and medium-sized birds were scaled to represent a higher risk to aircraft than small birds. Nocturnal bird hazards beyond the fall study were estimated using U.S. Air Force bird-strike records.

The main section of the web page allows the user to select the area and time of year, which links to the appropriate color-coded bird-strike-risk graph. The graphs describe the bird-strike risk by time of day and altitude with red for high risk, yellow for moderate risk, and green for low risk. The web page also identifies and describes the most hazardous bird species in the area, recommends methods of hazard management, and provides links to bird-strike-information sources on the web.

(104 pages)

ACKNOWLEDGMENTS

My research was funded by the U.S. Navy, Naval Facilities Engineering Command, Southwest Division, Natural and Cultural Resources Team; special thanks to Tricia Cutler and Bill Fischer of that office. I appreciate the cooperation of several NAF El Centro personnel, including Jim Collins, Carl David, David Golding, Senior Chief Patrick Friel, and Lt. Holly Hutchinson. I am grateful for the support of the USGS, Cooperative Fish & Wildlife Research Unit and the Berryman Institute for Wildlife Damage Management. I offer special thanks to John Bissonette, my major professor, and to Mike Conover and Paul Box for supporting me on my advisory committee and sharing their expertise with me.

I appreciate my dedicated field assistant, Patrick Lieske. I am indebted to Eugene LeBoeuf, Lt. Col. Pete Windler, and Lt. Curt Burney of the U.S. Air Force BASH Team for sharing their data and expertise. I appreciate the support of all of my friends at Geo-Marine, Inc., especially Adam Kelly, Andreas Smith, and Ron Merritt. Special thanks to my officemates Bill Adair and Curtis Bjurlin who had much to teach me these past few years. Most of all, I would like to thank my wife, Kirstie, without whose support and encouragement I could never have achieved this goal.

Edward J. Zakrajsek

FOREWORD

This thesis is in a multiple-paper format. Chapter 1 is an introduction and literature review in *Journal of Wildlife Management* style and format. Chapters 2-4 are the main research chapters. Chapter 2 describes a ranking of the most hazardous wildlife species to military aircraft. It uses *Wildlife Society Bulletin* style and format. The results from Chapter 2 are used in Chapter 3 to assess the bird-strike hazards at Naval Air Facility El Centro during daylight hours. Chapter 3 uses *Journal of Wildlife Management* style and format. Chapter 4 assesses the nocturnal bird hazards at the installation. It uses the *Journal of Field Ornithology* style and format. Last, Chapter 5 is a conclusion chapter. It is intended as an article in *Approach,* the Naval Safety Center's flight safety magazine. An overview of the study in this publication will provide awareness of the research to Navy pilots, the end users.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

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 1950s (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, air passenger enplanements increased 110%, over 4% per year, 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.

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 species known to be hazardous to aircraft (Dolbeer 2000). Resident Canada goose (*Branta canadensis*) populations have increased at an annual rate of 13% from 1966 to 1998 (Cleary et al. 2000, Dolbeer 2000). During the same period, ring-billed gull (*Larus delawarensis*) populations increased 6% per year (Cleary et al. 2000, Dolbeer 2000). Turkey vulture (*Cathartes aura*) and red-tailed hawk (*Buteo jamaicensis*) populations increased 1% and 3% 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 1973). Seventy-five to ninety percent of the birdstrikes to civil aircraft occur near airports, primarily during takeoff and landing (Blokpoel 1976). 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 1999). During low-level flight maneuvers, military aircraft usually operate at altitudes from 50 to 300 m above ground, and at 450 to 1,100 km/h (DeFusco 1993). Low-level flight increases the probability of a strike because most birds are found at lower altitudes. Also, if a serious bird strike occurs at low altitude, the pilot has much less time or space 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 bird strikes go unreported to USAF and FAA databases (Dolbeer et al. 1995; Cleary et al. 1996, 1997, 1998; Linnel et al. 1999; Barras and Dolbeer 2000). The Navy reporting rate, though unknown, is likely less than the USAF and the FAA reporting rates because of less support for bird-strike management within the service. Despite their 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. The replacement cost of $30 million suggests the need to establish a prevention protocol. The aircrew of the F-18 safely ejected, although this is not always possible when serious damage occurs 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, Alaska. This modified Boeing 707 reportedly struck over 30 Canada geese on take-off, lost power in 2 of its 4 engines, and crashed, destroying the $300 million aircraft and killing all 24 crew members on board (Robbe 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 data show that, on average, bird strikes destroy 1 USAF aircraft every year, cause at least 1 human fatality every other year, and cause at least $38-million damage per year. Clearly, efforts to manage the bird-strike hazard are warranted.

BIRD-AIRCRAFT STRIKE HAZARD MANAGEMENT

Comprehensive Bird-Aircraft Strike Hazard (BASH) Management incorporates several components to reduce the risk of bird strikes. These include: 1) collecting and analyzing bird-strike data, 2) designing bird-resistant aircraft components, 3) managing birds at airfields, 4) reducing bird attractants near airfields, and 5) developing and using Bird-Avoidance Models. Minimization of risk (lowering the bird-strike rate) is dependent on the successful integration of all these components.

Bird Strike Database Management

In the United States, the Navy, USAF, and Federal Aviation Administration (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 1981-1997 (Lovell 1997). The USAF BASH Team is one of the world leaders in the prevention of bird strikes. 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 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).

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 may be considered stationary objects (Solman 1981). At 925 km/hour, a typical fighter aircraft airspeed, a bird must be sensed more than 1.6 km away in order for a pilot to avoid collision with it (DeFusco and Turner 1998). Most birds are not seen by pilots before they are struck.

Though aircraft engines and other components are designed and constructed with lightweight materials, they are engineered to withstand much of the high-impact force resulting from a bird strike. For example, fighter-aircraft windscreens are designed to withstand a strike with a 1.8-kg bird at 740 km/hour. This equates to over 8 tons of force on a 300-sq cm area. Improvements in the bird resistance of aircraft windscreens will likely improve in the future. Still, large birds have penetrated aircraft windscreens resulting in destroyed aircraft and human fatalities. 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 designed to be as bird resistant as possible, jet engines contain relatively delicate components that are completely exposed to damage through large frontal-air intakes. The main components of a jet engine are a series of several high-speed compressor fans, a combustion chamber, and an exhaust nozzle. The problem of a bird strike is exacerbated when the bird breaks one or more pieces of a 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). 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, a 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 aircraft speed doubles, the impact force quadruples (Solman 1973). Currently no jet engine can ingest a large bird (e.g., Canada goose, tundra swan [*Cygnus columbianus*], 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 takeoff and landing operations (Blokpoel 1976). Near airfields, aircraft are flying at low altitudes, where most birds are found (Tedrow 1998). The high bird-strike rate at airfields also is related to the attractiveness of airfields to birds (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 rural areas and away from urbanized areas. As a result, agricultural fields, wetlands, water bodies, or landfills often surround airfields. These land uses may 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 fields can attract large numbers of birds. For this reason, it is unwise to locate landfills near airfields. Existing landfills can, however, be managed to reduce their attractiveness to birds. Those that do not accept putrescible waste attract fewer birds. Those that do can maintain a clean operation and insure that waste is kept covered as much as possible.

Landfills that do attract large numbers of birds can use active control measures as described above. Agricultural fields adjacent to airfields often attract birds seasonally (Morrison et al. 1992). Crops may be grown that are less attractive to birds, or active bird dispersal may be warranted. In all cases, 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 variation in the timing of favorable weather for migration, the 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 (Defusco 1993, Lovell 1997, Defusco and Turner 1998, Burney 1999). BAMs are generally disseminated as a computer program 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 to birds 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 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 (Defusco 1993, Defusco and Turner 1998, Lovell 1997, 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 (Defusco 1993). From these data, predictions are generated regarding the presence of birds across the U.S. and throughout the year (Defusco 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 1999, 2000; Kelly et al. 2000). Migration is monitored with the National Weather Service's NexRad Weather Radar System (Kelly 1999, 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 of 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 main frame 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 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 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 hr, 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 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, North Carolina, and Moody Air Force Base, Georgia) 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 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 revealed the need for models that are easy to use, and that operate on existing computer equipment. They were both designed as multimedia programs similar to current web pages. They were from a CD-ROM or a local hard drive. They were based on historical data and needed to be updated at some future time to account for changes in bird patterns due to population changes or changes in local land-use patterns. Both models were relatively expensive and were funded at the national level.

BASH MANAGEMENT AT NAF EL CENTRO

A draft BASH Management Plan for NAF El Centro and the East and West Mesa Bombing Ranges was completed in May 2000 (Costi et al. 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.

The draft BASH Management Plan states that almost no actual BASH management occurs on the base (Costi et al. 2000). An interview with operations personnel on the base confirmed that statement (Petty Officer McCoy, 5 Aug 1999, and Senior Chief Petty Officer Friel, 9 Aug 1999, personal communication). The BASH Management Plan (Costi et al. 2000), an ornithological survey (Aigner and Koehler 1996), and a study of the relationship between birds and agricultural fields (Morrison et al. 1992) are examples of bird-hazard work at NAF El Centro. Except for the initiation of this project, however, NAF El Centro is not actively engaged in managing bird-strike hazards on the base.

OBJECTIVE

The objective of this study was to develop a bird-avoidance model for NAF El Centro. The model was designed 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. The

BAM was designed as a pragmatic, management-oriented model intended as a problem-solving tool (Starfield and Bleloch 1991, Starfield 1997). The intent of the BAM is to help Navy personnel visualize bird-strike risk and make decisions regarding flight scheduling.

Curtailing flying operations during periods of high bird activity can lower the bird-strike probability and corresponding damage by lowering the level of exposure to birds aloft. This is the basic premise of a BAM. On the other hand, during periods of low bird-hazard, aircraft can operate with greatly diminished risk of bird-strike damage. Flights can be concentrated at these times.

The BAM is comprised of two submodels: one for diurnal bird-strike risk and one for nocturnal bird-strike risk. 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, involved in over 5,000 strikes, were ranked by 3 damage levels. A composite-hazard index was computed from these rankings. These species-hazard indices were used to scale the hazard of the bird species recorded in the visual surveys.

A specialized bird-radar system was used to quantify nocturnal-bird migration in the area, during 20 October to 29 November 2000. The bird-radar system recorded the relative size of birds but could not differentiate between species. The number of birds in the radar sample, weighted for size, was used as an index of the hazard to aircraft. Both the radar and visual-count analyses were summarized into 26 biweekly periods throughout the year and 4 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.

It should be noted that this study relies on historical data to estimate future risk. Bird movements, though changing year to year, change slowly enough to allow predictions to be made for several years into the future. Eventually the model's effectiveness will need to be evaluated and updated if necessary.

The results of these two models were compiled and published as a web page to be maintained on NAF El Centro's web server and on the USGS, Utah Cooperative Fish and Wildlife Research Unit 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. The most common hazardous species were described as well as management options and recommendations. 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.

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 El 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.

Costi, V., E. Kellogg, J. Giessow, and J. Giessow. 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.

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, United Kingdom.

_____. 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.

_____, 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.

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. 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.

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.

CHAPTER 2

RANKING THE HAZARDOUS WILDLIFE SPECIES TO MILITARY AIRCRAFT

Introduction

Collisions between aircraft and birds (bird strikes) have been a problem since the beginning of powered flight (Blokpoel 1976, Solman 1978, Steenblik 1997). United States Air Force Instruction (AFI) 91-202 (mishap prevention program) and AFI 91-204 (safety investigations and reports) require flight and maintenance crews to report wildlife strikes to the United States Air Force (USAF) Bird Aircraft Strike Hazard (BASH) Team at the Air Force Safety Center, Kirtland Air Force Base, New Mexico. The BASH Team maintains these bird-strike records in their Bird Strike Database. For the period 1985 to 1998, bird strikes cost the USAF an average of $35 million/year in damage to or loss of aircraft. During this period, 22 Class-A bird strikes (mean = 1.6 Class-A strikes/year) were sustained accounting for 80% of total monetary losses caused by birds. Damage of this kind provides a serious incentive to develop methodologies to reduce the number and severity of bird strikes.

Bird strikes are categorized by the USAF according to three classes of damage: Class A, B, and C. Class-A strikes are those that result in > $1 million damage, the loss of an aircraft, the loss of human life, or permanent total disability of personnel (Table 2.1). Class-B damage is between $200,000 and $1 million, permanent partial disability, or inpatient hospitalization of three or more personnel. Class-C damage is between $10,000 and $200,000 or an injury resulting in a lost workday. Damage < $10,000 is considered non-damaging.

One method of reducing the number and severity of bird strikes is the development and use of bird-avoidance models (BAM). A BAM is a quantitative or qualitative assessment of the distribution of risk of a damaging-bird strike over time and space. Recent examples of BAMs include the USAF's US BAM, Avian Hazard Advisory System, Dare County Range BAM, and Moody Air Force Base BAM. These are all computer-based models that describe the bird-strike risk over time and space to those in charge of aircraft operations (pilots, schedulers, air traffic controllers, etc.). They all rely on some description of the expected distribution of birds in the area and an assessment of the hazard imposed by these birds.

To assess the hazard imposed by birds to civil aircraft, Dolbeer et al. (2000) ranked the hazardous species or species groups using the Federal Aviation Administration's (FAA) Wildlife Strike Database. A similar analysis would be useful in the development of a military BAM. Military aircraft, however, are flown quite differently than civil aircraft. Civil aircraft strike most birds near airports: on takeoff, climb, decent, and landing (Cleary et al. 2000). Military aircraft strike birds near airfields but additionally strike many birds during low-level training and at bombing ranges (Tedrow 1998). My objective was to rank the avian-species groups hazardous to military aircraft using records in the USAF Bird Strike Database.

Methods

I selected those species or species groups (Appendix A) that caused damage to USAF aircraft in the U.S. For each species group, I summarized the mean number of damaging strikes (Class-A, -B, or -C damage) per year. The species groups were ranked in ascending order most to least hazardous based on the calculated hazard indices.

Damage to USAF aircraft is classified by factors such as cost (Table 2.1). Class-C strikes are most numerous but cause the least amount of damage. They are not adjusted in 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.

I 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 (Fig. 2.1), I used their medians as measures of central tendency. The weights 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. I then developed the following algorithm to calculate a 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 the weighting constants, described above, to adjust for the increased severity of Class-A and Class-B strikes, respectively.

Results

The 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 (Appendix A), 46 of which caused Class A, B, or C damage to USAF aircraft. Only 10 of the 53-species groups had sample sizes $\geq$10 (Table 2.2).

The weighting constants used in the hazard index algorithm were 12 for Class-B strikes and 320 for Class-A strikes. An average Class-B bird strike caused 12 times more damage per strike than an average Class-C bird strike. Likewise, an average Class-A bird strike caused 320 times as much damage as a Class-C strike. These weights were used in the bird hazard algorithm.

Vultures (*Cathartes aura, Coragyps atratus, Polyborus plancus*) were ranked by far the most hazardous species group to USAF aircraft (Table 2.3). They were followed by geese (mostly *Branta canadensis* and *Chen caerulescens*), and pelicans (*Pelecanus erythrorhynchos* and *Pelicanus occidentalis*), which were only 60% and 36% as hazardous as vultures, respectively. The 7 species groups (coyote, small mammal, woodcock, sky lark, dove, woodpecker, and flycatcher [see Appendix A for species contained in each group]) that 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 to 23rd in Table 2.3). These were all bird species groups that caused low numbers of Class-C strikes and no Class-A or -B strikes.

Discussion

Military personnel in charge of flight operations, safety, and natural-resource management are in need of decision-making tools to assist them in managing the bird-strike hazard at their installations. This analysis will assist in the development of bird-avoidance models at military air bases based on visual bird counts. It will also be useful when making habitat-management decisions that may attract different avian species and for issuing warnings to pilots concerning hazardous bird activity near airfields.

These rankings, based on empirical data, account for the many factors that cause birds to be hazardous to aircraft. Only species that were struck and inflicted damage to aircraft in the past were ranked. It has been noted that bird size is a major component of damaging bird strikes (Blokpoel 1976, Tedrow 1998, Dolbeer et al. 2000). This is part of the reason why vultures are highly ranked. The flocking behavior of blackbirds and starlings contributes to their hazardous ranking. The size and flocking behavior of pelicans makes them highly ranked. Horned larks (*Eremophila alpestris*) were highly ranked because of their preference for habitats associated with airfields. This analysis does not parse out the different variables involved, but incorporates them empirically.

Military aircraft sustain different levels of wildlife damage than civil aircraft. An objective comparison of my rankings with Dolbeer et al.'s rankings revealed that several species are hazardous to both military and civil aircraft. Several other species apear to be much more hazardous to one or the other types or aircraft. Vultures, geese, ducks, and pelicans were ranked high on both lists. Horned larks, thrushes, and meadowlarks (see Appendix A for species contained in each species group) were ranked high on the military list but were not ranked at all on the civil list. Dolbeer et al. (2000) found deer (especially white-tailed deer [*Odocoileus virginianus*]) to be by far the most hazardous species to civil aircraft. Few wildlife strikes with deer were recorded in the USAF data. Either they do not sustain the same level of damage from deer or deer strikes are not being entered in the database. Dolbeer et al. (2000) found 367 deer strikes reported in the FAA database, 87% of which caused some degree of damage. The USAF database contained only 13 records of deer. Of those, only 5 resulted in Class-C damage and none resulted in Class-A or -B damage. As well, coyotes did not damage any USAF aircraft but were ranked 15th on the civil list. Further study of the differences between civil and military bird-strike risks would be enlightening.

Lastly, for this type of analysis it is imperative to improve reporting of wildlife strikes in all flying communities. Improved reporting by the USAF, other military services, civilian pilots, as well as access to reports from other nations would be beneficial. It has been estimated that reporting rates for bird strikes to civil aircraft is only 20 or 25% (Cleary et al. 1996, 1997, 1998, Linnel et al. 1999). Analysis of the USAF's bird-strike reporting rate and nonreporting biases in their data should be addressed in future studies. An increase in data quality would entail an increase in reporting rate as well as improved identification of species involved in wildlife strikes.

Literature Cited

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

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.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer. 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.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer. 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.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer. 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.

Dolbeer, R.A., S. E. Wright, and E. C. Cleary. 2000. Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin 28:372-378.

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

Solman, V. E. F. 1978. Gulls and aircraft. Environmental Conservation 5:277-280.

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. Master's Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

Table 2.1. U.S. Air Force aviation-damage categories.

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

Table 2.2. 10 species groups in the U.S. Air Force bird-strike database (1985-1998) with sample sizes $\geq$ 10.

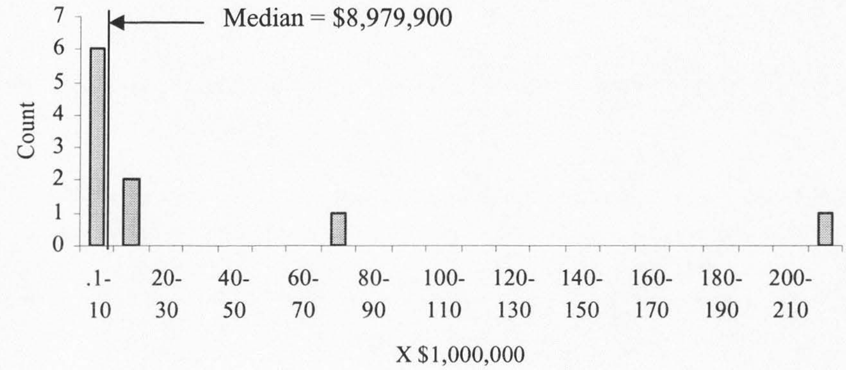
Sample Size	Species Group
119	Vulture
70	Buteo
41	Duck
34	Goose
27	Gull
19	Horned Lark
13	Mourning Dove
11	Thrush
11	Swallow
10	Meadowlark

Table 2.3. Hazard index and ranking of hazardous species groups* to USAF aircraft in the US, 1985-1998.

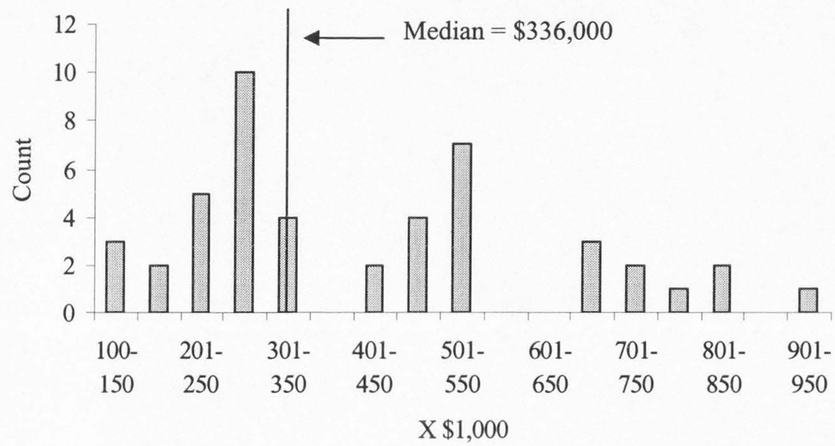
Species Group	C/Yx1	B/Y	B/Yx12	A/Y	A/Yx320	Hazard Index	Rank
Vulture	7.714	0.429	5.148	0.357	114.240	127.888	1
Goose	1.786	0.429	5.148	0.214	68.480	76.057	2
Pelican		0.071	0.852	0.143	45.760	46.826	3
Blackbird/Starling	0.357			0.143	45.760	46.260	4
Buteo	4.714	0.214	2.568	0.071	22.720	30.287	5
Horned 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.

a) USAF Class A bird-strike costs.



b) USAF Class B bird-strike costs.



c) USAF Class C bird-strike costs.

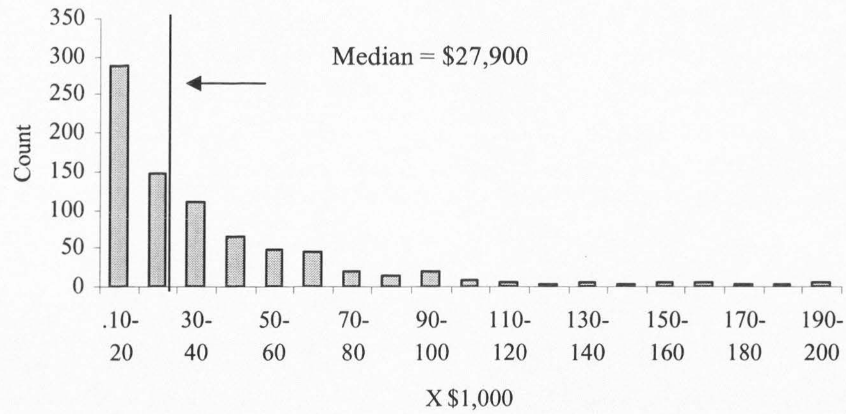


Figure 2.1. Distribution of a) Class A, b) Class B, and c) Class C bird-strike costs, with median indicated, from the U.S. Air Force bird-strike database, 1985-1998.

CHAPTER 3

DIURNAL BIRD HAZARDS AT NAVAL AIR FACILITY EL CENTRO

INTRODUCTION

Collisions between aircraft and birds (bird strikes) have been a problem since the beginning of powered flight (Blokpoel 1976, Solman 1978, Steenblik 1997). Civil and military bird-strike damage to aircraft in North America likely exceeds $500 million/year (MacKinnon 1998) and threatens human health and safety (Blokpoel 1976, Conover et al. 1995, Cleary et al. 2000). One method of reducing the number and severity of bird strikes is the development and use of bird-avoidance models (BAM). A BAM is a quantitative or qualitative assessment of the distribution of risk of a damaging-bird strike over time and space. Recent examples of BAMs include the U.S. Air Force's (USAF) US BAM, Avian Hazard Advisory System, Dare County Bombing Range BAM, and Moody Air Force Base BAM. These are all computer-based models that describe the bird-strike risk over time and space to those in charge of aircraft operations (pilots, schedulers, air traffic controllers, etc.). They rely on some description of the expected distribution of birds in the area and an assessment of the hazard imposed by these birds.

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 attitudes used by birds in the area is necessary. These data are 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, I conducted a year-long visual count of the birds in the area. In chapter 2, I evaluated the hazard level of different species to military aircraft.

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([NWR] [Fig. 3.1]).

The base encompasses 927 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 m below sea level and is surrounded by irrigated agricultural land.

NAF El Centro operates 2 bombing ranges (Fig. 3.1). These are both predominantly in a creosote (*Larrea tridentata*) scrub plant community (Costi et al. 2000). East Mesa Range is located approximately 50-km northeast of NAF El Centro. It contains 2 target areas, Target 68 to the south and Target 95 to the north. West Mesa Range is located approximately 15-km west of NAF El Centro. It also contains 2 target areas, Target 103 to the south and Target 101 to the north. Target 101 is the only target with personnel regularly on site. A range-management contractor occupies a building and control tower, and scores pilot's accuracy at Target 101. Target 95 is scored by a remote camera system, operated by the contractor at Target 101. The other 2 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.

METHODS

Required for this study is the number of records of species groups across time periods, altitude bands, and sites. This data was collected by simple point counts without distance estimation (Verner 1985). I established 7 fixed, 300-m., circular-plots for conducting modified-point counts (Reynolds and Nussbaum 1980, Verner 1985, Ralph et al. 1993). Two points were located at the airfield (Fig. 3.1); 1 at the east end of the main runway (Latitude 32° 49' 55", Longitude 115° 39' 20") and 1 at the west end (32° 49' 53", Longitude 115° 41' 31"). Two points were located at the East Mesa Range; 1 near Target 68 (Latitude 32° 57' 08", Longitude 115° 13' 50") and 1 near Target 95 (Latitude 32° 59' 40", Longitude 115° 14' 30"). Two points were located at the West Mesa Range; 1 near Loom Lobby Target (Latitude 32° 51' 28", Longitude 115° 52' 07") and 1 near Shade Tree Target (Latitude 32° 57' 03", Longitude 115° 45' 09"). The last point was located at the Salton Sea NWR (Latitude 33° 10' 41", Longitude 115° 37' 21"). This was considered as a worst case scenario for bird hazards to aircraft.

Birds were visually counted at all points for an entire year (10 January 2000 to 9 January 2001) during daylight hours (half-hour before sunrise to half-hour after sunset).

Counts were 1 hour long to sample the birds present and moving through the area over time. I recorded date, time, species, number, and altitude of birds (individuals or in flocks). Species were categorized into the same logical species groups used in chapter 2 for ease of analysis (Appendix B). Grouping species decreased the number of avian categories and allowed the use of partly identified species (e.g., unknown gull species). Species groups were based on taxonomy, behavior, size, and bird-strike history. I assumed that species groups were equally detectable. This is a reasonable assumption in the open habitats surveyed (Verner 1985). I summarized the data in 26 biweekly periods throughout the year (Appendix C).

I developed a relative species-hazard index (SHI) in chapter 2 using 5,204 records of species identified as causing USAF bird-strikes from 1985-1998 (Table 3.1). I assessed the hazard level of each species group by the number of bird strikes it caused in 3 damage categories (see Table 2.1). This assessment accounted for both the number and severity of strikes caused by each species group.

I multiplied the number of records of each species group per biweek, time period, and altitude band by its SHI 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. I plotted the resulting bird-hazard indices on a histogram and categorized them as high, moderate, or low bird-strike hazard.

RESULTS

From 10 January 2000 to 9 January 2001, 637 1-hour surveys were conducted

(Appendix C). No birds were counted during 5 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 in the 40°- 50° C temperatures.

I recorded 90,948 individual birds in 5,260 records and 145 species in 36 species groups across all sites (Table 3.2). 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, I recorded 59,639 birds, 2,838 records, and 91 species in 33 species groups (Table 3.3). The average flock size at the airfield was 21.0 birds/flock. At the East Mesa Range I tallied 1,909 birds, 594 records, and 43 species in 19 species groups. The East Mesa Range averaged only 3.2 birds/flock. At the West Mesa Range I 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 NWR I tallied 44,137 birds, 1,573 records, and 115 species 32 species groups. The Salton Sea NWR 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 3 records (Canada geese [*Branta canadensis*], white-faced ibis [*Plegadis chihi*], and an unknown gull species [*Larus* spp.]) 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 ([see Appendix B] [n = 266]) and meadowlarks (n = 260) were the most common species groups recorded at the airfield (Table 3.4). Warblers (n = 220) were by far the most commonly observed species group at the East Mesa Range.

Horned larks ([*Eremophila alpestris*] [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 NWR.

All calculated bird-hazard indices (across all sites, biweeks, daily time periods, and altitude bands) were between 0-500 ([no units] [Fig. 3.2]). Because most hazard indices at the Salton Sea NWR were > 150, this was considered the threshold for high bird-strike hazard (Figs. 3.3 & 3.4). The data do not indicate a threshold to distinguish between low and moderate bird-strike hazard. To be conservative, I chose one third 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 Tables 3.5-3.7.

DISCUSSION

The risk categories (low, moderate, and high) are relative indices having no units. For this study, they ranged from 0-500. Along this scale, thresholds (50 and 150) were selected to define the three risk categories. The bird-hazard indices at the Salton Sea NWR, having high bird activity much of the time, were used to define the high-risk category. Although the high-risk category had the widest range (150-500), few high-risk indices were calculated (Fig. 3.2a). The East and West Mesa Bombing Ranges, both located in desert areas, support fewer birds, were most often in the low-risk category, and computed no high-risk indices (Fig. 3.4).

The Salton Sea NWR, as expected, recorded the greatest variety of avian species. A large number of these were of the species groups most hazardous to aircraft (ducks, geese, pelicans, gulls). The Navy does not fly low over the Salton Sea NWR. Rather, the surveys here were conducted to represent a high bird-hazard location. The airfield had a large number of species recorded but only a few were of the species groups most hazardous to aircraft. The bombing ranges in the desert had roughly 0.3-0.5 of the number of species recorded at the airfield. This concurs with the previous avian survey at NAFEC (Aigner and Koehler 1996).

Species groups of most concern at the airfield include meadowlarks, blackbirds/starlings, mourning doves, kestrels, cattle egrets, shorebirds, owls, horned larks, ibis, gulls, and vultures. Several of these groups (meadowlarks, mourning doves, kestrels, owls, and horned larks) are attracted to the airfield itself. Vultures are attracted to carrion along local roadways, in agricultural fields, and on the airfield. The rest (cattle egrets [*Bubulcus ibis*], blackbirds/starlings, shorebirds, ibis, and gulls) are attracted to the agricultural fields adjacent to the airfield. All of these species can be managed to reduce their occurrence at or near the airfield (Blokpoel 1976, Jarmen 1993). Swallows and nighthawks were fairly common at the airfield. They are more likely to be involved in airfield bird strikes and more difficult to manage because of their behavior of flying in dispersed flocks and preying upon aerial insects.

The West Mesa Range had few hazardous species groups recorded. No birds were recorded above 150 m. Birds that were observed would likely occur lower than the aircraft operating at the range. A single red-tailed hawk (*Buteo jamaicensis*) was observed at the West Mesa Range during the year. Swallows and nighthawks were present and could be struck during low-altitude deliveries.

Six buteos and 10 vultures were recorded at the East Mesa Range. Except for the swallows and nighthawks discussed above, the East Mesa Range does not have a bird-hazard problem during the daylight hours.

Though altitude has been visually estimated in past studies (Machalek 1990, Morrison et al. 1992), I feel that it is a very tenuous technique at best. If any degree of accuracy is needed, radar should be used (Harmata et al. 1999). The few visual records above 150 m were all of large, flocking and vociferous species (gulls, ibis, geese). A single, silent vulture will likely be missed above 150 m.

This analysis represents a first attempt at understanding the bird hazards at NAF El Centro and its two associated bombing ranges. Continued avian monitoring along with diligent bird-strike reporting is necessary to judge the effectiveness of and improve the predictions of this model.

LITERATURE CITED

Aigner, P. A., and C. E. Koehler. 1996. Final report: ornithological survey, natural resource management plan, Naval Air Facility, El Centro. El Centro, California, USA.

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

Cleary, E. C., S. E. Wright, and R. A. Dolbeer . 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.

Conover, M. R., W. C. Pitt, K. K. Kessler, T, J, Dubow, and W. A. Sanborn. 1995. Review of data on human injuries, illnesses, and economic losses caused by wildlife in the U.S. Wildlife Society Bulletin 23:407-414.

Costi, V., E. Kellogg, J. Giessow, and J. Giessow. 2000. Draft 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.

Harmata, A. R., K. M. Podruzny, J. R. Zelenak, and M. L. Morrison. 1999. Using marine surveillance radar to study bird movements and impact assessment. Wildlife Society Bulletin 27:44-52.

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

Machalek, M. J. 1990. A bird aircraft strike hazard expert system (B.A.S.H.E.S.). Thesis, Utah State University, Logan, Utah, USA.

MacKinnon, B. 1998. A reminder about bird strikes. Aviation Safety Letter 2:10-11.

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, Southwest Division, San Diego, California, USA.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Handbook of field methods for monitoring landbirds. United States Forest Service: Pacific Southwest Research Station, Albany, California, USA.

Reynolds, R. T., and R. A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. Condor 82:309-313.

Solman, V. E. F. 1978. Gulls and aircraft. Environmental Conservation 5:277-280.

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

Verner, J. 1985. Assessment of counting techniques. Pages 247-302 *in* R. F. Johnston, editor. Current ornithology. Volume 2. Plenum Press, New York, New York, USA.

Table 3.1. Hazard indices for hazardous species groups* based on USAF bird strikes in the U.S., 1985-1998.

Species group	Hazard index	Species group	Hazard index
Vulture	127.888	Ibis	0.214
Goose	76.057	Kestrel	0.214
Pelican	46.826	Grackle	0.143
Blackbird/Starling	46.260	Bat	0.143
Buteo	30.287	Kite	0.143
Horned Lark	24.928	Thrasher	0.143
Swallow	23.434	Grebe	0.143
Gull	7.077	Small Shorebird	0.143
Duck	5.496	Large Shorebird	0.143
Crane	2.145	Other	0.071
Thrush	1.637	Roadrunner	0.071
Meadowlark	1.566	Warbler	0.071
Rock Dove	1.423	Tern	0.071
Egret/Heron	1.280	Stork	0.071
Owl	1.066	Sea Bird	0.071
Mourning Dove	0.929	Loon	0.071
Eagle	0.500	Quail	0.071
Rail	0.500	Waxwing	0.071
Sparrow	0.357	Falcon	0.071
Accipiter	0.357	Coyote	0.000
Osprey	0.357	Small Mammal	0.000
Deer	0.357	Woodcock	0.000
Cattle Egret	0.357	Sky Lark	0.000
Cormorant	0.286	Dove	0.000
Killdeer	0.214	Woodpecker	0.000
Nighthawk	0.214	Flycatcher	0.000
Crow	0.214		

Table 3.2. 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

Table 3.3. 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.

Table 3.4. 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

Table 3.5. 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

Table 3.5 cont.

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

Table 3.5 cont.

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

Table 3.5 cont.

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

Table 3.6. 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

Table 3.6 cont.

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

Table 3.6 cont.

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

Table 3.7. 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

Table 3.7 cont.

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

Table 3.7 cont.

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

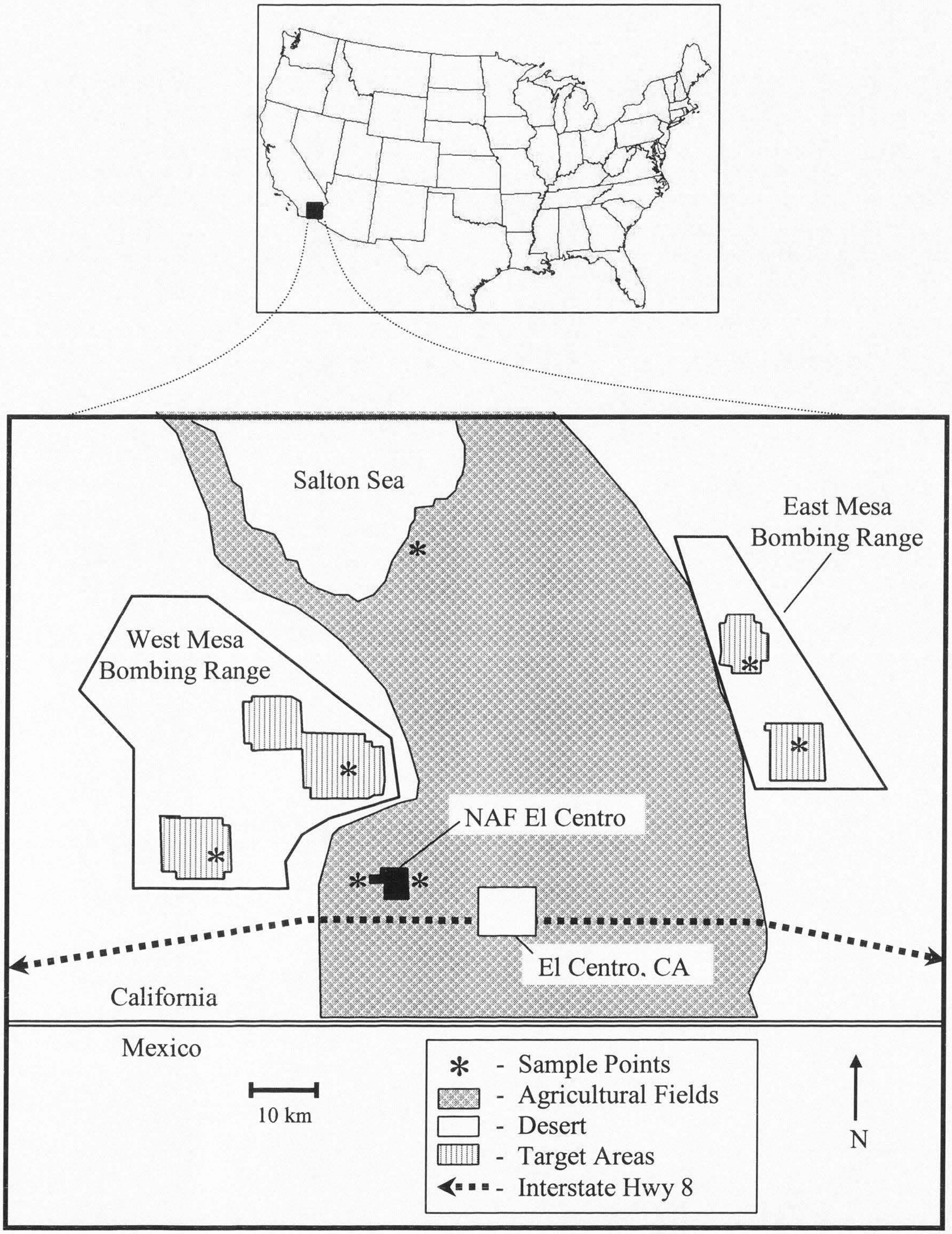
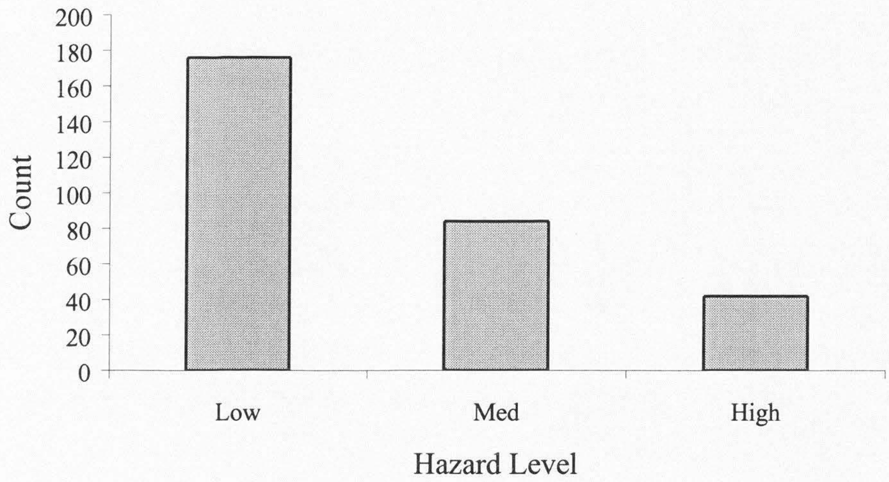


Fig. 3.1. Map (not to scale) of southern California showing NAF El Centro and the East and West Mesa Bombing Ranges. Inset shows location within the United States.

a)



b)

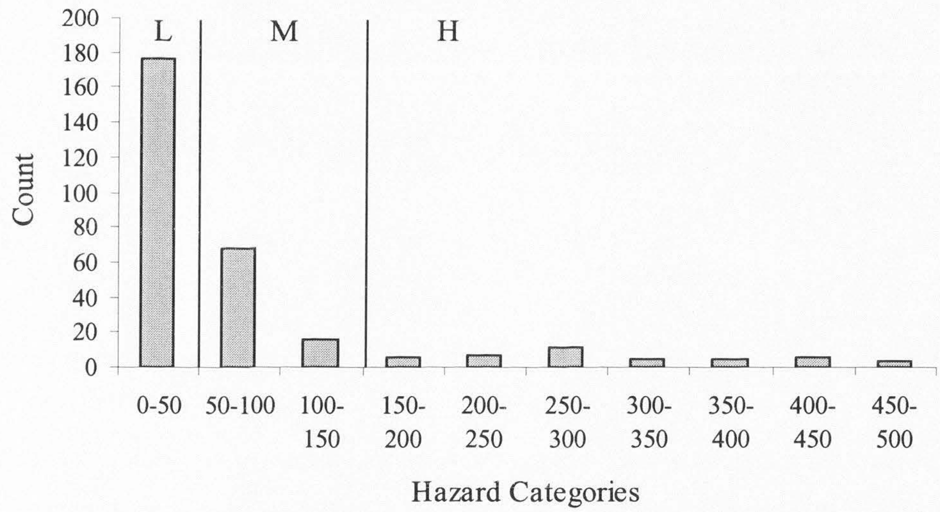
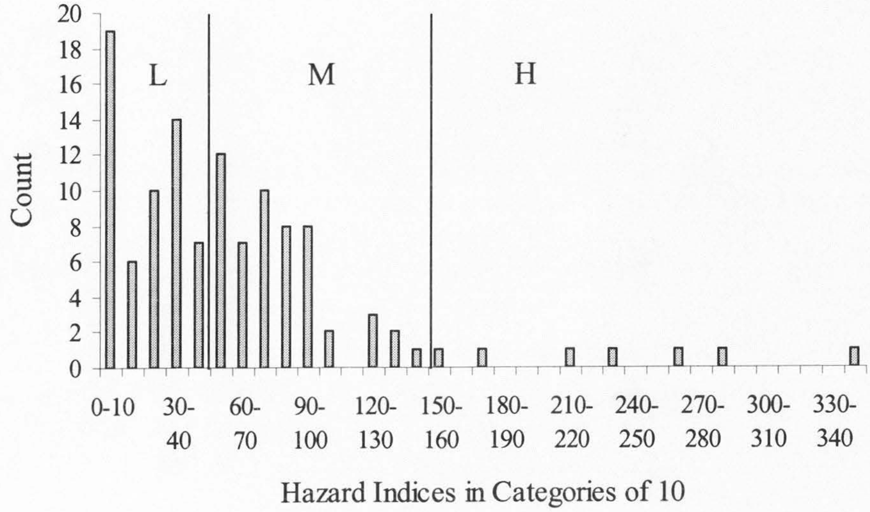


Fig. 3.2. All calculated hazard indices (across all sites, biweeks, time periods, and altitude bands) at NAF El Centro a) frequency histogram in classes of 50 (no units) and b) the number of indices in each bird-strike-risk category [(low (L), moderate (M) and high(H)].

a) Airfield bird-hazard indices.



b) Salton Sea bird-hazard indices.

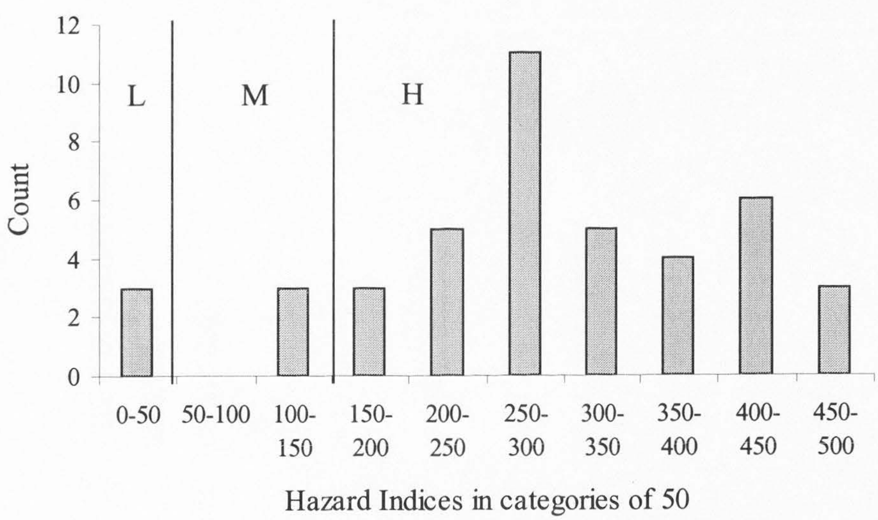
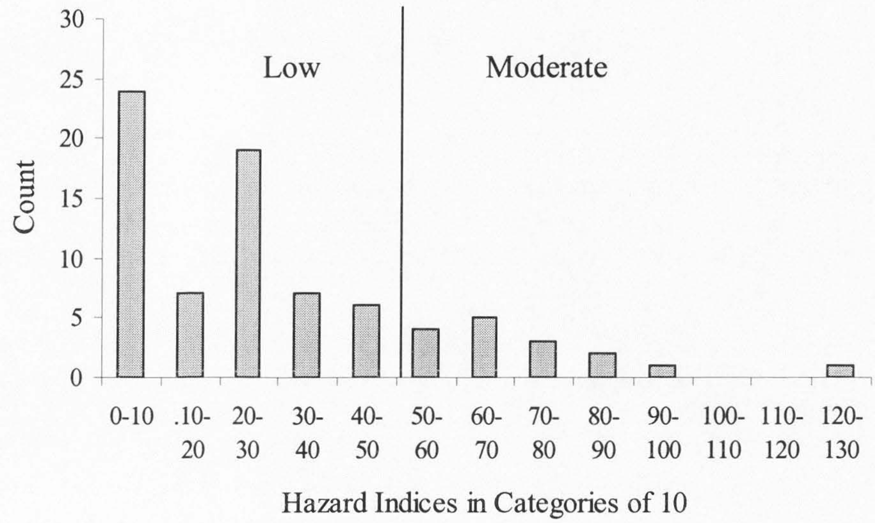


Fig 3.3. All calculated hazard indices at each site (biweeks, time periods, and altitude bands) with low (L), moderate (M), and high (H) risk thresholds shown. a) NAF El Centro b) Salton Sea. The Salton Sea site was considered to be a high bird-strike hazard. The high-risk threshold was set below most of the Salton Sea hazard levels.

a) East Mesa Range bird-hazard indices.



b) West Mesa Range bird-hazard indices.

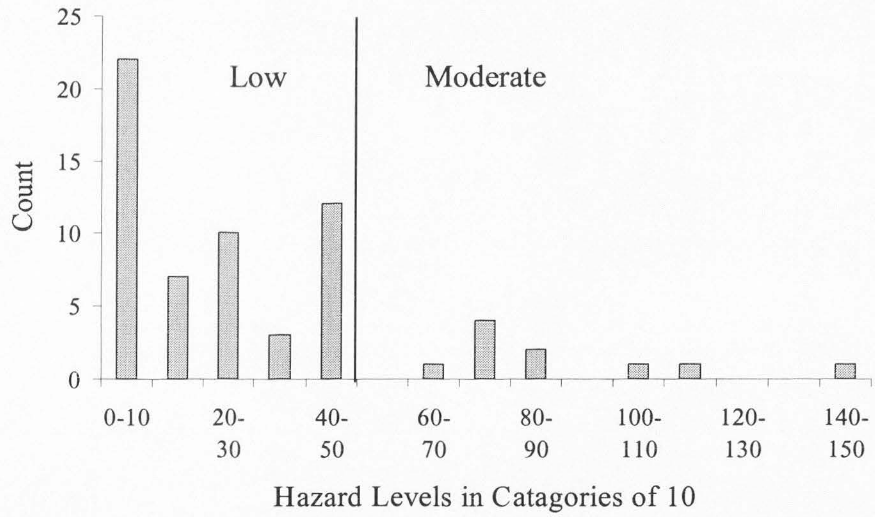


Fig. 3.4. All calculated hazard indices at each site (biweeks, time periods, and altitude bands) with Low and Moderate risk thresholds shown. a) East Mesa Range b) West Mesa Range.

CHAPTER 4

NOCTURNAL BIRD HAZARDS TO AIRCRAFT AT NAVAL AIR FACILITY EL CENTRO

INTRODUCTION

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

Each model relies on some description of the expected distribution of birds in the area and an assessment of the hazard posed by these birds. In chapter 3 I described diurnal bird-strike risk using visual-bird-count data and the empirical-hazard level of different species. Both birds and aircraft also fly at night and bird strikes do occur at night. Seventeen percent of USAF bird strikes/hour occurred at night, and 34.9% occurred at dusk (Tedrow 1998). Thus, an understanding of nocturnal bird use of an air space would be useful in bird-hazard management. Additionally, a description of the disproportionate occurrence of birds at different altitudes would allow pilots to avoid altitudes with higher concentrations of birds. In this chapter, I develop a bird-avoidance model describing the nocturnal bird hazards to aircraft at Naval Air Facility (NAF) El Centro, in southern California. Although an avian survey was conducted at NAF El Centro in 1996, it did not describe nocturnal bird use (Aigner and Koehler 1996).

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

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

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

The objective of this study was to create a nocturnal bird-avoidance model for NAF El Centro using radar as the primary sampling tool. Bird hazards identified by the radar system were categorized as high, moderate, or low risk of a damaging strike.

Nocturnal bird hazards were described from sunset until midnight because the Navy does not typically fly from midnight to sunrise. Curtailing flight operations during high-risk periods of heavy nocturnal bird activity can lower the bird-strike probability and corresponding damage by lowering the level of exposure to birds aloft. This is the basic premise of a BAM. On the other hand, during periods of low bird hazard, aircraft can operate with greatly diminished risk of bird-strike damage. Flights can be concentrated at these times.

STUDY AREA

NAF El Centro is located in Imperial County, California, approximately 193 km east of San Diego and 93 km west of Yuma, Arizona. It is 11 km north of the Mexican border and 26 km south of the Salton Sea National Wildlife Refuge (see Fig. 3.1). The base encompasses 927.5 hectares, including the airfield and other facilities. NAF El Centro is situated in a low-lying basin of the Salton Sea Trough in the Sonoran Desert. The airfield is 13.1 m below sea level and is surrounded by year-round, irrigated agricultural land.

NAF El Centro operates two bombing ranges (see Fig. 3.1). 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. 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's accuracy at Target 101. Target 95 is scored by a remote camera system, operated by the contractor at Target 101. The other two targets are not scored. All of the target areas are surrounded by public, undeveloped, and natural landscape, managed by the US Department of Interior, Bureau of Land Management.

METHODS

I 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 October to 29 November 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. Visible-light 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 conveyance into frequency bands. X-band marine-radar (2.5-4 cm wavelengths) has been used in several bird-radar studies (Cooper 1995; Harmata et al. 1999; Kelly et al. 1995, 1997).

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. 4.1). 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. I operated the radar at its 1,400-m range setting. The radar beam first pointed west across the surface of the ground, then rotated upward through an arc crossing vertical, and continuing through the arc until it pointed east along the surface of the ground. It then continued through the arc pointing at the ground, collecting no data until the beam rose above the ground once again to the west and continued its vertical-rotation.

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

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

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

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

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

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

For each biweek and altitude band, the algorithm adds the number of small birds, the number of SBEs based on medium-sized birds, and the number of SBEs based on large birds. This yields the total number of SBEs for a specific biweek and altitude band. Altitude bands were classified as 0-150 m, 151-300 m, 301-600 m, and >600 m. The mean number of SBEs per radar sample was then calculated by dividing by the number of radar images sampled per biweek. Lastly, I computed the mean SBE density using the area of airspace sampled as the divisor. The algorithm weighted birds according to a standardized relative size and calculated a mean density of birds per radar sample. GMI's proprietary image-analysis software easily calculated the area of the slice of airspace sampled by the radar by counting the number of image pixels within each altitude band and multiplying by the area of each pixel. I plotted the hazard indices in a histogram to identify break points between high, moderate, and low bird-strike hazard.

RESULTS

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 Table 4.1. The distributions of small, medium, and large-bird masses are all allokurtic (Fig. 4.2) 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 4.2.

The MARS was operated for 34 nights, distributed across six biweeks, between 20 October and 29 November 2000 (Appendix C). I 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 numbers of birds per size class and their SBEs in each biweek and altitude band are shown in Table 4.3.

Calculated hazard indices ranged from a low of 0.23 to 29.48 (Fig. 4.3). Hazard indices $\leq$ 10.00 were classified as low, between 10.00 and 18.00 were classified as moderate, and > 18.00 were classified as high. The distribution of classified-bird hazards at NAF El Centro is shown in Table 4.4.

DISCUSSION

The model predicted relative bird-strike hazards throughout the six biweeks sampled. Risk levels were relative, not absolute, values. The hazard indices were highest at the very beginning of the study with a declining trend toward the end in November. I assumed that an increasing trend would have been revealed from early August to mid-September, had the radar been operational at the time. Unfortunately funding constraints dictated our late start. This bird-hazard level closely follows the USAF bird-strike count by month (Fig. 4.4). The study ended as migration appeared to taper off substantially by the end of November.

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

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

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

LITERATURE CITED

Aigner, P. A. and C.E. Koehler. 1996. Final report: ornithological survey, natural resource management plan, Naval Air Facility, El Centro, California. 49 pp.

Blokpoel, H. 1976. Bird hazards to aircraft. Clarke, Irwin and Company, Ottawa, Canada. 235 pp.

Brooks, M. 1945. Electronics as a possible aid in the study of bird flight and migration. Science 101:329.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer . 1999. Wildlife strikes to civil aircraft in the United States 1990-1998. U.S. Department of Transportation, Federal Aviation Administration, Washington D.C. 26 pp.

Conover, M. R., W. C. Pitt, K. K. Kessler, T, J, Dubow, and W. A. Sanborn. 1995. Review of data on human injuries, illnesses, and economic losses caused by wildlife in the U.S. Wildlife Society Bulletin 23:407-414.

Cooper, B. A. 1995. The altitude of bird migration in east-central Alaska: a radar and visual study. Journal of Field Ornithology 66:590-608.

Costi, V, E. Kellogg, J. Giessow, and J. Giessow. 2000. Draft bird air strike hazard plan: Naval Air Facility, El Centro and Target Ranges 2510 and 2512. Naval Facilities Engineering Command, San Diego, California. 58 pp.

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

Dunning, J. R. 1993. CRC handbook of avian body masses. CRC Press. Boca Raton, Florida. 371 pp.

Eastwood, E. 1967. Radar ornithology. Methuen & Co. London, England. 278 pp.

Harmata, A. R., K. M. Podruzny, J. R. Zelenak, and M. L. Morrison. 1999. Using marine surveillance radar to study bird movements and impact assessment. Wildlife Society Bulletin 27:44-52.

Kelly, T. A. 1995. Monthly report, April 1995. Unpublished Dare BAM project report. U.S. Air Force, Air Combat Command, Langley, Virginia. 4 pp.

_____, A. G. Smith, and E. J. Zakrajsek. 1995. Dare County Range bird avoidance model. Unpublished proceedings of Bird Strike Committee USA 5.

_____, _____, and _____. 1997. Moody AFB/Grand Bay Weapons Range bird avoidance model. Unpublished proceedings of Bird Strike Committee USA 5.

Lack, D. and G. C. Varley. 1945. Detection of birds by radar. Nature 156:446.

MacKinnon, B. 1998. A reminder about bird strikes. Aviation Safety Letter 2:10-11.

Solman, V. E. F. 1978. Gulls and aircraft. Environmental Conservation 5:277-280.

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.

Table 4.1. 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.

Table 4.1 Cont.

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.

Table 4.1 Cont.

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.

Table 4.1 Cont.

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 > 800 g, M = between 71-800 g, S < 70 g.

Table 4.2. Small-bird equivalents (SBE) for large and medium-sized birds based on multiples of small-bird mass at NAF El Centro, CA.

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

Table 4.3. 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

Table 4.4. 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.

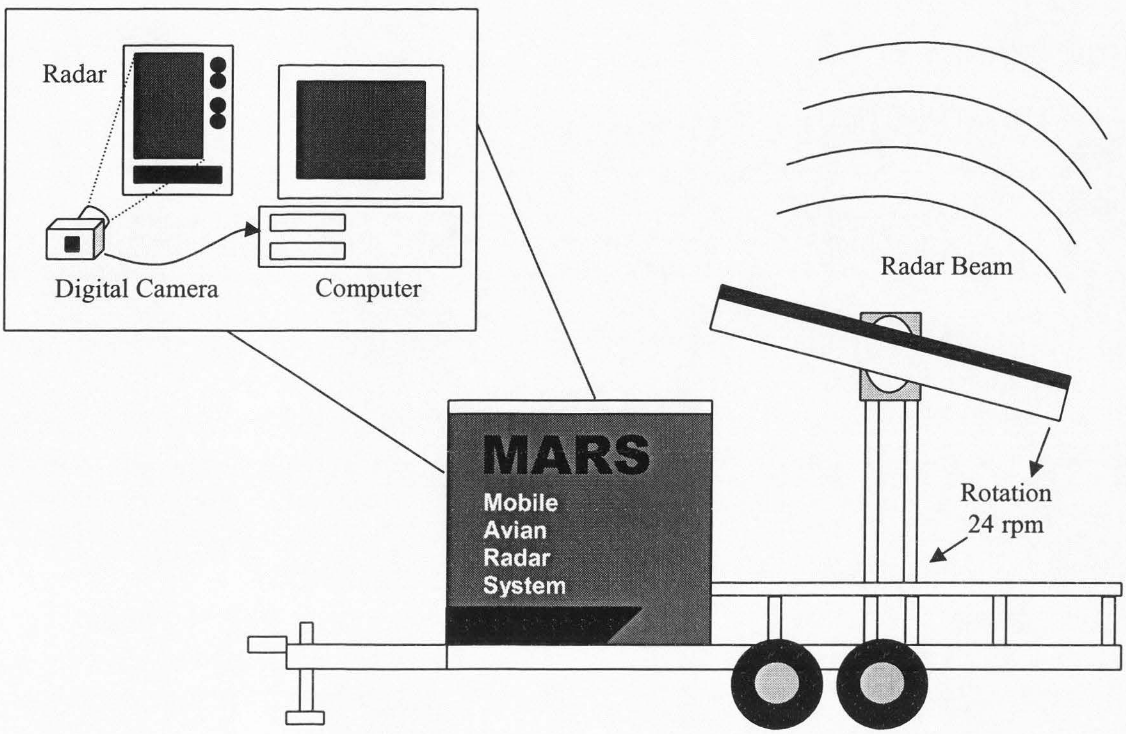
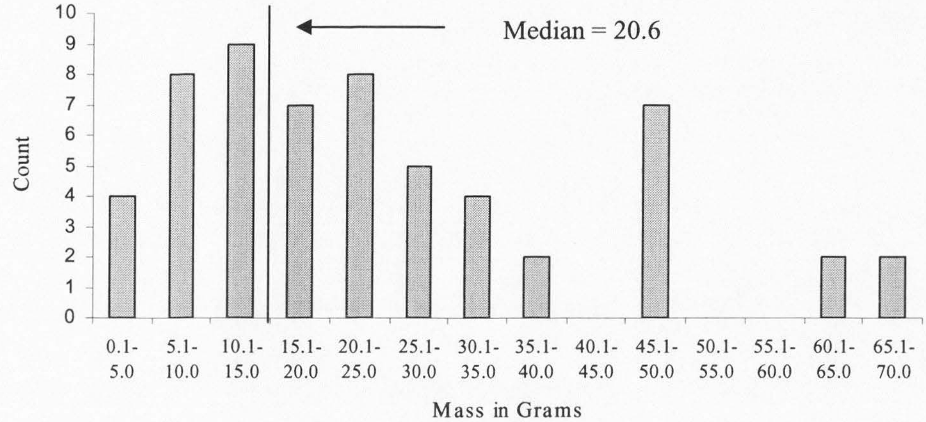
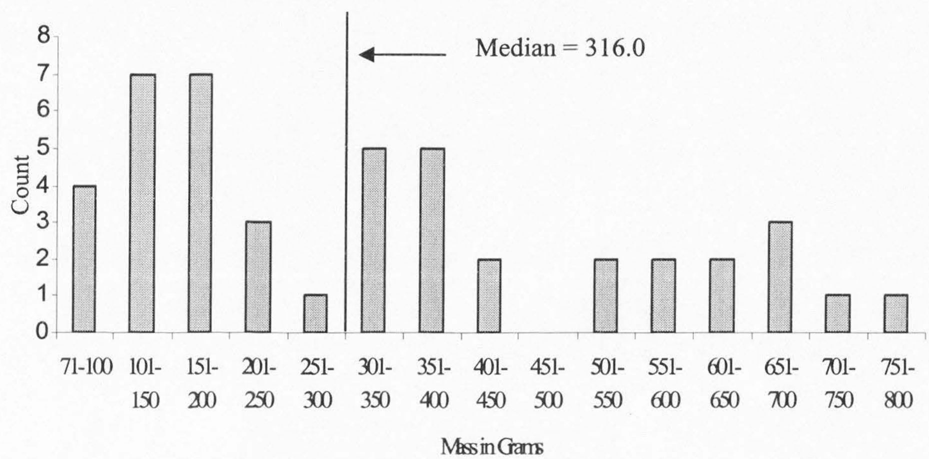


Fig. 4.1. Mobile Avian Radar System (MARS) used to collect nocturnal bird-migration data at NAF El Centro, 20 Sep – 29 Nov 2000. Inset shows the radar monitor and computer equipment within the trailer's office space.

(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.

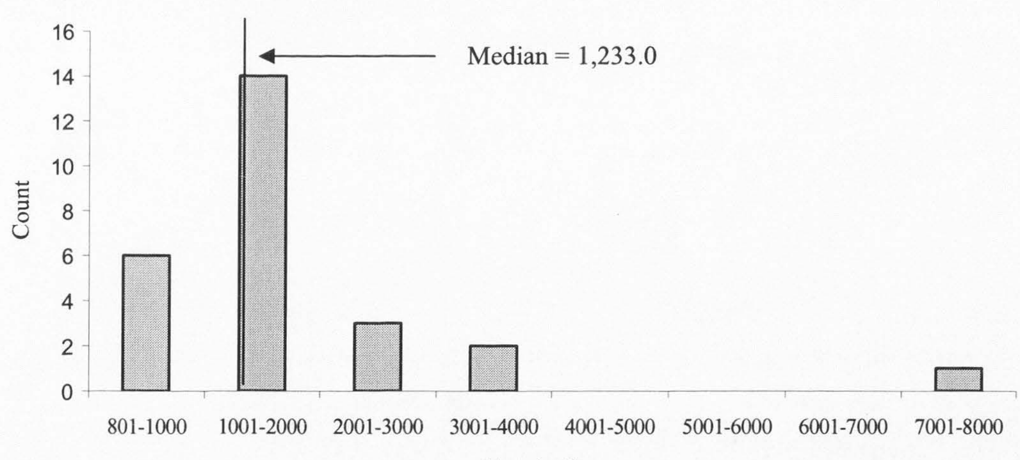
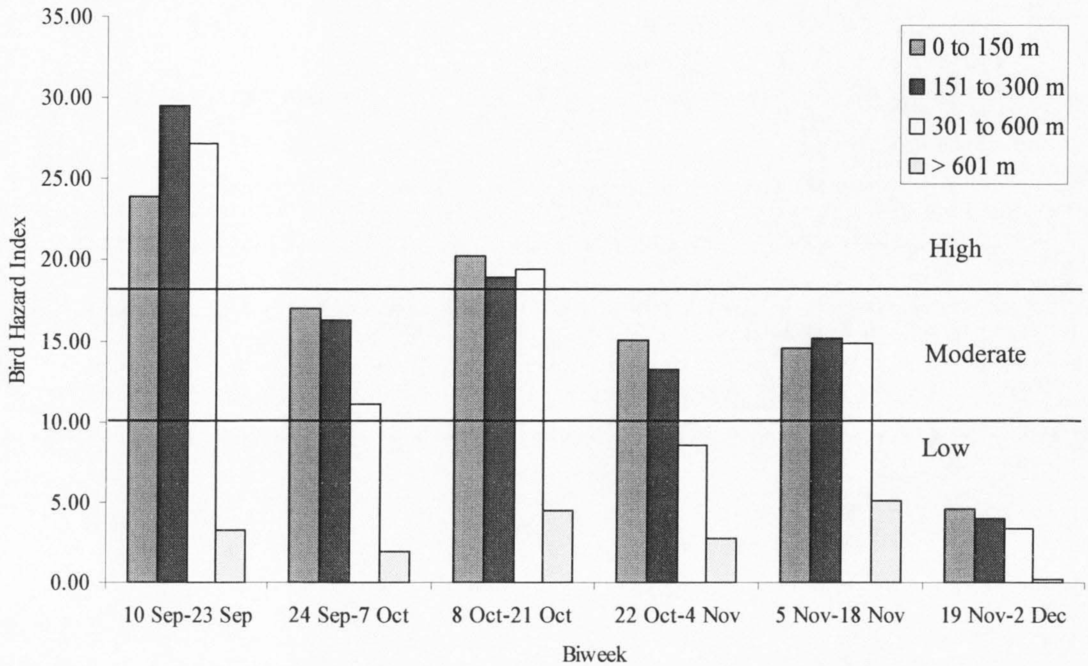


Fig. 4.2. Distributions of (a) small, (b) medium, and (c) large birds by mean body mass at NAF El Centro.

a)



b)

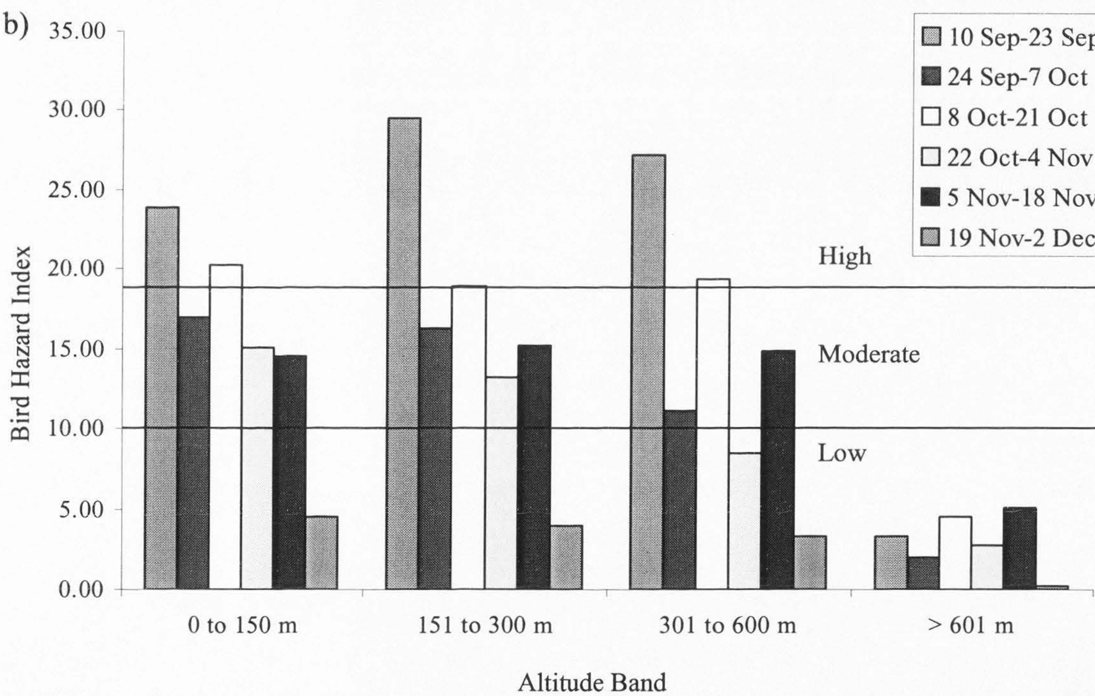


Fig. 4.3. Fall nocturnal bird-hazard indices by biweek and altitude band at NAF El Centro, CA. a) groups the altitude bands per biweek b) the same data with biweeks grouped per altitude band. High (18) and Moderate (10) thresholds are indicated.

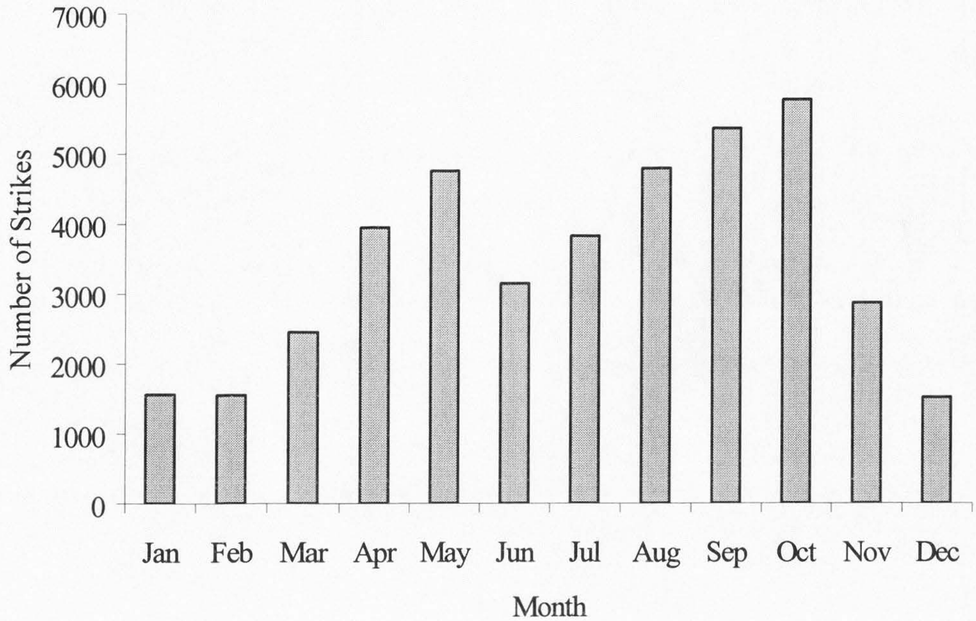


Fig. 4.4. US Air Force bird strikes per month, worldwide from Jan 1985 – Jun 2000 (data from the USAF BASH Team web page).

CHAPTER 5

CONCLUSION

Bird Strikes

Naval Air Facility El Centro, California, 5 October 1995: "Bird-strike followed by in-flight fire/loss of hydraulic control on low-level navigation training flight. No injuries. Aircraft destroyed." That was the end of an F-18D. The "large bird" had severed wire bundles, fuel lines, and hydraulic lines. The leaking fuel ignited, causing loss of AC power and aircraft controllability. The crew ejected and the plane made a hole in the desert.

An isolated incident? The U.S. Air Force, which keeps some of the best bird-strike records, records over 2,700 bird strikes/year, and it is estimated that only 25% are reported. That is an estimated 40 bird strikes per day. More shocking, the USAF looses one aircraft/year to bird strikes. One aircraft a year to birds! Studies show the problem is getting worse. Populations of some of the most hazardous species are growing rapidly.

There are tried and true methods for managing the bird-strike hazard at airfields. An airfield should deter birds by denying them food, water, and shelter. Birds that remain in the area should be scared away with pyrotechnics, distress calls, shotguns, propane cannons, remote-control airplanes, border collies, or falcons. But, bombing ranges and low-level routes are another problem. These are huge areas of airspace where direct control of the birds is all but impossible. Migrating birds are also a problem. When birds migrate over an airfield, bird-scaring tactics will not alter their course. These are situations where bird avoidance is the answer.

El Centro BAM

Naval Facilities Engineering Command, Southwest Division and the USGS, Utah Cooperative Fish & Wildlife Research Unit at Utah State University, recently developed the NAF El Centro Bird-Avoidance Model (BAM). The BAM is a risk-management tool that describes the relative probability of a bird strike over time at the airfield and the East and West Mesa Bombing Ranges (R-2510 & R-2512). The BAM accounts for the number and species of birds present in the area and the hazard level posed by each species to aircraft. This is where bird-strike reports come into play. Before we can find effective solutions, we need to know what kinds of birds are getting struck by aircraft and which ones cause damage.

A bird-radar system was used to count birds after dark. It is interesting to note that radar was invented for the specific purpose of identifying aircraft, but from the beginning it identified birds as well. In fact, much effort was required to eliminate bird clutter from early radar screens. Radar now allows us to collect data on bird movements over large areas and at night when many birds migrate.

The results of the BAM are published as a web page on NAF El Centro's web server (http://www.nafec.navy.mil) and on the USGS, Utah Cooperative Fish & Wildlife Research Unit/Utah State University, College of Natural Resources web page (http://ella.nr.usu.edu/~utcoop). The BAM consists of sets of risk graphs for the three areas (airfield, R-2510, & R-2512) at different times of the day and at different altitude bands. A few mouse clicks link the user to the correct risk graph, which is intuitively color-coded red for high risk, yellow for moderate risk, and green for low risk. The BAM also contains additional information and recommendations for understanding and managing the bird hazards at NAF El Centro.

Mission planners/flight schedulers can use the BAM to "avoid" scheduling flights during times of high bird-strike risk. Flight crews can use the BAM to identify the bird hazard in their airspace. They can check for bird hazards like they check for hazardous weather. Airfield managers and ATC personnel can learn what bird hazards to expect and what they can do about it. Natural resource managers can use the BAM to learn what needs to be done to reduce the airfield's attractiveness to birds.

Report Bird Strikes

Although bird strikes may seem unavoidable, the risk of damage, loss of aircraft, and loss of life warrants serious attention to preventative actions. Airfields should be maintained as bird free as possible, and bird-strike risk-management tools like the NAF El Centro BAM should be developed and used regularly. And don't forget to report all bird strikes!

APPENDICES

APPENDIX A

SPECIES GROUPS USED IN ANALYSIS OF UNITED STATES AIR FORCE BIRD-STRIKE DATA

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. I 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 5 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	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*

KESTREL	KILLDEER
American Kestrel *Falco sparverius*	Killdeer *Charadrius vociferus*
Merlin *Falco columbarius*	

KITE	LARGE SHOREBIRD (>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*		

SMALL MAMMAL		SMALL SHOREBIRD (<100 g)	
Black-tailed Jackrabbit	*Lepus californicus*	American Golden Plover	*Pluvialis dominicus*
Chipmunk	*Tamias striatus*	Baird's Sandpiper	*Calidris bairdii*
Domestic Cat	*Felis domesticus*	Black-bellied Plover	*Pluvialis squatarola*
Domestic Dog	*Canis domesticus*	Buff-breasted Sandpiper	*Tryngites subruficollis*
Rabbit	*Sylvilagus spp.*	Common Snipe	*Gallinago gallinaga*
Bacoon	*Procyon lotor*	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*

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 GROUPS USED IN ANALYSIS OF NAF EL CENTRO BIRD-STRIKE DATA

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
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*

KESTREL	KILLDEER
American Kestrel *Falco sparverius*	Killdeer *Charadrius vociferus*

LARGE SHOREBIRD	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	SMALL SHOREBIRD
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
	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

NUMBER OF ONE-HOUR, VISUAL BIRD SURVEYS PER TIME PERIOD AND BIWEEK AT EACH SITE.

		Airfield				East Mesa Range			
Dates	Biweek	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
15 Jan - 28 Jan	2	4	4	3	1	3	3	2	1
29 Jan - 11 Feb	3	4	4	1	3	1	1	2	4
12 Feb - 25 Feb	4	0	1	8	3	2	4	0	0
26 Feb - 11 Mar	5	3	4	3	0	2	2	4	0
12 Mar - 25 Mar	6	4	4	1	3	0	2	2	4
26 Mar - 8 Apr	7	2	2	4	4	4	0	2	4
9 Apr - 22 Apr	8	1	4	0	0	0	0	4	0
23 Apr - 6 May	9	6	3	4	6	5	5	0	0
7 May - 20 May	10	3	1	0	4	3	1	0	2
21 May - 3 Jun	11	6	4	0	7	3	1	0	2
4 Jun - 17 Jun	12	7	1	0	1	5	1	0	1
18 Jun - 1 Jul	13	8	2	0	4	6	2	0	1
2 Jul - 15 Jul	14	2	0	0	2	3	1	0	1
16 Jul - 29 Jul	15	6	2	0	4	3	1	0	2
30 Jul - 12 Aug	16	6	2	0	1	2	2	0	0
13 Aug - 26 Aug	17	6	2	0	4	5	1	0	2
27 Aug - 9 Sep	18	6	4	0	2	2	4	0	6
10 Sep - 23 Sep	19	0	0	3	2	2	2	0	2
24 Sep - 7 Oct	20	0	2	1	3	0	0	3	0
8 Oct - 21 Oct	21	1	1	2	2	0	2	0	2
22 Oct - 4 Nov	22	3	2	1	0	2	0	0	2
5 Nov - 18 Nov	23	0	0	4	2	1	3	1	0
19 Nov - 2 Dec	24	2	2	2	0	2	1	1	0
3 Dec - 16 Dec	25	4	4	3	1	0	4	2	2
17 Dec - 31 Dec	26	7	3	1	1	0	1	3	0

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

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

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