CHAPTER 9

Conclusions and Recommendations

This report summarizes the findings of a four-year research effort involving more than 4,000 wind turbines, and aimed at better understanding bird mortality at the world's largest wind farm, the Altamont Pass Wind Resource Area. Yet, as with most research efforts, we finished with many questions remaining unanswered about the factors associated with fatalities at wind turbines, and about the biological significance of the mortality we estimated.

Additional research that adjusts its methodology based on what we have learned, and that addresses the questions left unanswered, may one day result in additional solutions to the perplexing problems facing the wind industry in the APWRA. We trust that the findings presented here are sufficient for the wind industry to begin implementing a series of mitigation measures that will more effectively avoid, reduce, and offset impacts caused by existing and future wind turbines in the APWRA. We believe that the results presented here provide the foundation for the aggressive implementation of management strategies that appear most likely to substantially reduce bird mortality. Lastly, it is our hope that our recommendations will help to reduce bird morality at wind farms throughout the world, and help to avoid similar situations in the future.

9.1 ASSESSMENT AND RECOMMENDATION OF MITIGATION MEASURES

The most recent phase of our study has allowed us to test some rudimentary fatality reduction experiments that had begun in the APWRA. For example, we were able to relate mortality to blade-painting schemes which were implemented in the past (and which still exist) and to perch deterrents on lattice towers. Additionally, we were able to further test the effectiveness of the current rodent control program. What follows are our recommended mitigation measures, or suggested changes for turbine management/operations. These are not provided in any order of priority. For that recommendation, see 9-2.0 below.

- No. 1. Replace the WRRS with scientifically defensible monitoring program

The Wildlife Reporting and Response System (WRRS) relies on volunteer reporting of bird carcasses discovered by turbine workers during routine but unsystematic maintenance or repair services, and is therefore not a scientific sampling program. The WRRS documents only 18%–26% of the red-tailed hawk fatalities our monitoring documented, and only 24%–41% of the golden eagles, and these are the two largest and most easily found species. The WRRS is not only inadequate as a monitoring program for golden eagle and red-tailed hawk mortality, but is very unlikely to detect more than a tiny fraction of the burrowing owl fatalities or the fatalities of many smaller-bodied species of bird. The WRRS should be replaced by a scientifically defensible monitoring program performed by independent, trained professionals.

Results of the monitoring program should be regularly published in outlets readily accessible to the public and in standardized formats. Reports should include the identification of the personnel involved, their qualifications for performing the work, detailed descriptions of methods used, dates of site visits, analytical methods, and results presented in a consistent fashion. The Energy Commission's documents page on its Web site (http://www.energy.ca.gov/sitingcases/alphabetical.html) is a good example of a standardized approach for presenting environmental documentation related to the site licensing of power plants. A similar page could be developed for the reporting of mortality monitoring results in the APWRA and other wind resource areas.

- No. 2. Cease the rodent control program

Our evidence indicates that rodent control has not changed bird behaviors in the APWRA in the manners we assume were expected. Raptors have not abandoned the areas subjected to rodent control, and substantial numbers of them continue to be killed by wind turbines. We suggest that the rodent control program be terminated because it is ineffective, and because of the adverse effects the program is likely having on special-status species such as burrowing owl, California red-legged frog, California tiger salamander, and San Joaquin kit fox.

Even if the rodent control program managed to eradicate rodents, raptors would likely continue to visit the APWRA because it is a migratory route and because birds are known to recognize prey-bearing habitat by gestalt rather than by enumeration and inventory methods. And even if the program managed to displace raptors after eradicating rodents (assuming that they could eradicate rodents), this displacement necessarily would result in a net loss of raptors from the remaining habitat. Populations would be reduced through displacement because these species cannot be crowded into smaller spaces. The social behaviors of these species are rather inflexible regarding home range size and plural occupancy of territories.

Should the wind turbine owners seek to continue the rodent control program, we recommend an environmental assessment pursuant to California Environmental Quality Act (CEQA) requirements, to fully examine the potential effects to special-status species.

- No. 3. Alter habitat to reduce raptor foraging near wind turbines

It may be possible to alter habitat conditions within 50 m of wind turbines in order to reduce prey vulnerability to raptor predation near wind turbines, thereby reducing raptor use of these areas as well as mortality. Habitat alterations other than the use of rodenticides remain untested in the APWRA. However, the U.S. Fish and Wildlife Service expressed some skepticism that such localized habitat alterations would shift raptor foraging from near the vicinity of wind turbines to farther away, and the Service might be correct. Still, it might be worth studying cattle exclusion around some select wind turbines, allowing the grass to grow tall, and encouraging fossorial animals at locations farther from the wind turbines.

- No. 3a. Reduce and minimize vertical and lateral edge

Cuts into hillsides for wind turbine lay-down areas and access roads (e.g., Photo 9-1) might be re-contoured in order to reduce the vertical edge in the landscape that is preferred by pocket gophers and some other species of small mammal. Also, access roads should be minimized, along with buried pipelines near wind turbines. This measure should be applied wherever it is needed across the APWRA.

Photo 9-1. Vertical edge is often abundant along the string of wind turbines, which attracts certain small mammals and likely attracts foraging raptors.

- No. 3b. Move rock piles

Rocks were piled near wind turbines as a mitigation measure for the APWRA (Photo 9-2). These rocks were moved from the laydown areas and piled as cover for prey species of San Joaquin kit fox. The measure worked to harbor prey species of the kit fox, but these same prey species are also targeted by large foraging raptors. Also, burrowing owls use the rock piles as den sites and as perches. Relocating rock piles away from the wind turbines might reduce the mortality of some species, based on results of association analysis performed on fatalities found at the 1,536 wind turbines that were searched longest. However, we believe this measure would not substantially reduce mortality by itself. Moving the artificial rock piles to locations farthest from wind turbines (e.g., to the bottoms of ravines or the lower slopes) would cost little, so this measure ought to be pursued.

Photo 9-2. Rocks gathered from wind turbine laydown areas and piled nearby.

- No. 3c. Exclude cattle from around wind turbines

Cattle congregate around wind turbines, perhaps due to the shade or wind-breaks afforded by the towers (Photos 9-3 and 9-4). This concentration of cattle activity also concentrates the distribution of cattle pats (Photo 9-5), which are fed upon by hundreds of grasshoppers per pat and serve as a principal base of a food web attracting birds to the near vicinity of wind turbines. It might be possible to encourage this food web to proliferate more distant from the wind turbines by fencing off the area immediately surrounding the wind turbines and excluding cattle from that area. A 50-m exclusion area might suffice; however, the fence may attract burrowing owls, which readily perch on cattle fences where they are available. It may be necessary to fence cattle out of groups of wind turbine strings, thereby minimizing the length of fencing occurring relatively near to wind turbines.

Photo 9-3. Cattle routinely congregate in the shade of wind towers on hot days.

Photo 9-4. Cattle congregate around wind turbine for shade and foraging, and they reduce grass height and expose small mammals to foraging raptors.

Photo 9-5. Cattle pats abound where cattle congregate near the shadow of a wind turbine. These pats attract numerous grasshoppers, which in turn attracts raptors that feed on the grasshoppers close to turbine blades.

- No. 3d. Retrofit turbine-tower pads to prevent burrowing by small mammals

Small mammals often burrow under the concrete pads of the wind turbines and the junction boxes (Photo 9-6). It might be helpful to apply gravel to the perimeters of these concrete pads as a means to discourage such under-burrowing. Also, it might help to apply fill to pads when gaps form under them due to long-term burrowing or other forms of erosion.

A more practical solution to this problem in the long-term is to rely on wind towers that do not require concrete pads. Many of the wind turbines in the APWRA do not require concrete pads and therefore do not experience under-burrowing. As the repowering program proceeds, perhaps new wind turbines could be installed without concrete pads.

Photo 9-6. Burrows appear under concrete pads in the APWRA, and these might attract foraging raptors into close proximity of wind turbines.

- No. 4. Perch Guards

The results of our behavior study suggest that perching on wind turbines and their towers is likely not the problem that it was portrayed in the past. Birds are disproportionately killed by wind turbines mounted on tubular towers, which provide fewer perch sites than do lattice towers. Also, we found that birds carefully perched on turbines/towers while wind turbines were not operating

(Photos 9-7 to 9-10) or when broken (Photo 9-9). For these reasons, we do not believe perch guards will substantially reduce mortality. Additionally, we tested mortality against whether perch guards were implemented in the APWRA, and found that mortality was no different for most species and even a little greater for a couple of raptor species.

We will point out, also, that the perch guards implemented thus far in the APWRA are unlikely to thwart perching on the wind turbines. Chicken wire was erected atop horizontal supports of some lattice towers, but this wire loses its integrity relatively quickly and falls apart (Photo 9-11). Also, raptors are perching on the rotors, work platforms and engine housing of wind turbines on both lattice and tubular towers (e.g., Photos 9-7 to 9-10), and the chicken wire cannot prevent perching on these elements when the blades are still (nor does it appear to matter).

Photo 9-7. A golden eagle perches on a lattice tower while the wind turbines of the entire string are not operating.

Photo 9-8. A raptor perches on the work platform while wind turbine is not operating.

Photo 9-9. A raptor perches on the work platform of a tower that is missing its wind turbine, and while the adjacent wind turbines are not operating.

Photo 9-10. Red-tailed hawk perched on tip of wind turbine blade.

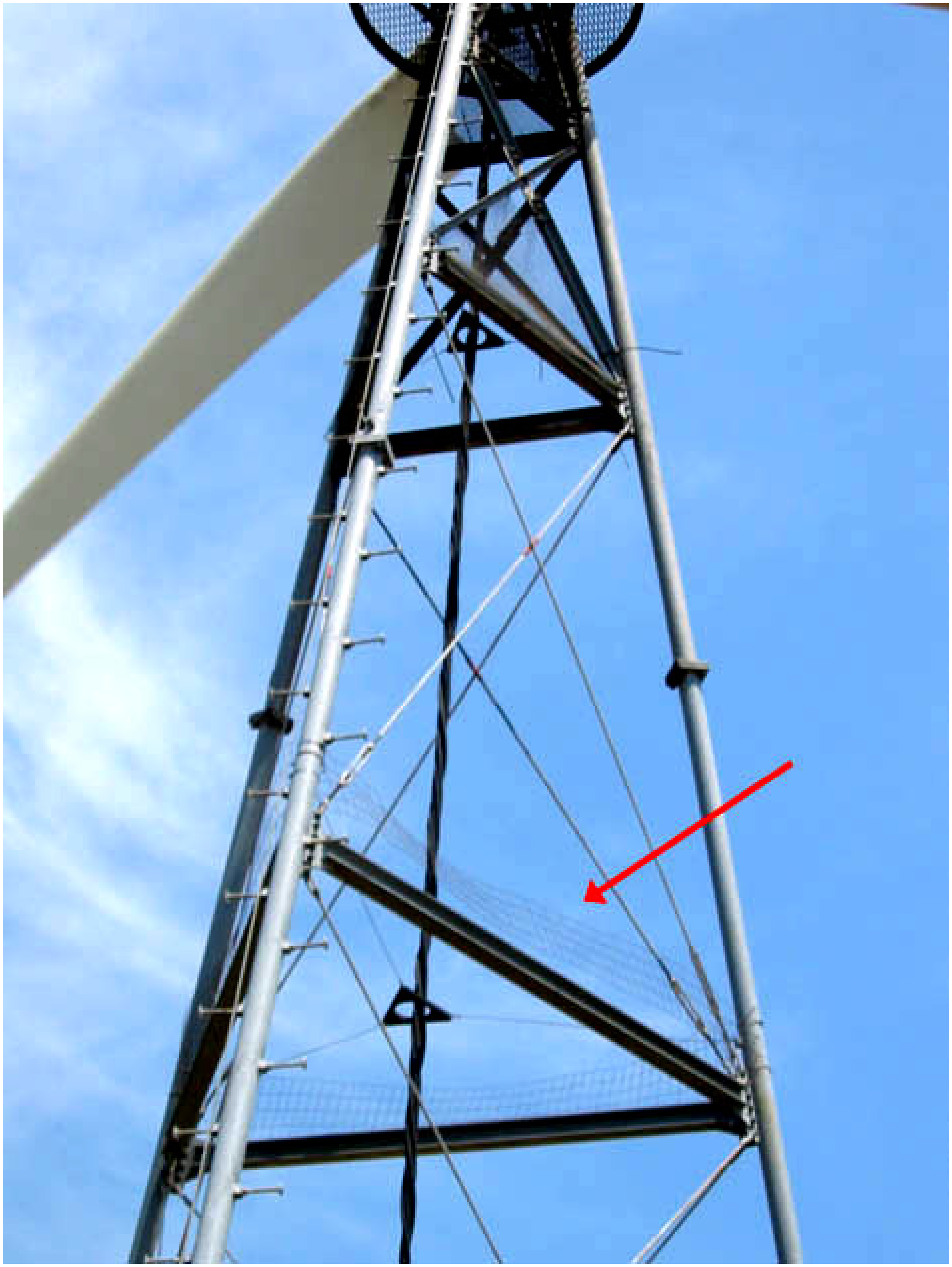

Photo 9-11. Hardware cloth (i.e., chicken wire) used as perch guard on lattice tower.

- No. 5. Install bird flight diverters

Because we found wind turbines at the ends of strings and at the edges of clusters of turbines to kill disproportionately more birds, we hypothesized that a pair of benign pole structures could serve as dummy wind turbines beyond the ends of strings and edges of turbine clusters. These poles could be placed 5 to 10 m apart and just beyond the rotor plane of the wind turbine at the end of a string, and they could extend upward to near the high reach of the turbine's blades (Photo 9-12). The idea is to encourage birds to fly wider around the end of the turbine string, thereby adding distance between the bird's flight path and the operating wind turbines.

Poles serving as flight diverters should be installed without guy wires, because guy wires pose collision hazards to flying birds. They should also be designed to disallow perching. Pointed tops might be one design to achieve this. Coarse wire mesh strung between poles might enhance the barrier effect, though it might also reduce wind reaching the rotor planes of the wind turbines. Another way to achieve the desired effect in some cases is to remove the wind turbine from an existing tower and leave the tower in place.

Photo 9-12. Two poles placed at the end of a turbine row might divert bird flights away from the end turbine, thereby reducing mortality.

- No. 6. Alternative perches

The APWRA now offers birds many perches that were not present prior to construction of the wind turbines. These perches are on thousands of wind turbines and their towers, and on many ancillary structures. We do not believe alternative perches would substantially attract perching birds away from the thousands of perches available already.

- No. 7. Barricade the rotor plane

Many who first learn of the wind turbine-caused bird mortality problem ask why barriers cannot be erected to keep birds from flying into moving blades. Simply put, this measure would be overwhelmingly costly and impractical, and it would likely reduce the wind power that could be generated because any such structure would impede wind flow.

- No. 8. Paint blades using the Hodos et al. scheme

The patented (U.S. Patent No. 6,623,243) blade-painting scheme developed by Hodos et al. (2001) may reduce the distance upon which motion smear is experienced by raptors from ~10 m to ~5 m. Essentially, it involves one blade painted black and two painted white, but achieved cumulatively by precise, evenly distributed painting of black bands on all blades. We cannot predict whether this will work to reduce fatalities. However, it appears to have promise and we recommend that this painting scheme be implemented on an experimental basis, beginning with a selection of wind turbines with the worst fatality records.

- No. 9. Remove derelict and non-operating wind turbines and coordinate timing of operational turbines

We found evidence that suggests raptors are killed disproportionately more often by wind turbines adjacent to broken wind turbines. Possibly, birds often fly wide of broken wind turbines because another raptor is perched on the broken wind turbine. (Recall our results revealed that perching on wind turbines was mostly on wind turbines that were either turned off or broken.) A raptor flying through the rotor zone in which another raptor is perched atop the tower of a broken or missing wind turbine might not notice or see the moving blades of an adjacent wind turbine, subsequently getting struck. Broken or non-operational wind turbines should be fixed, replaced, or removed along with their towers and the gaps created filled with wind turbines moved from other, more dangerous locations, but while not creating gaps from where these relocated turbines are moved.

The relationship between broken wind turbines and raptor mortality, as well as our results on perching behaviors, also suggest that turbine strings are most dangerous when some wind turbines are turned on while others are turned off. Bird mortality might be reduced by coordinating the operations of the wind turbines in a string, so they are either all on or all off. In the APWRA this practice is likely made difficult by the site variation in wind speeds due to a complex topography.

- No. 10. Relocate selected wind turbines

Certain wind turbines kill disproportionately more birds because of where those wind turbines are located. Relocating some wind turbines might substantially reduce bird mortality. For example, wind turbines could be moved out of canyons, and more isolated wind turbines could be moved closer to clusters of other wind turbines. If relocations are pursued, we recommend prioritizing wind turbines that are more isolated and in canyons or on steep slopes, especially those at lower elevations. They could be moved to fill existing gaps in strings of wind turbines, or to replace derelict wind turbines or towers lacking turbines.

- No. 11. Install wind turbine designs beneficial to the APWRA

Based on our findings that raptors appear to avoid operating wind turbines as well as densely packed turbine fields and wind walls, we hypothesize that increasing the busy appearance of a wind farm might discourage many bird species from flying there. We suggested rearranging the APWRA so that gaps are filled and isolated wind turbines are moved into groups of others, but this concept could be taken in a different direction, as well. Another wind turbine design—one that appears busy—might be preferable for use in the APWRA over conventional horizontal- and vertical-axis rotor designs.

Busy turbine designs could be installed in between the larger wind turbines, thereby forming wind walls. These wind walls could be developed on the most prominent ridge crests, where raptor mortality has been disproportionately less than on other landscape features. We predict that such wind walls, covering a smaller and less dangerous portion of the APWRA, could substantially reduce bird mortality.

- No. 12. Install accelerometers to improve turbine operation safety

Researchers and others familiar with the wind turbine-caused mortality problem have frequently suggested shutting down wind turbines during more dangerous times of the year. We found, however, that periods of the year during which birds are most susceptible vary substantially among species. For example, shutting down wind turbines during summer to protect golden eagles will do little to curb the mortality of red-tailed hawk, burrowing owl, and many other species.

Upon further research it might be learned that wind turbine operations during specific times of the day are more hazardous to birds. For example, operations during the night might be more dangerous, or operations during the early morning (this is only speculation on our part, and serves as examples). Precise periods of greatest danger might be ascertained by installing specially designed accelerometers. These devices, properly designed and installed, may be able to detect the precise time of each bird collision. With sufficient data on times and conditions of bird collisions, patterns might emerge that inform manages of opportune times of the day, or year, when temporary shutdowns of certain wind turbines can substantially lessen bird mortality.

- No. 13. Implement the means to effectively monitor each wind turbine's operation

We suspect that the proportion of time the wind turbine operates also relates to the number of bird fatalities occurring at that turbine. The distribution of times each wind turbine operates throughout the day and throughout the year also likely influences bird mortality specific to each turbine. However, we were unable to measure these factors because we were unable to produce adequate data on individual wind turbine operations. By installing the appropriate equipment and the appropriate database structure and software, and by employing qualified administrators of the system, the information gained would contribute substantially toward more resolute and therefore reliable estimates of future mortality. Such an improved monitoring system of wind turbine operations would also enable analysts to quantify associations between mortality and other measured factors more reliably, because the system would then account for much of the current noise in the data set produced by differential operations of wind turbines in the APWRA. We suspect that such a system would also lead to more cost-effective decisions in how the APWRA is managed.

- No. 14. Retrofit hazardous electrical distribution poles

Birds continue to be electrocuted in the APWRA, so all APLIC non-compliant poles should be identified and retrofitted as soon as possible.

- No. 15. Repower using turbines with high rotor planes

Flight heights recorded for raptors indicate that taller rotor planes may reduce mortality. We recommend that wind turbine designs used for repowering should have rotor planes with the lowest reach no lower than 29 meters above ground.

- No. 16. Acquire off-site conservation easements

Because the bird mortality caused by wind turbines in the APWRA will likely never be reduced to zero, the wind industry ought to provide compensatory mitigation. The purchase of conservation easements on lands surrounding the APWRA would contribute to raptor conservation because the Altamont Hills and surrounding areas are under intense pressure to convert to homes, industrial facilities, and a highway. Conservation easements should include conditions, such as no rodent control, and they should permanently protect the land from conversions to uses incompatible with its use as wildlife habitat. The appropriate spatial area to be put in conservation easements could be arrived at by first estimating the species-specific mortalities that will remain after other mitigation measures are implemented. Second, the spatial areas typically used by the numbers of birds killed could by tallied and multiplied by a factor appropriate to the continuing annual loss of that number of birds. That is, a mitigation ratio could be derived that accounts for the APWRA's performance as an ecological sink.

The approach of Smallwood (2001) could be used to estimate the appropriate area needed to protect the number of individual birds of a particular species that will be taken in the APWRA following implementation of other mitigation measures. We recommend that the estimated number of birds killed over a ten-year period be used as the input term to Smallwood's (2001) estimator of the area need to support that number of individuals killed. For example, if it is estimated that 300 golden eagles will be killed over the next ten years following the implementation of mitigation measures, then the area needed to support 300 golden eagles should be protected with conservation easements. We cannot say what that area would be until we collected a sufficient number of population estimates for reliable application of the Smallwood (2001) method.

It would be reasonable to assume that the area protected for the largest and longest-lived raptor species, i.e., golden eagle, would sufficiently protect similar proportions of other raptor species such as red-tailed hawk, American kestrel, and burrowing owl (Cousins 1990).

9.2 IMPLEMENT MEASURES TO REDUCE IMPACTS

There are two approaches available to implement mitigation measures that are intended to reduce impacts to birds in the APWRA. Each has its own merits. One approach is experimental and the other is universal in implementation.

In the experimental approach, a particular mitigation measure is applied only to a sample of wind turbines, and the rest of the wind turbines are treated as experimental controls. This approach seeks to manipulate the variation in fatalities in order to attribute statistical confidence to any measured change in mortality due to the mitigation measure. A positive aspect of this approach is the accumulation of scientific certainty in the effectiveness of the mitigation measure as sample sizes of fatalities increase. This approach hedges expenditures against a potentially ineffective mitigation measure, or against one that causes unforeseen additional impacts. Should the experiment reveal the measure to be ineffective, then the measure can be withdrawn with less financial loss than would be realized by a universal implementation of the measure. Another positive aspect of this approach is that a withdrawal of an ineffective measure allows for the mitigation funds to be redirected toward a potentially more effective measure. A negative aspect of this approach is the unabated mortality that will take place amongst wind turbines treated as experimental controls. If this unabated mortality is unacceptable, then a different approach is warranted.

Universal implementation of a treatment is typical of conservation applications, such as endangered species habitat restoration. It is typical of situations where the resource managers cannot afford the luxury of experimental manipulations when enough is known to apply a remedy with a reasonable likelihood of success. Sometimes it is important to act universally in order to stem a dire outcome, and at times like these experimentation might hasten or contribute to the dire outcome. In this case the public and the regulatory agencies must decide whether knowingly allowing continued mortality for the sake of experimentation is warranted. It may be that enough is known about the likely effectiveness of certain mitigation measures to warrant their universal implementation. Perhaps certain other measures ought to be applied in an experimental fashion.

The context of this decision on approach is also important. In the case of the APWRA, a decade of research has provided an empirical foundation of mortality patterns against which future mortality patterns can be compared in the context of a mensurative experiment (*sensu* Hurlbert 1984), even if certain mitigation measures are universally applied. Associations between fatalities and a suite of factors in the measured set of wind turbines can be compared to similarly quantified future associations in order to assess the effectiveness of a universally applied mitigation measure. For example, it should be possible to detect the effectiveness of cessation of rodent control across the entire APWRA because we currently have measured associations between mortality and levels of rodent control, including where rodent control has not been implemented. In essence, we have the foundation of a before-after, control-impact (BACI) experimental design for ceasing rodent control. Even universal applications of certain mitigation measures can be studied in the context of an experiment.

The implementation of multiple mitigation measures will likely change the attributes of wind turbines that continue to operate in the same locations. For example, the removal of isolated wind turbines from canyons to fill gaps in wind turbine strings on ridge crests would fundamentally change the attributes of the wind turbines moved, as well as the attributes of their new neighbor wind turbines that formerly were positioned next to a gap. As the attributes of wind turbines change due to the implementation of multiple mitigation measures, our predictions of the wind turbines' relative threat to birds will also change. For this reason we do not recommend over-reliance on our indicators of relative threat (Chapter 7) for selecting wind turbines as priority targets of mitigation. Our indicators of relative threat should be useful as one of multiple tools in developing a management plan for the APWRA. The principal tool will be familiarity with the relationships described in this report, as well as with the shortcomings and strengths of the supporting study.

It is important to also recognize that the APWRA is composed of thousands of outdated wind turbines, machines that are not going to be installed elsewhere in the future. Certain mitigation measures that prove effective in the APWRA might be relevant to other wind farms, whereas others may be irrelevant to other wind farms or new wind turbines to be installed in the APWRA. Additional insights into patterns of mortality caused by existing wind turbines in the APWRA largely pertain to the remaining period of operations of these wind turbines in the APWRA, which may be relatively short. Experiments with broader implications to wind energy generation might be more effectively performed at wind farms with modern wind turbines or perhaps in the APWRA while modern wind turbines are installed during the repowering process.

We recommend that the following measures be withdrawn from further consideration as mitigation for bird fatalities in the APWRA.

- Installing perch Guards
- Providing alternative perches
- Barricading the rotor planes of turbines
- Rodent control
- The use of WRRS as a monitoring program

We suggest that the following measures be considered for implementation throughout the APWRA.

- Replace the WRRS monitoring approach with a more scientifically defensible monitoring program (see above)
- Cease the rodent control program (see above)
- Move rock piles away from wind turbines
- Reduce vertical and lateral edge in slope cuts and nearby roads
- Retrofit tower pads to prevent under-burrowing by small mammals
- Install flight diverters
- Remove broken and non-operating wind turbines
- Relocate selected, highly dangerous wind turbines
- Install wind turbine designs beneficial to the APWRA bird fatality issue
- Implement the means to effectively monitor each wind turbine's output
- Retrofit, using APLIC guidelines, noncompliant power poles
- Acquire conservation easements offsite

The following measures would be appropriately applied experimentally due to the degree of uncertainty in their likely effectiveness. However, these measures could also be applied universally, but with the understanding that they might not substantially reduce bird mortality.

- Exclude cattle from wind turbines
- Install flight diverters
- Paint blades using Hodos et al. scheme
- Experiment with devices that will identify when to operate problem wind turbines with the least effect on birds.

We recommend implementing mitigation measures generally in the following order of priority.

Priority	***Mitigation Measure***
(1)	• Cease rodent control program • Acquire conservation easements offsite • Replace the WRRS with a scientifically defensible monitoring program • Install flight diverters • Paint blades using Hodos scheme • Remove broken and non-operating wind turbines • Relocate wind turbines • Install wind turbine designs appropriate to the APWRA • Retrofit APLIC non-compliant power poles
(2)	• Reduce vertical and lateral edge • Move rock piles • Exclude cattle from wind turbines • Retrofit tower pads to prevent under-burrowing by small mammals • Install accelerometers to learn when to shutdown wind turbines • Implement the means to effectively monitor each wind turbine's operation

We recommend that scientifically defensible monitoring be conducted by qualified, independent scientists in concert with the implementation of any and all other mitigation measures. Also, thresholds of success should be decided upon prior to implementation of the monitoring program so that it is understood by all parties what level of mortality reduction is expected. Alternative prescriptions should also be decided upon so that if the success thresholds are not met it is understood what will happen next. One prescription could include taking certain turbines out of production in some portion of the APWRA, and another could be universally applying a measure that proves useful in limited, experimental trials.

9.3 FUTURE RESEARCH NEEDS FOR IMPROVED PERFORMANCE OF THE PREDICTIVE MODEL

We mapped and characterized 4,074 wind turbines, but we did not map or characterize 1,326 others in the APWRA. Therefore, we were unable to extend our model predictions to these wind turbines. It would be beneficial to return to the APWRA to complete our database of wind turbines so that mortality predictions could be extended across the entire wind farm. This would be especially useful if turbine siting or repowering occurs in areas where we collected no data.

More thorough mapping of animal burrows would be helpful, whereby we map all animal burrow systems within 90 m of many more of the wind turbine strings in the APWRA. This increased level of effort would be most productive in areas where rodent control is not implemented, such as in the northwestern portion of the APWRA.

Another small mammal burrow-system mapping effort should be performed at locations in the APWRA where there are no wind turbines but where wind turbines could be sited based on physical relief. This mapping effort would enable a comparison of natural fossorial animal distributions and those that occur around wind turbines.

9.4 WHAT HAVE WE LEARNED?

The research findings presented in this report offer insights, and hopefully solutions, to some long-standing and perplexing issues that confront the wind industry in the Altamont Pass Wind Resource Area. We have learned that these issues are complex and many of them may never be resolved. Research began in the APWRA with the goal of learning about the scope of the problem and searches for dead birds were the main focus. Studies soon moved toward learning more about the underlying causes of these fatalities. This research led us next to learn more about the complex ecological relationships that govern bird use and behavior, and how those translate into bird fatalities. We eventually honed the focus of the research into learning how raptors and their prey distribute themselves on the landscape, and how their interactions affect turbine-caused mortality. Lastly, we attempted to integrate these fragments of information into a coherent and useful predictive model. The purpose of this model is to provide a tool that will direct operational changes in the APWRA to achieve a reduction in fatalities. Eventually, as the next generation of fewer but larger turbines is installed, this same information will hopefully contribute to turbine siting criteria that will minimize bird mortality, at least for certain species.

As with most studies of this type and scale, we set out to achieve some specific objectives. We believe we met them, but in the process we learned that there are many more new questions that were uncovered and remain unanswered. Our research has left the door open for more research, but more importantly, for a next step in the process, to effectively reduce fatalities in a timely manner and with the least cost to the wind industry.

Through this research we have learned that more birds are being killed by the wind turbines in the APWRA than the habitat within its boundaries can support, a situation which many define as an ecological sink. For example, Hunt (2002) monitored about 60 pairs of golden eagles in his 9,000 km^2 study area, which overlapped the APWRA. Those 60 pairs translate to 0.013 golden eagles per km^2. Extrapolating Hunt's reported density for golden eagles to the 160-km^2 APWRA, we can expect its habitat capacity to support the equivalent to two golden eagles, or one pair. Therefore, our estimated annual death of 75 to 116 golden eagles far exceeds the APWRA's habitat capacity based on a regional comparison and, therefore, it is reasonable to conclude that the APWRA is an ecological sink for golden eagles. This is probably true for other bird species as well, especially some raptors.

Every year many golden eagles enter the APWRA but they do not leave. Many of these are subadults and 'floaters' (see Hunt 1998, Hunt 2002). Many originated in other portions of the species' geographic range, and not necessarily from the APWRA region. The annual loss of these important age classes is a cumulative impact attributable to the APWRA, but the biological significance of these losses is unknown.

As with golden eagles, the APWRA is likely an ecological sink for many other bird species, but again with unknown consequences to the species or the ecosystems of which they are a part. Given that the biological significance of these impacts are unknown, it is prudent, and consistent with state and federal regulatory policy, to consider the biological impacts of the APWRA to be significant and to require substantial measures to avoid, minimize, or otherwise compensate to offset these impacts.

In our study we considered multiple factors that may potentially influence bird mortality caused by wind turbines in the APWRA. Some of the factors we addressed were added to our study as it progressed. The more we studied the situation, the more we realized the complexity of the ecological inter-relationships that were affecting how and why certain species collide with wind turbines.

In addition to the ecological complexity of the APWRA, our study design was constrained by its post-hoc nature. We had little to no control over the replication and interspersion of treatments, including control treatments. Thus, our results were prone to inflation of measured effects and to confounding. We also had little control over the application of sampling effort across the APWRA, and so the differential sampling effort we applied precluded multivariate statistical methods, which would have been useful for managing the shared variation among measured variables. These factors required us to rely on univariate statistical tests. Our experience in performing this study taught us that the use of a before-after, control-impact (BACI) design will be critical to reducing fatalities in the near future, and to ensure that long term repowering efforts in the APWRA will result in significantly fewer bird kills.

Despite our experimental design limitations, we still learned enough about wind turbine-caused bird fatalities to recommend a series of useful mitigation measures. Most of these recommended mitigation measures assume that: (1) universal rather than experimental implementation is preferable, and (2) the current mix of wind turbines will be operating for an extended period and that repowering is at least 3-5 years in the future.

If the APWRA were repowered within the next 3 - 5 years, then experimental testing of mitigation measures would reduce mortality only where mitigation treatments were applied as tests. No progress at reducing mortality would occur at those wind turbines used as control treatments, or those not included in the experiment(s). Furthermore, the outcome of some experiment(s) may not apply to the repowered APWRA since there will be significant differences in wind turbine hardware designs and the wind farm configuration. The desired effects that could result from implementing our recommended mitigation measures are dependent upon their rapid implementation over most, if not all, of the APWRA.

If some of our mitigation measures are tested experimentally in the APWRA, then we recommend that the experiment(s) include an adequate sample size of wind turbines and a sufficiently long duration to detect treatment differences, as well as appropriate replication and interspersion of treatments. The appropriate sample size of wind turbines should be estimated by use of our data applied to power analysis. We determined that reliable estimates of mortality require at least three years of monitoring of bird carcasses under and around wind turbines. Therefore, three years should be the minimum duration of any experiment(s) of mitigation measures in the APWRA. An experiment lasting less than three years, and including only a few hundred wind turbines per treatment, would likely generate unreliable results, as would a pseudoreplicated experimental design. Mitigation experiments performed on a small portion of a nearly obsolete wind farm is not an effective solution to the bird mortality problem.

We predict that the near-universal implementation of all our recommended mitigation measures may reduce mortality by 20 to 40%, or perhaps as much as 50% if the mitigation measures act synergistically. These levels of mortality reduction may be unacceptable to some since the remaining level of mortality, which would be seemingly unavoidable, would represent continued violation of the federal Migratory Bird Treaty Act, plus other state and federal environmental laws and regulations. The environmental consequences of such long-term cumulative impacts to birds remain undetermined.

If avoidance and minimization techniques cannot entirely offset the number of bird kills, then compensatory mitigation may be warranted to offset the portion of unavoidable impacts. This compensatory mitigation typically involves the purchase and conservation of habitat, the amount of which is reached through negotiations with the appropriate agencies. Compensatory mitigation should be negotiated and implemented sooner than later because the impacts of the APWRA are on-going, as is habitat destruction due to other human activities throughout the region.

Potentially, the most substantial and the quickest means of reducing and minimizing wind turbine-caused bird mortality, short of decommissioning the APWRA, may be repowering the APWRA with fewer wind turbines mounted on taller towers and with larger individual output capacities. This is technically feasible given recent improvements in turbine design. Our flight height data indicate that the repowered APWRA would kill many fewer raptors than the current APWRA, especially if the repowered APWRA included using only the tallest proposed towers.

Turbines with blades that extend no closer to the ground than 29 m would sweep a portion of the sky that is visited rarely by American kestrels, perhaps never by burrowing owls, on far fewer occasions by red-tailed hawks, and about half as often by golden eagles. We believe that serious consideration should be given to wind turbine models and tower designs that significantly raise the rotor planes in the APWRA. Coupled with this consideration, a carefully designed new APWRA, in which wind turbines are sited on the portions of the landscape that were associated least with raptor fatalities, will likely result in more reduction and minimization of bird impacts than will the implementation of our palette of proposed mitigation measures and the continued operation of the existing turbines in the APWRA.

If a repowered APWRA is pursued, then an appropriate BACI monitoring design should be added to the careful siting of sufficiently tall wind turbines. At least one year of scientifically defensible behavior observations should precede wind turbine installation, both where the wind turbines are to be installed as well as at locations with similar conditions and that are to be used as experimental control sites. Pre- and post-project carcass searches should also be performed in order to reliably estimate the impacts of the repowered APWRA. Also, rodents and lagomorphs should be sampled and mapped prior to and following the installation of the new wind turbines, so that ecological changes can be factored into analyses of the mortality and behavior monitoring data. Future study designs should closely follow the protocols established in this report to allow for a reliable BACI experiment with comparable results that are necessary for robust statistical analyses.

We are optimistic that bird mortality can be reduced substantially if the wind turbine owners/operators implement most, if not all, of the recommended mitigation measures over much, if not all, of the APWRA. We have learned enough to develop an aggressive, practical, and cost effective implementation plan. We believe that thoughtful repowering of the APWRA in the long term offers the greatest potential for reducing bird mortality. But until that occurs, this report offers the means to reduce bird mortality while the existing turbines continue to operate.

REFERENCES

Alameda County. 1998. Repowering a portion of the Altamont wind resource area. Final Environmental Impact Report. Community Development Agency. State Clearinghouse No. 98022024.

Anderson, R., W. Erickson, D. Strickland, M. Bourassa, K. J. Bay, and K. J. Sernka. 2004a. Avian monitoring and risk assessment at the Tehachapi Pass Wind Resource Area: Subcontract Draft Report May 1996–October 1998. National Renewable Energy Laboratory, under preparation.

Anderson, R., W. Erickson, D. Strickland, M. Bourassa, K. J. Bay, and K. J. Sernka. 2004b. Avian monitoring and risk assessment at the San Gorgonio Wind Resource Area: Subcontract Draft Report May. Phase I: March 1997–May 1998. Phase II: August 1999–August 2000. National Renewable Energy Laboratory, under preparation.

Anderson, R., W. Erickson, D. Strickland, M. Bourassa, J. Tom, and N. Neumann. 2001. Avian monitoring and risk assessment at Tehachapi Pass and San Gorgonio Pass Wind Resource Areas, California. In *Proceedings of National Avian-Wind Power Planning Meeting III, San Diego, California, May 1998.* Prepared for the Avian Subcommittee of the National Wind Coordinating Committee, 31–46. King City, Ontario: LGL Ltd.

Anderson, R., M., Morrison, K. Sinclair, D. Strickland. 1999. Studying wind energy and bird interactions: A guidance document. National Wind Coordinating Committee. Washington, D.C. 87 pp.

Battaglin, W. A., and D. A. Goolsby. 1995. Spatial data in Geographic Information System format on agricultural chemical use, land use, and cropping practices in the United States. U.S. Geological Survey, Water Resources Investigations Report 94-4176, Denver. 87 pp.

Blackburn T. M., and K. J. Gaston. 1996. “Abundance-body size relationships: The area you census tells you more.” *Oikos* 75:303–309.

Cade, T. 1995. Industry research: Kenetech Windpower. In *Proceedings of National Avian-Wind Power Planning Meeting, Lakewood, Colorado*, ed. LGL Ltd., environmental research associates, 36–39. National Renewable Energy Laboratory, Golden, Colorado. 145 pp.

Cairns J., Jr. and P. V. McCormick. 1992. “Developing an ecosystem-based capability for ecological risk assessments.” *The Environmental Professional* 14:186–196.

California Fish and Game Department. 1992. Special animals list. Natural Diversity Data Base, Sacramento, California.

Carnie, S. K. 1954. “Food habits of nesting golden eagles in the coast ranges of California.” *Condor* 56:3–12.

Colson and Associates. 1995. Avian interactions with wind energy facilities: A summary. Prepared by Colson & Associates for AWEA, Washington, D.C.

Contra Costa County. 2004. Buena vista windpower project Draft EIR. Contra Costa County Community Development Department, Martinez, CA. http://www.co.contra-costa.ca.us/depart/cd/current/BuenaVistaDEIR/

Cousins, S. H. 1990. "Countable Ecosystems Deriving from a New Food Web Entity." *Oikos* 57:270–275.

Craighead, J. J., and F. C. Craighead, Jr. 1956. *Hawks, owls and wildlife.* Stackpole Books, Harrisburg, Pennsylvania. 443 pp.

Curry, R. C., and P. Kerlinger. 2000. Avian mitigation plan: Kenetech model wind turbines, Altamont Pass WRA, California. In *Proceedings of National Avian-Wind Power Planning Meeting III, San Diego, California, May 1998,* prepared for the Avian Subcommittee of the National Wind Coordinating Committee by LGL Ltd., King City, Ontario. 18–27.

Erickson, W. P., J. Jeffrey, K. Kronner, and K. Bay. 2003. Stateline wind project wildlife monitoring annual report, results for the period July 2001–December 2002. Technical Report submitted to FPL Energy, the Oregon Office of Energy and the Stateline Technical Advisory Committee.

Erickson, W. P., G. D. Johnson, M. D. Strickland, D. P. Young, Jr., K. J. Sernka, and R. E. Good. 2001. Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collision mortality in the United States. National Wind Coordinating Committee, c/o RESOLVE, Washington, D.C. 62 pp.

Erickson, W. P., G. D. Johnson, M. D. Strickland, K. Kronner, P. S. Becker, and S. Orloff. 1999. Baseline avian use and behavior at the CARES Wind Plant Site, Klitchitat County, Washington. Final Report (NREL/SR-500-26902). National Renewable Energy Laboratory, Golden, Colorado. 67 pp.

Estep, J. 1989. Avian mortality at large wind energy facilities in California: Identification of a problem. Staff report P700-89-001. California Energy Commission, Sacramento.

Environmental Science Associates. 2002. Solano County High Winds Power Project Environmental Impact Report. Prepared for Solano County Department of Environmental Management, Fairfield, California.

Fitch, H. S., R. Swenson, and D. F. Tillotson. 1946. "Behavior and food habits of the red-tailed hawk." *Condor* 48:205–237.

Gauthreaux, S. A. 1996. Suggested practices for monitoring bird populations, movements and mortality in wind resource areas. In *Proceedings of National Avian-Wind Power Planning Meeting II. Palm Springs, California, 20–22 September 1995,* prepared for the Avian Subcommittee of the National Wind Coordination Committee by RESOLVE Inc., Washington, D.C., and LGL Ltd., King City, Ontario. 152 pp.

Hodos, W., A. Potocki, T. Storm, and M. Gaffney. 2001. Reduction of motion smear to reduce avian collisions with wind turbines. In *Proceedings of National Avian-Wind Power Planning Meeting IV, Carmel, California,* ed. S. S. Schwartz, 88–105. Avian Subcommittee of the National Wind Coordinating Committee, Washington, D.C.

Hoover, S. L. 2001. The response of raptors and other prey to topographical features at the Altamont Wind Resource Area. M.S. Thesis, California State University, Sacramento. 83 pp.

Hoover, S. L., M. L. Morrison, C. Thelander, and L. Rugge 2001. Response of raptors and other prey to topographical features at the Altamont Wind Resource Area. In *Proceedings of National Avian-Wind Power Planning Meeting IV, Carmel, California,* ed. S. S. Schwartz, 16–21. Subcommittee of the National Wind Coordinating Committee, Washington, D.C.

Howell, J. A. 1997. Avian mortality at rotor swept area equivalents, Altamont Pass and Montezuma Hills, California. Transactions of the Western Section of the Wildlife Society 33:24–29.

Howell, J. A. and J. E. Didonato. 1991. Assessment of avian use and mortality related to wind turbine operations, Altamont Pass, Alameda and Contra Costa Counties, California, September 1998 through August 1989. Final report submitted to U.S. Windpower, Inc., Livermore, California. 168 pp.

Howell, J. A. and J. Noone. 1992. Examination of avian use and mortality at a U.S. Windpower wind energy development site, Montezuma Hills, Solano County, California. Final report. Prepared for Solano County Department of Environmental Management, Fairfield, California.

Howell, J. A., J. Noone, and C. Wardner. 1991. Visual experiment to reduce avian mortality related to wind turbine operations, Altamont Pass, Alameda and Contra Costa counties, California, April 1990 through March 1991. Final report. Prepared for U.S. Windpower, Inc., Livermore, California.

Hunt, G. 1994. A pilot golden eagle population project in the Altamont Pass Wind Resource Area, California. Prepared by the Predatory Bird Research Group, University of California, Santa Cruz, for the National Renewable Energy Laboratory, Golden Colorado. 212 pp.

Hunt, G. 1998. “Raptor floaters at Moffat’s equilibrium.” *Oikos* 82(1):191–197.

Hunt, G., and L. Culp. 1997. The influence of high ground squirrel densities on the occurrence of golden eagles on Altamont Ownership Consortium property. Unpublished report to Altamont Ownership Consortium. 16 pp.

Hunt, W. G. 2002. Golden eagles in a perilous landscape: Predicting the effects of mitigation for wind turbine blade-strike mortality. 500-02-043F. Consultant Report to California Energy Commission, Sacramento, California.

Hunt, W. G., R. E. Jackman, T. L. Hunt, D. E. Driscoll, and L. Culp. 1998. A population study of golden eagles in the Altamont Pass Wind Resource Area: population trend analysis 1997. Report to National Renewable Energy Laboratory, Subcontract XAT-6-16459-01. National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187–211.

Janss, G. and A. T. Clave. 2000. Bird behavior in and near a wind energy generating facility at Tarifa, Spain: Management considerations. In *Proceedings of National Avian-Wind Power Planning Meeting III, San Diego, California, May 1998,* prepared for the Avian Subcommittee of the National Wind Coordinating Committee by LGL Ltd., King City, Ontario, 110–114.

Johnson, G. J., W. P. Erickson, M. D. Strickland, M. F. Shepherd, D. A. Shepherd, and S. A. Sarappo. 2002. "Collision mortality of local and migrant birds at a large-scale wind-power development on Buffalo Ridge, Minnesota." *Wildlife Society Bulletin* 30:879–887.

Kerlinger, P. 2000. An assessment of the impacts of Green Mountain Power Corporation's Searsburg, Vermont, wind power facility on breeding and migrating birds. Pages 90-96 *in* Proceedings of National Avian-Wind Power Planning Meeting III, San Diego, California, May 1998. Prepared for the Avian Subcommittee of the National Wind Coordinating Committee by LGL Ltd., King City, Ontario. 202 pp.

Kerlinger, P., and R. Curry. 1998. A comparison of a company sponsored wildlife response and reporting system (WRRS) to intensive carcass search methods at wind turbines in the Altamont Pass, California: Golden eagle and red-tailed hawk fatalities. Unpublished report to Altamont Infrastructure Company, Livermore, California. 10 pp.

Kerlinger, P., and R. Curry. 1999. Analysis of flight patterns and pathways of golden eagles and red-tailed hawks in relation to wind turbines and topography in the Altamont Wind Resource Area (AWRA) of California. Unpublished report to Altamont Infrastructure Company, Livermore, California. 11 pp + 11 figures.

Kerlinger, P., and R. Curry. 2000. Impacts of a small wind power facility in Weld County, Colorado, on breeding, migrating, and wintering birds: preliminary results and conclusions. In *Proceedings of National Avian-Wind Power Planning Meeting III, San Diego, California, May 1998,* prepared for the Avian Subcommittee of the National Wind Coordinating Committee by LGL Ltd., King City, Ontario, 64–69.

Kerlinger, P., and R. Curry. 2001. Analysis of avian fatalities at Kenetech KVS-33 turbines in Alameda and Contra Costa Counties, California. Unpublished report to Green Ridge Power, L.L.C. 8 pp.

Kerlinger, P., and R. Curry. 2003. The relationship of golden eagle (*Aquila chrysaetos*) and red-tailed hawk (*Buteo jamaicensis*) collision fatalities in the Altamont Pass Wind Resource Area of California to ground squirrel management practices: 1989–2002. Report to Altamont Infrastructure Company, Livermore, California. 23 pp.

McIsaac, H. P. 2001. Raptor acuity and wind turbine blade conspicuity. In *Proceedings of National Avian-Wind Power Planning Meeting IV, Carmel, California,* ed. S. S. Schwartz, 59–87. Avian Subcommittee of the National Wind Coordinating Committee, Washington, D.C.

Morrison, M. L. 1996. Protocols for evaluation of existing wind developments and determination of bird mortality. In *Proceedings of National Avian-Wind Power Planning Meeting II, Palm Springs, California*, eds. Resolve, Inc. and LGL Ltd. Avian Subcommittee of the National Wind Coordinating Committee, Washington, D.C.

Morrison, M. L. 1998. Avian risk and fatality protocol. National Renewable Energy Laboratory, NREL/SR-500-24997, Golden Colorado. 7 pp.

Munsters, C. J. M., M. A. W. Noordervliet and W. J. Ter Keurs. 1996. "Bird casualties caused by a wind energy project in an estuary." *Bird Study* 43:124–126.

National Geographic Society. 1987. *Field Guide to the Birds of North America,* 2nd ed. Washington, D.C.

Olendorff, R. R. 1976. "The food habits of North American golden eagles." *Amer. Midland Naturalist*. 95:231–236.

O'Neill R.V., K. B. Jones, K. H. Ritters, J. D. Wickham, and I. A. Goodman. 1994. Landscape monitoring and assessment research plan. U.S. EPA 620/R-94/009, Environmental Protection Agency: 53 pp.

Orians, G. H., and F. Kuhlman. 1956. "Red-tailed hawk and horned owl populations in Wisconsin." *Condor* 58:371–385.

Orloff, S., and A. Flannery. 1992. Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas: 1989–1991. Report to California Energy Commission, Sacramento, California. BioSystems Analysis, Inc., Santa Cruz, California.

Orloff, S., and A. Flannery. 1996. A continued examination of avian mortality in the Altamont Pass Wind Resource Area. Report to California Energy Commission, Sacramento, California. BioSystems Analysis, Inc., Santa Cruz, California.

Pearson, Scott. Personal communication. 2000. U.S. Fish and Wildlife Service, Senior Resident Agent (retired), Sacramento, California.

Rapport D. J., H. A. Reiger, and T. C. Hutchinson. 1985. “Ecosystem behavior under stress.” *American Naturalist* 125:617–640.

Reynolds, R. T., J. M. Scott, and R. A. Nussbaum. 1980. “A variable circular-plot method for estimating bird numbers.” *Condor* 82:309–313.

Rogers, S. E., B. W. Cornaby, C. W. Rodman, P. R. Sticksel, and D. A. Tolle. 1976. Evaluation of the potential environmental effects of wind energy system development. Battelle Columbus Laboratories, Columbus, Ohio. 71 pp

Rotmans, J., M. B. A. van Asselt, A. J. de Bruin, M. G. J. den Elzen, J. de Greef, H. Hiderink, A.Y. Hoekstra, M. A. Janssen, H. W. Koster, W. J. M. Martens, L. W. Niessen, and H. J. M. de Vries. 1994. Global change and sustainable development. Global Dynamics & Sustainable Development Programme, GLOBO Report Series no. 4. RIVM, Bilthoven, The Netherlands.

Rugge, L. M. 2001. An avian risk behavior and mortality assessment at the Altamont Pass Wind Resource Area in Livermore, California. M.S. Thesis, California State University, Sacramento. 156 pp.

Schulze I., M. Colby, M. Conomos, W. Garetz, H. Lacayo, T. Stuart, P. Wilkinson, and C. Solloway. 1994. A conceptual framework to support the development and use of environmental information. Environmental Indicators Team, United States EPA, Office of Policy, Planning, and Evaluation. Washington, D.C.

Smallwood, K. S. 1993. Understanding ecological pattern and process by association and order. *Acta Oecologica* 14(3):443–462.

Smallwood, K. S. 2001. “Linking habitat restoration to meaningful units of animal demography.” *Restoration Ecology* 9:253–261**.**

Smallwood, K.S. 1999. Abating pocket gophers (*Thomomys* spp.) to regenerate forests in clearcuts. Environmental Conservation 26:59-65.

Smallwood, K.S. 2002. Habitat models based on numerical comparisons. Pages 83-95 in predicting species occurrences: Issues of scale and accuracy, J. M. Scott, P. J. Heglund, M. Morrison, M. Raphael, J. Haufler, and B. Wall, editors. Island Press, Covello, California.

Smallwood, K.S. and W.A. Erickson. 1995. Estimating gopher populations and their abatement in forest plantations. Forest Science 41:284-296.

Smallwood, K. S. and C. Schonewald. 1996. Scaling population density and spatial pattern for terrestrial, mammalian carnivores. Oecologia 105:329-335.

Smallwood, K. S. and M. L. Morrison. 1999. Spatial scaling of pocket gopher (Geomyidae) density. *Southwestern Naturalist* 44:73–82.

Smallwood, K. S, and C. M. Schonewald. 1998. Study design and interpretation for mammalian carnivore density estimates. Oecologia 113:474-491.

Smallwood, K.S., S. Geng, and M. Zhang. 2001. Comparing pocket gopher (*Thomomys bottae*) density in alfalfa stands to assess management and conservation goals in northern California. Agriculture, Ecosystems & Environment 87: 93-109.

Smallwood, K. S. and C. Thelander. 2004. Bird mortality at the Altamont Pass Wind Resource Area, March 1998 – September 2001 Final Report. National Renewable Energy Laboratory, Golden, Colorado. Draft submitted for review.

Strickland, M. D., D. P. Young, Jr., G. D. Johnson, C. E. Derby, W. P. Erickson, and J. W. Kern. 2000b. Wildlife monitoring studies for the SeaWest Wind Power development, Carbon County, Wyoming. Pages 55-63 *in* Proceedings of National Avian-Wind Power Planning Meeting III, San Diego, California, May 1998. Prepared for the Avian Subcommittee of the National Wind Coordinating Committee by LGL Ltd., King City, Ontario. 202 pp.

Strickland, M. D., G. Johnson, W. P. Erickson, and K. Kronner. 2001a. Avian studies at wind plants located at Buffalo Ridge, Minnesota and Vansycle Ridge, Oregon. Pages 38-52 *in* S. S. Schwartz, ed., Proceedings of the National Avian-Wind Power Planning Meeting IV. RESOLVE, Inc., Washington, D.C.

Strickland, M. D., W. P. Erickson, G. Johnson, D. Young, and R. Good. 2001b. Risk reduction avian studies at the Foote Creek Rim Wind Plant in Wyoming. Pages 107-114 *in* S. S. Schwartz, ed., Proceedings of the National Avian-Wind Power Planning Meeting IV. Avian Subcommittee of the National Wind Coordinating Committee, Washington, D.C., 179 pp.

Thelander, C.G. and L. Rugge. 2000a. Bird risk behaviors and fatalities at the Altamont Wind Resource Area. Pg. 5-14, *in* Proceedings of the National Avian-Wind Power Planning Meeting III. National Wind Coordinating Committee/RESOLVE. Washington, D.C.

Thelander, C. G., and L. Rugge. 2000b. Avian risk behavior and fatalities at the Altamont Wind Resource Area: March 1998 to February 1999. Report to National Renewable Energy Laboratory, Subcontract TAT-8-18209-01. National Technical Information Service, U. S. Department of Commerce, Springfield, VA.

Thelander, C. G. and L. Rugge. 2001. Examining relationships between bird risk behaviors and fatalities at the Altamont Wind Resource Area: a second year's progress report Pages 5-14 *in* S. S. Schwartz, ed., Proceedings of the National Avian-Wind Power Planning Meeting IV. Avian Subcommittee of the National Wind Coordinating Committee, Washington, D.C., 179 pp.

Thelander, C. G., S. Smallwood, and L. Rugge. 2003. Bird risk behaviors and fatalities at the Altamont Pass Wind Resource Area. Period of Performance: March 1998—December 2000. National Renewable Energy Laboratory, NREL/SR-500-33829. U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia.

Tucker, V. A, 1996a. A mathematical model of bird collisions with wind turbine rotors. *J. Solar Energy Engineering* 118: 253–262.

Tucker, V. A. 1996b. Using a collision model to design safer wind turbine rotors for birds. *J. Solar Energy Engineering* 118:263–269.

Ugoretz, S., R. Atwater, W. Fannucchi, and G. Bartelt. 2000. Wind/bird interaction studies in Wisconsin. Pages 88-89 in Proceedings of the National Avian-Wind Power Planning Meeting III. National Wind Coordinating Committee/RESOLVE. Washington, D.C.

USDA. 1994. Agricultural resources and environmental indicators. U.S. Department of Agriculture, Economic Research Service, Natural Resources and Environment Division. Agricultural Handbook No. 705, Wash., D.C.

Wilcox, B. A., K. S. Smallwood, and J. A. Kahn. 2002. Toward a forest Capital Index. Pages 285-298 *in* D.J. Rapport, W.L. Lasley, D.E. Rolston, N.O. Nielsen, C.O. Qualset, and A.B. Damania (eds.), Managing for Healthy Ecosystems, Lewis Publishers, Boca Raton, Florida USA.

Winkelman, J. E. 1992. The impact of the Sep wind park near Oosterbierum (Fr.), The Netherlands, on birds, 1: collision victims. RIN Report 92/2. DLO-Institut voor Bosen Natuuronderzoek, Arnhem, The Netherlands. 71 pp. + Appendices. (c.f., in English summary reported on pages 127-128 *in* S. S. Schwartz, ed., Proceedings of the National Avian-Wind Power Planning Meeting IV. Avian Subcommittee of the National Wind Coordinating Committee, Washington, D.C., 179 pp.)

Winkelman, J. E. 1995. Bird/wind turbine investigations in Europe. Pages 43-47 and 110-120 *in* LGL Ltd., environmental research associates, Ed. Proceedings of National Avian-Wind Power Planning Meeting, Lakewood, Colorado. National Renewable Energy Laboratory, Golden, Colorado. 145 pp.

Zhang, M., S. Geng, and K. S. Smallwood. 1998. Nitrate contamination in groundwater of Tulare County, California. Ambio 27(3): 170-174.

Zhang, M., K. S. Smallwood, and E. Anderson. 2003. Relating indicators of ecological health and integrity to assess risks to sustainable agriculture and native biota. Pages 757-768 *in* D.J. Rapport, W.L. Lasley, D.E. Rolston, N.O. Nielsen, C.O. Qualset, and A.B. Damania (eds.), Managing for Healthy Ecosystems, Lewis Publishers, Boca Raton, Florida USA.