The trend of golden eagle territory occupancy in the vicinity of the Altamont Pass Wind Resource Area: 2005 survey

Article · January 2006

2 authors, including:

Grainger Hunt
The Peregrine Fund, Boise, Idaho, United States

Arnold Schwarzenegger
Governor

THE TREND OF GOLDEN EAGLE TERRITORY OCCUPANCY IN THE VICINITY OF THE ALTAMONT PASS WIND RESOURCE AREA: 2005 SURVEY

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Grainger Hunt and Teresa Hunt

June 2006
CEC-500-2006-056

Prepared By:
Grainger Hunt
The Peregrine Fund
5668 West Flying Hawk Lane
Boise, Idaho

Teresa Hunt
Predatory Bird Research Group
University of California, Santa Cruz

Contract No. 500-01-032

Prepared For:
California Energy Commission
Public Interest Energy Research (PIER) Program

Linda Spiegel,
Contract Manager

Kelly Birkinshaw,
Program Area Team Lead

Martha Krebs, Ph.D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

B. B. Blevins
Executive Director

Acknowledgments

This research was funded by the California Energy Commission (Energy Commission). The Peregrine Fund provided support for the senior author. Tom Cade conceived of the original project and provided advice and encouragement throughout. Linda Spiegel of the Energy Commission provided valuable support and assistance, as did Brian Walton and Dawn Gable of the Predatory Bird Research Group. Hans Peeters, Pam Peeters, Brian Latta, Daniel Driscoll, Janet Linthicum, Tery Drager, Nick Todd, Danny Dufau, Gordon Woodcock, Paul Andreano, Mary Shea, Ron Jackman, Colleen Lenihan, and Brian Murphy provided technical assistance and support. Peter Law gave mathematical advice. We thank Joe DiDonato, Steve Bobzien, George Isaus, Steve Quick, Roger Epperson, Dan Reasor, Doug Bell, and Ron Mueller of the East Bay Regional Parks Department; Dan Black and Jasmine Molina of the Alameda County Fairgrounds; Tim Koopman, Frank Marino, Kathe Zaloz, Bob Sari, Diane Wells, Leon Elam, Rob Cyr, Mike Burns, and Joe Naras of the San Francisco Water Department; Ron Arnold, Don Tisher, and Jake Peters of Hetch Hetchy Power; Jennifer Buckingham at Carnegie State Vehicular Recreation Area; Ed Stewart, Mary Shea, and Bill Chilson of the Contra Costa Water District; Bob Borunda of SRI International; Daniel Bylin of Walnut Creek Open Spaces; Ken and Karen Chaulet of the N3 Cattle Company; Paul Banke of the Patterson Ranch; and Stan Duck of Diablo Grande. We thank Joe Betchart, Rene and Mary Meyers, Mark Connolly, Danny and Kathy Torres, Reese and Ilene Cowden, Dick Ryon, Russ Fields, John and Ann Lindl, Ernie and Bart Wool, Danny and Nancy Sachau, and the California Department of Fish and Game. Peter Bloom, Tom Cade, Wally Erickson, Ron Jackman, Janet Linthicum, Hans and Pam Peeters, Shawn Smallwood, Linda Spiegel, Sue Orloff, and Robert Risebrough provided comments and insight on various drafts of the manuscript. We thank Ian Newton and Karen Steenhof for their valuable reviews.

Please cite this report as follows:

Hunt, Grainger, and Teresa Hunt. 2006. *The Trend of Golden Eagle Territory Occupancy in the Vicinity of the Altamont Pass Wind Resource Area: 2005 Survey.* California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2006-056.

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $15 million annually for natural gas RD&D.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

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- Buildings End-Use Energy Efficiency
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- Energy-Related Environmental Research
- Energy Systems Integration

The Trend of Golden Eagle Territory Occupancy in the Vicinity of the Altamont Pass Wind Resource Area: 2005 Survey is the final report for the Avian-Energy System Mitigation Program project, contract number 500-01-032, Golden Eagle Nest Occupancy Trend in the Vicinity of the Altamont Pass Wind Resource Area, conducted by G. Hunt and T. Hunt, biologists. The information from this project contributes to the PIER Energy-related Environmental Research Program.

For more information on the PIER Program, please visit the Energy Commission's Web site at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

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Abstract

This report details the results of a survey in spring 2005 of golden eagle (*Aquila chrysaetos*) breeding territory occupancy in the vicinity of the Altamont Pass Wind Resource Area (WRA) where numerous eagles from a dense local population are killed each year by wind turbine blade strikes. A demographic investigation conducted during 1994–2000, and reported to the California Energy Commission in 2002, indicated that the blade-strike mortality prevented the maintenance of substantial reserves of nonbreeding adults characteristic of healthy populations elsewhere, suggesting the possibility of an eventual decline in the breeding population. The unanswered question of population trend prompted the present study, which was designed to detect any change in the local breeding population since the last survey. Within a sample of 58 territories, results showed that all territories occupied by eagle pairs in 2000 were occupied by pairs in 2005. No upward trend was apparent in the proportion of subadult eagles as pair members, a condition that would have suggested an insufficiency of non-breeding adults to replace annual deaths among breeders. However, the number of eagle pairs required to support estimated levels of blade-strike mortality is large. The authors estimate, for example, that to maintain a stable population, the young of 167 breeding pairs are necessary to support a blade-strike mortality of 50 eagles per year. Such mortality is likely additive with other lethal agents in influencing population health. The most effective way to minimize an eventual decline of the breeding population associated with the rapid expansion of human development in the region is to mitigate sources of current mortality and to preserve foraging areas for nonbreeders.

Photo by John Gilardi

Figure 1. Two golden eagles at the Altamont Pass Wind Resource Area.

Executive Summary

Introduction
The area surrounding the Altamont Pass Wind Resource Area (WRA) near Livermore, California contains a higher reported density of nesting golden eagles than anywhere else in the world. The Predatory Bird Research Group (PBRG) has been studying aspects of golden eagle ecology in the region since 1994 to determine if wind turbine blade strikes in the WRA are causing the population to decline (Figures 1, 2). Estimates of the number of eagles annually killed by turbines in the WRA range from 40 to more than 100. Because golden eagles mature and reproduce slowly, and their populations are particularly sensitive to changes in adult and subadult survival rates, state and federal wildlife agencies have been concerned for the welfare of the population.

Purpose
The PBRG's seven-year study (1994–2000) was based on aerial surveys of survival among a large sample of radio-tagged eagles and annual reproduction of about 60 pairs in the vicinity of the WRA. The telemetry study suggests that most of the eagles killed in the WRA derive locally from the Diablo Mountains. Demographic analysis of the survival and reproduction data, reported by PBRG to the California Energy Commission in 2002 in *Golden Eagles in a Perilous Landscape: Predicting the Effects of Mitigation for Energy-related Mortality*, produced a point estimate indicating no change in population size from year to year, but the variance of the estimate fell more or less equally into scenarios of increase and decrease. The implication of the point estimate was that the studied population was failing to maintain a healthy contingent of non-breeding adults (floaters) that would normally buffer the breeding sector by filling vacancies within breeding territories. The question therefore remained of the fate of the population, and the PBRG recommended that golden eagle breeding territories within 30 km (19 miles) of the WRA be resurveyed every few years.

Project Objectives
The present report, which the reader should regard as an addendum to the 2002 report, details the results of a survey in spring 2005 of 58 golden eagle breeding territories within 30 km (19 miles) of the WRA boundary, each of which was occupied by a pair of eagles in 2000. The work was designed to test the hypothesis that sufficient numbers of floaters exist within the area to fill all breeding vacancies as they occur. The PBRG further noted the age-class of each territory-holder because an increase in the proportion of young eagles (subadults) would suggest an unhealthy scarcity of floaters in the population.

Project Outcomes
The results showed that within the surveyed sample of territories, all 58 that were occupied by pairs in 2000 were occupied by pairs in 2005, and there was no trend of increase of subadult pair members that might suggest a decline in the floater buffer.

Conclusions
These findings indicate that the breeding population of golden eagles within the vicinity of Altamont Pass remains intact. This does not mean, however, that the impact of WRA fatalities is benign. The WRA kills more eagles than can be produced by the studied sample of 58 pairs—that sample necessarily being part of a larger population that has provided an influx of recruits to fill nesting territory vacancies. The authors estimate, for example, that 167 breeding pairs are required to sustain 50 blade-strike fatalities per year. Moreover, golden eagle survival can be expected to decrease with the projected expansion of the human population in the region, i.e., human-induced mortality is likely additive in its effect on the eagle population.

Recommendations
Current knowledge suggests that the most effective way to minimize an eventual decline is to mitigate the primary agents of human-related mortality and to preserve open grasslands for the benefit of nonbreeders.

Benefits to California
This report increases public knowledge and understanding of the conservation implications of golden eagle mortality at the Altamont Pass Wind Resource Area.

Photo by Daniel Driscoll

Figure 2. Golden eagle flying near turbine blades at Altamont Pass.

1.0 Introduction

During 1994–2000, the Predatory Bird Research Group (PBRG) studied the ecology of golden eagles (*Aquila chrysaetos*) in west-central California, a region containing a higher reported density of breeding pairs than elsewhere reported (Figure 3). The work centered upon estimating whether wind turbine blade strike fatalities at the Altamont Pass Wind Resource Area (WRA) were causing the local breeding population of eagles to decline. Various estimates of the annual number of golden eagles killed there each year by blade strikes have ranged from 40 (Orloff and Flannery 1992), to 40–60 (Hunt 2002), to 75–116 (Smallwood and Thelander 2004). Mortality at even the lowest of these estimates suggests a considerable impact on the breeding population from which the turbine-killed eagles originate and provides the basis for hypothesizing its decline.

Photo by Teresa Hunt

Figure 3. Golden eagle habitat in the Diablo Mountains east of Dublin, California (background). A golden eagle pair nests in the oaks and forages on the open hillsides. The California ground squirrel *(Spermophilus beecheyii)* is the principal prey of golden eagles in this region.

To address the question of impact upon the eagle population, PBRG radio-tagged 257 individuals of four life-stages and monitored their movements and survival in the 9,000 square kilometer (km^2) (3,500 square mile) study area by airplane over the seven-year study period (Hunt et al. 1995, 1997, 1999; Hunt 2002). It was soon apparent from the tracking data that the eagles frequenting Altamont Pass were from the Diablo Mountains region of west-central California.[1] PBRG obtained an estimate of the reproductive rate of eagles nesting within approximately 30 km (19 miles) of the WRA on the basis of five annual surveys of 59–69 pairs. Wind turbine blades accounted for 42 of 100 fatalities of radio-tagged eagles recorded during the study, and the actual number of blade strike deaths within the sample of tagged eagles may have been higher, because the blades destroyed the transmitters in an unknown proportion of cases. From the telemetry data, PBRG estimated annual survival rates of four eagle life stages: juveniles (age 0–1 year), subadults (1-, 2-, and 3-year-olds), floaters (nonbreeding adults), and breeders. These vital rate estimates of reproduction and survival were used within a standard trend model to estimate the potential growth rate (*lambda*) of the population, i.e., the annual rate of change in population size that would result if all eagles of the limiting sex obtained breeding territories upon maturity (Hunt et al. 1999; Hunt 2002).[2]

The resulting estimate of the potential growth rate (lambda) was 1.0047, predicting neither increase nor decline, its standard error of 0.0240 falling more or less equally into the two alternatives. If the point estimate of population growth indeed represented its true value, then few locally produced floaters would exist to fill breeder vacancies (Hunt 2002).[3] Stability in the breeding segment might therefore require a supply of immigrant floaters from outside the core study area (≥ 30 km radius from the WRA)—a condition also implied by the ratio of annual turbine-strike fatalities to the number of eagle pairs necessary to provide them (see Conclusion).

At the end of the study in 2002, the question therefore remained of the actual trend of the golden eagle population breeding in the vicinity of the WRA. Even though the earlier nesting surveys showed no indication of population instability, PBRG recommended long-term, periodic monitoring of territory occupancy and the proportion of subadult

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[1] In an earlier study (Hunt 2002), PBRG radio-tagged 117 itinerant golden eagles in the vicinity of Altamont Pass, primarily in winter. Of these, 108 survived long enough to indicate their geographic affiliation. Ninety (83%) showed clear evidence of residency within the Diablo Mountain study area (9,000 km^2) which contains the WRA. The movements of seven others (6%) indicated residency in the west-central California region. Eleven (10%) were detected only in winter and spring, and so may have originated elsewhere.

[2] For a population of golden eagles, lambda should be interpreted as follows: if lambda's true value is less than 1.00, the population is declining (e.g., if lambda were 0.98, the population would be declining at 2% per year). However, a lambda value of greater than 1.0 does not imply that the population is growing. The reason is that the core assumption of the growth model, that maturing eagles always acquire territories, is not necessarily true. Golden eagle pairs divide the landscape into a mosaic of breeding territories from which they exclude other adult eagles. A growing population expands until it fills all serviceable breeding locations with territorial pairs, at which point a surplus of nonbreeding adults ("floaters") begins to accumulate and finally stabilizes in a balance of survival and limited overall reproduction. This form of population limitation is called *Moffat's equilibrium* (Moffat 1903; Hunt 1998; Hunt and Law 2000).

[3] Floaters buffer the breeding population by replacing territory-holders that die, and may even fight with resident breeders, sometimes displacing them and/or interfering with reproduction (Haller 1996). For a healthy golden eagle population at Moffat's equilibrium, a lambda value of, say, 1.07 would very likely imply stability, with more or less equal numbers of floaters and breeders.

territory-holders (Hunt 2002).[4] These surveys would provide early warning of problems in the demographic balance that might result, for example, from new, additive impacts on survival and reproduction that may accompany the rapid urbanization characterizing the region (Hunt et al. 1999).

This report gives the results of a golden eagle territory occupancy survey conducted in spring 2005 of those territories that PBRG found occupied by pairs in 2000 within the core study area (Hunt 2002). The results test the hypothesis that the golden eagle nesting population within 30 km of the WRA is stable. This report should therefore be regarded as an addendum to the earlier report to the California Energy Commission (Hunt 2002). The interested reader would benefit by reviewing that report and by having on hand the earlier reports PBRG prepared for the National Renewable Energy Laboratory (Hunt et al. 1995, 1997, 1999). These reports offer additional details and discussions of golden eagle natural history that may serve to clarify our interpretations.

2.0 Methods

From 23 January to 25 May 2005, the authors surveyed 58 of 61 golden eagle territories that were occupied by pairs in 2000 within 30 km of the WRA boundary (Figure 4).[5] The three unsurveyed territories involved lack of access to observation points. The authors tried to concentrate survey efforts during the courtship period of the breeding cycle when territorial eagles were most conspicuous, i.e., displaying above their territories. However, unusually frequent precipitation reduced visibility, dampened eagle activity, and often left mountain roads too muddy for travel. These conditions necessarily extended the survey into the incubation and even the nestling periods. The survey procedure rarely required us to enter core defended areas, and in all cases, observation points were sufficiently distant that the birds remained unaffected. Evidence of pairs and territory occupancy included observations of perching together, copulation, incubation, nest repair, undulation displays (Harmata 1982), soaring together, attacking intruders, and vocalizing to one another (see Kochert et al. 2002).

The authors attempted to determine the age-class of each territorial eagle on the first visit, but sometimes additional visits and better observation points were required. Eagles were aged on the basis of plumage characteristics, with the knowledge that golden eagles mature in their fifth calendar year, at which point they rarely retain distinct white patches in their wings or tail. Techniques for ageing have improved with a recent publication by Bloom and Clark (2002), who detailed the molting sequence of golden eagles from juvenile plumage to adulthood. Bloom and Clark showed that while most adults are readily identifiable by appraising tail plumage, some occasionally retain whitish areas in the tail which resemble the white patches characteristic of subadults. Appraisal of eagle ages at each territory in the current survey conservatively considered any (non-juvenile)

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[4] An established golden eagle population with a healthy floater buffer contains few subadults (≤ 3%) as members of breeding pairs. A clear increase in the proportion of subadult pair members would indicate an insufficiency of available floaters and suggest a trend of population decline (Ferrer et al. 2003).

[5] All 61 territories had a prior history of pairs with nests. The authors did not survey four additional territories where pairs were reported in 2000, but nest presence was unverified.

eagle with white in its tail as a subadult, eagles with no white in the wings or tail were considered adults.[6] In total, the authors aged 57 pairs (114 eagles) of the 58 surveyed for occupancy.

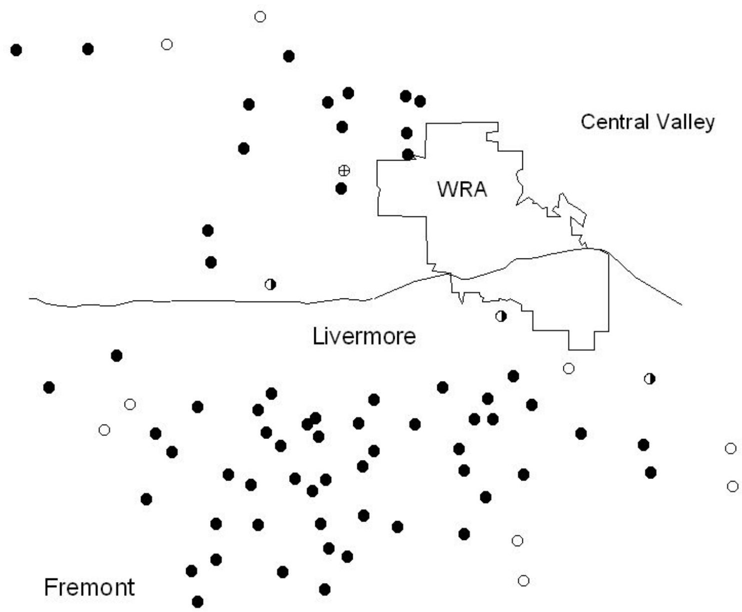

Figure 4. Golden eagle territories within 30 km (19 miles) of the Altamont Pass Wind Resource Area (WRA). Black dots show territories with studied histories of breeding; open dots depict unstudied territories where pairs have been observed; half-moons show territories with intermittent occupancy; and the single crossed circle shows a territory vacated after 1999.

This research was designed to test the hypothesis that the golden eagle demographic regime (including immigration) continues to maintain the full complement of occupied breeding territories apparent during 1994–2000 within 30 km of the wind farm; if this were the case, it would imply that sufficient numbers of floaters are available to fill all breeding vacancies as they occur. The strategy of hypothesis testing is as follows:

- The hypothesis is strengthened if eagle pairs are found to be present in all or virtually all surveyed territories and questioned if eagles are absent in some territories.

- The hypothesis is strengthened if eagle absences are explainable by changes in local conditions (breeding locations unserviceable), and weakened if absences are unexplainable by local changes (recruitment deficit).

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[6] Bloom and Clark (2002) mention that some captive adult eagles have retained white in the tail for more than 20 years.

- The hypothesis is strengthened if the proportion of subadults as members of breeding pairs in 2005 is comparable to that observed in earlier years (0%–3%), and weakened if that proportion is significantly higher.[7]

3.0 Results

3.1 Occupancy

All 58 surveyed territories (100%) occupied by pairs in 2000 were occupied by pairs in 2005.

3.2 Ages of Pair Members

At least 111 (97.4%) of 114 eagles were adults within the 57 territories where the authors determined the ages of territory-holders (Table 1). At one territory, the plumage of the female was that of a subadult.[8] At two other territories, the plumage (male and female, respectively) was more ambiguous. The male(s) observed at one of these territories had very similar subadult markings during the 2004 and 2005 breeding seasons, suggesting the presence of the same anomalous adult in both years. The base of the female's tail at the other territory contained some areas of white, but these appeared mottled with gray bands, unlike the typical third-year subadult. Subadults thus comprised a maximum of 2.6% of the sample of aged territory-holders in the 2005 breeding season.

Table 1. Ages of breeding golden eagles at territories within 30 km of the Altamont Pass Wind Resource Area during 1996–2005. The changing number of aged eagles over the years reflects increased sampling rather than increased population.

— Pair —							
Male	**Female**	**1996**	**1997**	**1998**	**1999**	**2000**	**2005**
adult	adult	48	41	49	54	55	54
subadult	adult	0	0	0	1	0	0
adult	subadult	2	0	2	3	2	1
adult	age uncertain	0	0	0	0	0	1
age uncertain	adult	0	0	0	0	0	1
No. eagles aged		100	82	102	116	114	112
Maximum no. of subadults		2	0	2	4	2	3
Maximum percent subadults		2.0	0.0	2.0	3.4	1.8	2.6

[7] Were no adults available to fill vacancies, we would expect the incidence of subadult territory-holders to approximate the annual breeder mortality rate—about 8% in our study area (Hunt 2002).

[8] As a matter of interest, we would expect that territory-holding subadults would most often be female, because there are fewer females overall than males in the population (ca. 60 males:40 females), i.e., in a declining population with unbiased mortality, female floater numbers would be exhausted before those of males (Hunt et al. 1999; Hunt 2002).

4.0 Conclusion

The results of the 2005 territory occupancy survey indicate that (1) the breeding population of golden eagles in the vicinity of Altamont Pass remains intact, and (2) subadult pair members show no trend of increase suggestive of a deficiency in the floater buffer. These findings support the hypothesis that floater numbers are still sufficient to buffer breeding territory vacancies despite the levels of blade strike fatalities in the WRA occurring during the past decade.

However, these findings of continued occupancy cannot be extended to indicate that the WRA has a benign effect on the population of golden eagles within the range of direct mortality and recruitment demand. The WRA decreases the resiliency of that population by reducing its demographic potential. Turbine blade strikes kill more eagles than are produced within the area of our survey, thereby demanding a flow of recruits from outside the area to fill breeding vacancies as they occur. For example, the authors calculate that 50 fatalities per year would consume the annual production of 78 pairs of golden eagles if all eagles were killed as recent fledglings and the annual reproductive rate were comparable to that estimated during our earlier studies (0.632 fledglings per territorial pair). However, the actual impact is far greater. The average age of death of turbine-killed eagles in our sample was 44 months. Applying the point estimates of age-specific mortality reported by Hunt (2002), the probability of a fledgling surviving to that age in the absence of blade-strike mortality is 63.3%. Fifty eagles annually killed by turbine blades would thus account each year for what remains of the issue of 124 pairs[9] and an additional 43 pairs would be necessary to compensate annual deaths among those breeders. In all, therefore, 50 turbine blade-strikes occurring annually would require the existence of 167 pairs of golden eagles, that population existing at the demographic "break even" point, i.e., producing no buffer of recruits in excess of that required to sustain itself.

Similar calculations can be made for the various other estimates of WRA mortality, i.e., 40–116 blade-strike kills would account for the issue of 134–388 pairs of eagles if all point estimates of vital rates and other measures were precise. These figures lead to the question of the WRA's geographic extent of influence. The sample of 58 pairs the authors studied near Livermore is part of a larger population extending from the Oakland Hills to Highway 152 along San Luis Reservoir. PBRG selected that 9000 km^2 region as our overall study area on the basis of movement patterns of radio-tagged eagles. In all, the authors know of about 100 territories within it, but estimate that at least twice that number exists, considering that perhaps one-third of the apparent suitable habitat has been surveyed.

Several lines of evidence suggest that eagles fledging near the WRA are more likely to be killed there than those produced in more distant regions. For example, of 25 fledgling eagles PBRG radio-tagged within 30 km of the WRA in 1994, six died or disappeared

[9] To understand this result, imagine that all 50 eagles were 44 months of age at the time of death and so fledged in the same year. Hence, year after year, none of the offspring of 124 pairs would survive to enter the breeding population (a bird-by-bird calculation yields 127 pairs).

during the first year (turbines rarely kill juveniles), leaving 19 in the study area as first-year subadults (Hunt 2002). From January 1995 to November 1999, turbine blades killed 11 of these eagles, an attrition rate of at least 58% arising from this single mortality agent. Only one was known to have died of other causes within the study area during this period. Note that these figures represent a minimum incidence because the blades are known to destroy transmitters in a proportion of cases (Hunt 2002). Subsequent yearly cohorts of radio-tagged eagles showed comparable rates of WRA-related attrition, although less time remained in the study to follow the fates of individuals. Another reason to think that locally produced eagles are at greatest risk is that more than 80% of those that PBRG tagged as free-ranging non-breeders showed evidence of residency in the Diablo Mountains (footnote 1)—a finding consistent with other studies reporting the tendency of golden eagles to gravitate to natal regions (see Kochert et al. 2002 for review).

All these considerations lead the authors to hypothesize that the study area from the Oakland Hills to San Luis Reservoir is the primary contributor of eagles to WRA mortality. The authors therefore recommend a comprehensive survey of nesting golden eagles within that region, based on stratified random sampling, to estimate the overall number of pairs. That estimate, and possibly an appraisal of golden eagle nesting densities in adjacent parts of west central California, would give perspective about the impact of blade strike mortality within the context of the region.

If rates of overall mortality increase, as can be expected to follow the projected expansion of human development within the region, then the number of eagle pairs required to sustain the number of blade-strikes will increase even if the latter remains constant. The mortality agents identified by Hunt (2002) are primarily human-related,[10] and whereas current knowledge does not reveal the point at which breeding populations may begin to decline, the most effective way to avoid that eventuality is to reduce human-related mortality on an agent-by-agent basis. For example, despite improvements to reduce nationwide raptor electrocutions with the configuration of new power poles and the retrofitting of existing poles during the last quarter century (APLIC 1996), many power lines and utility lines have yet to be retrofitted. Lead bullet fragments and shotgun pellets in carrion are potent sources of lead poisoning in eagles and other scavengers (Hunt et al. in press). Non-toxic bullets and pellets are efficacious for hunting (McMurchy 2003, Towsley 2005), and their increased use would likely reduce the number of eagle deaths. Liver assays of dead eagles sometimes show the rodenticide brodificoum despite prohibitions against its outdoor use; tighter regulation and consumer education are therefore needed. Reducing the frequency with which eagles collide with wires and road vehicles remains problematic.

Finally, as houses and farms fill open grasslands, the overall amount of foraging habitat for itinerant eagles (juveniles, subadults and floaters) may diminish to the point at which packing and competition in remaining areas increases mortality within those life stages.

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[10] At least 68% of 100 fatalities recorded among 257 radio-tagged eagles during 1994–2000 were human-related; turbine blade-strikes accounted for 42% and electrocution for 12%. An additional 21% of fatalities of unknown cause likely included some human-related events, e.g., lead and other poisonings.

For example, itinerants likely find the prey-rich WRA additionally attractive because virtually no territorial pairs are there to exclude them. If ground squirrel populations continue to flourish in the WRA as other grasslands are consumed by urban sprawl, the proportional use of this perilous landscape will intensify. Broad-scale preservation of open, treeless grasslands in hilly terrain and prey enhancement outside the WRA is therefore indicated, as are reductions of ground squirrel numbers within the WRA through direct control or habitat modification. Meanwhile, as a way of detecting any gradual downturn that may be occurring in the demographic balance of golden eagles within the Diablo Range, the authors recommend that the eagle territory occupancy survey be repeated every five years.

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