Avian Solar Working Group Research Questions Framework

Defining Research Questions[1] and Methodological Approaches for Addressing Potential Impacts of PV Solar Plants on Bird Populations

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[1] The research questions reflect the range of concerns of the ASWG; they are not a reflection of priorities of the ASWG or any ASWG members.

ASWG Research Questions Framework Introduction

The Avian Solar Work Group was established in summer 2015 with the mission of advancing coordinated scientific research to better understand how birds interact with solar facilities. The group spent the first year collaborating to identify research topics and formulate specific research questions. In January 2016, the ASWG convened a Research Panel – consisting of experts in ecology, ornithology, demographics, biostatistical analysis, and environmental engineering – to reformulate the questions into scientifically testable hypotheses. The result is the Research Questions Framework, below, which defines target questions and a range of potential methodological approaches to research the potential impacts of PV solar facilities on bird populations.

The questions and methodological considerations included constitute a broad range of scientific inquiries of interest to the ASWG and/or its individual members. Based on discussions between the Research Panel, Agency Observers, and ASWG members, the ASWG has decided to focus initial efforts on research that informs whether water birds or other birds are attracted to solar panels because they perceive them as water bodies, sometimes referred to as "Lake Effect". ASWG will also coordinate related research on siting, background mortality, population-level effects, and feather spots. ASWG envisions its role as facilitating the development of independent third party research, partnering with others to seek research funding, and coordinating across NGOs, government, industry sectors, and research institutions. Concurrent research efforts will be pursued in concert to maximize results while minimizing time, effort, and expense.

A. Siting

1) Do avian mortality rates at PV solar power plants differ from background rates at control sites?

An important first step should be reviewing existing published and unpublished literature that assesses mortality rates at PV solar plants and/or compares them to background rates (e.g., McCrary et al. 1986, Kagan et al. 2014). Collecting new information to answer the question will require selecting an existing survey protocol or developing a new survey protocol for assessing mortality rates at multiple PV solar power plants. Most likely this will involve walking pre-established transects and counting feather spots or other signs of apparent mortalities. Where possible, attempts should be made to identify bird remains by species. A pilot study and/or literature review may be necessary to assess mean and variance in mortality encounter rates during survey transects; this information could then be used to determine minimum necessary sampling effort (i.e., number and length of transects) for subsequent surveys.

Identify appropriate reference sites on nearby undeveloped lands with vegetation and other habitat characteristics relatively similar to what was present at the solar facilities before they were constructed. Any sampling design should encompass the broadest range of habitats while taking into account heterogeneity and should have sufficient statistical power to inform decision-making. Whenever possible the industry should work collaboratively to collect and pool data across sites in order to maximize sample size. Such an approach is much preferable to single facility assessments as is typically done currently. Reference sites should be close enough to PV sites to yield inference on the critical siting questions, but not so close as to jeopardize the study design. For example, if the reference sites are too close to the PV sites, scavengers could move carcasses from the PV sites to the reference sites. This would jeopardize the study design by resulting in an underestimate of mortality rate at the PV sites and an overestimate of mortality rates at the reference sites. The size (or transect length) of reference sites need not be the same as that of the solar plants. Conduct surveys at PV solar power plants and reference sites, and compare observed mortality rates, which could be expressed in relative terms, such as observed mortalities per linear distance of transect walked. Interpreting survey results will likely require experimental trials to assess possible differences in carcass detection probability at PV versus reference sites.

Although comparing mortality rates at PV and reference sites is an appropriate way to assess the effect of PV sites on avian morality fairly rapidly, where possible it would also be beneficial and inferentially powerful to assess avian mortality at the location of intended PV facilities before they are built, allowing for a before/after control impact (BACI) study design, in which mortality rates could be assessed at PV and control sites both before and after construction of PV facilities (Smith and Dwyer 2016).

2) What is the relationship of mortality rates to site characteristics (e.g., panels, fence lines, overhead transmission lines, scale/configuration of installations, proximity to other solar facilities or other natural or human landscape features such as levels of fragmentation and loss of habitat, migratory flyways and stop over sites, etc.)?

This question operates on at least two distinct spatial scales: within individual solar facilities, and across multiple solar facilities.

a) Within a facility, are mortalities associated with particular elements of that facility (e.g., panels, fence lines, overhead transmission lines)?

This could be answered by collating and interpreting existing information on mortalities, and/or by establishing new mortality monitoring efforts that classify observed mortalities at one or (preferably) more facilities according to the particular elements with which they are associated. Statistical modeling, using a frequentist or Bayesian framework, could then be used to test for associations between mortality and particular facility elements. Comparing mortality rates associated with particular elements of facilities may require explicitly assessing carcass detection probability in proximity to those different elements.

b) Among facilities, do location and landscape features affect mortality rates?

Define *a priori* a small set of site variables (e.g., scale/configuration of installations, proximity to other solar facilities or other natural or human landscape features such as levels of fragmentation and loss of habitat, migratory flyways and stop over sites) and statistically test associations between those variables and mortality rates at different facilities, using data from past, ongoing, and perhaps new monitoring programs. Comparing mortality rates between sites may require explicitly assessing carcass detection probability at those different sites. Site variables could include time series of land use/land cover change and fragmentation, microclimate, vegetation phenology, and proximity to water bodies measured at a high spatial resolution using satellites such as ASTER, Landsat, MODIS, and PALSAR; or distance to known migratory flyway features such as the Colorado River drainage or the Pacific Coast.

This analysis will likely be heavily constrained by sample sizes (i.e., the number, locations, and characteristics of facilities providing data) and the difficulty in clearly assigning values to the features listed, and therefore may not be fully answerable in a statistically rigorous way.

3) How might siting be optimized to reduce potential impacts on vulnerable bird populations in a cost-effective manner?

A cost/benefit analysis should be performed to assess the financial costs of siting new facilities with respect to factors determined to affect bird mortality rates (based on findings from question 2b). Also important would be to conduct a meta-analysis of vulnerable bird populations within a GIS framework. This analysis could be used to identify migratory hotspots for many key species and the most heavily used routes for vulnerable populations (following the methods in 2b).

B. Population level effects

Are solar sites causing avian mortality that is significant at the scale of the population for individual species?

Prior to beginning any population-level analysis, it is important to generate a list of the species of greatest concern. This can be accomplished through discussions with industry, NGO's and governmental organizations (such as the Bureau of Land Management and Fish and Wildlife Service). The list of candidate species can then be forwarded to each agency and scored according to priority. Finally, Breeding Bird Survey (BBS) and MAPS (Monitoring Avian Productivity and Survivorship) data can be used to assess populations that may be at risk. This information can then be cross-referenced with the results of the species prioritization list to develop a final list.

1) How should populations be defined in this context?

The most robust method currently available for identifying populations of migratory birds is genome-wide genetic data. Recent studies show that genome-wide genetic data can resolve migratory bird populations at spatial scales that are similar to existing Bird Conservation Regions (see Ruegg et al 2014). Other methods include the use of demographic attributes from long-term monitoring data to delineate natural population structure (Rushing et al 2015) or the use of hydrogen isotope ratios to define birds from distinct ecoregions (Wassenaar & Hobson 2001). Given the general lack of resolution using isotope data this method alone would not be recommended. In some cases it may be possible or desirable to use a combination of the above approaches for better resolution of populations. There may also be situations where obtaining the genetic information on populations is not possible. In these situations it might be possible to use population projection models (e.g., Franklin et al., 2000; Franklin et al., 2004; Blakesley, 2010; Dugger et al., 2015) or more arbitrary definitions of populations based upon ecologically defined geographic regions such as Bird Conservation Region boundaries or political borders (Millard et al. 2012). Regardless of the method used, all population maps should be made accessible to interested parties and the public so that multi-species comparative analyses can be conducted across multiple sites.

2) What research and data would be required to determine if mortality associated with solar sites is additive or compensatory?

Additive and compensatory mortality represent the opposite ends of a spectrum of the effects of a new form of mortality on annual survival in a population.

If a specific type of mortality is ***additive****, it will increase baseline mortality by an amount equal to the sum of baseline and the new source of mortality. If a mortality factor is* ***compensatory****, annual mortality will not increase when the new source is "added" to the population, deaths from the new source of mortality will be compensated for by a decline in other sources of mortality.*

Compensatory mortality implies density-dependent factors are acting on the population, such that associated losses of individuals are counterbalanced by enhanced survival or reproduction of other individuals, as a result of having fewer conspecific competitors. In order to distinguish whether a new source of mortality is additive or compensatory, annual mortality must be measured in the presence and absence of the new source of mortality. If there is no change in annual mortality when the new source of mortality is present, compensatory mortality is occurring. If annual mortality increases by an amount equal to the new source of mortality, the new source of mortality is completely additive. Of course, it is also possible that annual mortality will increase less than the sum of baseline and the new source of mortality in which case the mortality is partly additive. The potential for compensatory mortality to occur is influenced by the demographic characteristics of the population and whether the population is above or below its carrying capacity (Péron 2013). Species with low annual survival and high recruitment (r-selected or "fast" species) are more likely to exhibit compensatory mortality than species with high annual survival and low recruitment. In addition, species that are close to or above their carrying capacity are more likely to exhibit density dependence in both survival and recruitment than species below their carrying capacity. Although these predictions are supported by analyses of the impacts of hunting on waterfowl populations (Péron 2013), this question has not been thoroughly addressed in other groups of birds.

In practice, it is very difficult to directly measure whether a source of mortality is additive or compensatory because it requires precise measurements of annual mortality in the presence and absence of the new source of mortality. For example, despite numerous band-recovery studies involving hundreds of thousands of banded birds, there is still disagreement about whether hunting mortality acts in an additive or compensatory manner on North American waterfowl populations (Pöysä et al. 2004, Pöysä et al. 2013, Sedinger and Herzog 2012). In case of solar arrays, the task would be even more difficult because the new source of mortality would likely be very small relative to natural sources of mortality requiring even larger sample sizes than those used in waterfowl studies. Directly addressing the question of whether mortality associated with the operation of solar arrays is additive or compensatory would take many years, cost millions of dollars per species, and may not provide a definitive answer.

In the absence of direct measures of changes in mortality, the question of whether a new source of mortality is additive or compensatory can be examined using indirect approaches. For instance, if the new source of mortality generally results in the death of sick or weak individuals that were likely to die anyway, or of primarily young individuals that faced an inherently low rate of recruitment into the adult population, the new source of mortality is likely to be compensatory. On the other hand, if the new source of mortality results in the death of healthy individuals that were likely to survive the annual cycle, the new source of mortality is likely to be additive. Thus, the additive and compensatory hypotheses make different predictions about the characteristics of the individuals that die from the new source of mortality. If the age, health, body condition, parasite load, etc. of individuals that die from the new source of mortality is similar to individuals randomly selected from the population, the new source is likely to be additive. If the individuals that die from the new source of mortality are generally less healthy (e.g., poorer body condition, higher parasite loads) or are less likely to survive the annual cycle (e.g., young birds) then the new source of mortality is likely to be compensatory. Additionally, for many bird species, existing information (e.g., MAPS data) may indicate whether density dependence is likely to be an important factor in population dynamics.

3) How do population impacts differ by species, guild, migratory pathway, taxonomic unit and classification (threatened versus non-threatened), etc.?

One could investigate how population impacts differ by species, guild, migratory pathway, taxonomic unit and classification (threatened versus non-threatened) first by defining a set of genetic or morphological markers that can be used to define each of these units. If morphological assessment is still possible (depending upon the state of the carcasses), this method could be used to identify most individuals to species-level. If carcasses can be further classified into age and sex categories, then this information could also be useful for determining which segments of a population are most likely impacted. Species could be placed into guild categories based upon known ecological characteristics. All other finer scale classification levels such as populations and migratory pathway would likely require the development of high-resolution genetic markers (genome-wide genetic markers) that could differentiate between threatened versus non-threatened populations and identify populations along their migratory pathways. In cases where species level ID is not possible with morphological traits, lower-resolution genetic markers (mtDNA) could also be used to identify species. In cases where the appropriate genetic markers have been developed, population specific flyway use can be augmented with on the ground surveys such as capturing birds in mist-nets at a site adjacent to a facility and using the resulting genetic samples to assess population flyway use over time. Such information can be used to help inform operational mitigation if sensitive species and populations are concentrated during a limited time of year.

If high-resolution genetic markers identify particular population segments represented among the mortalities then demographic (e.g., from the MAPS program) and count (e.g., from the Breeding Bird Survey) data could be analyzed to compare survival rates and population growth rates of the affected population segments with other population segments. Furthermore, once populations have been defined it would be possible to identify species and populations that are at a very low risk for impacts from solar facilities so that resources can be allocated towards groups with the greatest need (Beston et al 2016). Similarly, even in the absence of results from high-resolution genetic markers or other means to isolate particular population segments that may be adversely affected, count and demographic data could be harnessed to assess overall population growth rates of any species that is frequently represented among the mortalities.

C. Lake Effect

1) Are water or other birds attracted to solar panels because they perceive them as water bodies (i.e., a “Lake Effect”)?

a) Is a “Lake Effect” possible according to the geographic and environmental infrastructure characteristics of sites?

Summarize the current information on bird mortality at PV and trough facilities including species/taxa impacted, size of projects, type of technology (tracker vs. fixed), distance between rows, habitat, proximity to waterbodies/marshes of different sizes, bird count data if available.

Use standardized methods of measuring bird mortality at a number (10 or more) of solar arrays. Examine the relationship between mortality of all birds and select groups of birds (e.g., waterbirds) and environmental/physical variables using graphical methods as well as more sophisticated linear models. We suggest developing an *a priori* set of models and using model selection to identify the most parsimonious model. Environmental variables may include: size of the solar array, east-west extent of the array, a measure of bird migration density over the site using NEXRAD or some other radar system, the type of solar panels, the length of power lines adjacent to the site, the presence, number, or spatial extent of water bodies near (possibly use a number of different distances) the site, and habitat type surrounding the site. Whenever possible, the industry should work collaboratively to collect and pool data across sites in order to maximize sample size.

b) Do birds show evidence of attraction to large solar arrays (e.g. show changes in flight direction or behavior as they approach arrays)?

Quantify flight direction and behavior at solar sites and at nearby "reference" sites. The reference sites should be in similar habitat and landscape context as the solar site and sufficiently far away (> 1 km) to ensure the solar facility is not having an impact on flight behavior.

Evidence for a change in direction towards the solar array or a decrease in altitude as birds approach a solar array compared to birds at reference sites would constitute support for the "Lake Effect" hypothesis. In addition, evidence for an increase in "approach behavior" such as circling or gliding as birds approach solar arrays would also support the "Lake Effect" hypothesis. Mobile avian radar systems that may allow assignment of individual radar traces to a particular species or group (e.g., ducks, geese) could be used to quantify flight direction as birds approach but they could be cost prohibitive. Marine radar systems provide a less costly alternative for quantifying flight direction but radar traces cannot be assigned to a species or group so observers would be needed to identify approaching birds. During daylight hours observers can quantify approach behaviors, at night, infrared cameras may allow quantification of behaviors near the facilities. However, these approaches will need to be tested for their effectiveness.

Radio/satellite telemetry of some select species might also provide information on behavior during migration and could possibly provide information on whether birds are attracted to PV facilities. As mentioned above, these approaches will need to be tested for their effectiveness before implementation on larger scales.

c) What types of birds are affected?

Conduct analyses of groups of birds (e.g., ducks, geese, loons, grebes, all waterbirds, all land birds) using the approaches outlined for questions 1a and 1b. Analyses should focus on species/groups that suffer high mortality at the solar arrays because they are likely to be the most susceptible to the Lake Effect. The methods used for each of the analyses will influence the groups that can be identified. In most cases, birds can be identified to species with visual observations. Contrasting information on use by species with mortality can help define risk as well.

d) Is possible mortality due to stranding, strikes or some other process?

Fresh carcasses from carcass surveys within solar arrays should be necropsied. Cause of death may be able to be identified in fresh specimens. This can also be determined in the field if evidence of collision is observed in the field (broken necks, wings etc.) or on the facilities (bird imprints on panels, broken panels). Frequency of live "uninjured birds" should also be evaluated. For example, water birds may land safely but unable to take off again without a body of water. Camera systems or visual observations that can document bird behavior and incidence of collision or stranding might be applied as well. Background mortality levels and species at reference sites compared to the solar sites may also help to identify the likely cause of mortality.

e) If the Lake Effect is demonstrated, what cues are causing the birds to mistake the solar array as a water body (e.g., what wavelength of reflected light are they responding to)?

Birds may use a variety of cues to identify water bodies including reflected light, changes in temperature or humidity, sound, and smell. Previous studies may shed light on the cues that are most likely used by birds to detect water and additional studies may be able to identify specific cues. For instance, if previous studies suggest that birds respond to reflected light, studies of the wavelengths of light reflected from water bodies, in conjunction with laboratory studies of the optical properties of bird vision, may provide insight into specific wavelengths that birds use to detect water bodies. Satellite images such as Landsat could be analyzed to compare the reflectance of light by lakes and PV arrays. In the portion of the electromagnetic spectrum that is visible to humans, the reflectance of clear water is 5-15% whereas that of metals like aluminum and steel is 50-90% (Richards, 2012). To assess whether the reflectance of PV arrays and lakes are perceived as similar by birds, it will be necessary to account for climatic conditions such as rain during the migratory period and the characteristics of avian vision such as birds' ability to see polarized light (Muheim et al. 2006).

Meta-analysis could be performed to better understand the sensory information birds use and design studies to test hypothesized sensory cues.

f) If a Lake Effect can be demonstrated, how might the threat be mitigated or eliminated?

If the cues that birds use to detect water bodies can be identified, research can focus on reducing those cues at solar arrays. For instance, if birds are responding to specific wavelengths of reflected light, coatings on solar panels that reduce reflectance of those wavelengths may reduce attraction but may be costly and may decrease transmittance of irradiation to the active layers. Hazing methods (harassing birds with sounds, light, or other measures) can reduce bird use of areas but their effectiveness may be temporary and often diminishes with time. Changing the deterrent response over time may diminish habituation. Layout designs and panels that match the color of existing landscape should be investigated and tested for effectiveness. If tracking technology is used, and mortality is at levels of concern and are determined to be occurring at night, stowing the panels in positions that might decrease attraction could be considered. Measuring behavior and mortality at sites in an experimental approach where different stow positions are considered might help determine optimal stow position.

D. What are the avian risk-reduction options that might lower avian mortality?

Research should focus on the decision-making processes to identify risk reduction options. This may best be accomplished by first developing a risk assessment framework (Sutter 2007). In other words, before embarking on specific risk mitigation options, detailed efforts should be made toward identifying and characterizing risks and impacts.

If it is determined that micro and macro scale factors such as location of certain arrays or the entire project influences the level of mortality, then risk-reduction would entail siting the facility or sections of the facilities into areas that are less risky for birds. Fatality rates at facilities in different locations can be compared and contrasted to identify factors that may be correlated with higher mortality. The size of the effect of these factors will affect how much monitoring data will need to be collected. Focused monitoring during a peak season at multiple sites in a region may be useful for isolating some factors, for others monitoring at multiple facilities over time may be necessary.

Other factors such as the size and configuration of the facility, type of technology (e.g. tracker vs. fixed-tilt), may be found to impact species differently. The level of the potential impact of such factors on species would also need to be evaluated to determine the necessity and degree of their implementation as risk reduction measures.

Many factors have been associated with increased collision risk to birds, especially migrating songbirds, these include: inclement weather, intense facility lighting, and height of structures. Downlighting and minimizing lights on the facility (e.g. building lighting, substation lighting) could minimize songbirds being attracted to the facility and colliding with buildings, panels, overhead lines, and other elements of the facility. For example, as a first step, lighting's possible effects on mortality could be explored through a review of existing literature (e.g. Kerlinger 2000 Kerlinger et al. 2010, Gehring et al. 2009, Gehring et al. 2011, Smith and Dwyer 2016).

Burying collector lines when feasible, and ensuring overhead lines are built to Avian Powerline Interaction Committee (APLIC 2006 and 2012) standards for minimizing potential for bird electrocution and collision are standard practices. Marking sections of lines that are considered high risk/high mortality may reduce collision risk or siting overhead lines away from high avian use areas (e.g., near wetlands) may prove to be beneficial.

A recent review of the potential effectiveness and limitations of auditory, visual and other types of avian-risk deterrents can be found in Erickson et al (2014a). However, there are few published studies on the effectiveness of deterrents. Therefore, rigorous experimental approaches to field testing of possible deterrents under different conditions should be considered. These might best be achieved through BACI studies. An important component of these studies should be to evaluate the sensitivity of specific deterrents to habituation, a factor that has limited the successful use of deterrents in the past.

E. Feather spots

1) What do feather spots represent? Can feather spots be better defined and quantified?

Surveyors conducting carcass searches often discover evidence of a carcass that only includes feathers of a bird, also called feather spots. At a PV solar energy facility it is unlikely that collision with a facility component would result in a bird's body breaking into pieces to create multiple feather spots. However, birds killed by collision with facility components could be scavenged creating feather spots prior to being discovered by personnel. In addition, evidence of bird mortality from other project related causes, such as water birds that land safely between rows of panels and die of exposure or exhaustion, could be scavenged creating feather spots. Bird mortality from other natural causes could also be scavenged creating feather spots. Natural predation by raptors or mammals can also create feather spots. Thus, when only a feather spot is detected determining an exact cause of death is problematic.

In avian fatality monitoring studies at solar energy facilities, feather spot is often defined in the survey protocol.

Finds will be classified as a fatality according to standards commonly applied in California (Altamont Pass Avian Monitoring Team 2007, CEC and CDFG 2007), which dictate that when only feathers are found, to be classified as a fatality, each find must include a feather spot of at least five tail feathers or two primaries within 5 m or less of each other, or a total of 10 feathers. Searchers will make their best attempt to classify feather spots by size according to the sizes of the species of birds or identifying features of the feathers.

Similar definitions have been used in avian fatality monitoring studies at wind energy facilities since the mid-90's. However, when looking at the origin of what constitutes a feather spot, a justification is not provided for the number of feathers used in the definition. Most wind energy avian fatality studies include feather spots as a project-caused fatality. This conservative approach has been used to avoid added monitoring costs for determining actual cause of death, and determining species of all feather spots. Further, a bird that is hit by a moving turbine blade could be broken into multiple parts and create feather spots.

The frequency at which feather spots are discovered is a function of many factors, including size of the area searched, predation rates, and carcass search interval. Higher predation rates and larger areas surveyed will likely increase the number of feather spots found. Given the potentially large number of variables involved, perhaps the best ways to determine if feather spots are due to solar installations would be to statistically compare the number of feather spots at solar facilities to a similarly-sized reference site (see below).

a) What methods can be used to identify the species and number of individuals that comprise feather spots?

Utilizing experienced personnel, including those with bird banding (or museum experience), and repeated practice, is invaluable in identifying feather spots to a species level. Bird banding/specimen experience can be difficult to find. Failing this, the skills for fatality ID can be learned with practice.

Time varies widely depending on specimen and circumstance, but based on experience from one consulting company, they are able to arrive at ID within 5-15 minutes in a lab equipped with a computer for access to online feather photographs, books, and a microscope. Experts in feather identification at universities can also be utilized. Contracting with local or national museums may also be a possibility. For many decades the Smithsonian National Museum of Natural History in Washington D.C. was considered to have one of the best trained staffs and have a long history of doing contract work for various agencies. However, whether they would have the capacity to address all the needs of the solar industry is unlikely, without more staff.

When identifying spots the following resources should be considered:

1. Pyle, P. 1997. Identification Guide to North American Birds. Part I. Slate Creek Press, Bolinas, CA.

2. Pyle, P. 2008. Identification Guide to North American Birds, Part II. Slate Creek Press, Bolinas, CA.

3. Feather Atlas (printed text and online feather guide http://www.fws.gov/lab/featheratlas/index.php)

4. Slater Wing & Tail Imaging Guide (online resource)

While visual inspection has typically been used, DNA testing can reduce uncertainty, especially for feather spots that contain parts of multiple species.

In summary, the most effective and cost efficient approach for identifying feather spots to species and determining the number of individuals they represent will be through the use of DNA technologies. Costs associated with species identification are modest while determining the number of individuals is also modest, but only if a SNP assay has already been developed.

b) Are feather spots a reliable indicator of avian strikes and/or fatalities?

Determining cause of death of a bird found at a facility is difficult, especially when the only evidence is a feather spot. As previously mentioned, the conservative approach that has been used has been to include all carcasses, including feather spots, as fatalities in the analysis. However, some studies suggest that the density of feather spots in a control area may be high enough to question the assumption that all feather spots found at a solar energy facility represent mortality caused by the facility (Erickson 2014b, Erickson et al. 2014). Additional and more robust studies of background mortality and solar facility mortality in different regions are needed to better understand impacts. It is important to ensure the reference sites are a large enough distance away from the facility to ensure there is no effect of the facility at the reference site. Placement of cameras on site to record possible collisions and interactions with panels is one approach to consider. However, because impact events may be rare, sophisticated systems for streamlining data processing (e.g. screening the videos for possible mortality events) will be necessary to reduce the resources needed and may not be cost effective.

Other methods are described below to provide context as to whether it is more likely than less likely that the feather spots were caused by the facility or other means.

Method 1: Comparison of density of carcasses, including density of feather spots between reference/control areas (without the solar facilities) and the solar facility.

These comparisons are useful in understanding background mortality for the control areas and how they compare to the solar facility mortality. However, the solar facility after being constructed could result in changes in bird densities within the facility, the predation rates, and other factors that could affect the background non-facility related mortality rate. These issues aside, a statistical comparison between a solar facility and an adjacent control site will generally allow one to estimate impacts. Comparing the species composition of the feather spots between the sites is also likely informative.

Method 2: Comparison of density of carcasses, and density of feather spots, before and after the facility is built at both the facility area and the control areas.

Using a BACI design by sampling prior to construction for live birds and carcasses at both reference areas and control areas will provide additional information as to whether the feather spots are more or less likely to be facility related.

c) Do feather spots from larger carcasses persist in the environment longer than spots from smaller ones?

Carcass persistence studies are typically a standard component of fatality studies at both wind and solar facilities. Several studies and meta-analyses have been conducted that show a very strong pattern that larger carcasses tend to persist longer in the environment than smaller carcasses. A meta-analysis of existing information from wind and solar studies will likely provide the strongest demonstration, confirming this hypothesis.

To test this particular hypothesis on a site-specific basis, implementation of standard protocols for carcass persistence trials can be conducted. The typical approach is the placing of fresh carcasses of different sizes at random locations throughout the facility and monitoring their condition over time through periodic site visits or through placement of cameras, that can also capture the type of predators. The time to transition from a carcass to a feather spot would be quantified as well as how long the feather spot persists.

F. Climate change and other broader impacts

1) What demographic effects may result from climate change in the absence of large-scale solar development, and how do these compare with the impacts of solar facilities for specific bird populations?

Climate change is likely to affect birds in complex ways, including: (a) changes to the onset of breeding and migration through changes in the timing of peak food resources that could reduce adult and juvenile survival and nesting success; (b) shifts in the geographic ranges of species in response to changes in precipitation and temperature that make portions of their ranges unsuitable to inhabit; (c) episodes of direct mortality from extreme heat waves; (d) loss of coastal or marsh habitat and flooding of nests from sea-level rise; and (e) increased mortality from the arrival of new pathogens and diseases that find a favorable habitat in California with a new climate. As a result of these processes, bird species are expected to shift their geographic ranges and avian communities are predicted to reshuffle, with new combinations of species arising.

It is difficult to determine how to compare these projected effects of climate change on birds with the impacts of solar facilities on specific bird species. Tackling this question could be done in two main ways. One approach would require developing simulation models to project the effects of climate change on demography and comparing model outcomes from various scenarios to simulations that included: (a) the direct effects of solar facilities on the demography of particular species; and (b) the potential for indirect effects on demography from the reductions of greenhouse emissions contributed by the solar plant. A second approach would be oriented toward modeling geographic ranges of birds. This approach would examine the habitat loss from current and projected solar facilities, and compare this impact to the impact on bird distributions projected from climate change scenarios in the absence of CO_2 reduction from solar facilities. Both approaches would be greatly limited by data availability, so should be considered heuristic exercises that were meant to provide general insights.

2) Using historical and contemporary data on the abundance and distribution of avian species with future climate projections, what are the predictions for the future avian distribution and population trends in California? How can this be used to mitigate the impacts of PV facilities?

In California, we are fortunate to have an unusually well documented historical record that can be used to examine changes in patterns of diversity over the past 100 years. Between 1904 and 1940, Joseph Grinnell and colleagues at the UC Berkeley Museum of Vertebrate Zoology documented and collected mammals, birds, amphibians, and reptiles from >700 locations on multiple transects spanning the environmental diversity of California. This effort resulted in a remarkable snapshot of early 20th century vertebrate diversity which includes >100,000 specimens, 74,000 pages of field notes including standardized bird count data and habitat (including vegetation) observations, and 10,000 images.

The Grinnell Resurvey Project http://mvz.berkeley.edu/Grinnell/ couples historical data with contemporary resurveys to measure avian responses to climate and land-use change and project responses to future change. Sites throughout California were originally surveyed for avian diversity from ~1908-1940 by Grinnell and colleagues. Resurveys have been completed at 240 sites of relatively low land-use change in the Sierra Nevada, Coast Ranges, and Mojave Desert. Ongoing resurveys will add 50 sites with histories of agricultural development in the Central Valley, and 30 sites in urbanized areas of the South Coast.

To make predictions on the future of birds in California, changes in species occupancy at each site can be related to changes in temperature and precipitation using existing historical climate data and to changes in land use from future efforts to map historic land cover. Bird responses to future scenarios of climate and land use could then be projected using direct measures of change over the past 75 years, in contrast to the typical space-for-time models that is used by species distribution models to predict future species occurrence based only on the climate that a species currently inhabits.

Projections of future avian occurrence provided by the Grinnell Resurvey Project could then be used to mitigate the impacts of PV facilities by identifying areas of high importance for future species range expansions, range persistence, and maintenance of bird community integrity. The project's focus on the effects of both climate and land use change enables a realistic projection of bird distributions in a state undergoing rapid human development. The project includes sites located in areas of high interest for solar development such as the Carrizo Plains, southern Central Valley, and Mojave Desert. Projected bird distributions in these areas of high relevance to PV facilities can be compared to expected distributional changes in more protected areas such as the Sierra Nevada and refuges of the Central Valley that provide a baseline of how birds are expected to respond to climate change alone, as well as to areas expected to undergo alternate forms of human development such as agricultural areas of the Central Valley and urban areas of the South Coast.

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