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Use of a Utility-Scale Solar Energy Facility by Avian Populations in Central California

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USE OF A UTILITY-SCALE SOLAR ENERGY FACILITY BY AVIAN POPULATIONS IN CENTRAL CALIFORNIA

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by

Quratulain Ahmed

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USE OF A UTILITY-SCALE SOLAR ENERGY FACILITY BY AVIAN POPULATIONS IN CENTRAL CALIFORNIA

by

Quratulain Ahmed

APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

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ABSTRACT

USE OF A UTILITY-SCALE SOLAR ENERGY FACILITY BY AVIAN POPULATIONS IN CENTRAL CALIFORNIA

by Quratulain Ahmed

With an ever-increasing demand for renewable energy in response to climate change, utility-scale solar energy (USSE) is on the rise, particularly in California. Although solar energy is viewed as an essential resource for transitioning from a fossil fuel economy, USSE installations can cover thousands of acres of habitat used by avian species. Little is known about the effects of USSE on avian populations, although some evidence suggests that USSE facilities may be leading to bird mortality. The lake-effect hypothesis suggests that birds may mistake solar arrays for large bodies of water resulting in injury or mortality. Though several studies describe the direct impacts of USSE on birds, far fewer evaluate indirect effects of USSE on birds. This study used point counts to contrast bird abundance, species richness, bird behavior and human disturbance at the Wright Solar Park (WSP), adjacent grasslands, and agricultural land. The USSE facility had lower bird abundances, species richness, and percent of birds foraging compared to both the grassland and the agricultural sites. These results indicate that USSE facilities should be placed in previously transformed locations especially urban settings that have little to no wildlife value.

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Introduction

Since the Industrial Revolution, human society has changed to be almost completely dependent on fossil fuels for energy generation. The combustion of fossil fuels, such as coal and petroleum, leads to the emission of carbon dioxide (CO_2) which is a powerful greenhouse gas and the leading culprit in the climate change crisis that humanity and all species are faced with today. The continuing emission of CO_2 for energy generation, transportation, and industry adds to the concentration of CO_2 in the Earth's atmosphere, increasing the overall temperature of the Earth. Climate change, due to increasing global temperatures, is already leading to significant changes globally that are likely have negative effects on the human population and on the natural world (Pörtner et al., 2022). Efforts to combat climate change have led to the growth and expansion of renewable energy resources, such as wind, solar and geothermal.

The primary objective of renewable energy is to produce clean, emission-free, inexhaustible energy to replace fossil fuel combustion. One of the most common forms of renewable energy is solar power. In 2020, solar generation made up only three percent of US electricity, but is projected to be 20% by 2050 (U.S. Energy Information Administration, 2021). In 2020, solar power made up 15% of California's in-state generation and made up 33% of the country's total solar generation (Nyberg, 2022). Clean energy contribution in California is expected to increase to 86% by 2030 and reach 100% by 2035 (Long et al., 2020). Solar power can be harnessed by converting energy from direct sunlight into electricity. Though the average consumer can install solar panels on their rooftops, large scale solar power plants are becoming the norm to provide energy for entire communities.

The two types of solar energy generating facilities are photovoltaic (PV) facilities and concentrated solar power (CSP) plants. Both require large tracts of land to compete with the average coal-fired power plant. These are called utility-scale solar energy (USSE) facilities and are typically placed in deserts or other empty, non-human inhabited areas with long-term, consistent sunlight exposure.

Although the solar power is considered an "environmentally-friendly" solution to the energy issue, solar power facilities occupy vast tracts of open land that support a diversity of species. Avian populations, in particular, may be negatively impacted by the rise of USSE because of these facilities' large land use footprint and geographic placement (Hernandez et al., 2014). The impact on the general use by avian species of areas occupied by USSE facilities has not been quantified. Wildlife managers need information on how such facilities are affecting species' use so that they can help find ways to mitigate or eliminate such impacts, as this branch of the solar industry continues to grow.

Literature Review

Since the Industrial Revolution, humankind has relied on fossil fuel combustion almost exclusively as the sole energy production method. The continuing use of fossil fuels over the years has led to a significant increase in the concentration of greenhouse gases in the Earth's atmosphere. Increasing greenhouse gas levels, especially CO_2, in the atmosphere are driving an overall warming of the Earth's climate. In 2018, the Intergovernmental Panel on Climate Change released a report stating that the world is on track to exceed its carbon budget within the next 12 years (Long et al., 2020). Anthropogenic climate change has begun to have severe detrimental effects on the Earth's natural systems, including an overall warming of land and ocean temperatures, spatial and temporal change of precipitation patterns, rising sea level, and increased frequency of severe weather events (Gitay et al., 2002).

These changes have already affected global biodiversity. Climate change has affected the timing of reproduction in plants and animals, and migration patterns of animals (Porter et al., 2000). It has also altered species distributions and population sizes, and the frequency of disease and pest outbreaks (Gitay et al., 2002). The risk of extinction amongst vulnerable species will increase (Gitay et al., 2002). This concern is compounded by recent research showing that biodiversity is declining significantly, and that decline is accelerating despite mitigation efforts (Butchart et al., 2010).

Avian diversity, in particular, has shown significant declines. In North America alone, almost three billion birds, or 29% of the avian abundance levels recorded in 1970, have been lost (Rosenberg et al., 2019). This immense loss of avifaunal diversity has profound negative effects on global ecosystems and human well-being. Birds play important roles in their respective ecosystems and losses are expected to have negative impacts on important interspecies interactions such as predation. With the disappearance of such interactions, we can expect to see a disruption of regular ecosystem functions potentially causing the extinction of other organisms that are dependent on them (Youngsteadt et al., 2019).

With the negative effects of climate change already occurring and becoming a reality, the transition to renewable energy resources is essential. Renewable energy resources, such as wind, solar and geothermal, emit no CO_2 in energy production or use, lowering greenhouse gas emissions. In September of 2018, California passed Senate Bill No. 100 (SB-100) that aims for the state to produce 100% of its energy from renewable sources by the end of 2045

(Long et al., 2020). As of 2016, 176 countries have set emission targets with renewable energy as central to lower their CO_2 emissions (Gibson et al., 2017).

Renewable Energy in California

California's economy is within the top ten in the world and is home to approximately 10% of the of the total US population (Long et al., 2020). As a result of this, California emitted 356.6 million metric tons of CO_2 in 2018 making it the second highest emitter behind Texas (U.S. Energy Information Administration, 2021). The California Energy Commission established the Renewables Portfolio Standards in 2002 which have promoted the replacement of fossil fuel sources with renewables and have led to 30% of total energy in California being produced by renewable energy in 2017 (Long et al., 2020). The California Renewable Portfolio Standards set a goal of 50% of all energy to be renewable by 2026, and 100% by 2045 (Huber-Lee et al., 2020). To meet these standards, the state will have to rely heavily on solar, wind and geothermal power.

In 2017, 12% of the total renewable energy produced in California came from solar power (Long et al., 2020). To produce solar energy on a large scale, energy companies are developing USSE power plants. These facilities typically last 25 to 40 years (Gasparatos et al., 2017). The two types of technologies used at USSE facilities are PV and CSP. Both require large spatial footprints, typically of up to 6.2 ha of land per MW, and are projected to have covered up to 1,100,000 ha of land by 2030 in the arid regions of the southwestern United States (Walston et al., 2016). USSE facilities require consistent sunlight and large tracts of land making Central and Southern California an ideal location. The southern half of

California has high solar energy production capacity because of its arid, desert conditions (Walston et al., 2016).

Renewable Energy and Biodiversity

Despite the need to transition to renewable sources of energy to combat climate change, an increasing number of studies have shown that renewable energy also negatively impacts biodiversity (Carrete et al., 2009; Gasparatos et al., 2017; Jackson, 2011; Skogen et al., 2018). Renewable energy infrastructure generating electricity from wind power, solar power, and hydropower are land intensive which can lead to the displacement of biodiversity and impact important ecological processes (Gasparatos et al., 2017; Gibson et al., 2017).

Hydropower is the oldest form of renewable energy and its negative impacts on biodiversity have been studied thoroughly (Gasparatos et al., 2017). Hydroelectric reservoirs cover approximately 340,000 km^2 globally, replacing important riparian and lowland habitats used by an innumerable amount of species (Gibson et al., 2017). Building transmission lines and roads, in addition to clearing land for reservoir construction leads to large amounts of methane and CO_2 emissions, hardly making hydroelectric power a zero-carbon energy source (Gibson et al., 2017). Additionally, this loss of land, particularly in tropical areas, has a profound effect on local species. According to Gibson et al. (2017) the Chiew Larn Reservoir in Thailand had such a catastrophic effect on the local ecosystem that all 12 native mammal species on the island disappeared within 25 years. Dams also significantly alter upstream and downstream flow patterns, negatively impacting important migration routes for diadromous fish species, fragmenting populations, and reducing macroinvertebrate populations (Gasparatos et al., 2017; Gibson et al., 2017).

Wind power has also shown to negatively impact biodiversity, particularly avian diversity. The effects of wind turbines on birds have been consistently studied more than any other man-made structure (Drewitt & Langston, 2008). Bird mortality at wind farms is caused by direct collision with turbines, rotors, motors, and other related structures. Additionally, evidence suggests that birds are forced to the ground due to heavy turbulence created by the turbine rotors (Drewitt & Langston, 2008). Endangered raptor species are especially sensitive to wind turbine mortality because of their low reproductive rates and because of the placement of large wind farms in their breeding habitats (Bellebaum et al., 2013). Because raptors are territorial, they remain close to their breeding sites even after large scale wind facilities are developed (Carrete et al., 2009). This, along with other anthropogenic factors, could contribute to the eventual extinction of certain species. Carrete et al. (2009) suggests that turbine caused mortality can be decreased significantly, especially if wind farms are not placed in critical areas for endangered species.

Altamont Pass, a wind farm in California, is often cited as a problematic site because it is located at a site of high bird activity. Species in this area are protected under legislation like the Endangered Species Act and Migratory Bird Treaty Act (Drewitt & Langston, 2008). Collisions here are a result of abundant prey and high raptor activity such as hunting, territorial disputes, pursuit flights, and soaring on rising winds (Barrios & Rodríguez, 2004). Affected raptor species include Golden eagles (*Aquila chrysaetos*), Red-tailed hawks (*Buteo jamaicensis*), American kestrels (*Falco sparverius*), and Burrowing owls (*Athene cunicularia*) (Smallwood & Thelander, 2008). Mortality, because of wind turbine collision, is affecting the populations of these already dwindling raptor species.

While the effects of wind turbines and hydroelectric power have been studied thoroughly, less has been done to study the impacts of USSE on biodiversity. The large land-use footprint of USSE increases the likelihood of habitat loss and fragmentation. Solar farms act as a barrier for movement for some species, resulting in the disruption of gene flow between populations (Hernandez et al., 2014). While it is true that species distribution is taken into consideration when determining the placement of a solar power plant through preplanning and biodiversity surveys, climate change is altering these distributions and solar farms may become a deterrent for certain species in the future (Hernandez et al., 2014). Additionally, to ensure consistent sunlight to the solar panels, cleared land is often maintained with harsh chemicals such as herbicides and dust suppressants which can pollute nearby waterways affecting aquatic organisms (Gasparatos et al., 2017; Lovich & Ennen, 2011).

CSP and Avian Mortality

Studies from Southern California and South Africa suggest that USSE facilities are having significant environmental impacts on avian diversity (Walston et al., 2016; Visser et al., 2019). In addition to altering and degrading natural habitats for birds, USSE facilities cause bird mortality. One of the ways that USSE plants have been causing bird mortality is through solar flux trauma (Smith & Dwyer, 2016). CSP plants use mirrors to direct solar energy to a receiver tube in the middle of the facility. Solar flux trauma occurs when birds are exposed to extreme temperatures when flying near the CSP tower where temperatures may reach beyond 400 degrees Celsius (Jeal et al., 2019). At the Ivanpah Solar Energy facility in Southern California, researchers found that birds flying through the facility were exposed to solar flux, singeing their feathers (Kagan et al., 2014). Severe singeing would result in loss of the bird’s ability to fly resulting in collision with the ground or other objects and ultimately resulting in mortality (Kagan et al., 2014). Less severe singeing resulted in flying impairment, thereby affecting the bird’s ability to forage and avoid predators, also leading to mortality (Kagan et al., 2014). Most importantly, Kagan et al. (2014) found that these facilities attracted insects, which would attract various bird species, who would experience solar flux trauma, and this would attract predator species. Researchers proceeded to label Ivanpah as a “mega-trap” due to its profound effect on the entire food chain (Kagan et al., 2014).

One of the first studies assessing solar impacts on bird mortality was done at the Solar One power plant in the Los Angeles area (McCrary et al., 1984). This was a CSP plant, and the largest one at the time. Here, researchers documented seventy bird mortalities of twenty-six species during a period of forty weeks (McCrary et al., 1984). At Ivanpah, researchers documented a total of 141 bird mortalities across forty-nine species (Kagan et al., 2014).

PV and Avian Mortality

Another common form of bird mortality often seen at USSE facilities is mortality caused by direct collision. In addition to CSP facilities, this is seen at utility-scale PV facilities. Light emitted by the solar panels may attract insects because it resembles a body of water. This attracts insect foraging birds and increases the likelihood of their collision with solar panels (Visser, 2016). In addition to this, the lake-effect hypothesis suggests that waterbirds may be mistaking large solar arrays for large bodies of water and proceeding to attempt to land in the water causing collision (Visser et al., 2019). Additionally, many of these collisions are with fences, overhead lines, or other infrastructure around the facilities

(Kosciuch et al., 2020). Collision could lead to mortality or injury leaving the birds increasingly vulnerable to predators. Factors that may be attracting birds to large scale solar facilities include standing water, insects, and prey availability.

Visser et al. (2019) conducted a study at Jasper Photovoltaic facility in South Africa and found eight mortalities of five species over the course of three months. Another study used previously available data to calculate a total mortality rate of approximately 10 birds per MW per year (Walston et al., 2016). Due to the small number of avian mortality studies conducted at PV USSE facilities, Kosciuch et al. (2020) conducted a study in which they analyzed data obtained from “state and federal agencies, and from solar energy developers and operators” looking at mortality rates at 10 different PV facilities in California and Nevada. They found a total of 669 avian mortalities at these sites with the most consistently found species to be Mourning doves (*Zenaida macroura*), Horned larks (*Eremophila alpestris),* and Western meadowlarks (*Sturnella neglecta*) (Kosciuch et al., 2020). The maximum mortality rate they calculated was 9.26 fatalities per MW per year (Kosciuch et al., 2020). These studies indicate that regardless of whether the lake-effect hypothesis is true, PV facilities may be having direct and negative impacts on avian populations.

Bird Use of USSE Facilities

Though there have been a few studies analyzing direct effects of USSE on birds, there have been even fewer studies on the indirect impacts of USSE on birds. In one study, researchers observed birds’ presence in PV arrays at airports and nearby grasslands to analyze the potential increase of bird-aircraft collisions (DeVault et al., 2014). The results showed that 46 species of birds were found in airfield grasslands compared to 37 bird species in the PV arrays (DeVault et al., 2014). This indicates that though PV arrays may be causing mortality due to collision (Lovich & Ennen, 2011; McCrary et al., 1984; Rudman et al., 2017; Visser et al., 2019; Walston et al., 2015), species are still able to survive and possibly thrive within the facilities. Higher numbers of bird species were found in the grassland habitat compared to the PV array, indicating that birds prefer grassland habitat. Visser et al. (2019) found that birds visiting a PV facility in South Africa used solar panels as foraging perches or for shade and shelter. There were species found to be drinking from the evaporation ponds, and others nesting on solar panel supports (Visser et al., 2019).

Evidence suggests that birds may be utilizing USSE facilities to their advantage, but it is important to consider how bird abundance and diversity compares to adjacent natural landscapes to more thoroughly understand the impact of USSE on avian communities and their potential displacement. Visser et al. (2019) compared bird species richness and density inside the facility, on the boundary zone, and on adjacent untransformed land. Results showed that bird species richness and density was the lowest within the solar facility and more comparable on the boundary and untransformed land. In a similar study, DeVault et al. (2014) showed that there was higher species richness in adjacent grasslands. This indicates that despite their use of the PV facility, birds prefer natural or untransformed landscapes. This leads to the question of how USSE facilities, that are built on naturally suitable habitat for birds, may be affecting bird abundance and diversity. Studies on the indirect effects of USSE on birds are few and far between, therefore more research in this field should be conducted.

Impact Assessment Mitigation Efforts

Before constructing a USSE facility, an Environmental Impact Assessment (EIA) is drafted to understand the potential environmental impacts of the project. The purpose of an EIA is to ensure that decision makers are considering the health of the environment before proceeding with projects. As part of the EIA, an Avian and Bat Protection Plan, or a similar avian monitoring plan, is drafted to understand the species composition, distribution, and risks of avian species in the area and to mitigate impacts of the USSE facility (Walston et al., 2015). Preconstruction monitoring is done to determine the presence of rare or threatened species in the area. Using species list to determine the presence of vulnerable species is allowed but is not to replace the monitoring which is to be done over several seasons to ensure that displacement, loss of habitat, and disturbance is kept to a minimum (Smit, 2011).

Overall, there are three main ways in which the negative impacts of USSE on birds are mitigated. The first is to avoid placing a facility near important bird habitat (Jenkins et al., 2015; Smit, 2011; Walston et al., 2015). Pre-construction monitoring efforts are key to avoidance; if a location is deemed as vital habitat for bird species of special concern, then construction of a USSE facility in such a location should be avoided. While this is the most obvious mitigation effort, it is not always implemented because of other factors that make the location viable for USSE. When projects are permitted to move forward in areas with vulnerable species, a second mitigation strategy is to focus on landscape management to ensure bird safety. Such measures include minimal clearing of natural vegetation, covering ponds to reduce drowning or poisoning, and avoiding conditions that attract birds such as standing water (Jenkins et al., 2015). The final mitigation strategy is infrastructure management. This includes adjusting the tilt of panels or mirrors when not in use to minimize collision and solar flux trauma, minimize lighting that may attract insectivorous birds or bats, and marking fencing so it is visible to birds and collisions are reduced (Jenkins et al., 2015).

Human Disturbance

In addition to the negative impacts of renewable energy, human disturbance can also play a role in negatively impacting biodiversity and avian populations. Human disturbance can cause animals to change their behavior from non-alert to alert or fleeing behavior, can disrupt breeding behavior, or can keep animals away from a food or reproductive resource and alter the animal's ability to exploit important resources (Gill, 2007; Hockin et al., 1992). This can impact a species by reducing its survival, reproduction, or population size.

Problem Statement

Climate change is arguably the greatest crisis humans have faced in the modern age. Unfortunately, its impact is degrading habitats and ecosystems and threatening biodiversity on Earth. The expansion of the renewable energy infrastructure is essential in an effort to curb greenhouse gas emissions. California leads the way in renewable energy production due to recent legislation like SB-100 and its Renewables Portfolio Standards. While the expansion and production of renewable energy is vital, it is important to do so in a sustainable way that protects, rather than harming species. Renewable energy facilities are causing a range of negative effects on species, including avian diversity.

Specifically, USSE facilities are possibly harming global bird populations. Solar energy is a swiftly expanding industry, and the commissioning of these facilities is on the rise globally. While it is true that USSE facilities emit zero carbon, at what cost? These facilities have incredibly large land-use footprints and they have proven to be a danger to birds. Birds play vital roles in their ecosystems and disruptions could have a cascading effect. Finding ways to expand solar energy production while ensuring natural populations are not harmed is imperative. This thesis research is designed to provide information for managers and planners on how solar facilities may be affecting avian use of areas occupied by USSE facilities, so that effective mitigation measures can be developed

Objectives

As solar facilities have grown in number and size, research is needed to understand their impact on a wide range of species, including birds. Results of such studies can assist in the location, design, and management of facilities to minimize their ecological impact. The objective of this study was to examine bird abundance, species richness, behavior, and disturbance during breeding and migratory seasons at a USSE facility, Wright Solar Park (WSP) in Los Banos, California, in relation to avian use of adjacent natural grasslands and farmland sites. The research questions and hypotheses this thesis addressed include:

Research Questions

RQ1: What bird species and abundances are found at WSP, adjacent grassland, and farmland sites, and how do they vary by season?

RQ2: How do bird species and abundances differ between these three types of sites?

RQ3: What behaviors, such as foraging and perching, are exhibited at the three sites and how do they differ?

RQ4: What is the rate of disturbance at each of the three sites and how might the disturbance be affecting bird abundance and species richness?

Hypotheses

H1: Neither bird abundance nor species richness will differ between WSP, adjacent grassland, and farmland, nor will they differ by season.

H2: Bird behavior, as determined by the percent of birds foraging, perching, and flying, will not differ between the three types of sites.

H3: The rate of disturbance by human-caused events will not differ between the three types of sites.

Methods

Study Site

This study encompassed three land uses: a solar facility, open-space grazing/grassland, and active agricultural cropland. WSP is PV USSE facility located in Los Banos, California, a small town in Merced County, in the San Joaquin Valley. It is approximately 130 km southeast of San Jose, California. Merced County is dominated by agriculture and has a Mediterranean climate. Merced County is one of the top five producers in the state of California of milk, cream, cheese, sweet potatoes, tomatoes, honey, almonds, eggs, chickens, cattle, and hay (UC Cooperative Extension, 2011). Approximately 82% of the land in the county is dedicated to farms or cattle ranches (UC Cooperative Extension, 2011).

The WSP is a facility run by Peninsula Clean Energy that provides energy to over 100,000 residences in San Mateo County, California. Peninsula Clean Energy is a community-controlled, not-for-profit, joint powers agency established by San Mateo County to provide clean energy to its residents (Peninsula Clean Energy, 2020). WSP officially came online on January 3, 2020. It has a 200 MW generating capacity and encompasses a total area of 1,105 hectares (2,730 acres), 563 of which are permanently developed. Annual grasses at the facility are managed through mowing and grazing. Panel washing to clean dust particles from the solar panels is done at least three times a year (County of Merced, 2014). The solar panels are fenced off in large sections. Prior to construction of the facility, the area was open-space grassland used for grazing.

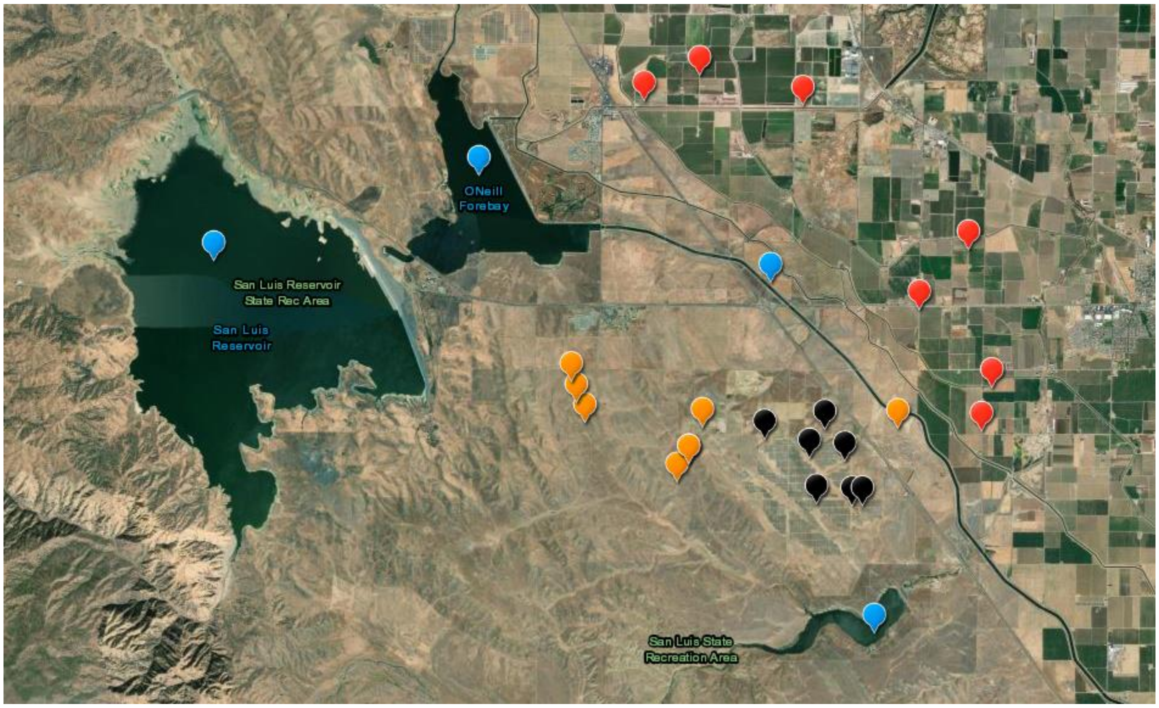
The landscape to the west of the facility is open-space grassland, typically used as cattle grazing areas for local ranchers. Grassland sites were established here and were accessible by paved and dirt roads. The landscape to the northeast of the facility consists of agricultural fields and sparse rural residences and businesses. Agricultural sites were established here. The type of crop varied by site, but was always a short crop, such as alfalfa or lettuce. In the springtime, alfalfa fields were flood irrigated. Some sites were located adjacent to very busy roads.

The San Luis National Wildlife Refuge is approximately 32 km to the east and serves as a sanctuary for migratory waterfowl. It is an important wintering ground and migratory stopover point for large concentrations of waterfowl, shorebirds, and other waterbirds (U.S. Fish and Wildlife Service, 2013). Additionally, the solar facility is approximately eight km southeast of the San Luis Reservoir State Recreation Area and the Los Banos Creek Reservoir is approximately 1.5 km from the facility's southernmost border. Interstate 5, a major freeway running North to South through California, is directly to the east of the facility. Figure 1 shows the locations of some of these bodies of water in relation to the solar facility.

Some species of special concern in this area include the Golden eagle (*Aquila chrysaetos*), Ferruginous hawk (*Buteo regalis*), Swainson's hawk (*Buteo swainsoni*), Northern harrier (*Circus cyaneus*), White-tailed kite (*Elanus leucurus*), Merlin (*Falco columbarius*), Prairie falcon (*Falco mexicanus*), and Western Burrowing Owl (*Athene cunicularia*) (County of Merced, 2014).

Figure 1

Map of the Los Banos area



Note: All solar, grassland, and agricultural sites are pinpointed. Solar sites are indicated by the black points, grassland sites are indicated by the orange points, and agricultural sites are indicated by the red points. Blue points indicate significant bodies of water in the area. The City of Los Banos is just east of the points.

Study Design

This was an observational field study. I established seven observation points in each land use type, for a total of 21 observation points within a 10-km radius of the solar facility (Figure 1). Sites were chosen based on habitat characteristics. Due to spatial patterns in grazing, solar and crop land uses, the study results may be affected by the underlying east/west gradient of observation points.

I counted birds in Summer 2020 (July 20, 2020 - September 3, 2020), Winter 2020/21 (December 18, 2020 - February 4, 2021), and Spring 2021(May 3, 2021 - May 29, 2021) to account for breeding, migratory, and resident birds. Each site was visited twice daily in each of the three seasons.

Excessive smoke from California wildfires during the summer created unfavorable weather conditions requiring surveys to occasionally be postponed. In December and January, when Tule fog lasted much of the morning or the entire day, surveys were postponed to later in the morning or to different days. I started some evening surveys earlier than sunset, but as close to sunset as possible, because of fog. This was done on four occasions in the winter. Spring surveys were completed on time because of favorable weather conditions throughout the month of May.

Data Collection

Point count surveys were used in this study because they are a well-known, powerful way to measure relative abundances efficiently (Bibby et al., 1992). Point counts are a simple method in which the observer establishes several points within their study site and then stands at these locations to count the number and species of birds they locate within an established vicinity (Calvo & Blake, 1998; Horn & Koford, 2000; Laube et al., 2007). Typically, surveys begin at sunrise and last 15 to 20 minutes. In this time, the observer uses a pair of binoculars or a scope to locate birds, identify their species, and note quantity (Calvo & Blake, 1998; Horn & Koford, 2000; Laube et al., 2007). Birds are also identified and noted as present if their call or song is heard (Horn & Koford, 2000). The surveys are conducted on days of good weather and not during times of intense weather such as storms, strong winds, or thick mist which may affect bird activity (Visser, 2016). Multiple surveys are completed at the same point at different times of the year to get a broader understanding of bird distribution in temporal terms.

I conducted point counts from the closest road, using binoculars and a scope, because of restricted access into the solar farm and to maintain homogeneity across the three land use types. I noted the GPS coordinates of each point count. Due to restricted access into the solar farm, I stood against the chain link fence surrounding the perimeter of the facility and observed birds between rows of solar arrays for best visibility. The distance to the solar panels from where I stood averaged approximately 10 meters. At the agricultural sites, I made observations from the side of the road and directly in the front center of the field. On the occasion that a field had been cleared between seasons and no crops were growing at the sample time, I moved to the nearest field with active crop. On average, I was approximately two meters from the first row of crops. Grassland sites were typically lined with a barbed wire fence, and I surveyed from the outside of the fence. This meant that I was right up against the grassland area with no empty space between. In the winter, rain and inclement weather damaged some dirt roads and certain sites became inaccessible. In that case, the surveys were completed as close to the summer site as possible or moved to a more suitable location.

During each survey, avian point count surveys were performed for 30 minutes at sunrise and sunset daily. I recorded the number of birds by species and behaviors of each individual. Behaviors included foraging, perching, and flying. Perching opportunities included fencing, barbed wire, transmission lines, electricity poles, and solar panels. While performing the point count survey, I also noted human-caused disturbances, such as cars passing or people yelling. During the summer surveys, disturbance surveys lasted an hour, but in the winter and spring, the disturbance surveys were reduced to 30 minutes for efficiency, so I could complete two surveys in one morning or evening to save on time, gas, and money.

Data Analysis

Species observed and types of disturbances between sites and seasons were analyzed qualitatively using lists, to determine important differences between sites and seasons. Quantitative data obtained on bird abundance, species richness, bird behavior, and levels of disturbance were analyzed using a Kruskal-Wallis analysis of variance test to determine whether there were differences in bird abundance or species richness between sites and seasons. Disturbance data were normalized “per hour” to ensure comparing data using the same measure of observation time. All tests were performed on the IBM SPSS Statistics software. To avoid biasing results, I removed large flocks of starlings from all three types of sites.

Results

I surveyed 21 sites, seven in each land use type, six times each for a total of 126 surveys. During these surveys, I observed a total of 55 species and 6,434 birds. A list of these species, in addition to which season and location they were observed in is shown in Appendix A and Appendix B. Species richness by season was as follows: Spring – 41, Summer – 31, and Winter – 34. Species richness by location for all locations was as follows: Agriculture – 49, Grassland – 29, Solar – 21.

Bird abundance was greatest at the agricultural site, followed by the grassland site, and lastly the solar site [$H(2) = 35.827$, $p < 0.001$, $n=126$; Figure 2A]. Overall bird abundance varied seasonally [$H(2) = 34.481$, $p < 0.001$, $n = 126$; Figure 2B]. Post hoc results showed total winter bird numbers significantly greater than both spring and summer ($p < 0.001$), although total abundances did not differ detectably between summer and spring ($p = 0.208$). Figure 3 shows that bird abundance was highest in the winter at all three locations, indicating that season was not a source of variation unlike location.

Species richness was highest at the agricultural sites, followed by solar and grassland [$H(2) = 38.522$, $p < 0.001$, $n = 126$; Figure 4A]. Post hoc results indicated species richness did not differ between solar and grassland sites ($p = 0.076$), but agricultural sites had a greater species richness than either grassland ($p < 0.001$) or solar sites ($p < 0.001$). Species richness was highest during the winter, followed by spring and summer respectively [$H(2) = 17.222$, $p < 0.001$, $n =126$; Figure 4B]. Post hoc results showed species richness was lower in

Figure 2

Bird Abundance Shown by A) Location and B) Season

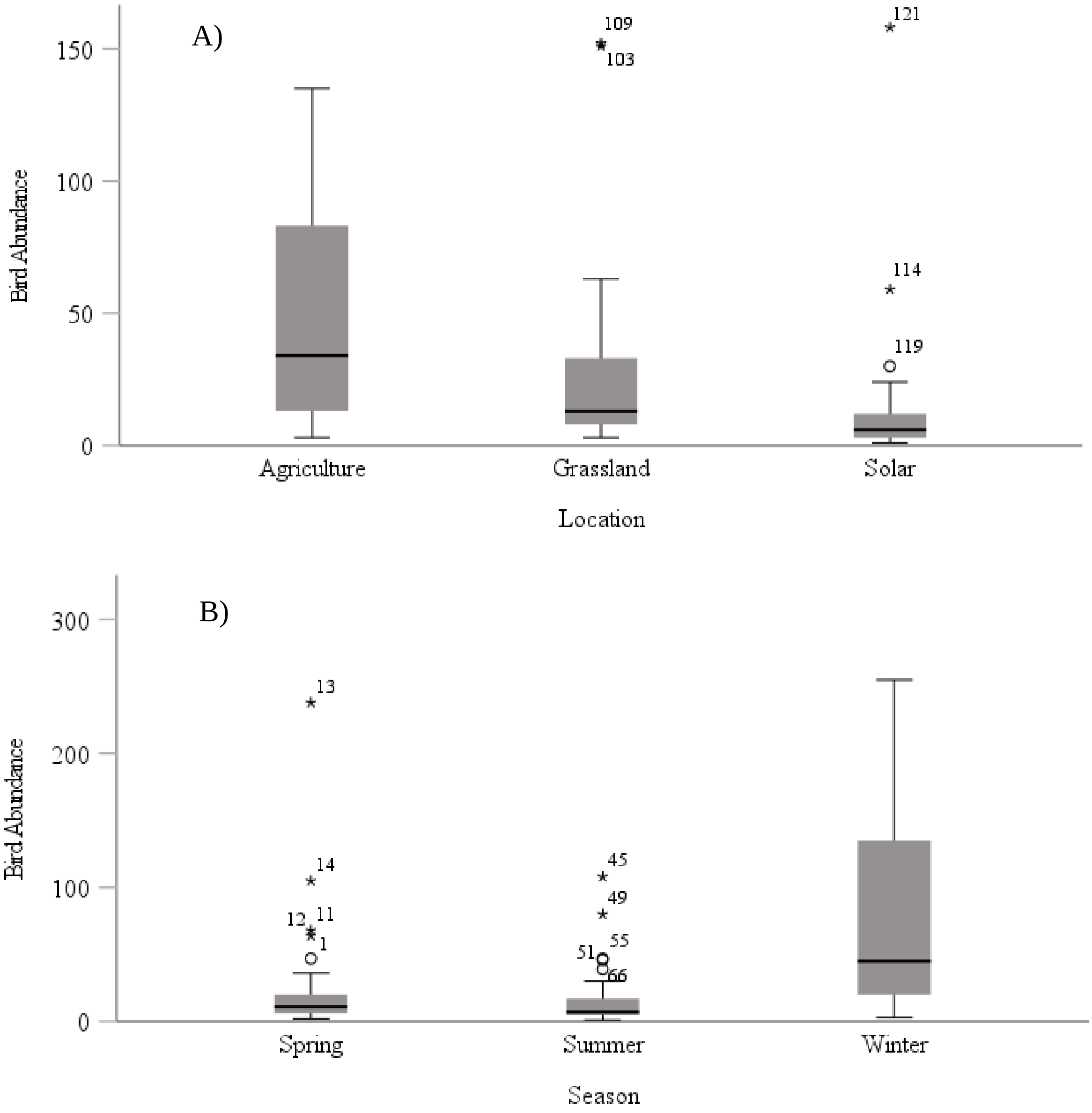


Figure 3
Bird Abundance by Season at Each Location: A) Solar, B) Grassland, and C) Agriculture

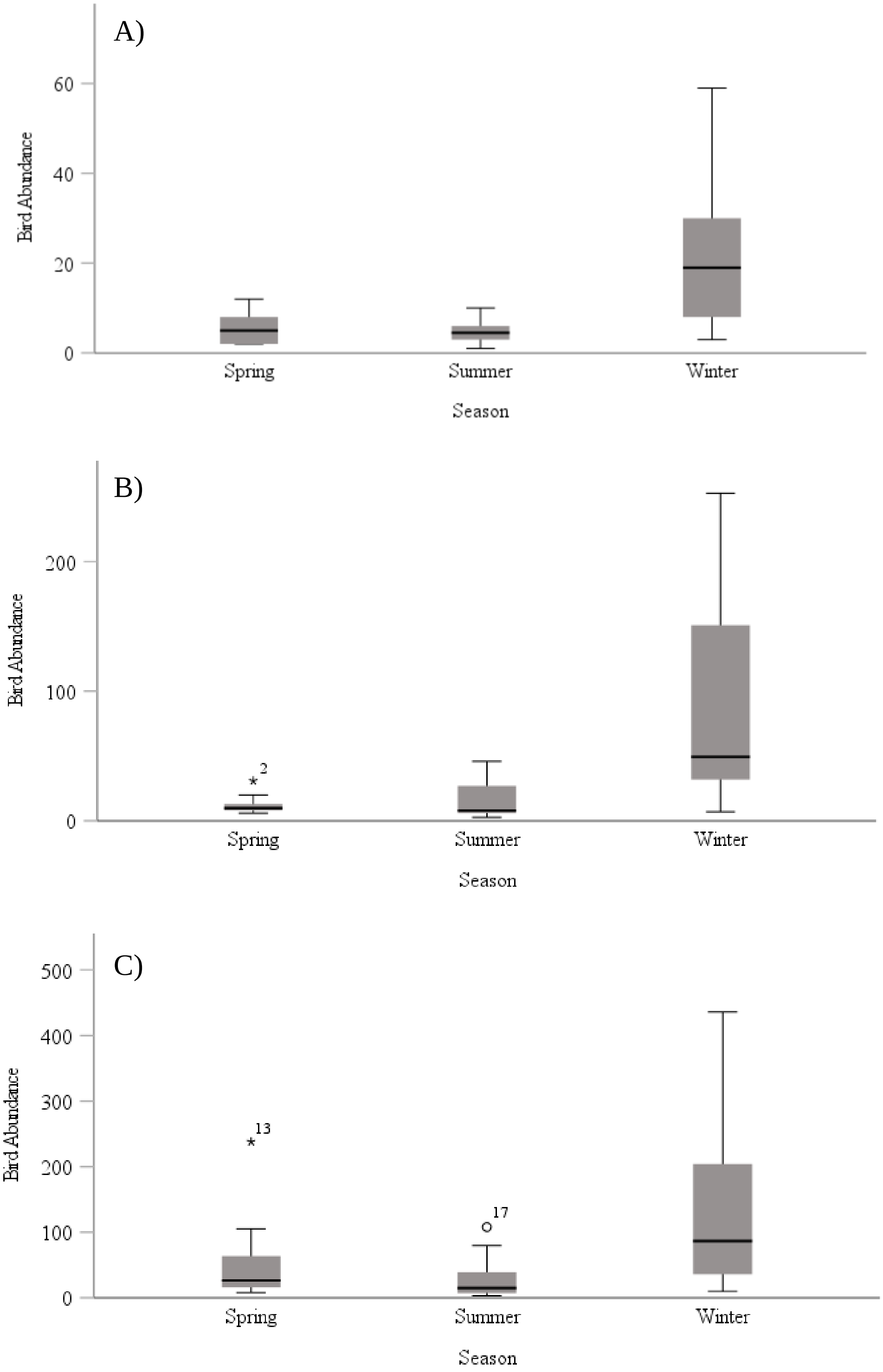
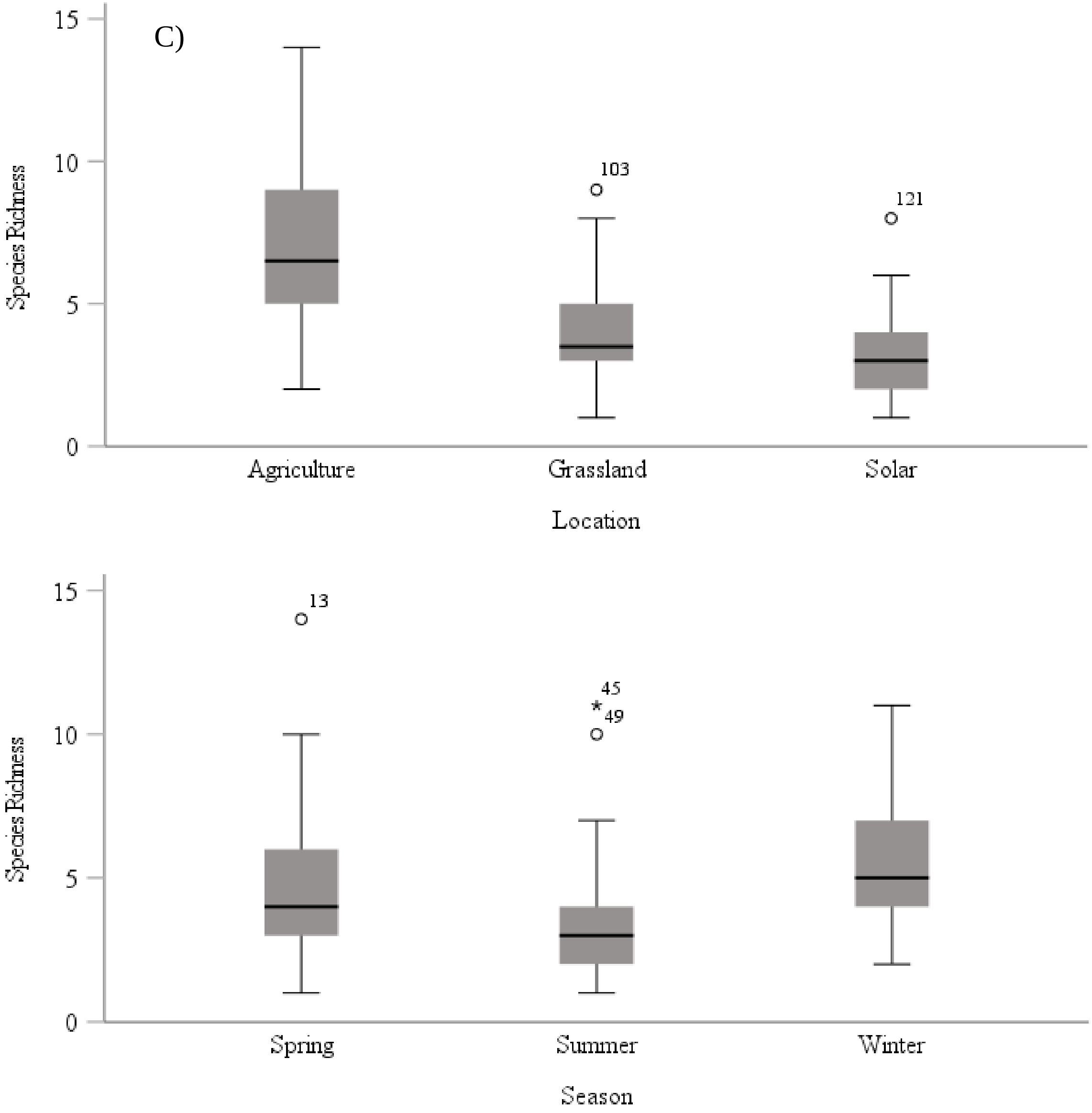


Figure 4

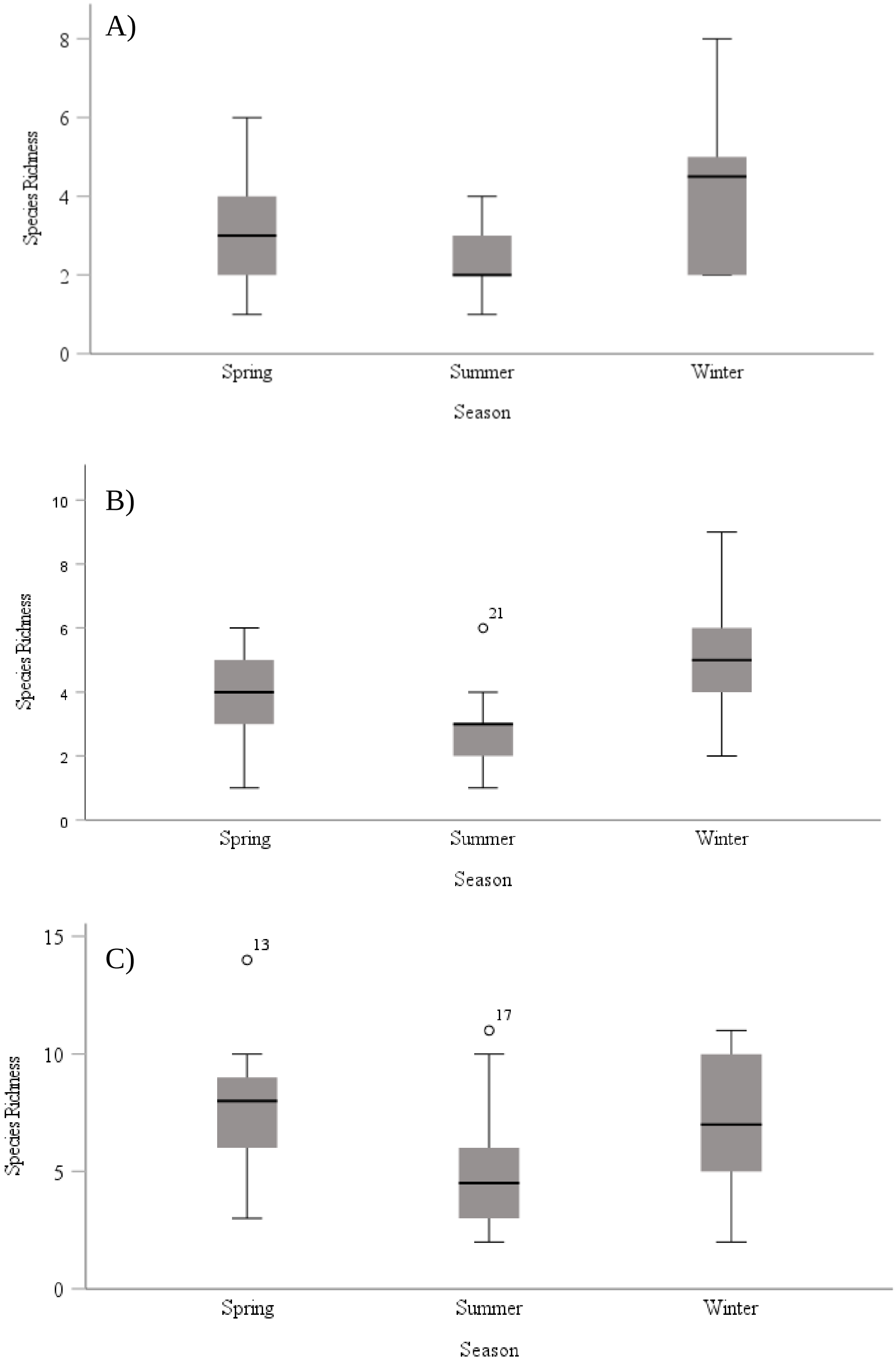
Species richness shown by A) Location and B) Season



summer than in spring (p = 0.006) and winter (p < 0.001), but it did not differ detectably between spring and winter (p = 0.192). Figure 5 shows species richness at each of the type of sites and the lack of variation between seasons, again indicating that season was not a source of variation.

Figure 5

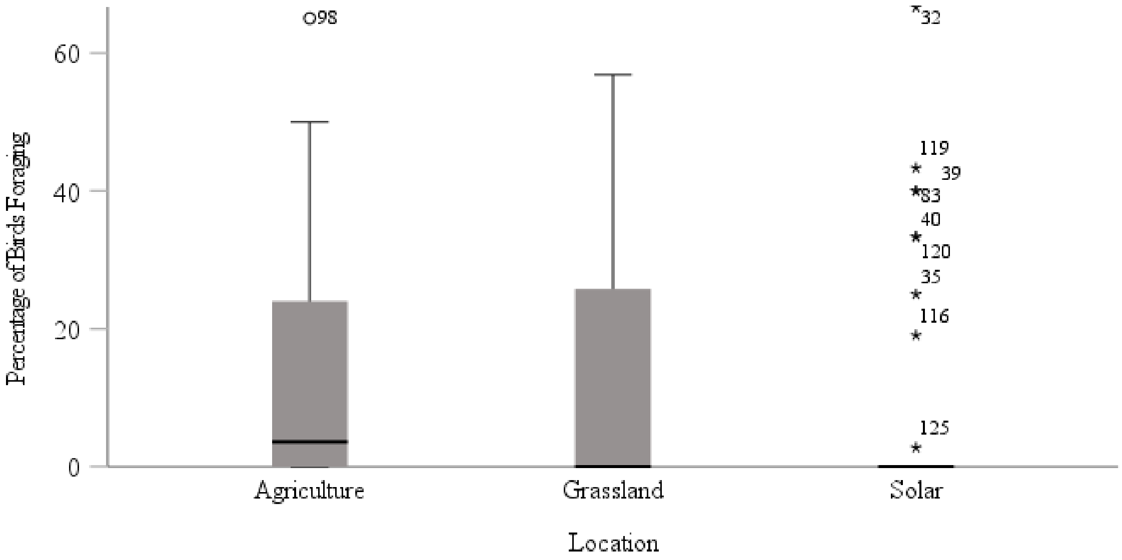
Species richness by season at each location: A) Solar, B) Grassland, and C) Agriculture.



Bird behavior was categorized into one of three categories: perching, foraging, or flying. Results indicated there was no significant difference in the percentage of birds perching [H(2) = 3.166, p = 0.205, n = 126] or a difference in the percentage of birds flying by site [H(2) = 0.423, p = 0.809, n = 126]. While the percentage of birds foraging did not differ between agricultural and grassland sites (p = 0.513), solar had fewer foraging birds than both grassland (p = 0.042) and agricultural land uses (p = 0.007), [H(2) = 7.842, p = 0.020, n = 126; Figure 6].

Figure 6

Percentage of Birds Foraging at each Location



When comparing rate of disturbance across location, the agricultural sites had a significantly higher level of disturbance with a median of 13.5 (IQR = 34.5 - 4.3) than grassland sites 0(2 - 0) and solar sites 0(0 - 0). Results indicated a significant difference [H(2) = 71.7, p <0.001, n=126]. There was no significant difference in disturbance between solar and grassland sites (p = 0.169).

Discussion

The purpose of this research was to assess the potential impacts of solar farms on the general use of habitat by avian species. Compared to cattle-grazed grassland or agricultural sites with crops, the Wright USSE facility attracted fewer numbers of birds, a lower diversity of species, and a lower percentage of birds foraging. Thus, the solar facility had a significant and negative impact on the general use of the area by birds. This is the first study to focus specifically on the impacts of USSE facilities on the general use of these areas by bird species. The 1,105-hectare facility was previously open-space grassland but is now covered predominantly with solar panels; The construction of facilities with such a large land use footprint can negatively impact native wildlife, vegetation, and cause a loss of habitat (Dhar et al., 2020). USSE facilities can dramatically change the landscape which in turn affects habitat quality, migration routes, and causes habitat loss and fragmentation (Dhar et al., 2020; Turney & Fthenakis, 2011). Fragmentation leads to migration obstacles and barriers to gene flow which could affect sensitive species (Dhar et al., 2020). The transformed landscape can make it more difficult for birds to hunt, forage, find shelter, and reproduce because of their unfamiliarity with the area (Dhar et al., 2020).

While some studies have found that birds visited solar facilities to forage (Visser et al., 2019; Walston et al., 2015), this did not seem to be the case at the Wright facility. At the USSE facilities where these other studies were conducted, birds were found to be foraging because of the presence of insects attracted to the polarized light from the panels, which they may have mistaken for water. The lake-effect is considered a significant source of bird mortality at some solar facilities (Jeal et al., 2019). However, I did not observe this effect at

WSP. Most birds I observed at the facility were seen either flying over the site or perching on fences or the solar panels themselves. There were no waterbirds observed at WSP during this study.

According to the WSP Final Environmental Impact Report, the lake-effect was minimized because the solar cells are covered with an anti-reflective coating (County of Merced, 2014). Additionally, WSP is easily distinguishable from neighboring bodies of water such as the San Luis Reservoir and the wetlands at the San Luis National Wildlife Refuge. Furthermore, the solar panels at WSP are placed on rolling hills, unlike the flat desert, with six-meter-wide spaces between panels, making the facility appear less contiguous (County of Merced, 2014). These design features may have contributed to the lower bird abundance and species richness at WSP.

The agricultural sites studied for this research provided the most attractive habitat of the three types of sites investigated--attracting a greater number of birds, greater diversity of species, and a higher percentage of foraging birds, even in comparison to grassland sites. Crops growing at these sites were low crops such as alfalfa and lettuce. Alfalfa is typically flood-irrigated, which is a significant factor in attracting birds. Bird abundance was particularly high in alfalfa fields because of the dynamic they create between birds and farms. According to a study by Hartman and Kyle (2010), up to 136 California bird species use flooded alfalfa fields for foraging, nesting, rest areas, hiding, or hunting. This includes various species of waterfowl, wading birds, raptors, Passeriformes, corvids and other non-water birds. During this study, at one alfalfa field alone, I observed multiple species of hawks, herons, egrets, and harriers. Waterfowl were also more commonly seen at agricultural sites. These included geese, ducks, seagulls, great blue herons, great egrets, long billed curlew, and the white-faced ibis. Alfalfa can be a direct food source for small granivorous birds that feed on newly planted seeds and seedlings (Clark, 1976). This crop is also used as habitat for many prey species including invertebrates such as insects, spiders, earthworms, and mites (Hartman & Kyle, 2010). Small rodents such as ground squirrels, voles, and gophers are also highly prevalent in alfalfa fields and are hunted and consumed by birds of prey. Rodent species that attract raptors in alfalfa fields in California include ground squirrels (*Spermophilus spp.*), voles (*Microtus spp.*), and pocket gophers (*Geomyidae spp.*) (Salmon, 2004).

Haim et al. (2007) found that as floodwater progressed across an alfalfa field, voles and other ground mammals were forced out of their burrows and to the surface where they become prey for raptors and other predators. Storks and herons commonly prey on voles when they escape from their flooded burrows during irrigation of fields, or during the winter when voles are active during the day (Haim et al., 2007). Additionally, the flooding of the field attracts insects which in turn attracts smaller birds. This phenomenon was observed during the spring 2021 agricultural surveys I conducted. In total there, were about 300 birds on one alfalfa field alone in the span of a 30-minute survey. The availability of water, food, and shelter attracted a large number of birds to these sites and provided a stark contrast with the nearby dry and empty grassland and solar sites.

A particular raptor species of interest observed during this study was the Swainson's hawk (*Buteo swainsoni*). During the spring surveys, I observed up to 23 Swainson's hawks (in addition to other hawk species) hunting in a single alfalfa field. Swainson's hawks are currently listed as a threatened species in California, with a 90% decrease in population in the 20th century due largely to a loss of habitat (Fleishman et al., 2016). Significant portions of their native habitats (used for foraging and breeding) have been converted for human use. Babcock (1995) found that Swainson's hawks were most often observed foraging in fallow fields or alfalfa fields. Alfalfa is suitable for Swainson's hawks because it provides reliable habitat for prey and good hunting conditions year-round for subpopulations that do not migrate (Estep, 1989). A field is best for the hawks when it has recently been cut or irrigated because prey can be easily captured (Swolgaard et al., 2008).

Despite their prevalence at the agricultural sites, no Swainson's hawks were observed at any of the solar sites. This was one of the species that specifically required mitigations for WSP (County of Merced, 2014). The potential for impact of construction activities was considered significant; however, this was apparently mitigated by minimizing effects on Swainson's hawks by establishing buffers around their nests and compensating for loss of their foraging habitat (County of Merced, 2014). The lack of Swainson's hawks at the solar facility indicated that these significant impacts were likely not successfully mitigated and Swainson's hawks were disturbed enough to desert the location. This is cause for concern because of the rapidly dwindling Swainson's hawk population that has no doubt been caused by loss of habitat.

The grassland sites, while more attractive to birds than the solar site, were less attractive than the agricultural sites. These grasslands are generally dry, hilly, and covered with non-native species and fenced with thin, barbed wire barriers along the roads. The fence posts provided perches, but there were fewer raptors in the area compared to agricultural sites.

Raptors seen here included the American kestrel, Golden eagle, Red tailed hawk, Red shouldered hawk, Swainson’s hawk, and Turkey vulture. A large population of ground squirrels at these particular sites (per observation) may have attracted these raptors to the area. Sparrows and other small birds were regularly perched on the barbed wire fencing.

Results of this research showed that, at all three types of sites, bird abundance was significantly higher during the winter than in spring or summer. Species richness was also higher in the winter than summer or equal to spring richness numbers. Because the region in which these sites occur is along the Pacific Flyway, the high bird abundance and diversity can be attributed to birds flying south for the winter and using the sites as stopping points. There are multiple large bodies of water, wetlands, and irrigation canals in the area that are ideal stopover locations for birds.

The presence of waterfowl in agricultural areas can be contributed to not only the large bodies of water in the Los Banos area, but also to irrigation canals, aqueducts, and the San Luis National Wildlife Refuge. Agricultural sites are in closer proximity to these features in comparison to solar and grassland sites. Additionally, agricultural sites are regularly irrigated.

With respect to levels of human disturbance, I hypothesized that sites with the highest rate of disturbance would have the lowest abundance and fewest species of birds present. However, results showed that the agricultural sites, which had a significantly higher rate of disturbance than solar and grassland sites, had the greatest abundance and diversity of species. Despite the location of agricultural sites near I-5, a major freeway, and other smaller highways such as Highway 33, 165, and 152, birds were not deterred from using the agricultural sites.

The grassland and solar sites were more remote in comparison and were only accessible via dirt roads. Although I-5 was directly to the east of the solar facility, very little traffic came into the solar facility. Most cars and other vehicles observed at the solar facility were people who lived in the ranches around the facility, people dirt biking in the hills, or employees at the facility. At the grassland sites, most vehicles that passed were ranchers or people living in the area. Disturbances at solar and grassland sites were relatively rare. Overall, these finding show that even with high levels of car traffic nearby, numerous birds representing a wide range of species will use agricultural sites. It is possible that, over time, birds may have become acclimated to these high traffic areas and learned that the benefits of these sites outweigh the risks.

Conclusion

Overall, this study indicated that WSP was negatively impacting bird populations in the facility site. Lower bird abundance and species richness were observed in comparison to surrounding locations. Additionally, fewer birds were found to be foraging within the facility. A very low rate of human disturbance did not help to attract more birds to the facility. The primary cause for this is suspected to be loss of important bird habitat and fragmentation of the habitat. Although some mitigation efforts were put in place to reduce environmental impact, more needs to be done to make sure that as these facilities grow in number and size, they are not taking a dramatic toll on biodiversity. Studies are also needed to assess whether birds may adapt to and begin to use USSE facilities more completely over time. Dhar et al. (2020) stated that because of stark changes, recovery of a disturbed ecosystem can take much longer than expected. WSP was commissioned and began providing power in January of 2020 and construction of the facility took a total of 11 months.

One of the main challenges of USSE is lowering the land use footprint. This change is needed even though PV requires the least amount of land among modern renewable energy options and generates the largest amount of energy per unit area after geothermal energy (Fthenakis & Kim, 2009). While solar facilities are promising in the fight against climate change, their placement can cause detrimental environmental impacts. Given that agricultural sites and other disturbed sites support species, PV should be place primarily on urban rooftops and parking lots.

This study also illustrated the potential benefits of certain types of agriculture on biodiversity. If certain agricultural methods are employed, a mutually beneficial system can be established in which wildlife and farmers are benefitted. In the Central Valley, the flooding of alfalfa fields provides a rich environment for birds, which in turn provides a natural pest control service for farmers. California has lost most of its wetlands over the years to development and agriculture so flooded alfalfa fields become a viable substitute. More of these mutually beneficial systems can be established to create an environmentally friendly agricultural system. However, it is important to note that California is currently in a drought and flooding may not be the most sustainable irrigation method in the near future.

This study examines three land uses in a relatively small geographic area. Some recommendations for future studies of this type would be to replicate this study at more sites to gain more representative data and gain access into the solar facility. Surveys for this study were conducted while standing against the fence line surrounding the panels. Although there was good visibility from this viewpoint, conducting the surveys from within the fence line could provide more accurate numbers. Replicating this study in other locations would provide more evidence as to whether USSE negatively impacts avian populations and how.

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Appendix A: Complete List of All Species Observed by Season

Species	Spring	Summer	Winter
American crow (*Corvus brachyrhynchos*)	X		X
American kestrel (*Falco sparverius*)	X	X	X
American pitpit (*Anthus rubescens*)			X
American robin (*Turdus migratorius*)			X
Bald eagle* (*Haliaeetus leucocephalus*)			X
Barn swallow (*Hirundo rustica*)	X		
Black-bellied plover (*Pluvialis squatarola*)			X
Black-crowned night heron (*Nycticora nycticora*)	X		
Black phoebe (*Sayornis nigricans*)	X	X	
Brewer's blackbird (*Euphagus cyanocephalus*)	X	X	X
Brown-headed cowbird (*Molothrus ater*)	X	X	X
California towhee (*Melozone crissalis*)	X		X
Canada goose (*Branta canadensis*)			X
Cliff swallow (*Petrochelidon pyrrhonota*)	X	X	
Eurasian collared dove (*Streptopelia decaocto*)	X	X	
European starling (*Sturnus vulgaris*)	X	X	X
Golden eagle* (*Aquila chrysaetos*)	X		
Great blue heron (*Ardea herodias*)	X	X	
Great egret (*Ardea alba*)	X	X	X
Horned lark (*Eremophila alpestris*)		X	
House finch (*Haemorhous mexicanus*)	X		X
House sparrow (*Passer domesticus*)	X	X	
Killdeer (*Charadrius vociferus*)	X	X	X
Lark sparrow (*Chondestes grammacus*)	X		X
Least sandpiper (*Calidris minutilla*)	X		
Lesser goldfinch (*Spinus psaltria*)		X	
Lesser nighthawk (*Chordeiles acutipennis*)		X	
Loggerhead shrike* (*Lanius ludovicianus*)	X	X	X
Long billed curlew (*Numenius americanus*)		X	
Mallard (*Anas platyrhynchos*)	X		
Mourning dove (*Zenaida macroura*)	X	X	X
Northern harrier (*Circus cyaneus*)	X	X	X
Northern mockingbird (*Mimus polyglottos*)	X		X
Osprey (*Pandion haliaetus*)	X		
Barn owl (*Tyto alba*)			X

Species	Spring	Summer	Winter
Common raven (*Corvus corax*)	X	X	X
Red-shouldered hawk (*Buteo lineatus*)	X	X	X
Red-tailed hawk (*Buteo jamaicensis*)	X		X
Red-winged blackbird (*Agelaius phoeniceus*)	X		X
Rock pigeon (*Columba livia*)	X	X	X
Savannah sparrow (*Passerculus sandwichensis*)	X		X
Say's phoebe (*Sayornis saya*)		X	
California scrubjay (*Aphelocoma californica*)	X	X	
California gull (*Larus californicus*)	X	X	X
Snowy egret (*Egretta thula*)	X	X	
Song sparrow (*Melospiza melodia*)	X		X
Swainson's hawk* (*Buteo swainsoni*)	X	X	
Tree swallow (*Tachycineta bicolor*)	X	X	X
Tricolored blackbird* (*Agelaius tricolor*)		X	X
Turkey vulture (*Cathartes aura*)	X		
Western meadowlark (*Sturnella neglecta*)	X	X	X
White-crowned sparrow spp. (*Zonotrichia leucophrys*)			X
White-faced ibis (*Plegadis chihi*)	X	X	X
White-throated swift (*Aeronautes saxatalis*)	X		
Yellow-billed magpie* (*Pica nuttalli*)		X	X
Total Richness	41	31	34

Note: Species designated as vulnerable, rare, or listed by federal or state agencies are shown with an asterisk (*).

Appendix B: Complete List of All Species Observed by Location

Species	Agriculture	Grassland	Solar
American crow (*Corvus brachyrhynchos*)	X	X	
American kestrel (*Falco sparverius*)	X	X	
American pitpit (*Anthus rubescens*)			X
American robin (*Turdus migratorius*)	X		X
Bald eagle* (*Haliaeetus leucocephalus*)	X		
Barn swallow (*Hirundo rustica*)	X	X	
Black-bellied plover (*Pluvialis squatarola*)		X	
Black-crowned night heron (*Nycticora nycticora*)	X		
Black phoebe (*Sayornis nigricans*)	X	X	
Brewer's blackbird (*Euphagus cyanocephalus*)	X	X	X
Brown-headed cowbird (*Molothrus ater*)	X		
California towhee (*Melozone crissalis*)	X	X	
Canada goose (*Branta canadensis*)	X		
Cliff swallow (*Petrochelidon pyrrhonota*)	X	X	X
Eurasian collared dove (*Streptopelia decaocto*)	X	X	
European starling (*Sturnus vulgaris*)	X		X
Golden eagle* (*Aquila chrysaetos*)		X	
Great blue heron (*Ardea herodias*)	X		
Great egret (*Ardea alba*)	X		
Horned lark (*Eremophila alpestris*)			X
House finch (*Haemorhous mexicanus*)	X	X	
House sparrow (*Passer domesticus*)	X	X	X
Killdeer (*Charadrius vociferus*)	X		
Lark sparrow (*Chondestes grammacus*)	X		X
Least sandpiper (*Calidris minutilla*)			X
Lesser goldfinch (*Spinus psaltria*)	X		
Lesser nighthawk (*Chordeiles acutipennis*)	X		
Loggerhead shrike* (*Lanius ludovicianus*)	X	X	X
Long billed curlew (*Numenius americanus*)	X		X
Mallard (*Anas platyrhynchos*)	X		
Mourning dove (*Zenaida macroura*)	X	X	X
Northern harrier (*Circus cyaneus*)	X	X	X
Northern mockingbird (*Mimus polyglottos*)	X		
Osprey (*Pandion haliaetus*)	X		
Barn owl (*Tyto alba*)	X		

Species	Agriculture	Grassland	Solar
Common raven (*Corvus corax*)	X	X	X
Red-shouldered hawk (*Buteo lineatus*)	X	X	
Red-tailed hawk (*Buteo jamaicensis*)	X	X	X
Red-winged blackbird (*Agelaius phoeniceus*)	X		
Rock pigeon (*Columba livia*)	X	X	X
Savannah sparrow (*Passerculus sandwichensis*)	X	X	X
Say's phoebe (*Sayornis saya*)	X		
California scrubjay (*Aphelocoma californica*)	X		
California gull (*Larus californicus*)	X	X	X
Snowy egret (*Egretta thula*)	X		
Song sparrow (*Melospiza melodia*)	X	X	X
Swainson's hawk* (*Buteo swainsoni*)	X	X	
Tree swallow (*Tachycineta bicolor*)	X	X	X
Tricolored blackbird* (*Agelaius tricolor*)	X	X	
Turkey vulture (*Cathartes aura*)		X	
Western meadowlark (*Sturnella neglecta*)	X	X	X
White-crowned sparrow spp. (*Zonotrichia leucophrys*)	X	X	
White-faced ibis (*Plegadis chihi*)	X		
White-throated swift (*Aeronautes saxatalis*)	X		
Yellow-billed magpie* (*Pica nuttalli*)	X	X	
Total Richness	49	29	21

Note: Species designated as vulnerable, rare, or listed by federal or state agencies are shown with an asterisk (*).