M107

Altamont Pass Wind Resource Area Bird Fatality Study, Monitoring Years 2005–2013

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Acronyms and Abbreviations

APWRA	Altamont Pass Wind Resource Area
AWPPS	Avian Wildlife Protection Program and Schedule
BLOB	base layer of operating group boundaries
CEC	California Energy Commission
CI	confidence interval
kW	kilowatt
MT	Monitoring Team
MW	megawatt
O&M	operations and maintenance
OP	observation point
SD	standard deviation
SRC	Scientific Review Committee
WRRS	Wildlife Reporting Response System

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Chapter 1
Introduction

The Altamont Pass Wind Resource Area (APWRA) is located in central California approximately 56 miles (90 kilometers) east of San Francisco (Figure 1-1). Temperature differences between the air of the warmer Central Valley east of Altamont Pass and the cooler marine air from San Francisco Bay cause steady winds of 15–30 miles per hour (25–45 kilometers per hour) to blow across the APWRA during mid-afternoon and evening between April and September, making the area an ideal setting for production of wind energy. Permits have been granted for 5,400 wind turbines, which together have a rated capacity of approximately 580 megawatts (MW), distributed over 37,000 acres (150 square kilometers) of rolling grassland hills and valleys.

The APWRA also supports a broad diversity of resident, migratory, and wintering bird species that regularly move through the wind turbine area (Orloff and Flannery 1992). In particular, diurnal raptors (eagles and hawks) use the prevailing winds and updrafts for foraging, soaring and gliding during daily movement, and migration. Birds passing through the rotor plane of operating wind turbines are at risk of being injured or killed. Multiple studies of avian fatality in the APWRA show that substantial numbers of golden eagles, red-tailed hawks, American kestrels, burrowing owls, barn owls, and a diverse mix of non-raptor species are killed each year in turbine-related incidents (Howell and DiDonato 1991; Orloff and Flannery 1992; Howell 1997; Smallwood and Thelander 2004). Many of these species are protected by both federal and state wildlife legislation. The numbers of birds killed annually in turbine-related incidents have led to significant controversy.

As a result of the controversy surrounding avian fatalities in the APWRA, in September 2005 the Alameda County Board of Supervisors attached extensive conditions of approval to use permits for the continued operation of wind power projects in the APWRA. Aimed at achieving major reductions in avian fatalities, these conditions included the establishment of an Avian Wildlife Protection Program and Schedule (AWPPS), the formation of a Scientific Review Committee (SRC), and retention of an independent consultant to implement monitoring of turbine-related avian fatalities (the Monitoring Team [MT]).

- The AWPPS consists of several measures and management actions, such as the strategic removal of turbines, strategic turbine shutdowns, and other actions, aimed at reducing turbine-related avian fatalities. The measures and actions taken are described in detail below.
- The SRC provides independent review and expertise on research related to wind energy production and avian behavior and safety. To this end, the goals of the group are to provide a neutral forum for open dialogue among experts in the field with different perspectives, reach agreement on analysis and interpretation of data, and ensure sound and objective scientific review of avian safety strategies. To date, the SRC has advised Alameda County and the power companies on actions to reduce turbine-related avian fatalities; these have included identification of hazardous turbines for removal or relocation and recommendations for the timing and duration of turbine shutdowns. In addition, the SRC has directed the MT on study design, set study priorities, suggested analyses, and reviewed and commented on reports.
- The MT implements the avian fatality monitoring program, analyzes data collected, and reports results in keeping with recommendations made by the SRC. Originally composed of three organizations—WEST, Inc., the Santa Cruz Predatory Bird Research Group, and ICF Jones &

Stokes—the MT has undergone several changes since its formation. The MT was headed by the Santa Cruz Predatory Bird Research Group until late 2008, when management of the MT was assumed by ICF Jones & Stokes (now ICF International).

In 2007, the AWPPS was modified by a settlement agreement to end litigation against Alameda County that had been initiated by environmental groups. This agreement included a goal to reduce turbine-related fatalities for American kestrel, burrowing owl, golden eagle, and red-tailed hawk (hereinafter referred to as the *four focal species*) by 50% from an estimate of annual raptor fatalities (referred to as the *baseline*) generated from data collected during the period 1998–2003 (hereinafter referred to as the *baseline study*). The original baseline estimate—1,300 raptors per year—was based on the work of Smallwood and Thelander (2004: Table 3-11). The baseline estimate of 1,300 raptors in the settlement agreement was an estimate of APWRA-wide annual fatalities for all raptors—it was not specific to the four focal species associated with the 50% reduction in the settlement agreement. The corresponding (i.e., baseline) value for the four focal species is 1,130 fatalities per year.

The primary goal of the current avian fatality monitoring program, which has been operating continuously since 2005 (hereinafter referred to as the *current study*), is to assess progress toward achieving the 50% reduction target. Evaluation of the efficacy of management actions and identification of issues and solutions associated with the accurate estimation of total APWRA-wide avian fatalities became necessary ancillary objectives of the monitoring program.

To account for differences in methods and sampling effort between the baseline and current studies, attempts were made to reanalyze data from Smallwood and Thelander (2004); however, these attempts raised substantial issues regarding the validity of comparing estimates based on such disparate datasets (ICF International 2011). For example, results of the reanalysis raised questions about the representativeness of the baseline sample and its applicability to the APWRA as a whole relative to the current study, as well as issues regarding probable differences in detection probability based on large differences in *search interval* (i.e., the period of time between successive searches of the same turbine string).

To better reflect the timing of annual movements of birds through the study area, all analyses in this report are presented on the basis of *monitoring years*, defined as October 1 through September 30, rather than calendar years.

Study Area

The APWRA is in the Diablo Range of central California at elevations ranging from 256 to 1,542 feet (78 to 470 meters) above mean sea level. The area contains a highly variable and complex topography and is composed primarily of nonnative annual grasslands that receive limited precipitation. The area is predominantly used for cattle grazing. Winters are mild with moderate rainfall, but summers are very dry and hot. Winter wind speeds average 9–15 miles per hour (15–25 kilometers per hour). The spring and summer high wind period is when 70–80% of the wind turbine power is generated in the APWRA (Smallwood and Thelander 2004).

The older-generation turbines in the APWRA are arrayed in *strings* along ridgelines and other geographic features. The *turbine string* was therefore selected as the basic sampling unit in the monitoring program. These turbines were not installed all at once; rather, they were brought online in a series of projects beginning in the 1960s and continuing into the 1980s. Historically, these

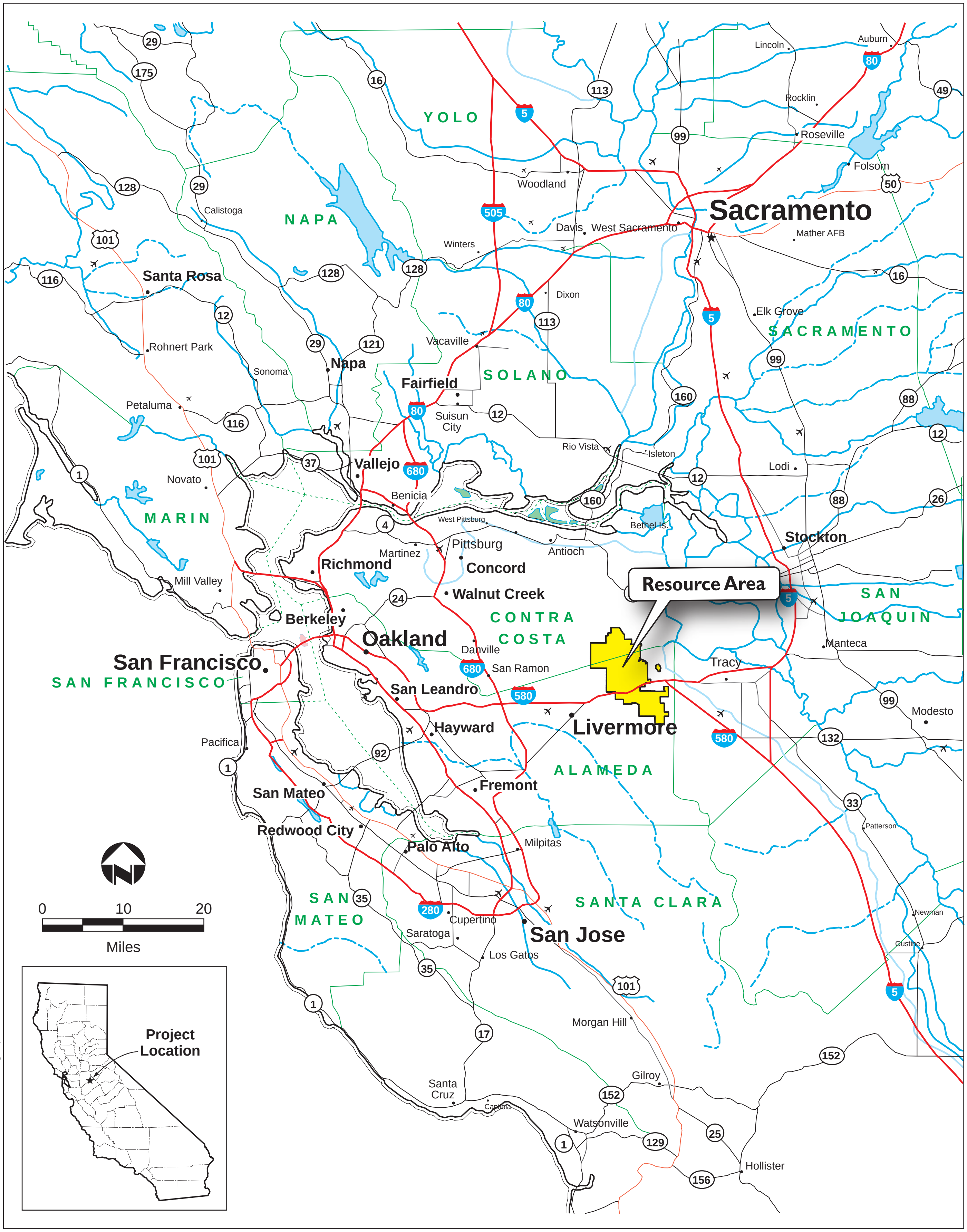

Figure 1-1
Location of the Altamont Pass Wind Resource Area (APWRA)

projects shared a common turbine type, geographic location, and owner/operator—although there have been changes that have muddled these relationships over the years—and are referred to as *operating groups* in this report. Operating groups were later refined into 30 BLOBs (i.e., *base layer of operating group boundaries*) to provide a basis for stratification across the variable turbine types, topographies, and geographies of the APWRA (Figure 1-2).

The number of turbines in operation has varied over time because of mechanical breakdowns, maintenance, seasonal and weather-related shutdowns, attrition of turbines, strategic turbine removals intended to reduce turbine-related avian fatalities, and repowering of turbines. *Attrition* refers to the loss of turbines due to mechanical breakdown. Because many turbines in the APWRA are older, replacement parts are no longer available, so mechanical breakdowns often result in loss of the entire turbine. *Repowering* refers to the replacement of old, smaller turbines with newer and larger (both in physical size and megawatt capacity) turbines. Information provided by power companies with wind projects in the APWRA indicates that the total *installed capacity*—defined as the sum of the rated capacities of all of the extant (i.e., not removed) turbines each year—in the APWRA has changed significantly over time, reaching a high of 525 MW in the 2006 monitoring year and a low of 442 MW in the 2010 monitoring year. Total installed capacity increased to 469 MW in the 2012 monitoring year with the repowering of the Vasco Winds facility (Figure 1-3). While the total installed capacity of older-generation turbines in the APWRA has declined steadily over the course of the study, installed capacity of newer-generation turbines has increased. Repowered turbines now comprise approximately 29% of the total installed capacity of the APWRA.

At least 13 different turbine types have been installed in the APWRA since the first project was built in 1966. These turbine types vary widely in *rated capacity* (defined as the amount of power a turbine can produce at its rated wind speed), height, configuration, tower type, blade length, tip speed, and other characteristics (Table 1-1). They also differ in their geographic distribution and abundance (Figure 1-2). Appendix A provides representative photographs of turbine types in the APWRA.

Table 1-1. Models, Sizes, and Capacities of Wind Turbines in the APWRA

Turbine Model	Rated Capacity (kW)	Height (feet)	Rotor Diameter (feet)	Total Number Installed	Total Installed Capacity (kW)	Number Operational 2012 Monitoring Year	Total Operational Capacity 2012 Monitoring Year (kW)	Description
Kenetech	100	60/80/140	59	3,500	350,000	1,861	186,100	Downwind, free yaw, variable pitch blades, remote computer control, lattice tower
Nordtank	65	80	52	394	25,610	302	19,630	Upwind, fixed pitch, steel tubular tower
Micon	65	80	52	221	13,260	200	13,000	Upwind, fixed pitch, steel tubular tower
Danregn Vind/Kraft Bonus	120	80	63.5	250	30,000	204	24,480	Upwind, fixed pitch, steel tubular tower
Danregn Vind/Kraft Bonus	65	60/80	50	211	13,715	199	12,935	Upwind, fixed pitch, steel tubular tower
Vestas	95	80	56	200	19,000	199	18,905	Upwind, lattice tower
Enertech	40	60	44	192	7,680	127	5,080	Downwind, free yaw, blade tip brakes, lattice tower
Danregn Vind/Kraft Bonus	150	80	76	100	15,000	80	12,000	Upwind, fixed pitch, steel tubular tower
Howden	330	82	102	85	28,050	78	25,740	Upwind, steel tubular tower with conical base
Kenetech – KVS	400	80/120	108	41	16,400	21	8,400	Upwind, variable speed, variable pitch, variable power factor, microprocessor-based turbine control system, lattice tower
Mitsubishi	1,000			38	38,000	38	38,000	
V-47	660	164		31	20,460	31	20,460	
Holec/Windmatic	65	60	48	26	1,690	18	1,170	Upwind, fixed pitch, dual yaw rotors, lattice tower
W.E.G. (three blade)	250	80	82	20	5,000	20	5,000	Upwind, tubular tower, variable pitch
Holek/Polenko	100	80	59	12	1,200	11	1,100	Upwind, fixed pitch, dual yaw rotors, tubular tower
Howden	750	112	149	1	750	1	750	Upwind, steel tubular tower with conical base
Siemens 2.3	2,300	262	331	34	78,200	34	78,200	Re-powered turbines in the Vasco Winds Operating Group
HMZ-Windmaster	50		72	5	250	0	0	Upwind, hydraulically pitched blades, tubular tower
HMZ-Windmaster	200		72	129	25,800	0	0	Upwind, hydraulically pitched blades, tubular tower
HMZ-Windmaster	250		76	30	7,500	0	0	Upwind, hydraulically pitched blades, tubular tower

Turbine Model	Rated Capacity (kW)	Height (feet)	Rotor Diameter (feet)	Total Number Installed	Total Installed Capacity (kW)	Number Operational 2012 Monitoring Year	Total Operational Capacity 2012 Monitoring Year (kW)	Description
Flowind	150	92	56	148	22,200	0	0	Vertical axis, steel tubular tower
Flowind	250	102	62	21	5,250	0	0	Vertical axis, steel tubular tower
Enertech	60	80	44	36	2,160	0	0	Downwind, free yaw, blade tip brakes, lattice tower
Danwin	110	80	62.3	25	2,750	0	0	Upwind, tubular tower
Danwin	160	80	62	14	2,240	0	0	Upwind, tubular tower
Vestas	65		50	2	130	0	0	Upwind, lattice tower
HMZ-Windmaster	300		82	15	4,500	0	0	Upwind, hydraulically pitched blades, tubular tower
Wind Power Systems	40		39	20	800	0	0	Downwind, tilt-down lattice tower, no nacelle
Danish Wind Technology	30		97	3	90	0	0	Downwind, free yaw with hydraulic damping, variable pitch, computer control, tubular tower
Energy Sciences, INC	50		54	99	4,950	0	0	Downwind, blade tip brakes, free yaw, tilt-down lattice tower
Energy Sciences, INC	65		54	96	6,240	0	0	Downwind, blade tip brakes, free yaw, tilt-down lattice tower
Energy Sciences, INC	80		54	109	8,720	0	0	Downwind, blade tip brakes, free yaw, tilt-down lattice tower
Fayette	75		33	222	16,650	0	0	Downwind, free yaw, blade tip brakes, guyed pipe tower
Fayette	95		36	1,202	114,190	0	0	Downwind, free yaw, blade tip brakes, guyed pipe tower
Fayette	250		80	30	7,500	0	0	Downwind, free yaw, blade tip brakes, guyed pipe tower
BSW/Wagner	65		56	15	975	0	0	Upwind, fixed pitch, driven yaw, lattice tower
Alternergy/Aerotech	75		51	4	300	0	0	Upwind, tubular tower
W.E.G. (two blade)	300		108	1	300	0	0	Upwind, tubular tower, variable pitch
Total				**7,582**	**897,510**	**3,424**	**471,795**	

Management Actions and Repowering

Two primary management actions have been taken to reduce avian fatalities in the APWRA: the seasonal shutdown of turbines (Smallwood and Spiegel 2005a) and identification and removal of turbines considered hazardous to birds (Smallwood and Thelander 2004; Smallwood and Spiegel 2005a, 2005b, 2005c). Repowering of turbines is another measure considered by some to have the potential to reduce turbine-related avian fatalities (Smallwood 2013), but others have concluded that the evidence is equivocal (Loss et al. 2013; AWWI 2014).

Seasonal Shutdown of Turbines

During the first 2 years of the current study—i.e., the 2005 and 2006 monitoring years—a crossover experiment was implemented to assess the effectiveness of shutting down turbines during the winter season as a means of reducing turbine-related avian fatalities. A *crossover design* is a sampling approach whereby a stratification of sampling units each receives the experimental treatment in sequence; such an approach is useful in cases with no suitable control groups. In this case, the APWRA was divided into north and south treatment units. Turbines in each unit were shut down for 2 months during the winter period. In the 2005 monitoring year, turbines in the northern treatment unit were shut down from November 1 to December 31, 2005, while turbines in the southern unit remained operational. Turbines in the southern treatment unit were shut down from January 1 to February 28, 2006, while turbines in the northern unit remained operational. The order of the shutdown was reversed during winter of the 2006 monitoring year.

The effectiveness of this sampling design was called into question by the SRC because carcasses could not be reliably aged when using a 30-day search interval, making the assignment of carcasses to treatments (that is, did the fatality occur during the shutdown period?) unreliable. Accordingly, the crossover experiment was discontinued in February 2007. The SRC determined at that time based on the information available that the management strategies then in place would be insufficient to achieve the 50% fatality reduction goal; as a result, the SRC recommended a 4-month seasonal shutdown.

The power companies agreed to a 2-month APWRA-wide winter-period shutdown of turbines, which was implemented beginning in November 2007 (the 2007 monitoring year). Non-monitored turbines were shut down on November 1, 2007, and reactivated on January 1, 2008, while monitored turbines were shut down and reactivated in phase with the fatality sampling schedule to help associate fatalities with the correct treatment category—in other words, each monitored string was shut down immediately following its last search prior to the shutdown period. Monitored turbines were shut down beginning October 29, 2007, and the shutdown was completed on November 29, 2007. Monitored turbines were reactivated beginning on January 10, 2008, with reactivation completed by February 16, 2008.

The seasonal shutdown was extended to 3 months in the 2008 monitoring year. Non-monitored turbines were shut down on November 1, 2008, and reactivated on February 1, 2009. Monitored turbines were shut down beginning on October 31, 2008, with the shutdown completed on December 2, 2008. Monitored turbines were reactivated beginning on February 2, 2009, with reactivation completed on February 24, 2009.

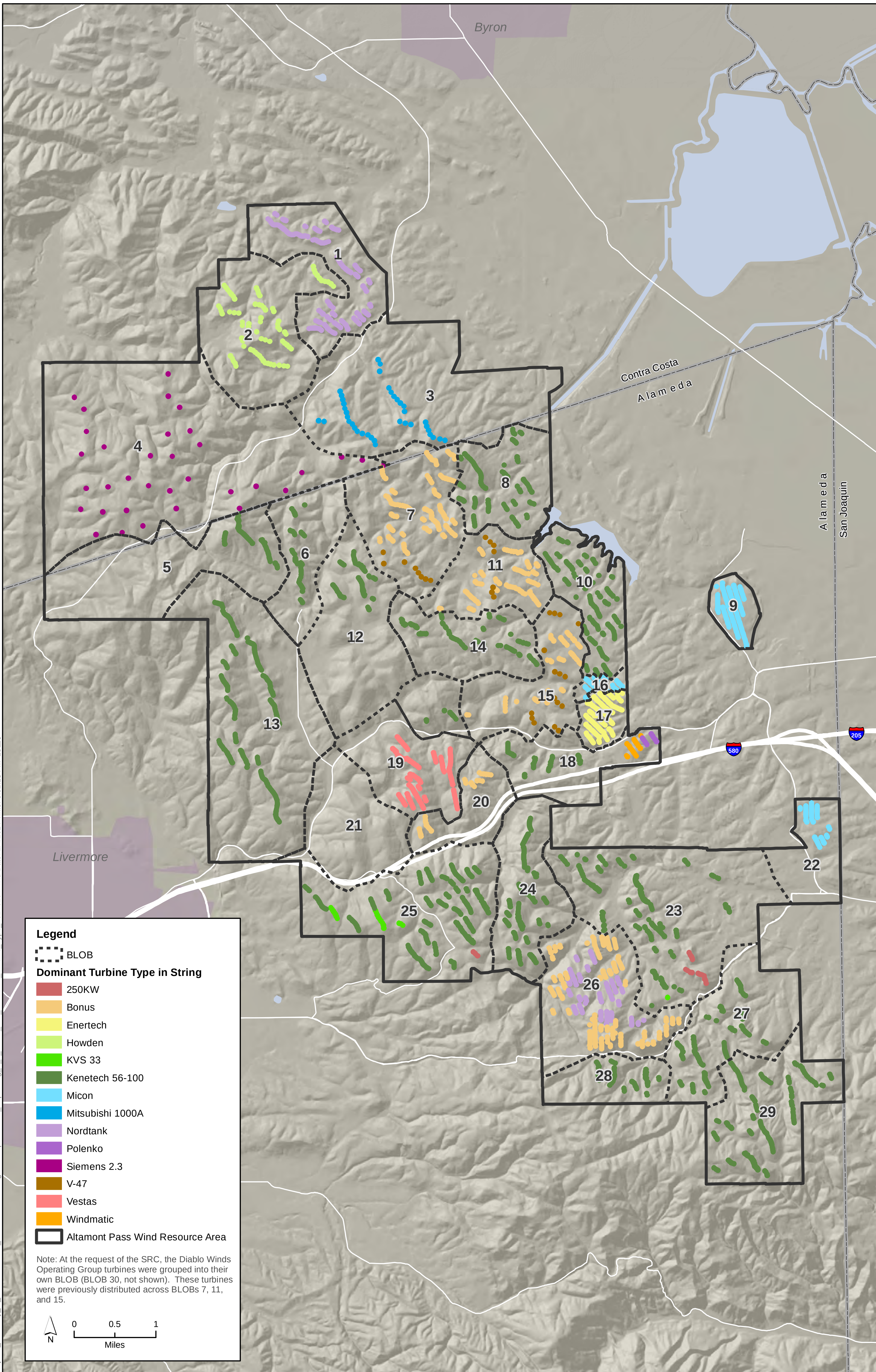

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Figure 1-2
Base Layer of Operating Group Boundaries (BLOBs) and Distribution and Abundance of Turbine Types in the APWRA

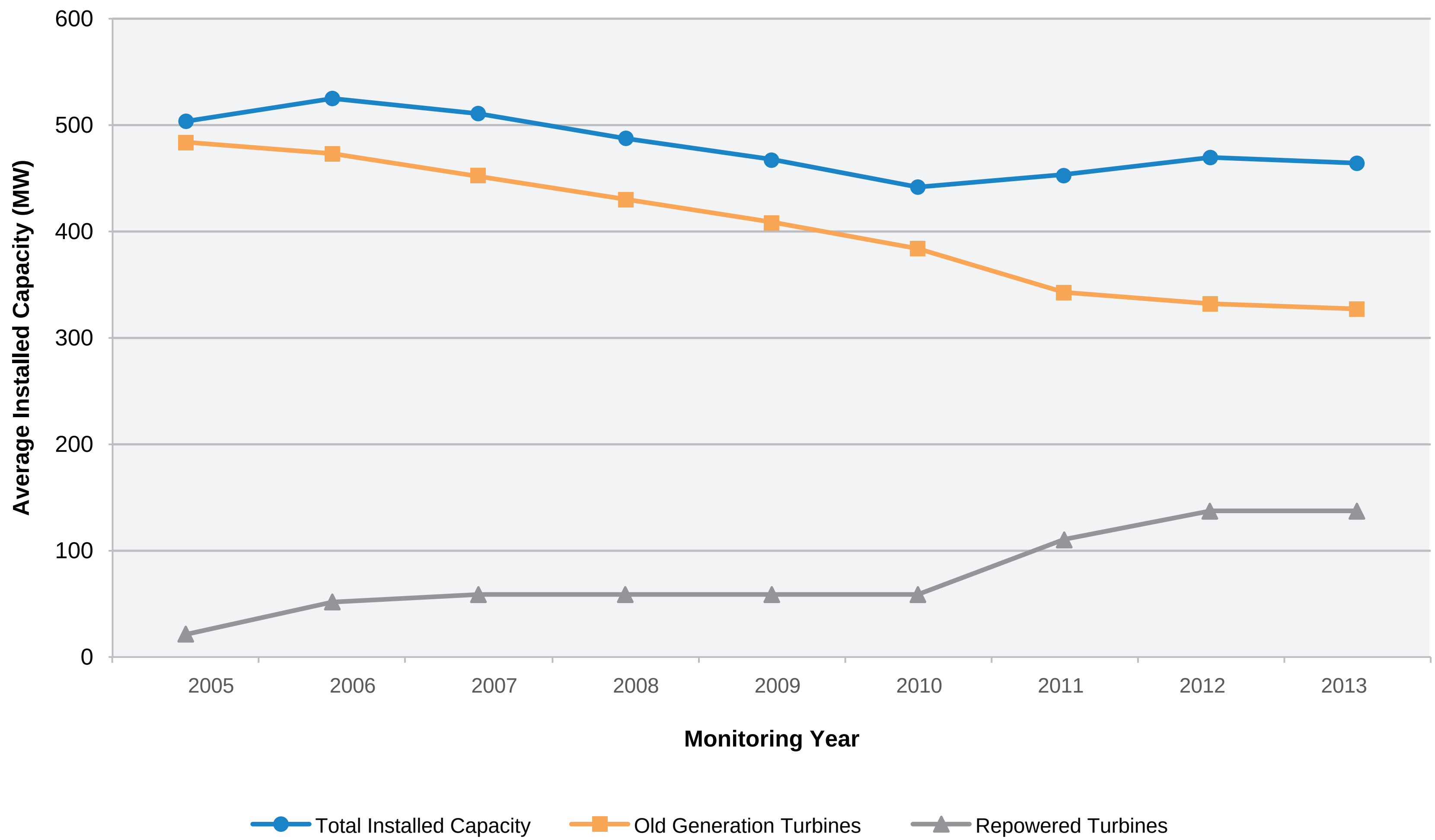

Figure 1-3
Changes in Average Installed Capacity of Turbines in the APWRA, Monitoring Years 2005–2013

In the 2009 monitoring year, the shutdown period was extended to 3.5 months with the shutdown of all turbines occurring simultaneously so that the entire APWRA would experience as complete a shutdown as possible (i.e., the shutdown was not phased). Turbines were shut down on November 1 and reactivated on February 16. The simultaneous 3.5-month shutdown was continued through the 2013 monitoring year. Characteristics of the various winter shutdown treatments are shown in Table 1-2.

Table 1-2. Timing, Duration, and Other Characteristics of the Winter Shutdown of Turbines in the APWRA, Monitoring Years 2005–2013

Monitoring Year	Shutdown Type	November	December	January	February
2005	Crossover	Crossover	Crossover	Crossover	Crossover
2006	Crossover	Crossover	Crossover	Crossover	Crossover
2007	Phased universal 2-month shutdown	Phased	Shutdown	Phased	Phased
2008	Phased universal 3-month shutdown	Phased	Shutdown	Shutdown	Phased
2009	Universal 3.5-month shutdown	Shutdown	Shutdown	Shutdown	Operating[a]
2010	Universal 3.5-month shutdown	Shutdown	Shutdown	Shutdown	Operating[a]
2011	Universal 3.5-month shutdown	Shutdown	Shutdown	Shutdown	Operating[a]
2012	Universal 3.5-month shutdown	Shutdown	Shutdown	Shutdown	Operating[a]
2013	Universal 3.5-month shutdown	Shutdown	Shutdown	Shutdown	Operating[a]

Crossover = Turbines in half of APWRA shut down while other half continued normal operations.
Phased = Individual turbine strings shut down immediately following a search of that string by the Monitoring Team.
Universal = All turbines APWRA-wide completely and simultaneously shut down.
[a] The operational period was February 16 through the end of the month.

It should be noted that there are several minor exceptions potentially confounding the seasonal shutdown treatment. The Tres Vaqueros operating group in the Contra Costa County portion of the APWRA did not participate in the seasonal shutdown until after completion of the crossover experiment in 2007. Also, the 40-kilowatt (kW) Enertech turbines (the Altech operating group) have always been shut down for the winter as part of standard operations, and the Santa Clara operating group was shut down from January 2006 to February 2007 because of a transfer in project ownership. Other minor exceptions also occurred. None of the three repowered projects—Diablo Winds (BLOB 30), Buena Vista (BLOB 3), or Vasco Winds (BLOB 4)—participate in the seasonal shutdown.

Removal of High Risk and Hazardous Turbines

Two efforts have been made to identify turbines whose permanent shutdown, removal, or relocation would reduce turbine-related avian fatalities. Smallwood and Spiegel (2005a, 2005b, 2005c) examined associations among the location of avian fatalities, environmental variables, and various physical attributes of specific turbines to assess the collision threat posed by those turbines. Only those turbines in the APWRA with the requisite data (i.e., those studied in the baseline study by Smallwood and Thelander [2004]) were evaluated. Based on these associations, turbines were ranked from 1 (highest risk) to 5 to reflect their perceived risk to birds. Smallwood and Spiegel concluded that the permanent shutdown of turbines ranked 1–3 would significantly reduce avian fatalities. This subset of turbines consisted of 152 turbines with a total capacity of 15.23 MW.

In December 2007, at the request of Alameda County and the power companies, the SRC conducted a field review of turbines in strings with relatively high numbers of turbine-related avian fatalities (APWRA Scientific Review Committee 2007). Based on the configuration and environmental settings of these turbines, the SRC ranked them from 2.5 to 10 in increments of 0.5 based on their perceived hazard to birds, with 10 being the most hazardous. Based on this review, the SRC recommended the removal of 331 turbines ranked 8–10 with a capacity of 24.9 MW (APWRA Scientific Review Committee 2008).

The two ranking systems are not mutually exclusive; some turbines ranked using Smallwood and Spiegel's system were also ranked using the SRC's system. Not all turbines recommended for removal have been removed. Table 1-3 shows the number and timing of turbine removals.

Table 1-3. Turbine Removals (Megawatts) in the APWRA, Monitoring Years 2005–2013

	Number of Turbines (Megawatts) Removed per Monitoring Year			
Monitoring Year	Attrition	High-Risk Turbines[a]	Total Removed	Percentage of Annual Average Installed Capacity Removed (MW)
2005	131 (12)	0 (0)	131 (12)	2%
2006	67 (7)	23 (3)	90 (10)	2%
2007	76 (9)	100 (10)	176 (19)	4%
2008	79 (8)	106 (11)	185 (19)	4%
2009	149 (15)	55 (6)	204 (21)	4%
2010	28 (3)	18 (2)	46 (5)	1%
2011	7 (1)	0 (0)	7 (1)	0%
2012	14 (1)	3 (1)	17 (2)	0%
2013	0 (0)	0 (0)	0 (0)	0%

[a] Both Smallwood and Spiegel (2005a, 2005b, and 2005c) and the APWRA Scientific Review Committee (2007) identified turbines in the APWRA to be removed, relocated, or permanently shut down to reduce avian fatalities. These two ranking systems are not mutually exclusive; some turbines identified for removal by Smallwood and Spiegel were also identified by the Scientific Review Committee.

Repowering Turbines

Through repowering, several smaller, older-generation turbines can be replaced by a single newer-generation turbine without any loss of rated capacity. There is some evidence to suggest that repowering turbines may potentially reduce turbine-related avian fatalities for the four focal species in the APWRA (Smallwood and Karas 2009). To date, three operating groups in the APWRA have been repowered.

The Diablo Winds operating group was repowered in 2005. One hundred sixty nine FloWind vertical axis turbines with a combined rated capacity of 21 MW were replaced by 31 Vestas V47 660 kW turbines with a combined rated capacity of 20.46 MW. The FloWind turbines were removed in 2004, and the new turbines began operating in 2005. The newer-generation turbines are distributed among older generation turbines. Although they cross the physical boundaries of three BLOBs (7, 11, and 15), they are assigned to their own BLOB (30) for analytical purposes. These are the only repowered, newer-generation turbines that were monitored by the MT. Monitoring occurred from the 2005 through the 2009 monitoring years.

The Buena Vista operating group was also repowered in 2005. One hundred seventy nine Windmaster 150 and 160 kW turbines with a combined rated capacity of approximately 38 MW were replaced with 38 Mitsubishi 1 MW turbines. Construction began in 2005, and the new turbines became operational in 2007. This is the only project in BLOB 3. The Buena Vista operating group was not monitored by the MT but was monitored by a separate entity for 3 years following construction (Insignia Environmental 2012).

The Vasco Winds operating group was shut down in January 2011. Four hundred thirty-eight KVS 33 turbines with a combined rated capacity of approximately 80 MW were shut down, removed, and replaced with 34 Siemens 2.3 MW turbines with a combined rated capacity of 78.2 MW. This is the only project in BLOB 4. The new turbines became operational in February 2012, 4 months into the 2011 monitoring year.

Chapter 2
Methods

Field Methods

Sample Selection

An average of 2,297 (45%) of the 5,077 turbines operating in the APWRA as of October 1, 2005, were monitored from monitoring years 2005 through 2009 (i.e., October 2005 through September 2010) (Figure 2-1, Table 2-1).

Table 2-1. Search Effort and Average Search Interval (Days ±1 Standard Deviation) in the APWRA, Monitoring Years 2005–2013

Monitoring Year	Strings Sampled	Turbines Sampled	Average Search Interval in Days (±1SD)[a]
2005	289	2,073	50.8 (7.4)
2006	295	2,114	35.3 (3.9)
2007	340	2,552	35.1 (1.7)
2008	337	2,417	30.0 (1.3)
2009	332	2,329	34.2 (1.5)
2010[b]	169	1,343	34.9 (2.1)
2011	185	1,289	40.6 (2.8)
2012	167	1,286	37.2 (2.6)
2013	186	1,375	39.6 (1.8)

[a] Denotes average search interval across BLOBs.
[b] In the 2010 monitoring year, the number of turbines sampled was reduced to approximately 58% of the original sample.

Turbine strings were selected for sampling using the following procedure. The entire APWRA was divided into blocks by geographic location and turbine size. Each block contained 10–60 turbines aligned in 1–7 turbine strings. All blocks containing very small (40–65 kW) and large (>250 kW) turbines (e.g., the Diablo Winds, Tres Vaqueros, and Altech operating groups) were selected. Eighty-four blocks from the set of blocks containing medium-sized turbines (95–200 kW) were randomly selected for monitoring. Turbine strings were the sampling unit, so in all cases all turbines within a string are searched at the same time.

At the beginning of the 2010 monitoring year, resources were reallocated away from monitoring and toward directed studies—and a new sampling scheme for monitoring was implemented. The number of turbine strings monitored was reduced, and a spatially balanced randomized rolling-panel design (Stevens and Olsen 2003, 2004) was implemented. BLOBs were introduced at this time to replace the blocks previously used to select turbines and to serve as a better unit of stratification for analysis. This design was chosen to ensure that the sampling scheme adequately addressed the significant geographic variation in turbine-related fatality rates across the APWRA that became apparent during the first 5 years of the study and to address variation in fatality rates attributable to differences among different turbine types.

Under the revised sampling scheme, approximately 58% of the turbines in the original sampling scheme (1,343 turbines in the 2010 monitoring year design) were searched each year. Of these, approximately 60% are *core turbines* (turbines that have been monitored every year of the study), while the remaining 40% are part of a *rotating panel* (i.e., rotated annually) to ensure adequate sampling of the various turbine types, topographies, and geographies of the APWRA (Figure 2-1).

Carcass Searches

The area around each monitored turbine string was systematically searched for carcasses approximately every 30–40 days. The search area for each turbine extended 50 meters from the turbine in all directions, except for the Tres Vaqueros operating group in Contra Costa County, where the search radius was 60 meters, and the Diablo Winds operating group, where the search radius was 75 meters to accommodate the much greater tower heights. The distance between *transects* (defined as the path followed by a searcher) averaged 6–8 meters, depending on the terrain, vegetation height, and height of the individual searcher.

When evidence of a fatality was found, the location was documented, and specific data on the condition of the find were recorded. To be considered a fatality, each find had to include body parts or feathers. In the case of feathers, at least five tail feathers, two primaries from the same wing within 5 meters of each other, or a total of 10 feathers had to be found. Whenever partial remains were found, the data were cross-referenced with finds from previous searches and adjacent turbines to avoid double counting. The location of the find was marked with flagging, and the search continued until the entire search area was covered. Cause of death was noted when it was determinable (e.g., line strike, electrocution, turbine strike), but for most fatalities the cause of death was unknown and in most cases was indistinguishable from other mortality factors. Therefore, with the exception of burrowing owl remains documented within 1 meter of an active burrow (for which predation was considered the cause of death), all fatalities found during a search for which the cause of death was unknown were considered turbine-related fatalities.

Each fatality was assigned to one of six carcass-age categories used to estimate a death date for that carcass. A complete description of field methods and protocols is given in Appendix B.

During the first 5 years of the current study, the number of turbine strings included in the sample ranged from 289 to 340, with average search intervals of 30–51 days (Table 2-1). Over the next 4 monitoring years under the new sampling scheme, the number of turbine strings searched ranged from 167 to 186, with an average search interval of 35–41 days.

Detection Probability Studies

Estimating the total number of fatalities that occur in the APWRA each year requires an assessment of the extent to which carcasses are imperfectly detected. Traditionally, detection probability has been divided into separate components that are then measured using carcass placement trials (California Energy Commission and California Department of Fish and Game 2007; Smallwood 2007a; Strickland et al. 2011). The two largest components of detection probability are often referred to as the *carcass removal rate* (the probability of removal of carcasses from the search area by scavengers or abiotic forces) and *searcher efficiency* (the probability that a searcher will detect a carcass given that it is still present and available to be detected).

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Figure 2-1
Distribution of Turbines Monitored in the APWRA, 2005–2013 Monitoring Years

Three separate studies have been conducted in the APWRA that provide information that can be used to estimate detection probability; documents pertaining to these studies are listed below.

- *Altamont Pass Carcass Removal/Scavenging Trial* (ICF Jones & Stokes 2008) (hereinafter referred to as the *carcass removal/scavenging trial*).
- *Altamont Pass Wind Resource Area 48-Hour Search Interval Bird Fatality Study* (ICF Jones & Stokes 2009) (hereinafter referred to as the *48-hour search interval study*).
- *Altamont Pass Wind Resource Area Study Plan for Future Monitoring* (ICF International 2010) (hereinafter referred to as the *QAQC study*).

In the carcass removal/scavenging trial, fresh carcasses of primarily large birds (defined as larger than a rock pigeon) found during regular searches were left in place and their condition tracked for a period of 60 days or more. The trials began in December 2005 and continued until October 2010. Carcasses were checked daily for the first 3 days after discovery, twice per week for the next 2 weeks, then once per week for the remainder of the trial period. At each visit, the condition of the trial carcass was noted—i.e., whether the carcass was intact, scavenged, a feather pile (more than 10 feathers), or absent (fewer than 10 feathers). In addition, the type and degree of scavenging was noted, photos were taken, and pertinent notes were recorded on the physical condition and age metrics of the carcass. Upon the conclusion of each individual trial, the remaining carcass and feathers (if any) were removed from the site. This study provided detailed information on the carcass removal rate primarily for large bird carcasses in the APWRA.

In the 48-hour search interval study, an independent second search crew searched a subset of monitored turbines using a 2-day search interval. The study spanned two separate 2-month periods (September–October 2007 and March–April 2008). When fresh carcasses of small birds were detected, the carcass would be marked and left in place in the field. The carcass would then be checked every 48 hours to track the disposition of the carcass. Results of searches were not shared between the regular and 48-hour search interval crews. This study provided detailed information on the carcass removal rate primarily for smaller birds, while also providing information on searcher efficiency.

In an effort to integrate detection probability monitoring into the regular fatality search protocol, the QAQC study was conducted using carcasses actually deposited by wind turbines within the study area (with some exceptions); this study was intended to provide information on searcher efficiency and carcass removal rates simultaneously. A blind repeated sampling design was used; two separate search crews were established that were blind to the results of the others searches. Fresh carcasses found during regular searches and searches by the study field supervisor both before and after regular searches were occasionally collected and then volitionally placed at other sites during the course of the study. A relatively small number of carcasses obtained from wind company personnel or from raptor rehabilitation facilitates outside the APWRA were also used in the study. Only the freshest carcasses available were used. The first carcass was placed on December 27, 2010, and the last carcass was placed on January 3, 2012.

During each search rotation, three monitored strings were randomly selected within three to five randomly selected BLOBs for carcass placement. Selected strings and BLOBs are referred to here as *QAQC strings* and *QAQC BLOBs*. A *pre-search*—a search similar to a *clearing search* that is conducted by a field supervisor—was conducted at each QAQC string prior to carcass placement. One carcass was then placed at each QAQC string at a random location within 50 meters of a monitored turbine. Each search crew then searched monitored strings within the randomly selected QAQC BLOBs at different times in the rotation. Search crews were blind to which BLOBs were part of the QAQC study trials. During the period of the QAQC study, search crews were instructed to leave all carcasses in the field so that the field supervisor could determine if another blind search could be conducted at that carcass location. If no additional blind searches could be conducted on a carcass, the field supervisor collected it. The first search of a QAQC string was called a *primary search*, and the second search of a QAQC string was called a *secondary search*. The interval between pre- and primary searches ranged from 0 to 26 days; the interval between primary and secondary searches ranged from 0 to 10 days. A *post-search*—defined as a search by a field supervisor immediately following the secondary search—was then conducted at QAQC strings. During the post-search, the field supervisor would attempt to locate and document any placed carcasses that were still extant. Carcasses located during the post-search that were not detected by either team were left in the field because all search crews were still blind with respect to that carcass. Carcasses that were detected by one or both teams were documented and collected during the post-search.

Toward the end of the QAQC study, it was determined that a greater sample of small raptor carcasses would improve the estimates. Twelve such carcasses—all complete, fresh carcasses obtained from raptor rehabilitation facilities—were incorporated into the study.

The resulting dataset constitutes a series of sequences of detections and non-detections during pre-, primary, secondary, and post-search types that were used to estimate the detection probability of a carcass. Additional details on field and analytical methods are provided in Appendix C.

Avian Use Surveys

Avian use surveys for the four focal species were first implemented at the Diablo Winds operating group in April 2005. Eight observation points (OPs) were established that focused on the 31 Vestas V-47 turbines of the Diablo Winds operating group. From April 2005 until September 2007, 30-minute surveys were conducted at each OP twice per calendar month. The first 20 minutes were devoted to behavior surveys, with the last 10 minutes used to conduct a 10-minute point count. These surveys were expanded to the entire APWRA in December 2005. Seventy additional OPs were established. The number of OPs has changed over time, ranging from 92 in the 2006 monitoring year to 72 in the 2011 monitoring year (Figure 2-2). The non–Diablo Winds OPs were surveyed twice during each search rotation (i.e., twice during each search interval), a longer interval between surveys than the Diablo Winds OPs.

In January 2007, collection of behavior data ended and the total survey time was reduced from 30 minutes to 10 minutes. Under this protocol, the surveyor continuously rotated in a circle, making one revolution approximately each minute while scanning for birds. In October 2007, the schedule for surveying the Diablo Winds OPs was merged with the APWRA-wide OPs so that all OPs were surveyed twice during each rotation. Beginning in August 2007, the maximum radius within which bird species were recorded at Diablo Winds OPs was reduced from 800 to 600 meters. In September 2007, the maximum radius within which a bird species was recorded was reduced from 800 meters to 500 meters at all non–Diablo Winds OPs.

An initial analysis of the bird use data conducted in 2012 made clear that the 10-minute survey duration was both inefficient and potentially inadequate for tracking changes in relative abundance for some species, and the survey protocol was revised again. Beginning in January 2013 (3 months after the start of the 2012 monitoring year), the number of OPs was reduced to 47, the survey time was expanded to 30 minutes per session, and a maximum 600-meter search radius was established,

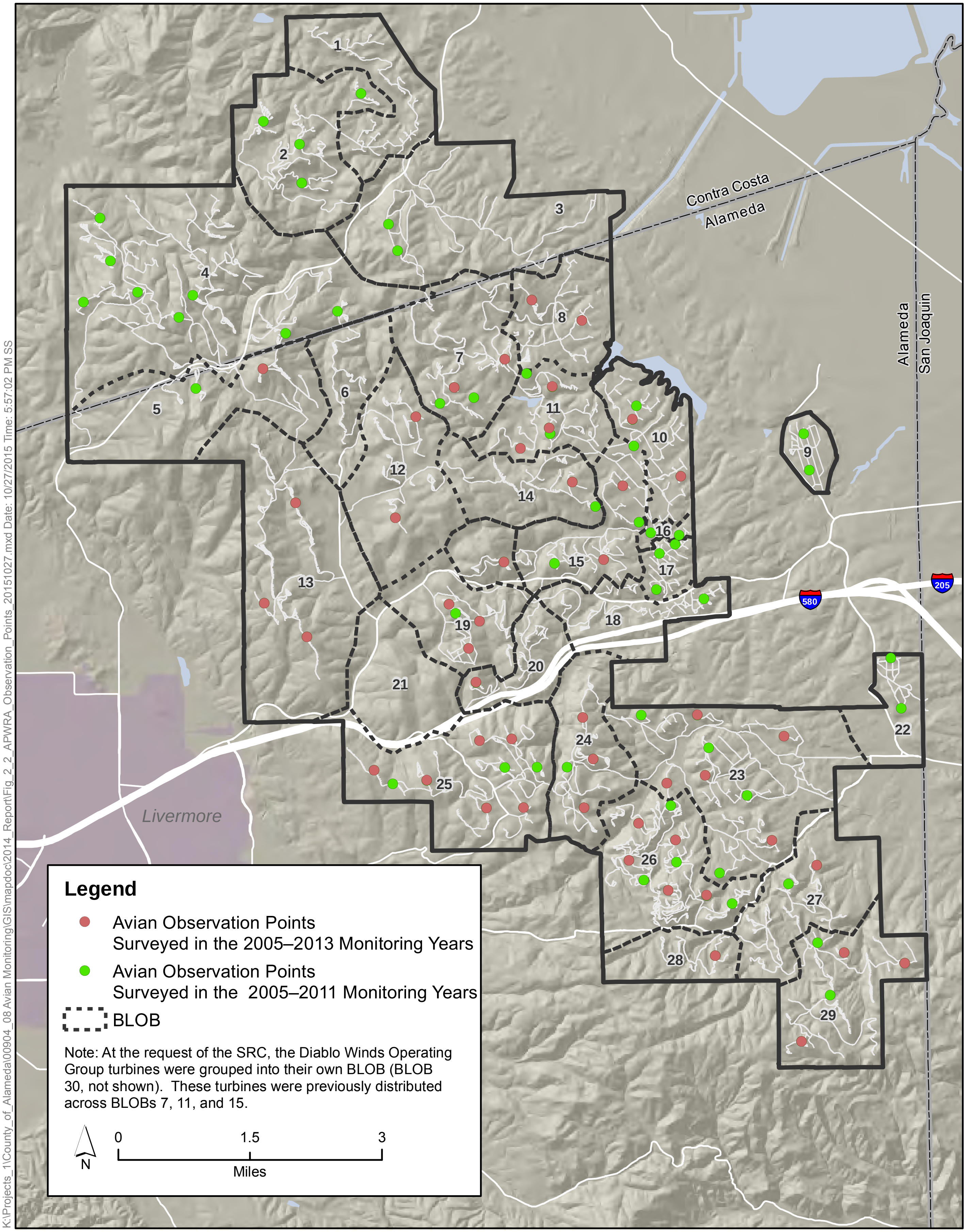

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Figure 2-2
Distribution of Observation Points Surveyed in the APWRA, Monitoring Years 2005-2013

except for golden eagles, for which all detections were recorded irrespective of distance. In addition, information was recorded on all species present, rather than just diurnal raptors. Under this protocol, the surveyor continuously rotated in a circle and recorded the numbers of all birds seen at 1-minute intervals.

Standard weather information (percent cloud cover, temperature, wind direction, average wind speed, maximum wind speed, visibility, and precipitation) was collected at the beginning of each survey using a handheld Kestrel® pocket weather meter and a compass. Surveys were not conducted when winds reached more than 34 miles per hour (55 kilometers per hour), when heavy rain or fog limited visibility, or when power company technicians were working in the area.

Background Mortality Study

By the end of the 2012 monitoring year, a substantial body of evidence suggested that predation may be confounding the analysis of management action effectiveness and the estimates of APWRA-wide total focal species fatalities. The evidence came primarily from fatalities found during the seasonal shutdown. Specifically, a substantially higher-than-expected proportion of burrowing owl fatalities was estimated to have occurred during the seasonal shutdown, with the majority of those burrowing owl carcasses being feather piles.

To investigate this issue, the SRC approved a study recommended by the MT to examine background mortality in the APWRA during the seasonal shutdown. Searches were conducted on ridges with turbines and ridges without turbines during the seasonal shutdown. We used a matched pairs design with a sample of 32 matched sites.

Because ridges without turbine strings are rare in the APWRA, we initially used the database to identify all ridges where turbines have been removed. We then used GIS to model the characteristics of ridges with turbines, and the model was used to identify ridges without turbines with similar characteristics. Once all suitable ridges without turbines had been identified, proximity, slope, and elevation were used to match turbine ridges with non-turbine ridges. Each matched pair was then visited in the field, and refinements were made to ensure that all matches were suitable.

It was imperative to the study to maintain equal search effort and search area between turbine ridges and non-turbine ridges. To accomplish this, some matched pairs consisted of more than two ridges.

- In four cases, more than one non-turbine ridge was matched with a turbine ridge.
- In one case, more than one turbine ridge was matched with a non-turbine ridge.
- In one case, more than one turbine ridge was matched with more than one non-turbine ridge.

Thus, although a matched pair consisting of one turbine ridge and one non-turbine ridge was the sample unit in most cases, equivalent search areas composed of more than two ridges was the sample unit in the six cases outlined above.

Thirty-nine non-turbine ridges were matched with 34 turbine ridges based on elevation, slope, aspect, size, proximity, and habitat (Figure 2-3).

Five non-turbine ridges had no history of turbines, while the remaining 34 non-turbine ridges were ridges where turbines had been removed. In these cases, the power box (a metal box approximately 3 feet tall that previously served as a collection point for electrical wiring) was usually still present.

We conducted clearing searches at several sites prior to the beginning of the study, and we conducted one round of clearing searches at all sites once the study began. A two-person search crew searched each treatment and control site together on the same day. Searches began on November 1, 2014, and ended on February 15, 2015. The average search interval for each matched pair was less than 11 days.

Analytical Methods

Avian fatality rates were estimated by adjusting raw fatality counts by their estimated detection probabilities to account for fatalities that were missed. This method—which originated as the Horvitz–Thompson estimator—is now widely used in the wildlife sciences (Horvitz and Thompson 1952; Cochran 1977; Steinhorst and Samuel 1989; Williams et al. 2002) and is commonly applied in monitoring studies of avian fatalities at wind power facilities (California Energy Commission and California Department of Fish and Game 2007; Strickland et al. 2011). Williams et al. (2002:256) presented a general form of the estimator as

$$\hat{N} = \sum_{i=1}^{C} \frac{1}{\beta_i}, \qquad \textbf{Equation 1}$$

where the hat symbol (^) distinguishes the estimated total fatalities ($\hat{N}$) from the actual total fatalities (N), C is the number of fatalities actually counted, and $\beta_i$is the detection probability for the ith fatality. Note that if the detection probability is equal for all fatalities, then the estimator simplifies to

$$\hat{N} = \frac{C}{\beta}. \qquad \textbf{Equation 2}$$

Detection probabilities (β_i) were estimated using data collected during the QAQC study, the carcass removal/scavenging trial study, and the 48-hour search interval study. A composite model was used to estimate detection probabilities in a Bayesian framework. Wingspan was included in the model as a covariate, resulting in unique detection probabilities for each species. Details on methods, analyses, and results are provided in Appendix C. The detection probabilities derived from this analysis were used to estimate fatality rates and total APWRA-wide annual fatalities across all years of the current study.

We used an alpha level of 0.05 for hypothesis testing. Probability values between 0.05 and 0.1 were considered marginally significant.

Fatalities Excluded from the Analyses

Because of factors associated with the adjustment of fatalities for imperfect detection, it is inappropriate to include all fatalities documented in the APWRA in the analysis. Three types of fatality records were documented during the current study: those documented during searches, those documented by search crews outside of standard searches (incidental records), and those documented by operations and maintenance (O&M) crews (Wildlife Reporting Response System

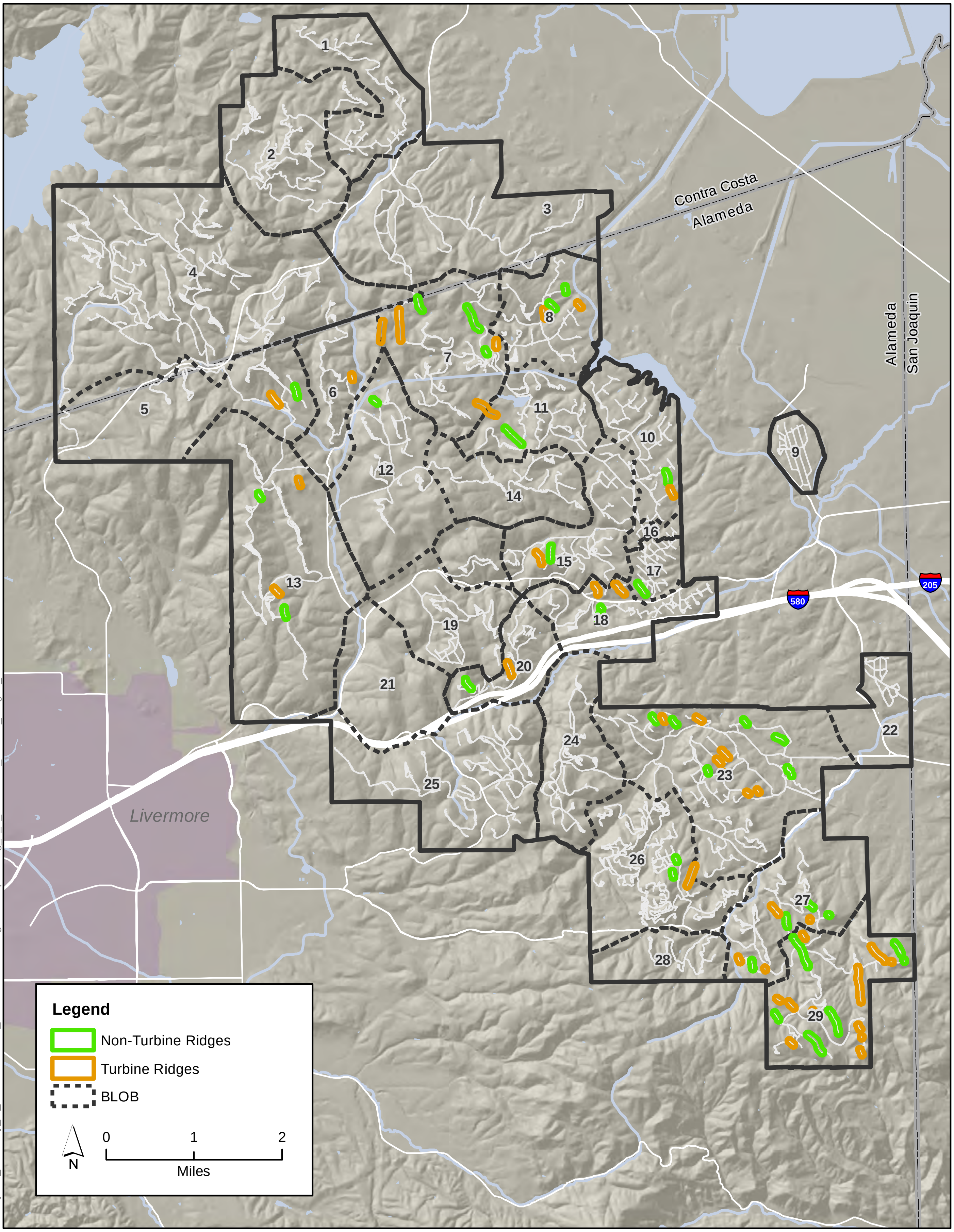

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Figure 2-3
Location of Turbine Ridges and Non-Turbine Ridges Selected for the Background Mortality Study in the APWRA

[WRRS] records). In general, only fatalities documented during regular searches are reported here and included in the analyses.

Prior to 2007, all fatalities found by power company O&M personnel were documented and removed from the field when found (and therefore rendered unavailable for detection by search crews, resulting in a bias toward underestimating total fatalities). Beginning in 2007, all fatalities found at monitored turbines—with the exception of golden eagles—were marked and left in the field for search crews to find. Golden eagles found by O&M personnel are immediately removed from the field due to permit requirements associated with protections afforded to golden eagles under the Bald and Golden Eagle Protection Act. However, golden eagle carcasses found by O&M personnel were included in the analysis if the fatality was documented at a monitored turbine string. Thirty-two turbine-related golden eagle fatalities were documented by WRRS crews at monitored turbines over the course of the study and were included in the analysis.

Fatalities that were clearly not turbine-related or that could not be identified to a taxonomic level to permit a reasonable wingspan measurement were excluded from the analysis.

Turbine-related fatalities are occasionally found outside the standard search radius. For American kestrel, golden eagle, and red-tailed hawk, 90%, 84%, and 85%, respectively, of carcasses are found within the search radius. For burrowing owls, 73% of carcasses are found within the search radius. As the distance from the turbine increases, the search area increases geometrically, and searcher coverage becomes spottier and less predictable. Detection probability of these carcasses decreases substantially with distance beyond the search radius, making an unbiased adjustment problematic. One hundred percent of American kestrel carcasses, and more than 98% of all burrowing owl, golden eagle, and red-tailed hawk carcasses found during regular searches were within 125 meters of a turbine. Accordingly, all carcasses found more than 125 meters from turbines were excluded from the analysis.

Some carcasses are estimated to be older than 90 days or of undeterminable age. Because these fatalities are likely to be older than the search interval, they would have been missed during a previous search. These fatalities have thus already been accounted for by the adjustment of other detected fatalities, and were therefore excluded from the analyses.

Estimating Fatality Rates and Total Fatalities

The California Energy Commission (CEC) has recommended that avian fatality rates associated with wind turbines be estimated based on the rated capacity of the turbine, turbine string, operating group, or entire wind generation facility (California Energy Commission and California Department of Fish and Game 2007). The *rated capacity* of a turbine is defined as the amount of power that turbine could generate at its rated wind speed. The rated capacity of turbine strings and wind generation facilities are therefore the sum of the rated capacities of the individual turbines. Using the fatalities-per-megawatt metric makes sense in the APWRA due to the high diversity of turbine types and rated capacities that have been installed there.

Average Installed Capacity and Monitored Capacity

Because the rated capacity of the APWRA was dynamic over the course of the study, *installed capacity*—defined as the sum of the rated capacities of all extant turbines each year—was the metric used to calculate fatality rates and extrapolate them to the entire APWRA. The power companies provided information on the number of installed turbines and turbine strings and their rated capacities for each year of the study along with the approximate date of any turbine removals that occurred.

The installed capacity of an individual turbine is prorated on a monthly basis. If a turbine was installed at any time during a particular month, its rated capacity is included in the installed capacity of the string for that month. If during the entire month the turbine was not installed (i.e., it had been removed or was not yet installed), its rated capacity is not included in the installed capacity of the string for that month.

A string is considered monitored during a monitoring year if at least six searches were conducted on that string during that monitoring year. The *monitored capacity* of a monitored string in a monitoring year is equal to the string's average installed capacity throughout the year.

Search Coverage and Amortized Fatality Counts

Because of the size and complexity of the sampling effort, the search interval was not fixed. Searches conducted through a monitoring year sometimes resulted in search intervals that did not completely cover that monitoring year. For example, searches may start late or end early in the year because of turbine removals, changes in the sampling design, and occasionally logistic constraints. To account for strings with interrupted searches due to these factors, search coverage for each string within a BLOB was estimated (see Appendix D for details). *Search coverage* was defined as the ratio between the length of search coverage (in days) and the length of the monitoring year (in days). This ratio was used to generate *amortized fatality counts*. When the search coverage of a monitored BLOB in a given monitoring year was less than 100%, the raw counts were amortized to account for missed opportunities for detection during that monitoring year. The *amortized fatality count* for a species at a BLOB was calculated as the fatalities detected at the BLOB's monitored strings divided by the search coverage at that BLOB. Regardless of coverage, strings with fewer than six searches in a monitoring year were considered inadequately sampled and were therefore excluded from the analyses.

Detection Probability and Search Interval

The *detection probability* is the probability of a carcass being detected by the search crew and is related to the search interval. The average search interval for each BLOB along with the wingspan for each species (see Appendix C for details) was used to estimate the detection probability for each species at each BLOB. That detection probability was then used to produce the *adjusted fatality count*, calculated as the amortized fatality count of a species divided by the detection probability of that species at each BLOB.

Adjusted Fatality Rate

Annual adjusted fatality rates were estimated by summing the adjusted and amortized fatality counts for all monitored strings within a BLOB for each complete monitoring year, and dividing by the average installed capacity of the BLOB's monitored strings. The annual APWRA-wide adjusted fatality rates for older-generation turbines were calculated by taking the APWRA-wide adjusted and amortized fatality counts and dividing by the APWRA-wide monitored capacity, which is equivalent to taking the average of the adjusted fatality rates across BLOBs weighted by the installed capacity of each BLOB. See Appendix D for details on the calculation of variance terms and confidence intervals.

Trends in fatality rates over time were evaluated using simple linear regression. The significance of annual variation in APWRA-wide fatality rates and estimates of APWRA-wide total fatalities were evaluated by examining the degree of overlap in 95% confidence intervals around the estimates.

Expanded Fatality Estimates

As noted above, the APWRA was stratified into 30 BLOBs to better account for variance in the distribution of turbine types and the variable topographies and geographies of the APWRA. Thus, BLOBs were used as the basis for estimating total fatalities across the APWRA—i.e., the expanded fatality estimate is the sum of the adjusted fatality counts across BLOBs. Note that this is different from summing the fatality rates at the APWRA level and multiplying by its installed capacity.

The post-stratification of the study area into BLOBs resulted in an inadequate sample for a few of the BLOBs in the first 2 years of the study. When a small proportion of a BLOB's installed capacity is sampled, the estimated number of fatalities is especially sensitive to the exact number of carcasses detected during searches. For example, one American kestrel carcass was discovered at BLOB 5 in the 2005 monitoring year, while zero American kestrel carcasses were detected in the 2006 monitoring year. After adjusting for detection probability (23%) and applying the expansion factor (i.e., the ratio of installed to monitored capacity, or 18.3 MW / 0.8 MW), the estimated number of American kestrel fatalities at BLOB 5 in the 2005 monitoring year was 108, while the number at that same BLOB in the 2006 monitoring year was 0. To avoid such extreme adjustments a BLOB was considered inadequately sampled if less than 10% of its installed capacity was searched during a monitoring year. The 10% threshold was chosen because it excluded only two BLOB-years of data from the analysis. At the same time, the 10% threshold ensures that the expansion factor from monitored capacity to installed capacity is never more than 10.

Confidence intervals for the estimates of total annual fatalities were calculated by expanding the lower and upper confidence intervals around the adjusted fatality rates. Confidence intervals around the 3-year rolling average (geometric mean) of the estimates of annual total fatalities were calculated by taking the average of confidence intervals around the annual estimate of total annual fatalities. Additional details on the calculation of fatality rates, estimates of total fatalities, and their associated sampling variances are provided in Appendix D.

Inclusion of Fatality Estimates from Other Data Sources

Not all the BLOBs within the APWRA are monitored each year. For example, some BLOBs were repowered and monitored separately by other parties. BLOBs without monitored strings (5 of 30 BLOBs) were assigned fatality rates based on the best available information. The sources of estimated fatalities by BLOB, bird group, and monitoring year are provided in Table 2-2.

Table 2-2. Sources of Estimated Fatality Rates Included in the APWRA-Wide Estimate by BLOB, Monitoring year, and Bird Group, Monitoring years 2005–2013

BLOB	Bird Group	Monitoring Year and Source[a]								
		2005	2006	2007	2008	2009	2010	2011	2012	2013
1 (Northwind)	Focal	1	1	1	1	1	1	1	1	1
	Nonfocal	1	1	1	1	1	1	1	1	1
2 (Tres Vaqueros)	Focal	0	0	0	0	0	2	2	2	2
	Nonfocal	0	0	0	0	0	2	2	2	2
3 (Buena Vista)	Focal	1	4	4	4	4	4	4	4	4
	Nonfocal	1	3	3	3	3	5	5	5	5
4 (Vasco Winds)	Focal	0	0	0	0	0	8	7	7	7
	Nonfocal	0	0	0	0	0	8	7	7	7
5	Focal	6	6	0	0	0	0	0	0	0
	Nonfocal	6	6	0	0	0	0	0	0	0
27[b]	Focal	6	6	0	0	0	0	0	0	0
	Nonfocal	6	6	0	0	0	0	0	0	0

[a] For all BLOB year combinations where less than 10% of the installed capacity was monitored, the average fatality rate across all old-generation turbines for that species in that year was used.
0 = Rates are taken from the monitored turbines within the BLOB.
1 = Rates are taken from the APWRA-wide adjusted fatality rate for the relevant species in the relevant year.
2 = The average of the 2005–2009 monitored rates from BLOB 2.
3 = Diablo fatality rates for the relevant species in the relevant monitoring year.
4 = Average rates provided by the Buena Vista monitoring report.
5 = The average fatality rates from Diablo Winds turbines monitored from 2005 to 2009.
6 = Fatality rates from BLOBs containing all Kenetech 56–100 turbines for the relevant species in the relevant year.
7 = Fatality rates provided by the Vasco Winds Monitoring Report (Brown et al. 2013).
8 = The average of the 2005 – 2009 monitored rates at BLOB 4.

[b] Turbines in this BLOB were not added to the sampling scheme until the 2007 monitoring year. All turbines in this BLOB were Kenetech 56-100 turbines.

Estimating Bird Use

Avian surveys were conducted to assess trends in the relative abundance of the focal species both seasonally and annually (hereinafter referred to as *bird use*). The average number of observations per minute of survey was calculated to account for differences in survey duration (30- versus 10-minute survey durations) over the course of the study. To account for variations in the maximum search radius and to allow for valid comparisons of bird use across BLOBs, it was necessary to standardize for differences in the area visible from each OP for each of the maximum search radii used in the study. Accordingly, the average number of detections per minute of survey per cubic kilometer of visible airspace was the metric used to assess changes in bird use. For small birds (including burrowing owl and American kestrel), the average number of observations per minute per cubic kilometer was calculated using the volume derived from a 500- or 600-meter maximum search radius (depending on the OP) because these species are generally not detectable beyond 600 meters. For golden eagle, a maximum radius of 800 meters was used beginning with the protocol change in January 2013.

One-way analysis of variance (ANOVA) was used to evaluate patterns in bird use among years, months, BLOBs, and between seasons. Two-way ANOVA was used to test for interactions between monitoring years and BLOBs. Simple linear regression was used to evaluate trends in bird use over time.

Evaluation of the Effectiveness of Management Actions and Repowering

Although the study was designed to estimate the APWRA-wide total annual fatalities occurring each year, we nevertheless attempted to evaluate individually the effectiveness of the various management actions taken to reduce annual fatalities.

Hazardous Turbine Removal

Two operating groups, the Santa Clara operating group (BLOB 19) and the Diablo Winds operating group (BLOB 30), have been exempted from hazardous turbine removals. However, the Diablo Winds operating group is composed of newer and larger repowered turbines, is interspersed with older generation turbines, and for these reasons is not suitable for use as a control group. Therefore the Santa Clara operating group was used as a control group and fatality rates at these turbines were compared with fatality rates at other old-generation turbines over time. If hazardous turbine removal were effective, we would expect fatality rates to decline over time at a greater rate at non–Santa Clara older generation turbines than at Santa Clara turbines over the course of the study.

We also looked for correlations between the cumulative total of hazardous turbine removals (measured in turbines and MWs) and changes in fatality rates over time.

Season Shutdown

We used the Diablo Winds turbines—the only set of repowered turbines in the APWRA that are interspersed with older-generation turbines and that were monitored by the MT—as a control group because these turbines do not shut down in the winter. We compared the annual adjusted fatality rates of the four focal species at these turbines with the annual rates from non–Diablo Winds older-generation turbines.

We then examined the proportion of annual carcasses estimated to have a death date during and outside the shutdown period and compared these to the proportions that might be expected under various assumptions. We also calculated carcass detection rates during and outside the shutdown period for the four focal species. We limited some of these analyses to the 5 years of the study in which the 3.5-month universal shutdown was in effect because the shutdown period was long and the shutdown and startup dates were consistent, which together minimized the potential errors associated with incorrectly assigning a carcass to the appropriate period (shut down or not shut down).

Because predation could potentially confound analysis of the effectiveness of the seasonal shutdown, we examined the proportion of fatalities occurring during the shutdown period consisting of feather piles and compared it to the proportion of fatalities occurring outside the shutdown period consisting of feather piles. Assuming that carcasses resulting from predation become feather piles faster than those resulting from turbine collisions, one would expect the proportion of carcasses consisting of feather piles to be significantly higher during the shutdown period than during the rest of the year.

Repowering

To assess the effectiveness of repowering as a means of reducing turbine-related avian fatalities, the average annual adjusted fatality rates for the older generation were compared to the average annual adjusted fatality rates of repowered turbines (Diablo Winds, Vasco Winds, and Buena Vista operating groups).

Evaluation of the 50% Fatality Reduction Goal

The most straightforward measure of the reduction in focal species fatalities over time is the difference between the estimate of the APWRA-wide total focal species fatalities for the latest monitoring year (2013) and the estimate of total annual focal species fatalities identified in the settlement agreement (i.e., 1,130 focal species fatalities). However, using a static point estimate for the baseline is problematic in that it does not account for sampling variation or inter-annual variation. As noted above, attempts to jointly analyze the baseline and current study datasets resulted in the identification of several problems associated with making valid comparisons between the two datasets. Consequently, the MT—in conjunction with the SRC—developed an alternative baseline based on the 3-year rolling geometric means of the annual estimate of APWRA-wide total fatalities.

The alternative baseline was calculated by taking the 3-year rolling geometric mean of the estimates of APWRA-wide total fatalities for the first of the seven 3-year periods of monitoring data. We evaluated trends in the rolling average across the seven 3-year periods and derived several measures of the reduction in focal species fatalities.

Chapter 3
Results

Bird Use

We conducted 12,304 surveys throughout the APWRA over a period of 9 years (Table 3-1), focusing primarily on the four focal species. While the number of person-hours dedicated to bird surveys remained relatively constant across years, the total number of surveys completed each year was lower for the first and last years of the study, primarily because those years had a higher number of surveys using a 30-minute survey protocol.

Table 3-1. Total Number of Surveys per Month and Monitoring Year

Monitoring Year	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2005	61	97	0	0	32	84	55	111	16	16	16	24	512
2006	168	16	136	78	117	189	140	61	185	151	151	0	1,392
2007	153	129	196	117	133	175	177	151	140	183	0	0	1,554
2008	175	182	176	177	149	171	122	184	166	149	171	184	2,006
2009	117	185	156	161	178	142	100	211	168	202	101	186	1,907
2010	158	194	176	141	102	135	132	131	121	116	153	140	1,699
2011	100	114	140	131	97	101	96	122	92	164	126	107	1,390
2012	105	108	85	53	117	54	85	75	55	110	64	111	1,022
2013	69	65	75	79	61	77	76	83	49	63	65	60	822
Total	**1,106**	**1,090**	**1,140**	**937**	**986**	**1,128**	**983**	**1,129**	**992**	**1,154**	**847**	**812**	**12,304**

Use of the 30-minute survey protocol was clearly more efficient, as the total number of survey hours was higher for those years in which a 30-minute survey protocol was used, despite the completion of fewer total surveys (Table 3-2). In addition, the proportion of surveys in which a focal species was detected was higher in those years when the 30-minute survey protocol was used (Table 3-3).

Because avian use surveys were not designed to assess use by burrowing owls, burrowing owl use is not discussed further.

Seventy-seven avian species were detected during use surveys across all years (Table 3-4). However, relative abundance for non-focal species could only be evaluated for the 2013 monitoring year because that was the only year in which use by all species was consistently recorded.

Various gulls (California, western, and ring-billed gulls), common raven, red-tailed hawk, and blackbirds (Brewer's, tricolored, and red-winged blackbirds) were the most abundant species in the APWRA in the 2013 monitoring year. Fourteen species of raptor (including owls and turkey vulture) were detected in 2013, with the four focal species and turkey vulture being the most common. Red-tailed hawks were five times more abundant than American kestrels, the next most abundant raptor species in the 2013 monitoring year (Table 3-4).

Table 3-2. Total Number of Survey Hours per Month and Monitoring Year

	Month												
Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2005	31	49	0	0	16	42	28	56	8	8	8	12	256
2006	84	8	23	13	28	39	29	10	31	76	76	0	415
2007	26	22	33	20	22	29	30	25	23	31	0	0	259
2008	29	30	29	30	25	29	20	31	28	25	29	31	334
2009	20	31	26	27	30	24	17	35	28	34	17	31	318
2010	26	32	29	24	17	23	22	22	20	19	26	23	283
2011	17	19	23	22	16	17	16	20	15	27	21	18	232
2012	53	54	43	27	59	27	43	38	28	18	11	56	454
2013	35	33	38	40	31	39	38	42	25	32	33	30	412
Total	**319**	**277**	**243**	**200**	**243**	**267**	**241**	**278**	**205**	**269**	**219**	**201**	**2,963**

Table 3-3. Percentage of Surveys in Which Focal Species Were Detected

	Monitoring Year								
Species of Bird	2005	2006	2007	2008	2009	2010	2011	2012	2013
American kestrel	21%	17%	7%	12%	12%	11%	13%	18%	20%
Burrowing owl[a]	3%	2%	1%	1%	1%	1%	1%	1%	1%
Golden eagle	23%	14%	12%	11%	10%	11%	11%	23%	31%
Red-tailed hawk	75%	51%	27%	28%	22%	33%	37%	47%	51%

[a] Survey protocols were not designed to sample burrowing owls. The higher proportion of surveys with burrowing owl detections in the 2005 and 2006 monitoring years was due to a higher sampling rate at the Diablo Winds operating group, an area of high burrowing owl density.

Table 3-4. Mean Number of Detections per Minute of Survey per Cubic Kilometer of Visible Airspace for Avian Species Recorded during Surveys in the APWRA, 2005–2013 Monitoring Years[a]

	Monitoring Year									
Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
American kestrel	0.258 (0.183–0.332)	0.252 (0.203–0.300)	0.204 (0.146–0.262)	0.336 (0.271–0.401)	0.266 (0.215–0.317)	0.245 (0.149–0.341)	0.162 (0.131–0.192)	0.239 (0.183–0.295)	0.269 (0.201–0.337)	0.251 (0.229–0.273)
Burrowing owl	0.347 (0.027–0.666)	0.059 (0.029–0.089)	0.063 (0.016–0.109)	0.056 (0.017–0.094)	0.032 (0.011–0.054)	0.071 (0.027–0.114)	0.028 (0.009–0.047)	0.084 (0.003–0.165)	0.058 (0.014–0.101)	0.067 (0.048–0.086)
Golden eagle	0.190 (0.131–0.249)	0.126 (0.095–0.156)	0.250 (0.200–0.300)	0.261 (0.212–0.310)	0.221 (0.175–0.266)	0.211 (0.161–0.260)	0.140 (0.109–0.171)	0.232 (0.177–0.287)	0.198 (0.159–0.237)	0.208 (0.192–0.224)
Red-tailed hawk	1.519 (1.333–1.705)	1.179 (1.055–1.304)	1.198 (1.051–1.346)	1.022 (0.898–1.146)	0.673 (0.576–0.770)	0.941 (0.812–1.070)	0.753 (0.667–0.839)	1.051 (0.918–1.185)	1.350 (1.176–1.524)	1.012 (0.968–1.055)
Turkey vulture	0.332 (0.271–0.393)	0.372 (0.242–0.502)	0.622 (0.440–0.804)	0.388 (0.304–0.471)	0.373 (0.298–0.449)	0.514 (0.354–0.673)	0.338 (0.282–0.393)	0.292 (0.235–0.349)	0.248 (0.209–0.288)	0.405 (0.365–0.446)
Osprey	0.005 (0.000–0.014)	0.001 (0.000–0.004)	0.007 (0.000–0.017)	0.007 (0.000–0.016)	0.026 (0.002–0.049)	0.006 (0.000–0.016)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.007 (0.003–0.012)
White-tailed kite	0.001 (0.000–0.001)	0.006 (0.002–0.011)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.001 (0.000–0.002)	0.003 (0.000–0.008)	0.000 (0.000–0.000)	0.000 (0.000–0.001)	0.001 (0.001–0.002)
Bald eagle	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.002 (0.000–0.005)	0.000 (0.000–0.001)	0.007 (0.000–0.015)	0.002 (0.000–0.005)	0.002 (0.000–0.004)	0.004 (0.000–0.007)	0.002 (0.001–0.003)
Northern harrier	0.035 (0.023–0.046)	0.018 (0.013–0.023)	0.006 (0.000–0.012)	0.016 (0.010–0.022)	0.010 (0.002–0.018)	0.023 (0.015–0.030)	0.010 (0.006–0.015)	0.021 (0.008–0.033)	0.003 (0.001–0.005)	0.015 (0.012–0.017)
Sharp-shinned hawk	0.001 (0.000–0.002)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)
Cooper's hawk	0.001 (0.000–0.001)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.001)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.001)
Swainson's hawk	0.007 (0.000–0.017)	0.001 (0.000–0.002)	0.000 (0.000–0.001)	0.001 (0.000–0.003)	0.000 (0.000–0.001)	0.000 (0.000–0.000)	0.001 (0.000–0.003)	0.023 (0.004–0.042)	0.003 (0.000–0.006)	0.003 (0.001–0.004)
Ferruginous hawk	0.059 (0.027–0.091)	0.014 (0.007–0.021)	0.028 (0.011–0.045)	0.059 (0.035–0.083)	0.030 (0.015–0.046)	0.062 (0.034–0.091)	0.039 (0.026–0.052)	0.049 (0.024–0.073)	0.016 (0.009–0.024)	0.040 (0.033–0.047)
Rough-legged hawk	0.000 (0.000–0.000)	0.000 (0.000–0.001)	0.000 (0.000–0.000)	0.004 (0.000–0.008)	0.000 (0.000–0.000)	0.002 (0.000–0.005)	0.003 (0.000–0.006)	0.004 (0.000–0.008)	0.004 (0.000–0.009)	0.002 (0.001–0.003)
Merlin	0.003 (0.000–0.009)	0.002 (0.000–0.006)	0.000 (0.000–0.000)	0.003 (0.000–0.009)	0.001 (0.000–0.001)	0.000 (0.000–0.000)	0.001 (0.000–0.002)	0.001 (0.000–0.002)	0.000 (0.000–0.001)	0.001 (0.000–0.002)
Peregrine falcon	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.008 (0.000–0.019)	0.010 (0.000–0.020)	0.005 (0.000–0.011)	0.005 (0.000–0.010)	0.001 (0.000–0.002)	0.001 (0.000–0.003)	0.001 (0.000–0.001)	0.004 (0.002–0.007)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Prairie falcon	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.046 (0.021–0.071)	0.019 (0.014–0.023)
Canada goose	0.000 (0.000–0.001)			0.000 (0.000–0.001)			0.114 (0.000–0.245)	0.000 (0.000–0.001)	0.000 (0.000–0.001)	
Gadwall			0.030 (0.000–0.064)							
American wigeon			0.405 (0.000–0.870)	0.086 (0.000–0.253)		0.001 (0.000–0.002)		0.015 (0.000–0.032)		
Mallard	0.019 (0.000–0.041)	0.269 (0.026–0.513)	0.267 (0.089–0.445)	0.346 (0.118–0.573)	0.092 (0.000–0.235)	0.021 (0.000–0.044)	0.006 (0.000–0.012)	0.104 (0.004–0.205)	0.003 (0.000–0.006)	
Greater scaup		0.006 (0.000–0.019)								
Bufflehead		0.221 (0.000–0.455)	0.062 (0.000–0.130)	0.100 (0.000–0.255)	0.010 (0.000–0.021)	0.001 (0.000–0.004)	0.004 (0.000–0.011)		0.000 (0.000–0.001)	
Common goldeneye		0.005 (0.000–0.013)	0.006 (0.000–0.017)	0.033 (0.000–0.098)						
Barrow’s goldeneye						0.003 (0.000–0.009)				
Common merganser	0.001 (0.000–0.003)		0.001 (0.000–0.003)		0.000 (0.000–0.001)					
Clark’s grebe		0.001 (0.000–0.002)								
American white pelican	0.006 (0.000–0.017)	0.006 (0.000–0.014)	0.001 (0.000–0.003)	0.003 (0.000–0.010)	0.017 (0.000–0.041)	0.000 (0.000–0.001)	0.003 (0.000–0.008)			
Double-crested cormorant	0.005 (0.000–0.012)	0.000 (0.000–0.001)	0.003 (0.000–0.006)	0.000 (0.000–0.001)	0.002 (0.000–0.004)	0.002 (0.000–0.005)	0.001 (0.000–0.002)	0.000 (0.000–0.001)	0.001 (0.000–0.002)	
Great blue heron	0.002 (0.000–0.003)	0.001 (0.000–0.001)		0.003 (0.000–0.009)	0.001 (0.000–0.002)	0.000 (0.000–0.001)	0.001 (0.000–0.002)			
Great egret	0.001 (0.000–0.002)	0.003 (0.000–0.007)	0.002 (0.000–0.004)	0.002 (0.000–0.005)	0.000 (0.000–0.001)	0.001 (0.000–0.001)	0.003 (0.000–0.005)	0.000 (0.000–0.001)		
American coot	0.000 (0.000–0.001)	0.021 (0.000–0.050)	0.001 (0.000–0.002)					0.000 (0.000–0.001)		
Killdeer	0.001 (0.000–0.002)	0.020 (0.000–0.048)	0.014 (0.000–0.035)	0.215 (0.000–0.489)	0.025 (0.000–0.054)	0.008 (0.000–0.016)	0.005 (0.000–0.011)	0.041 (0.000–0.087)	0.042 (0.000–0.084)	

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Black-necked stilt	0.001 (0.000–0.002)	0.005 (0.000–0.012)	0.044 (0.004–0.085)		0.012 (0.000–0.028)		0.001 (0.000–0.002)	0.022 (0.000–0.061)		
American avocet				0.011 (0.000–0.028)						
Greater yellowlegs				0.005 (0.000–0.015)						
Lesser yellowlegs				0.005 (0.000–0.015)						
Long-billed curlew		0.099 (0.000–0.249)	0.002 (0.000–0.004)	0.081 (0.000–0.203)	0.140 (0.000–0.400)	0.004 (0.000–0.013)			0.002 (0.000–0.007)	
Ring-billed gull	0.016 (0.003–0.029)									
Western gull			0.000 (0.000–0.001)	0.009 (0.000–0.019)	0.002 (0.000–0.005)					
California gull	0.002 (0.000–0.007)	0.000 (0.000–0.001)	0.000 (0.000–0.001)	0.002 (0.000–0.004)		0.055 (0.000–0.132)	0.002 (0.000–0.004)			
Unidentified gull	5.556 (3.207–7.905)	3.090 (1.397–4.782)	32.900 (14.639–51.160)	17.901 (9.865–25.937)	8.374 (0.601–16.148)	18.485 (8.616–28.354)	45.302 (0.000–103.660)	111.513 (44.250–178.777)	6.845 (4.213–9.476)	
Rock pigeon	0.299 (0.035–0.562)	0.326 (0.135–0.517)	0.800 (0.147–1.453)	1.437 (0.447–2.427)	22.980 (3.231–42.729)	2.966 (0.000–6.388)	0.960 (0.209–1.712)	1.554 (0.000–3.123)		
Mourning dove	0.036 (0.000–0.101)	0.002 (0.000–0.005)	0.055 (0.000–0.160)	0.025 (0.000–0.051)	0.019 (0.002–0.035)	0.071 (0.000–0.185)	0.020 (0.000–0.045)	0.015 (0.000–0.036)	0.003 (0.001–0.005)	
Greater roadrunner								0.007 (0.000–0.020)	0.003 (0.000–0.010)	
White-throated swift								0.018 (0.000–0.054)	0.006 (0.000–0.012)	
Ruby-throated hummingbird							0.000 (0.000–0.001)			
Anna's hummingbird									0.000 (0.000–0.001)	
Black phoebe								0.000 (0.000–0.001)	0.000 (0.000–0.001)	
Say's phoebe							0.001 (0.000–0.002)	0.001 (0.000–0.003)	0.005 (0.003–0.007)	

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Western kingbird								0.000 (0.000–0.001)	0.000 (0.000–0.001)	
Loggerhead shrike	0.098 (0.057–0.140)	0.047 (0.029–0.065)	0.026 (0.008–0.045)	0.000 (0.000–0.001)			0.029 (0.020–0.037)	0.017 (0.010–0.024)	0.013 (0.009–0.017)	
Yellow-billed magpie	0.001 (0.000–0.002)									
American crow	0.064 (0.027–0.102)	0.057 (0.026–0.089)	0.166 (0.000–0.380)	0.003 (0.000–0.007)	0.111 (0.071–0.152)	0.013 (0.001–0.025)	0.016 (0.004–0.028)	0.150 (0.024–0.276)	0.126 (0.042–0.209)	
Common raven	0.694 (0.557–0.830)	0.828 (0.727–0.930)	1.947 (1.526–2.368)	1.562 (1.363–1.762)	1.331 (1.105–1.558)	1.374 (1.176–1.573)	0.987 (0.837–1.138)	2.029 (1.406–2.652)	1.949 (1.463–2.435)	
Horned lark					0.014 (0.000–0.033)		0.004 (0.000–0.008)	0.077 (0.058–0.096)	0.100 (0.079–0.121)	
Cliff swallow							0.001 (0.000–0.002)	0.008 (0.003–0.014)	0.001 (0.000–0.002)	
Barn swallow								0.001 (0.000–0.002)	0.002 (0.000–0.004)	
Rock wren								0.000 (0.000–0.001)	0.000 (0.000–0.001)	
Western bluebird							0.001 (0.000–0.003)		0.003 (0.000–0.006)	
Mountain bluebird							0.010 (0.000–0.025)	0.011 (0.004–0.018)	0.029 (0.013–0.046)	
Northern mockingbird								0.001 (0.000–0.002)	0.000 (0.000–0.001)	
European starling		0.007 (0.000–0.018)					0.045 (0.014–0.076)	0.217 (0.000–0.478)		
American pipit							0.003 (0.000–0.010)	0.024 (0.000–0.058)	0.097 (0.031–0.163)	
Yellow-rumped warbler									0.001 (0.000–0.003)	
Vesper sparrow									0.013 (0.000–0.040)	
Lark sparrow									0.001 (0.000–0.002)	

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Savannah sparrow							0.012 (0.000–0.036)	0.011 (0.000–0.026)	0.036 (0.000–0.074)	
Lincoln's sparrow								0.001 (0.000–0.003)		
White-crowned sparrow								0.000 (0.000–0.001)		
Black-headed grosbeak									0.000 (0.000–0.001)	
Red-winged blackbird	0.002 (0.000–0.005)						0.001 (0.000–0.002)	0.041 (0.007–0.076)	0.113 (0.000–0.288)	
Tricolored blackbird								0.058 (0.013–0.104)	0.007 (0.000–0.016)	
Western meadowlark	0.004 (0.000–0.013)						0.010 (0.003–0.017)	0.232 (0.174–0.291)	0.133 (0.103–0.164)	
Brewer's blackbird					0.168 (0.000–0.498)	0.000 (0.000–0.001)	0.067 (0.000–0.172)	0.142 (0.050–0.234)	0.046 (0.016–0.076)	
Unidentified blackbird								0.138 (0.000–0.337)	0.128 (0.030–0.227)	
House finch							0.008 (0.000–0.023)	0.119 (0.000–0.292)	0.019 (0.000–0.052)	

[a] Avian use data was reliably recorded in all years of the study only for the four focal species, although the vast majority of raptor observations were recorded in every year. Relative abundance and use for all species were reliably recorded throughout the 2013 monitoring year.

Red-tailed hawks were consistently the most abundant of the four focal species across all years of the study. American kestrel was the second most abundant of the four focal species across all years of the study except the 2007 monitoring year. Although burrowing owl use was high in the 2005 monitoring year, surveys were not designed to measure relative abundance of burrowing owls. The high value in the 2005 monitoring year was due to a bias towards more surveys being conducted near the Diablo Winds turbines at a time when burrowing owl abundance near those turbines was high.

There was significant annual (monitoring years) and seasonal (monthly) variation in use for American kestrel ($F [8,12295] = 2.35$, $p < 0.016$ and $F [11,12292] = 12.31$, $p < 0.001$, respectively, Figure 3-1). There was also significant geographic (BLOBs) variation in use across the APWRA ($F [12,12279]= 8.35$, $p = 0.001$). Although there was significant annual variation in American kestrel use, there was no significant trend over time in use ($r = -0.008$, $p = 0.370$, Figure 3-1). Use by kestrels peaked during the winter months (November through February), coinciding with the seasonal shutdown. An additional peak occurred in August, coinciding with the timing of fledgling dispersal (Figure 3-1). For the 2009–2013 monitoring years—the period of the universal 3.5 month shutdown—mean use by kestrels was approximately 1.8 times higher during the seasonal shutdown than during the rest of the year ($t [6838] = 4.85$, $p < 0.001$).

The pattern was similar for golden eagle. There was significant annual and seasonal variation in use over the course of the study ($F [8,12295]= 3.85$, $p < 0.001$ and $F [11,12292]= 6.50$, $p < 0.001$, respectively, Figure 3-2). There was also significant geographic variation in use across the APWRA ($F = [12,24279]=11.79$, $p < 0.001$). Although there was significant annual variation in golden eagle use, there was no significant trend over time in use ($r < 0.001$, $p = 0.998$, Figure 3-2). There was also a significant interaction between monitoring year and BLOB, indicating that trends over time in use by eagles varied across BLOBs ($F [192,12091] = 1.62$, $p < 0.001$). Use by eagles also peaked during the winter months (November through February), coinciding with the seasonal shutdown (Figure 3-2). For the 2009–2013 monitoring years—the period of the universal 3.5 month shutdown—mean use by golden eagles was approximately 1.4 times higher during the seasonal shutdown than during the rest of the year ($t [6838] = 2.88$, $p = 0.004$).

There was also significant annual and seasonal variation in mean use for red-tailed hawks over the course of the study ($F [8,12295] = 13.1$, $p < 0.001$ and $F [11,12929] = 46.1$, $p < 0.001$, Figure 3-3), as well as significant geographical variation ($F [25,12279] = 14.8$, $p < 0.001$). There was also a significant interaction between monitoring year and BLOB, indicating that trends over time in use by red-tailed hawks varied across BLOBs ($F [192,12091] = 2.30$, $p < 0.001$). In contrast to American kestrel and golden eagle, red-tailed hawk use exhibited a decline over the course of the study ($r = -0.029$, $p = 0.001$, Figure 3-3). Like that of the other focal species, red-tailed hawk use peaked during the winter months (November through February), coinciding with the seasonal shutdown (Figure 3-2). For the 2009 through 2013 monitoring years—the period of the universal 3.5 month shutdown—mean use by red-tailed hawks was almost twice as high during the seasonal shutdown as it was during the rest of the year ($t [6838] = 10.76$, $p < 0.001$).

Fatality Incidents

Carcasses of 72 species, 15 of which were raptors (turkey vulture and owls are considered raptors in this report), were documented during carcass searches over the 9 years of the study (Table 3-5).

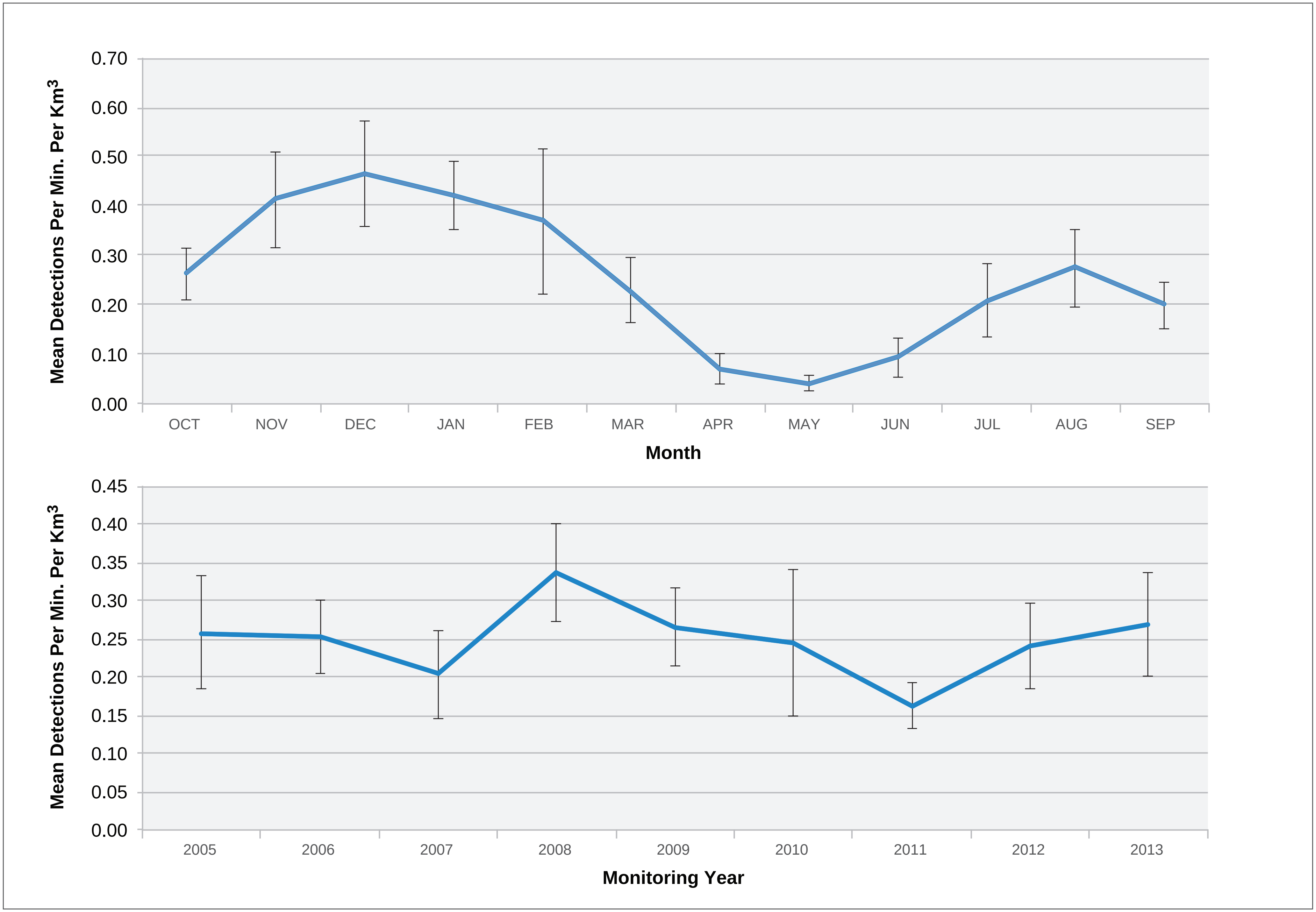

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Figure 3-1
Annual and Seasonal Variation in Use (Mean Detections per Minute per Cubic Kilometer ± 95% CI) by American Kestrel in the APWRA, Monitoring Years 2005–2013

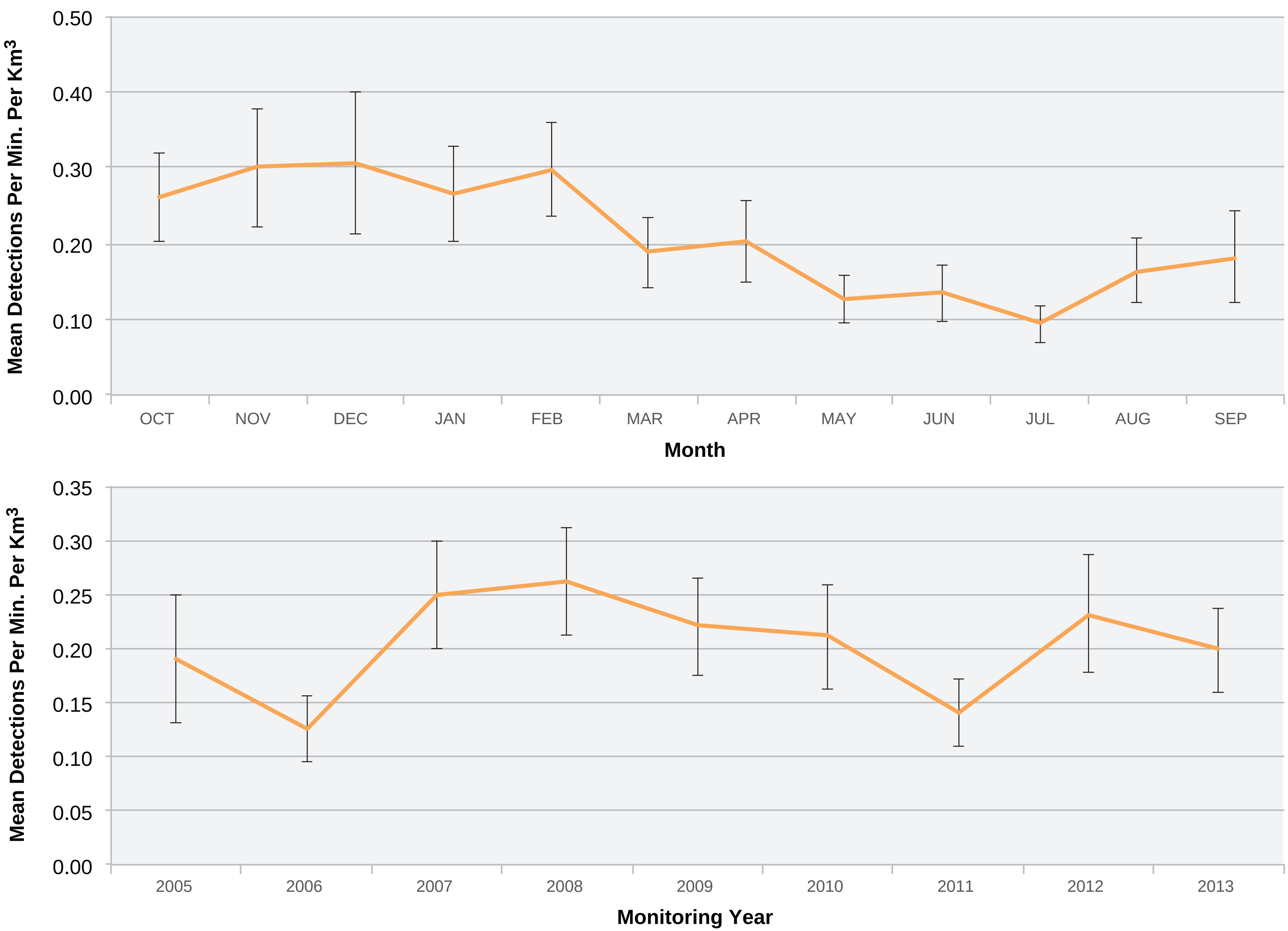

Figure 3-2
Annual and Seasonal Variation in Use (Mean Detections per Minute per Cubic Kilometer ± 95% CI) by Golden Eagle in the APWRA, Monitoring Years 2005–2013

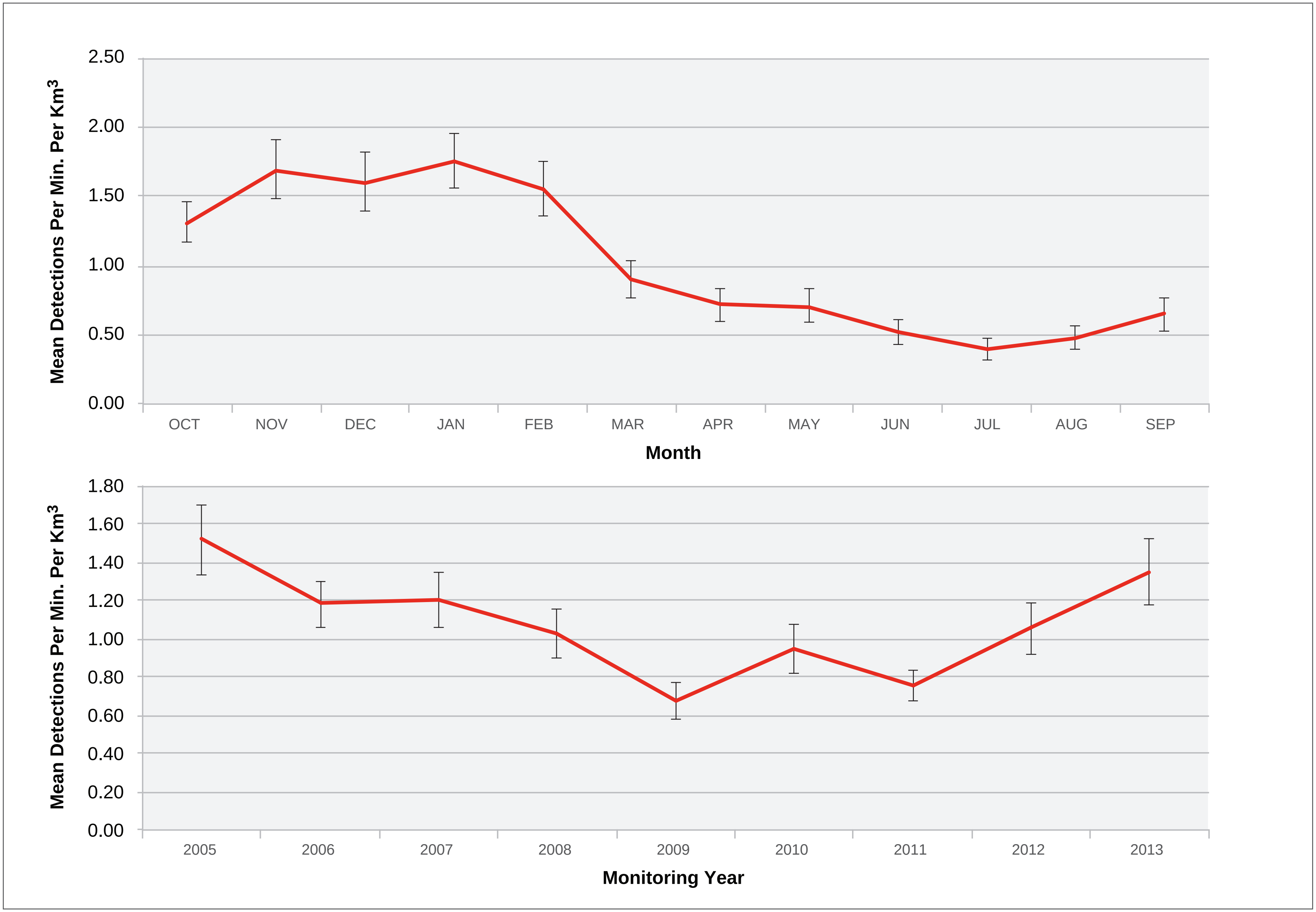

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Figure 3-3
Annual and Seasonal Variation in Use (Mean Detections per Minute per Cubic Kilometer ± 95% CI) by Red-Tailed Hawk in the APWRA, Monitoring Years 2005–2013

Five species were nonnative species, including the two most commonly detected fatalities, rock pigeon (n = 1,386) and European starling (n = 691). More than 37% of fatalities detected were nonnative species. The most commonly detected native species fatalities over the 9 years of the study were western meadowlark (n = 553), red-tailed hawk (n = 453), burrowing owl (n = 302), unidentified gulls (mostly *Larus* spp., n = 253), and American kestrel (n = 250). The number of gull fatalities has increased steadily since the 2010 monitoring year due to completion of a new landfill facility in the area. Two new species—acorn woodpecker and eared grebe—were documented for the first time in the 2013 monitoring year (Table 3-5).

Over the 9 years of the study, 23 bat fatalities comprising four species have been detected during regular searches at monitored turbines (Table 3-5).

Table 3-5. Annual Fatality Detections in the APWRA by Species, Monitoring years 2005–2013

	Monitoring Year									
Species/Category	2005	2006	2007	2008	2009	2010[a]	2011	2012	2013	Total
American kestrel	20	44	48	35	29	16	18	26	14	250
Burrowing owl	27	113	44	20	37	13	21	16	11	302
Golden eagle	16	31	18	13	11	11	8	11	14	133
Red-tailed hawk	76	104	70	37	29	46	29	35	27	453
Total focal species	**139**	**292**	**180**	**105**	**106**	**86**	**76**	**88**	**66**	**1,138**
Turkey vulture	3	4	4	1	3	0	1	3	3	22
White-tailed kite	0	0	0	0	0	2	1	0	0	3
Northern harrier	0	3	3	2	0	0	1	0	0	9
Red-shouldered hawk	0	1	1	0	0	0	0	0	0	2
Swainson's hawk	1	0	0	0	0	0	0	0	0	1
Ferruginous hawk	2	0	1	1	0	0	0	0	0	4
Unidentified Buteo	0	4	5	3	3	1	0	7	3	26
Peregrine falcon	0	1	0	0	0	0	0	1	0	2
Prairie falcon	1	2	1	0	0	2	4	0	0	10
Unidentified falcon	0	0	2	0	0	0	0	0	0	2
Barn owl	40	49	8	11	22	24	14	5	2	175
Great-horned owl	5	13	7	1	14	4	4	5	0	53
Short-eared owl	0	0	0	0	0	0	0	1	0	1
Unidentified raptor	0	0	0	0	0	0	0	1	0	1
Total raptors[b]	**191**	**369**	**212**	**124**	**148**	**119**	**101**	**111**	**74**	**1,449**
Mallard	6	6	6	3	4	5	3	1	0	34
Common goldeneye	0	0	0	1	0	0	0	0	0	1
Unidentified duck	0	0	2	0	2	1	0	0	0	5
Pied-billed grebe	0	1	0	0	0	0	0	0	0	1
Eared grebe	0	0	0	0	0	0	0	0	1	1
Wild turkey	0	2	0	0	0	0	0	0	0	2
Brown pelican	0	0	0	1	0	0	0	0	0	1
Great blue heron	1	0	0	0	0	0	0	2	0	3
Great egret	1	0	0	0	0	0	0	0	0	1
American coot	0	1	0	0	0	2	0	0	1	4
Sandhill crane	0	1	0	0	0	0	0	0	0	1
Killdeer	0	2	3	1	2	2	0	2	0	12
Black-necked stilt	0	1	0	0	0	0	0	0	0	1
American avocet	0	0	0	2	0	0	0	0	0	2
Bonaparte's gull	0	0	1	0	0	0	0	0	0	1
Ring-billed gull	0	0	0	1	0	0	0	0	0	1
Western gull	0	0	1	0	0	0	0	0	0	1
California gull	0	2	6	7	4	4	4	21	2	50
Glaucous-winged gull	0	0	0	0	0	0	1	0	0	1

Species/Category	Monitoring Year 2005	2006	2007	2008	2009	2010[a]	2011	2012	2013	Total
Unidentified gull	4	16	19	18	8	17	42	81	48	253
Rock pigeon	102	198	229	240	217	109	98	94	99	1,386
Mourning dove	11	21	16	18	21	6	2	17	4	116
Eurasian collared dove	0	0	0	0	0	0	0	1	0	1
Unidentified dove	0	12	13	4	6	3	3	8	17	66
Common poorwill	0	0	1	0	0	0	0	0	1	2
White-throated swift	0	2	0	0	0	0	0	0	0	2
Acorn woodpecker	0	0	0	0	0	0	0	0	3	3
Northern flicker	1	0	2	3	2	1	3	1	1	14
Cockatiel	1	0	0	0	0	0	0	0	0	1
Hammond’s flycatcher	1	1	0	0	0	0	0	0	0	2
Unidentified empidonax	0	1	0	0	0	0	0	0	0	1
Say’s phoebe	0	1	0	0	1	0	1	0	0	3
Loggerhead shrike	5	10	3	5	1	4	2	3	0	33
Warbling vireo	0	0	1	0	0	0	0	0	0	1
Western scrub-jay	1	0	0	0	0	0	0	0	0	1
American crow	1	2	3	2	1	0	0	2	2	13
Common raven	8	17	24	18	8	12	8	11	16	122
Unidentified corvid	0	1	0	0	0	0	0	0	0	1
Horned lark	3	14	19	6	9	6	1	1	2	61
Cliff swallow	2	0	2	0	0	1	0	0	0	5
Barn swallow	0	0	2	2	0	0	0	0	0	4
Unidentified swallow	0	0	0	1	0	0	0	0	0	1
Rock wren	2	0	0	0	0	0	0	0	0	2
House wren	0	1	0	1	0	0	0	0	0	2
Mountain bluebird	0	6	1	0	1	0	0	0	0	8
Unidentified bluebird	0	3	1	5	8	2	9	0	1	29
Swainson’s thrush	0	1	1	0	1	0	0	0	0	3
Northern mockingbird	2	0	0	0	0	0	2	0	0	4
European starling	66	114	110	137	95	56	50	41	22	691
American pipit	0	2	1	2	0	0	0	0	0	5
Wilson’s warbler	0	0	1	1	0	0	1	0	0	3
Spotted towhee	0	0	1	0	0	0	0	0	0	1
Savannah sparrow	0	0	0	1	2	0	0	0	0	3
Lincoln’s sparrow	0	1	0	0	0	0	0	0	0	1
Golden-crowned sparrow	0	0	1	0	0	0	1	0	0	2
Unidentified sparrow	1	0	0	0	1	0	0	0	0	2
Dark-eyed junco	0	0	0	1	1	0	0	0	0	2
Western tanager	0	1	1	1	0	0	1	0	0	4
Red-winged blackbird	4	10	4	5	1	1	1	1	1	28

Species/Category	Monitoring Year 2005	2006	2007	2008	2009	2010[a]	2011	2012	2013	Total
Tricolored blackbird	0	0	1	1	0	0	0	1	0	3
Western meadowlark	78	118	88	78	88	44	31	17	11	553
Brewer's blackbird	3	10	1	2	0	2	0	0	0	18
Unidentified blackbird	3	13	12	5	4	3	3	0	1	44
Brown-headed cowbird	0	1	0	0	0	0	0	0	0	1
Unidentified oriole	0	0	1	0	0	0	0	0	0	1
House finch	1	0	0	0	0	0	1	0	0	2
House sparrow	0	0	1	0	0	0	0	0	0	1
Unidentified passerine	4	6	0	0	0	0	0	0	0	10
Unidentified small bird	5	29	56	43	40	21	11	19	9	233
Unidentified medium bird	1	30	36	11	18	12	1	9	5	123
Unidentified large bird	2	19	9	7	11	5	13	16	5	87
Total non-raptors	**320**	**677**	**680**	**634**	**557**	**319**	**293**	**349**	**252**	**4,081**
Total birds	**511**	**1,046**	**892**	**758**	**705**	**438**	**394**	**460**	**326**	**5,530**
Hoary bat	1	2	1	0	2	1	0	1	0	8
Little brown bat	0	0	0	0	1	1	0	0	0	2
Mexican free-tailed bat	0	1	1	1	1	0	0	0	0	4
Western red bat	1	1	1	1	0	0	0	0	1	5
Unidentified bat	0	0	0	0	1	2	1	0	0	4
Total bats	**2**	**4**	**4**	**2**	**5**	**4**	**1**	**1**	**1**	**23**

[a] In the 2010 monitoring year, the number of turbines sampled was reduced to approximately 58% of the original sample.

[b] Includes the four focal species.

Detection Probability Estimates

Estimates of detection probability derived from the QAQC study, the carcass removal/scavenging trial study, and the 48-hour search interval study are depicted in Figure 3-4 as a function of search interval.

For all species, the searcher efficiency component of detection probability exhibits a decline through time (i.e., across the search interval) as carcasses age. Using a diverse set of species in the three studies allowed for the inclusion of wingspan as a covariate in the model, resulting in a species-specific estimate of detection probability—a significant improvement over using arbitrary size classes with significant variation in each class—as the basis for adjustment. Using a composite model of detection probability that estimates the searcher efficiency and carcass removal components of detection probability simultaneously represents another significant step forward in the accurate estimation of detection probability. Additional details regarding the results of the QAQC study are presented in Appendix C.

It should be noted that the resulting estimates of detection probability are derived from a composite data set with different information collected on different components/aspects of detection

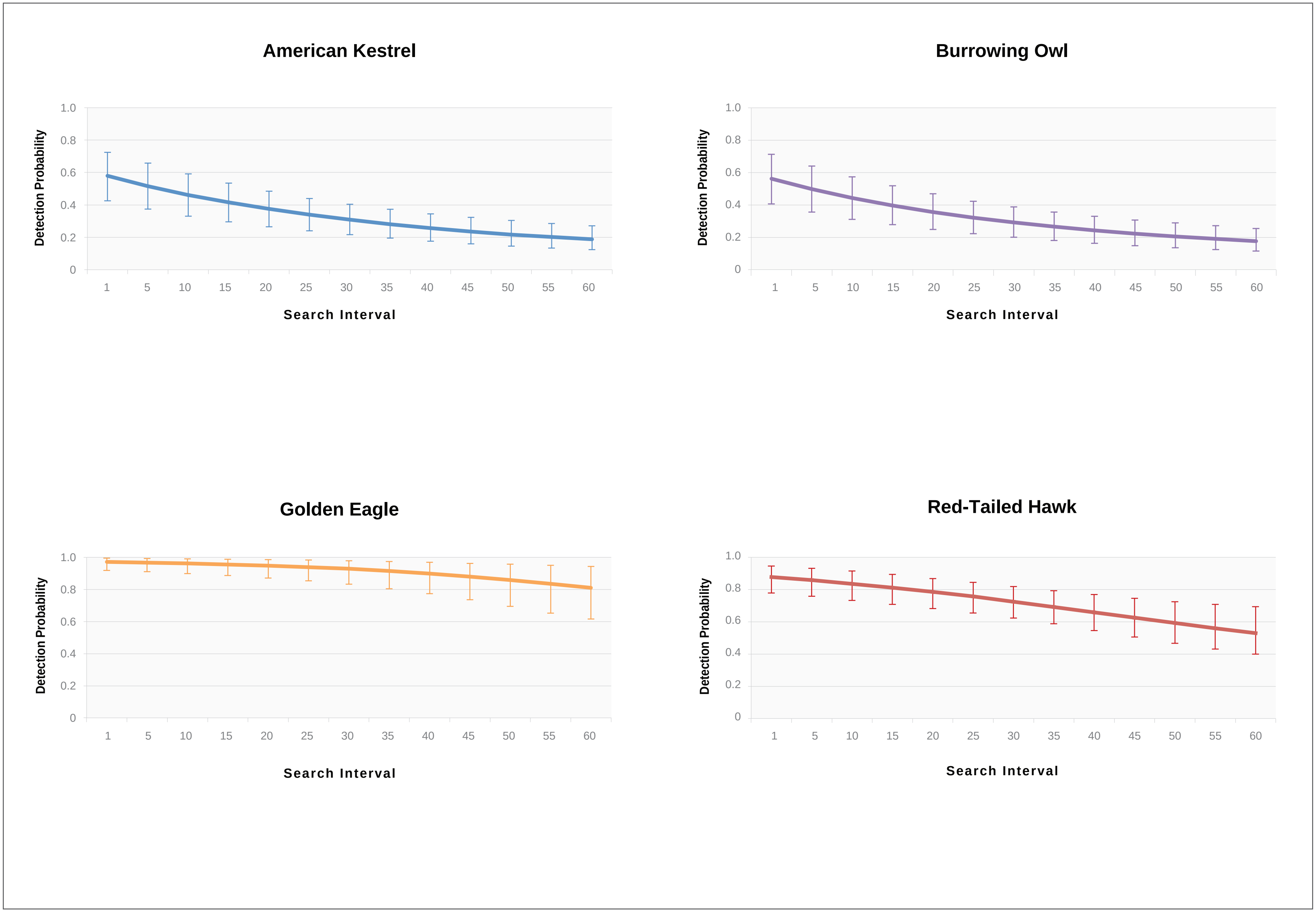

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Figure 3-4
Detection Probabilities (± 95% CI) as a Function of Search Interval for the Four Focal Species Derived from the QAQC, the 48-Hour Search Interval, and the Carcass Removal / Scavenging Trial Studies

probability at different times. Thus, while the estimates are reflective of detection probability of birds in the APWRA that are actually killed by turbine strikes over a range of conditions and time periods, they do not account for annual or seasonal variation because detection probability trials were not conducted on an annual basis.

Adjusted Fatality Rates

Estimates of the APWRA-wide annual adjusted fatality rates at monitored, older-generation turbines (i.e., all monitored non–Diablo Winds turbines) are presented in Table 3-6 (see Appendix E for BLOB-specific adjusted fatality rates). Rock pigeon and European starling had the highest mean fatality rates over the 9 years of the study. Among native species, western meadowlark, burrowing owl, American kestrel, red-tailed hawk, and various gull species (primarily California, western, and ring-billed gulls) had the highest mean fatality rates, followed by mourning doves and barn owls. For the 2013 monitoring year, native species with the highest fatality rates were gulls, western meadowlark, American kestrel, burrowing owl, and common raven.

Table 3-6. Annual Adjusted Fatality Rates (Fatalities per Megawatt and 95% CI) in the APWRA, Monitoring Years 2005–2013

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
American kestrel	0.445 (0.281–0.608)	0.668 (0.452–0.884)	0.629 (0.429–0.83)	0.440 (0.305–0.576)	0.408 (0.279–0.538)	0.482 (0.325–0.64)	0.696 (0.445–0.946)	0.829 (0.559–1.099)	0.428 (0.286–0.570)	0.558 (0.374–0.743)
Burrowing owl	0.64 (0.395–0.884)	1.778 (1.177–2.379)	0.611 (0.407–0.816)	0.266 (0.180–0.352)	0.554 (0.369–0.739)	0.386 (0.255–0.518)	0.811 (0.516–1.106)	0.562 (0.369–0.754)	0.386 (0.252–0.521)	0.666 (0.436–0.897)
Golden eagle	0.093 (0.078–0.109)	0.111 (0.100–0.122)	0.068 (0.062–0.075)	0.050 (0.046–0.054)	0.044 (0.040–0.048)	0.101 (0.090–0.112)	0.081 (0.064–0.097)	0.099 (0.089–0.110)	0.117 (0.103–0.132)	0.085 (0.075–0.095)
Red-tailed hawk	0.613 (0.468–0.758)	0.547 (0.464–0.631)	0.372 (0.315–0.428)	0.197 (0.171–0.224)	0.161 (0.137–0.185)	0.539 (0.452–0.626)	0.42 (0.328–0.511)	0.439 (0.366–0.512)	0.327 (0.268–0.385)	0.402 (0.33–0.473)
Total focal species	**1.79 (1.222–2.359)**	**3.105 (2.194–4.016)**	**1.681 (1.213–2.149)**	**0.954 (0.701–1.206)**	**1.168 (0.826–1.51)**	**1.509 (1.122–1.896)**	**2.007 (1.353–2.661)**	**1.929 (1.383–2.475)**	**1.258 (0.909–1.608)**	**1.711 (1.214–2.209)**
Turkey vulture	0.02 (0.016–0.024)	0.01 (0.009–0.012)	0.017 (0.015–0.019)	0.004 (0.004–0.005)	0.014 (0.012–0.016)	0.00 (0.00–0.00)	0.012 (0.01–0.014)	0.032 (0.028–0.036)	0.032 (0.027–0.036)	0.016 (0.015–0.018)
White-tailed kite	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.030 (0.025–0.035)	0.019 (0.014–0.023)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.005 (0.004–0.007)
Northern harrier	0.00 (0.00–0.00)	0.014 (0.012–0.017)	0.018 (0.015–0.021)	0.012 (0.010–0.014)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.017 (0.013–0.021)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.007 (0.013–0.009)
Red-shouldered hawk	0.00 (0.00–0.00)	0.008 (0.006–0.009)	0.006 (0.005–0.008)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.002 (0.001–0.002)
Swainson's hawk	0.009 (0.006–0.011)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Ferruginous hawk	0.015 (0.012–0.019)	0.00 (0.00–0.00)	0.005 (0.004–0.005)	0.005 (0.004–0.005)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.003 (0.002–0.004)
Unidentified Buteo	0.00 (0.00–0.00)	0.012 (0.011–0.014)	0.026 (0.022–0.030)	0.016 (0.013–0.018)	0.017 (0.014–0.019)	0.012 (0.010–0.014)	0.00 (0.00–0.00)	0.077 (0.065–0.090)	0.038 (0.032–0.045)	0.022 (0.018–0.025)
Peregrine falcon	0.00 (0.00–0.00)	0.008 (0.006–0.009)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Prairie falcon	0.011 (0.008–0.014)	0.016 (0.013–0.018)	0.006 (0.005–0.008)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.029 (0.024–0.034)	0.072 (0.054–0.090)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.015 (0.012–0.021)
Barn owl	0.376 (0.280–0.472)	0.287 (0.239–0.335)	0.049 (0.041–0.057)	0.067 (0.057–0.077)	0.139 (0.116–0.161)	0.330 (0.272–0.387)	0.225 (0.178–0.273)	0.075 (0.062–0.088)	0.030 (0.024–0.036)	0.175 (0.141–0.210)
Great-horned owl	0.048 (0.037–0.060)	0.078 (0.065–0.091)	0.041 (0.034–0.048)	0.006 (0.005–0.007)	0.082 (0.069–0.095)	0.041 (0.033–0.048)	0.066 (0.052–0.081)	0.075 (0.062–0.089)	0.00 (0.00–0.00)	0.049 (0.040–0.065)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Short-eared owl	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.016 (0.013–0.019)	0.00 (0.00–0.00)	0.002 (0.001–0.002)
Total raptors[a]	**2.270 (1.581–2.959)**	**3.538 (2.555–4.520)**	**1.849 (1.355–2.343)**	**1.063 (0.795–1.332)**	**1.420 (1.038–1.801)**	**1.950 (1.486–2.414)**	**2.419 (1.675–3.163)**	**2.205 (1.599–2.779)**	**1.358 (0.992–1.724)**	**2.006 (1.143–2.559)**
Mallard	0.074 (0.054–0.095)	0.054 (0.044–0.065)	0.045 (0.036–0.053)	0.022 (0.018–0.026)	0.032 (0.026–0.038)	0.086 (0.069–0.102)	0.058 (0.045–0.070)	0.018 (0.015–0.022)	0.00 (0.00–0.00)	0.043 (0.034–0.059)
Common goldeneye	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.009 (0.007–0.011)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Wild turkey	0.00 (0.00–0.00)	0.011 (0.010–0.013)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.003 (0.001–0.004)
Pied-billed grebe	0.00 (0.00–0.00)	0.024 (0.013–0.035)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.000 (0.000–0.001)
Eared grebe	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.036 (0.024–0.048)	0.004 (0.003–0.005)
Brown pelican	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.004 (0.004–0.004)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.003 (0.003–0.004)
Great blue heron	0.006 (0.005–0.007)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.020 (0.018–0.023)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Great egret	0.008 (0.006–0.010)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.008 (0.006–0.011)
American coot	0.00 (0.00–0.00)	0.014 (0.010–0.018)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.030 (0.021–0.039)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.028 (0.020–0.037)	0.001 (0.000–0.001)
Sandhill crane	0.00 (0.00–0.00)	0.005 (0.004–0.005)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.024 (0.017–0.034)
Killdeer	0.00 (0.00–0.00)	0.029 (0.020–0.038)	0.035 (0.025–0.045)	0.011 (0.008–0.014)	0.025 (0.018–0.033)	0.053 (0.037–0.070)	0.00 (0.00–0.00)	0.058 (0.041–0.075)	0.00 (0.00–0.00)	0.001 (0.001–0.002)
Black-necked stilt	0.00 (0.00–0.00)	0.011 (0.008–0.013)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.002 (0.001–0.002)
American avocet	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.017 (0.013–0.020)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Bonaparte's gull	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.008 (0.006–0.010)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Ring-billed gull	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.005 (0.005–0.006)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.000–0.001)
Western gull	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.005 (0.004–0.005)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.052 (0.043–0.060)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
California gull	0.00 (0.00–0.00)	0.006 (0.005–0.007)	0.030 (0.025–0.034)	0.035 (0.030–0.039)	0.021 (0.018–0.024)	0.046 (0.039–0.053)	0.058 (0.045–0.070)	0.244 (0.202–0.287)	0.024 (0.020–0.028)	0.001 (0.001–0.002)
Glaucous-winged gull	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.013 (0.010–0.017)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.000–0.001)
Unidentified gull	0.031 (0.024–0.037)	0.076 (0.064–0.087)	0.100 (0.085–0.115)	0.095 (0.082–0.108)	0.045 (0.039–0.052)	0.206 (0.173–0.239)	0.615 (0.478–0.752)	0.992 (0.814–1.171)	0.624 (0.514–0.735)	2.208 (1.643–2.773)
Rock pigeon	1.678 (1.152–2.204)	2.121 (1.596–2.645)	2.225 (1.684–2.766)	2.247 (1.732–2.762)	2.243 (1.706–2.779)	2.280 (1.683–2.877)	2.462 (1.787–3.137)	2.236 (1.680–2.792)	2.380 (1.764–2.995)	0.317 (0.190–0.445)
Mourning dove	0.346 (0.193–0.498)	0.394 (0.237–0.551)	0.272 (0.165–0.380)	0.290 (0.179–0.401)	0.384 (0.233–0.534)	0.193 (0.115–0.271)	0.090 (0.053–0.127)	0.718 (0.432–1.004)	0.171 (0.101–0.240)	0.004 (0.002–0.005)
Eurasian collared dove	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.033 (0.022–0.044)	0.00 (0.00–0.00)	0.007 (0.004–0.010)
Common poorwill	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.018 (0.011–0.026)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.044 (0.025–0.063)	0.006 (0.003–0.009)
White-throated swift	0.00 (0.00–0.00)	0.050 (0.027–0.074)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.041 (0.026–0.056)
Acorn woodpecker	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.138 (0.079–0.197)	0.015 (0.009–0.022)
Northern flicker	0.025 (0.015–0.035)	0.00 (0.00–0.00)	0.030 (0.019–0.040)	0.042 (0.028–0.057)	0.032 (0.021–0.043)	0.034 (0.022–0.046)	0.130 (0.079–0.182)	0.037 (0.024–0.051)	0.036 (0.023–0.049)	0.010 (0.003–0.020)
Hammond's flycatcher	0.047 (0.013–0.080)	0.046 (0.013–0.079)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.001 (0.001–0.001)
Unidentified empidonax	0.00 (0.00–0.00)	0.007 (0.006–0.008)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.014 (0.006–0.024)
Say's phoebe	0.00 (0.00–0.00)	0.030 (0.014–0.046)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.027 (0.013–0.041)	0.00 (0.00–0.00)	0.068 (0.031–0.105)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.152 (0.064–0.270)
Loggerhead shrike	0.261 (0.104–0.419)	0.301 (0.129–0.473)	0.084 (0.036–0.131)	0.130 (0.057–0.202)	0.029 (0.013–0.046)	0.187 (0.080–0.294)	0.163 (0.065–0.261)	0.212 (0.090–0.333)	0.00 (0.00–0.00)	0.004 (0.001–0.009)
Warbling vireo	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.039 (0.011–0.068)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.0.00 (0.000–0.000)
Western scrub-jay	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.014 (0.011–0.016)
American crow	0.011 (0.008–0.014)	0.008 (0.007–0.010)	0.020 (0.016–0.023)	0.013 (0.011–0.015)	0.007 (0.006–0.008)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.032 (0.027–0.038)	0.032 (0.025–0.038)	0.108 (0.090–0.125)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Common raven	0.062 (0.048–0.077)	0.078 (0.066–0.089)	0.120 (0.102–0.137)	0.091 (0.079–0.102)	0.043 (0.037–0.049)	0.137 (0.115–0.159)	0.104 (0.084–0.124)	0.136 (0.115–0.158)	0.197 (0.163–0.231)	0.239 (0.102–0.376)
Horned lark	0.158 (0.063–0.253)	0.373 (0.160–0.586)	0.527 (0.227–0.827)	0.156 (0.069–0.243)	0.267 (0.115–0.418)	0.385 (0.163–0.607)	0.073 (0.031–0.115)	0.068 (0.029–0.108)	0.143 (0.060–0.227)	0.022 (0.010–0.037)
Cliff swallow	0.093 (0.041–0.145)	0.00 (0.00–0.00)	0.048 (0.023–0.072)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.054 (0.025–0.082)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.009 (0.005–0.015)
Barn swallow	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.043 (0.023–0.064)	0.041 (0.022–0.059)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.003 (0.001–0.005)
Unidentified swallow	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.027 (0.011–0.043)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.016 (0.004–0.031)
Rock wren	0.146 (0.040–0.252)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.012 (0.002–0.026)
House wren	0.00 (0.00–0.00)	0.063 (0.008–0.118)	0.00 (0.00–0.00)	0.049 (0.007–0.091)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.024 (0.012–0.040)
Mountain bluebird	0.00 (0.00–0.00)	0.166 (0.083–0.250)	0.023 (0.012–0.035)	0.00 (0.00–0.00)	0.025 (0.012–0.037)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.156 (0.065–0.246)
Unidentified bluebird	0.00 (0.00–0.00)	0.100 (0.043–0.157)	0.028 (0.012–0.043)	0.130 (0.057–0.203)	0.237 (0.103–0.372)	0.130 (0.056–0.204)	0.702 (0.283–1.121)	0.00 (0.00–0.00)	0.073 (0.031–0.116)	0.006 (0.003–0.011)
Swainson’s thrush	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.026 (0.012–0.041)	0.00 (0.00–0.00)	0.030 (0.013–0.047)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.025 (0.012–0.043)
Northern mockingbird	0.083 (0.039–0.127)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.143 (0.067–0.219)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	2.143 (1.175–3.111)
European starling	2.127 (1.108–3.145)	2.018 (1.121–2.915)	2.162 (1.206–3.118)	2.550 (1.448–3.652)	1.978 (1.107–2.849)	2.475 (1.366–3.584)	2.805 (1.475–4.135)	2.044 (1.127–2.961)	1.127 (0.615–1.639)	0.019 (0.007–0.034)
American pipit	0.00 (0.00–0.00)	0.076 (0.028–0.124)	0.032 (0.012–0.052)	0.060 (0.023–0.097)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.026 (0.005–0.052)
Wilson’s warbler	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.049 (0.009–0.089)	0.043 (0.009–0.078)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.138 (0.023–0.252)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.003 (0.001–0.006)
Spotted towhee	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.031 (0.011–0.050)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.016 (0.003–0.034)
Savannah sparrow	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.045 (0.009–0.081)	0.104 (0.018–0.189)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.006 (0.001–0.012)
Lincoln’s sparrow	0.00 (0.00–0.00)	0.053 (0.012–0.094)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.015 (0.005–0.029)

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Golden-crowned sparrow	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.036 (0.012–0.061)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.099 (0.030–0.168)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.012 (0.003–0.023)
Unidentified sparrow	0.067 (0.018–0.116)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.040 (0.012–0.068)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.008 (0.003–0.016)
Dark-eyed junco	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.034 (0.011–0.057)	0.040 (0.012–0.067)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.019 (0.008–0.034)
Western tanager	0.00 (0.00–0.00)	0.034 (0.014–0.054)	0.030 (0.012–0.047)	0.027 (0.011–0.043)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.081 (0.032–0.130)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.112 (0.051–0.172)
Red-winged blackbird	0.187 (0.081–0.293)	0.306 (0.142–0.469)	0.101 (0.047–0.155)	0.119 (0.057–0.181)	0.027 (0.013–0.041)	0.057 (0.026–0.087)	0.077 (0.034–0.120)	0.065 (0.030–0.100)	0.065 (0.030–0.101)	0.011 (0.006–0.019)
Tricolored blackbird	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.023 (0.012–0.035)	0.022 (0.011–0.032)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.058 (0.029–0.088)	0.00 (0.00–0.00)	1.904 (0.963–2.845)
Western meadowlark	3.027 (1.454–4.599)	2.736 (1.403–4.069)	1.954 (1.007–2.900)	1.634 (0.859–2.410)	2.092 (1.082–3.101)	2.131 (1.092–3.170)	1.972 (0.961–2.983)	0.968 (0.492–1.444)	0.622 (0.314–0.930)	0.047 (0.025–0.077)
Brewer's blackbird	0.113 (0.057–0.169)	0.250 (0.135–0.364)	0.020 (0.011–0.030)	0.039 (0.021–0.056)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.148 (0.073–0.224)
Unidentified blackbird	0.129 (0.060–0.197)	0.312 (0.155–0.468)	0.279 (0.139–0.418)	0.109 (0.056–0.162)	0.099 (0.050–0.148)	0.158 (0.079–0.238)	0.188 (0.091–0.285)	0.00 (0.00–0.00)	0.063 (0.031–0.095)	0.004 (0.002–0.007)
Brown-headed cowbird	0.00 (0.00–0.00)	0.034 (0.015–0.053)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.003 (0.001–0.005)
Unidentified oriole	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.028 (0.012–0.043)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.016 (0.005–0.029)
House finch	0.043 (0.014–0.073)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.097 (0.030–0.163)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.004 (0.001–0.008)
House sparrow	0.043 (0.014–0.073)	0.00 (0.00–0.00)	0.036 (0.011–0.061)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.004 (0.001–0.008)
Total nonraptors	**8.722 (4.597–12.846)**	**9.785 (5.592–13.978)**	**8.506 (5.036–11.975)**	**8.096 (4.936–11.257)**	**7.826 (4.667–10.985)**	**8.642 (5.161–12.123)**	**10.135 (5.733–14.536)**	**7.942 (5.186–10.697)**	**5.804 (3.736–7.523)**	**8.365 (4.960–11.769)**
Total birds	**10.992 (6.178–15.805)**	**13.323 (8.147–18.498)**	**10.355 (6.39–14.319)**	**9.16 (5.731–12.589)**	**9.245 (5.705–12.786)**	**10.592 (6.647–14.537)**	**12.553 (7.408–17.698)**	**10.146 (6.784–13.476)**	**7.162 (4.728–9.247)**	**10.371 (6.413–14.328)**

[a] Includes the four focal species.

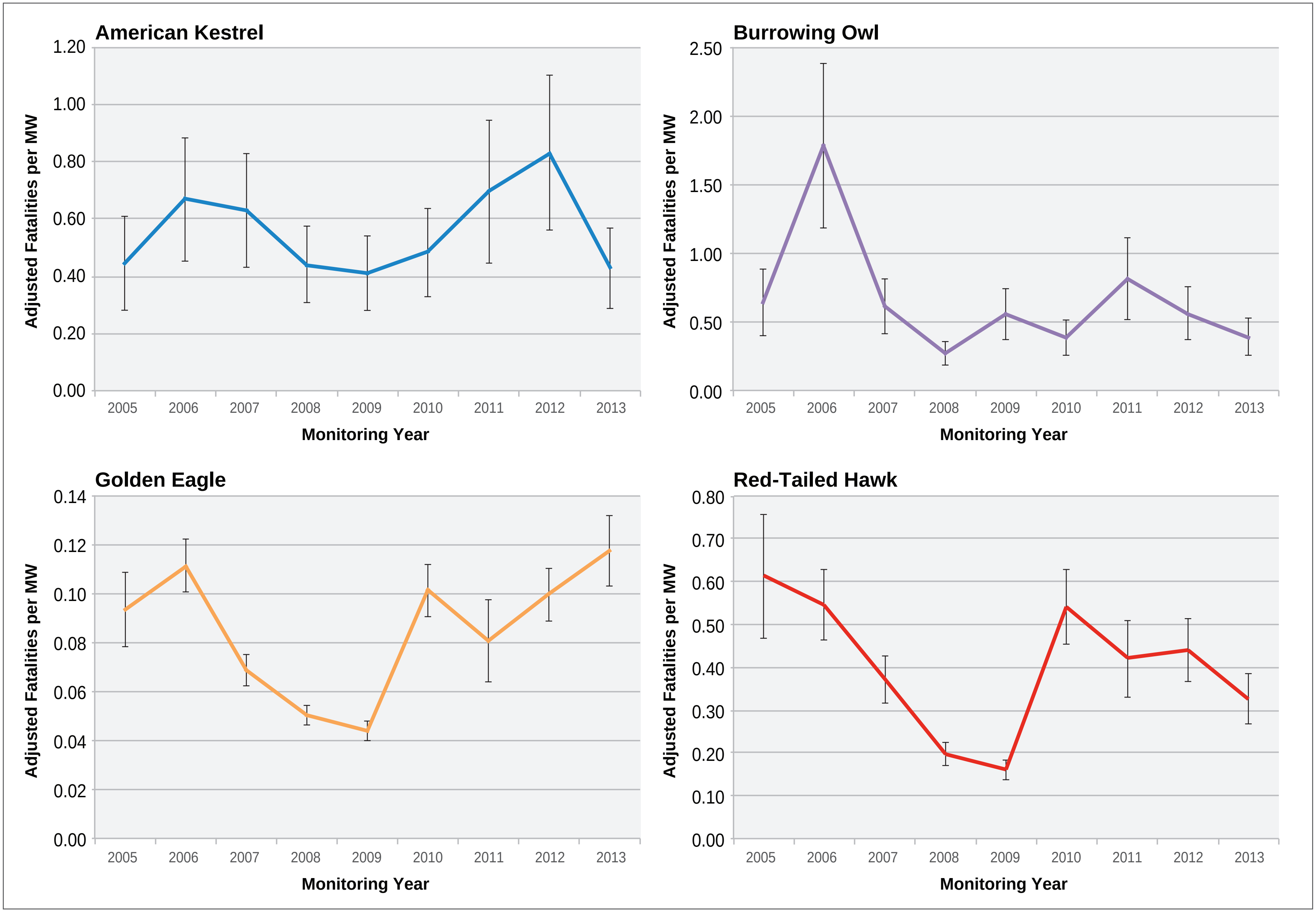

Figure 3-5
Annual Adjusted Fatality Rates (Fatalities per MW ± 95% CI) at Old Generation Turbines for the Four Focal Species in the APWRA, Monitoring Years 2005–2013

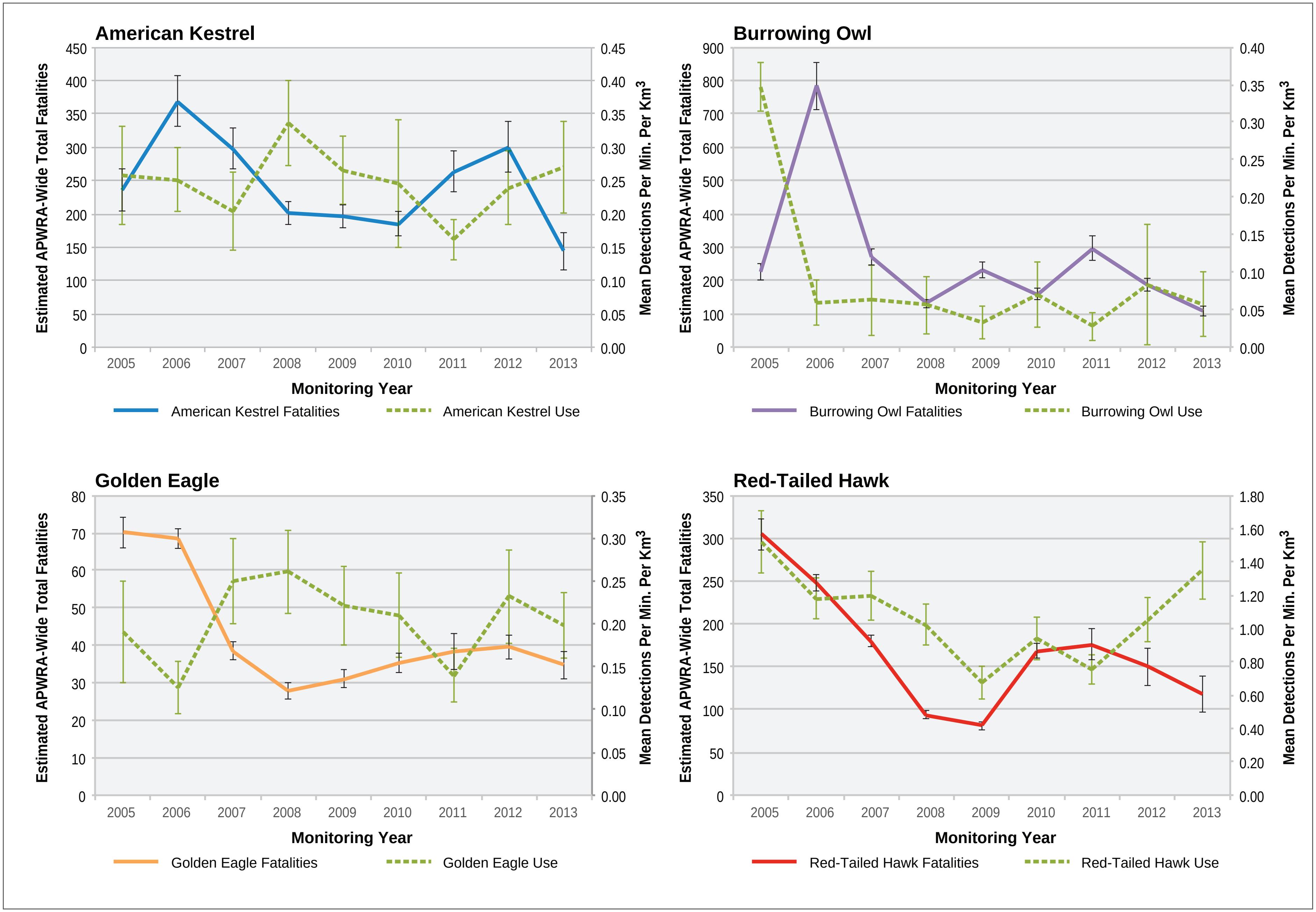

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Figure 3-6
Annual Estimated Total APWRA-Wide Fatalities (±95% CI) and Average Annual Bird Use (±95% CI) for the Four Focal Species, Monitoring Years 2005–2013

For the focal species, burrowing owl and American kestrel had the highest mean fatality rates across all years of the study, followed by red-tailed hawk and golden eagle. This contrasts with mean use rates across all years of the study, which are highest for red-tailed hawk followed by American kestrel and golden eagle.

There is considerable annual variation in the APWRA-wide annual adjusted fatality rates of the four focal species (Figure 3-5). In general, the direction and magnitude of annual changes in fatality rates among the four focal species did not correspond to one another, indicating that different factor(s) were driving changes in fatality rates or that the same factor(s) were driving changes in rates in different ways among the four species. However, trends over time in fatality rates for golden eagle and red-tailed hawk were generally similar to each other, as were trends in fatality rates between American kestrel and burrowing owl (Figure 3-5).

Annual variation in the APWRA-wide adjusted fatality rates was significant for American kestrel, but there was no significant upward or downward trend in adjusted fatality rates over time ($r = 0.180$, $p = 0.656$). The only pair of years with non-overlapping confidence intervals were the 2009 (lowest) and 2012 (highest) monitoring years.

Similarly, annual variation in the adjusted fatality rates was significant for burrowing owl, but there was no significant upward or downward trend in adjusted fatality rates over time ($r = -0.423$, $p = 0.269$). The 2006 monitoring year fatality rate was the primary driver of annual variation for burrowing owl (Figure 3-5), although 95% confidence intervals for the 2008 monitoring year do not overlap with those of the 2005, 2007, 2009, 2011, and 2012 monitoring years.

For golden eagle and red-tailed hawk, there were also significant differences in adjusted fatality rates among years, but no significant upward or downward trend in adjusted fatality rates over time ($r = 0.237$, $p = 0.554$ and $r = -0.304$, $p = 0.442$, respectively).

Fatality Rates and Bird Use

Mean annual bird use was not correlated with annual adjusted fatality rates for American kestrel ($r = -0.588$, $p = 0.099$), golden eagle ($r = -0.519$, $p = 0.159$), or red-tailed hawk ($r = 0.497$, $p = 0.181$). Because the majority of annual variation in use occurs during the period of the seasonal shutdown, while variation in fatality rates are—in theory—driven by collision risk outside the period of the seasonal shutdown, we estimated mean annual bird use using only those observations occurring outside the shutdown period. For American kestrel there was a negative correlation between mean annual use with shutdown observations excluded and the annual adjusted fatality rate ($r = -0.668$, $p = 0.048$). For golden eagle and red-tailed hawk, there was no correlation between mean annual use with shutdown observations excluded and annual adjusted fatality rates ($r = -0.508$, $p = 0.171$ and $r = 0.562$, $p = 0.119$, respectively).

Estimates of APWRA-Wide Total Fatalities

The estimates of APWRA-wide total fatalities are provided in Table 3-7 and presented graphically for the four focal species along with mean annual bird use in Figure 3-6. There is considerable annual variation present in the estimates of the APWRA-wide total fatalities for the four focal species (Figure 3-6). In general, the patterns over time are similar to the patterns in the annual adjusted fatality rates for all focal species except golden eagle (Figures 3-5 and 3-6).

Table 3-7. Estimated Annual Total APWRA-Wide Fatalities (95% CI), Monitoring Years 2005–2013

	Monitoring Year									
Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
American kestrel	236 (204–267)	369 (331–406)	298 (267–330)	201 (184–219)	196 (178–214)	185 (167–203)	264 (232–295)	301 (262–339)	144 (116–173)	244 (216–272)
Burrowing owl	225 (200–251)	783 (713–854)	272 (247–297)	130 (117–144)	231 (208–255)	158 (141–175)	296 (259–333)	187 (168–206)	109 (92–125)	266 (238–293)
Golden eagle	70 (66–74)	68 (66–71)	38 (36–41)	28 (26–30)	31 (29–33)	35 (33–38)	38 (34–43)	40 (36–43)	35 (31–38)	43 (40–46)
Red-tailed hawk	304 (286–323)	247 (238–257)	180 (173–187)	94 (89–98)	81 (76–86)	168 (159–176)	176 (158–194)	150 (128–172)	118 (97–139)	169 (156–181)
Total focal species	**836 (756–915)**	**1,468 (1,347–1,589)**	**788 (722–854)**	**453 (415–491)**	**540 (491–588)**	**547 (501–593)**	**774 (683–865)**	**677 (594–760)**	**406 (336–476)**	**721 (649–792)**
Turkey vulture	11 (10–12)	6 (5–6)	10 (9–10)	3 (3–3)	6 (5–6)	1 (1–1)	5 (4–5)	11 (10–12)	15 (13–16)	7 (7–8)
White-tailed kite	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	7 (6–8)	11 (8–13)	0 (0–0)	0 (0–0)	2 (2–2)
Northern harrier	0 (0–0)	6 (6–7)	6 (6–7)	5 (5–6)	0 (0–0)	0 (0–1)	10 (8–12)	0 (0–0)	0 (0–0)	3 (3–4)
Red-shouldered hawk	0 (0–0)	3 (3–4)	2 (2–2)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)
Swainson’s hawk	6 (5–7)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (1–1)
Ferruginous hawk	7 (6–8)	0 (0–0)	1 (1–2)	4 (3–4)	0 (0–0)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–1)	2 (2–2)
Peregrine falcon	0 (0–0)	3 (3–4)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Prairie falcon	7 (5–8)	10 (9–11)	5 (4–5)	0 (0–0)	0 (0–0)	13 (11–15)	22 (19–25)	0 (0–0)	0 (0–0)	6 (5–7)
Barn owl	240 (219–261)	124 (118–129)	22 (21–24)	24 (22–25)	44 (40–48)	73 (69–78)	91 (83–98)	22 (18–26)	12 (8–16)	72 (66–78)
Short-eared owl	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	7 (5–8)	0 (0–0)	1 (1–1)
Great-horned owl	38 (33–44)	40 (37–43)	18 (16–20)	4 (3–4)	40 (38–43)	21 (19–23)	14 (12–16)	26 (17–21)	0 (0–0)	22 (19–24)

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Total raptors[a]	**1,144 (1,033–1,212)**	**1,660 (1,528–1,750)**	**852 (781–903)**	**492 (451–529)**	**630 (574–643)**	**664 (608–697)**	**927 (818–1,021)**	**738 (645–808)**	**434 (358–509)**	**837 (755–897)**
Mallard	25 (21–30)	16 (14–18)	20 (18–22)	11 (10–12)	23 (20–26)	31 (28–34)	34 (27–41)	9 (8–11)	1 (1–1)	19 (16–22)
Common goldeneye	0 (0–0)	0 (0–0)	0 (0–0)	5 (4–6)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)
Wild turkey	0 (0–0)	8 (7–9)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (1–1)
Pied-billed grebe	0 (0–0)	14 (10–19)	0 (0–0)	0 (0–0)	0 (0–0)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (2–3)
Eared grebe	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	5 (3–6)	1 (0–1)
Double-crested cormorant	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (–1–3)	1 (–2–4)	1 (–2–4)	0 (0–1)
Brown pelican	0 (0–0)	0 (0–0)	0 (0–0)	1 (1–1)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Great blue heron	1 (1–2)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	11 (10–12)	0 (0–0)	1 (1–2)
Great egret	2 (1–2)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Virginia rail	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	9 (–31–50)	14 (–47–75)	14 (–47–75)	4 (0–22)
American coot	0 (0–0)	8 (7–10)	0 (0–0)	0 (0–0)	0 (0–0)	5 (4–7)	1 (1–2)	1 (1–2)	5 (4–6)	2 (2–3)
Sandhill crane	0 (0–0)	1 (1–1)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Killdeer	0 (0–0)	20 (17–24)	15 (12–18)	4 (3–5)	12 (10–15)	11 (8–13)	0 (0–0)	8 (7–10)	0 (0–0)	8 (6–9)
Black-necked stilt	0 (0–0)	5 (4–6)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)
American avocet	0 (0–0)	0 (0–0)	0 (0–0)	9 (8–10)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (1–1)
Bonaparte's gull	0 (0–0)	0 (0–0)	5 (4–6)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Ring-billed gull	0 (0–0)	0 (0–0)	0 (0–0)	3 (2–3)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Western gull	0 (0–0)	0 (0–0)	2 (2–3)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
California gull	0 (0–0)	13 (11–15)	20 (18–21)	24 (22–25)	11 (10–12)	22 (20–24)	15 (13–17)	89 (80–99)	12 (10–13)	23 (21–25)
Glaucous-winged gull	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	9 (7–11)	0 (0–0)	0 (0–0)	1 (1–1)
Unidentified gull	16 (14–18)	62 (58–67)	53 (50–57)	56 (53–59)	26 (24–27)	79 (74–85)	208 (186–229)	352 (314–390)	250 (224–276)	122 (111–134)
Rock pigeon	624 (568–680)	826 (771–880)	862 (794–931)	852 (788–917)	774 (706–842)	529 (462–596)	529 (473–586)	472 (428–516)	534 (484–585)	667 (608–726)
Mourning dove	108 (88–129)	160 (143–178)	145 (125–165)	148 (128–168)	145 (126–163)	64 (55–74)	49 (35–63)	202 (175–228)	74 (55–92)	122 (103–140)
Eurasian collared dove	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	6 (4–8)	0 (0–0)	1 (0–1)
Common poorwill	0 (0–0)	0 (0–0)	5 (3–7)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	6 (4–8)	1 (1–2)
White-throated swift	0 (0–0)	33 (23–44)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (3–5)
Northern flicker	10 (6–14)	0 (0–0)	21 (14–28)	13 (10–17)	10 (8–13)	9 (6–12)	69 (53–84)	5 (4–7)	5 (3–6)	16 (12–20)
Acorn woodpecker	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	22 (18–26)	2 (2–3)
Hammond’s flycatcher	11 (4–19)	20 (6–34)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–7)	4 (1–7)	4 (1–7)	4 (1–7)	5 (2–9)
Unidentified empidonax	0 (0–0)	3 (3–4)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Say’s phoebe	0 (0–0)	13 (6–20)	0 (0–0)	0 (0–0)	7 (3–11)	0 (0–0)	39 (18–60)	0 (0–0)	0 (0–0)	7 (3–10)
Loggerhead shrike	122 (92–151)	170 (121–218)	44 (29–58)	65 (47–84)	8 (4–12)	37 (23–51)	54 (32–77)	63 (43–83)	0 (0–0)	62 (43–82)
Warbling vireo	0 (0–0)	0 (0–0)	14 (4–25)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	2 (0–3)

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
American crow	5 (4–6)	6 (5–6)	14 (12–16)	8 (7–9)	3 (2–3)	0 (0–0)	0 (0–0)	8 (7–9)	16 (13–19)	6 (5–7)
Common raven	51 (45–56)	39 (37–41)	63 (61–66)	41 (39–42)	32 (29–34)	52 (49–56)	32 (29–34)	42 (39–45)	74 (70–78)	47 (44–50)
Horned lark	73 (45–100)	154 (116–192)	272 (220–324)	77 (56–98)	107 (80–135)	167 (123–211)	21 (11–32)	18 (10–27)	42 (24–59)	103 (76–131)
Tree swallow	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	8 (–8–24)	12 (–12–36)	12 (–12–36)	3 (0–11)
Northern rough-winged swallow	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	8 (–9–26)	13 (–13–39)	13 (–13–39)	4 (0–11)
Cliff swallow	22 (11–34)	0 (0–0)	25 (18–33)	0 (0–0)	0 (0–0)	14 (8–20)	2 (1–4)	2 (1–4)	2 (1–4)	8 (4–11)
Barn swallow	0 (0–0)	0 (0–0)	31 (17–45)	19 (13–26)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	6 (3–8)
Rock wren	35 (11–59)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–7)
House wren	0 (0–0)	27 (4–50)	0 (0–0)	25 (4–46)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	6 (1–11)
Ruby-crowned kinglet	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	9 (–10–28)	14 (–15–42)	14 (–15–42)	4 (0–12)
Mountain bluebird	0 (0–0)	126 (96–156)	14 (7–21)	0 (0–0)	12 (6–18)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	17 (12–22)
Unidentified bluebird	0 (0–0)	40 (26–54)	10 (4–15)	74 (51–97)	89 (69–110)	59 (34–84)	272 (195–350)	0 (0–0)	17 (8–26)	62 (43–82)
Swainson’s thrush	0 (0–0)	0 (0–0)	21 (12–29)	0 (0–0)	10 (5–16)	3 (1–4)	3 (1–4)	3 (1–4)	3 (1–4)	5 (2–7)
Northern mockingbird	34 (22–47)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	43 (27–59)	0 (0–0)	0 (0–0)	9 (5–12)
European starling	1,209 (1,039–1,379)	977 (875–1,078)	1,146 (995–1,297)	1,306 (1,165–1,447)	1,059 (927–1,190)	981 (865–1097)	902 (792–1,012)	678 (588–767)	353 (311–395)	957 (840–1,074)
American pipit	0 (0–0)	63 (29–97)	20 (8–33)	29 (15–42)	0 (0–0)	2 (1–4)	0 (0–0)	0 (0–0)	0 (0–0)	13 (6–19)
Wilson’s warbler	0 (0–0)	0 (0–0)	22 (4–39)	12 (3–21)	0 (0–0)	0 (0–0)	48 (9–87)	0 (0–0)	0 (0–0)	9 (2–16)

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Spotted towhee	0 (0–0)	0 (0–0)	24 (13–35)	0 (0–0)	0 (0–0)	3 (1–5)	3 (1–5)	3 (1–5)	3 (1–5)	4 (2–6)
Savannah sparrow	0 (0–0)	0 (0–0)	0 (0–0)	12 (3–22)	27 (12–42)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (2–7)
Lincoln's sparrow	0 (0–0)	23 (6–40)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	3 (1–4)
Golden-crowned sparrow	0 (0–0)	0 (0–0)	26 (9–43)	0 (0–0)	0 (0–0)	0 (0–0)	69 (22–116)	0 (0–0)	0 (0–0)	11 (3–18)
Dark-eyed junco	0 (0–0)	0 (0–0)	0 (0–0)	20 (7–33)	14 (5–23)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–6)
Western tanager	0 (0–0)	20 (11–28)	19 (8–29)	11 (5–17)	0 (0–0)	0 (0–0)	56 (23–90)	0 (0–0)	0 (0–0)	12 (5–18)
Red-winged blackbird	62 (44–79)	123 (102–143)	46 (34–59)	52 (40–65)	13 (6–20)	23 (14–31)	37 (20–54)	25 (14–35)	21 (13–30)	45 (32–57)
Tricolored blackbird	0 (0–0)	0 (0–0)	16 (8–24)	6 (3–9)	0 (0–0)	0 (0–0)	0 (0–0)	8 (5–12)	0 (0–0)	3 (2–5)
Western meadowlark	1,693 (1,489–1,897)	1,440 (1,279–1,601)	1,035 (903–1,167)	853 (751–955)	963 (855–1,070)	873 (773–973)	863 (745–981)	424 (367–481)	432 (333–531)	953 (833–1,073)
Brewer's blackbird	113 (70–156)	82 (64–101)	13 (7–19)	15 (10–19)	0 (0–0)	2 (1–2)	5 (–5–15)	7 (–8–22)	7 (–8–22)	27 (15–40)
Unidentified blackbird	120 (68–172)	131 (104–157)	154 (123–185)	71 (53–90)	63 (43–82)	85 (63–108)	81 (55–107)	5 (2–7)	44 (24–63)	84 (60–108)
Brown-headed cowbird	0 (0–0)	8 (4–12)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)
Unidentified oriole	0 (0–0)	0 (0–0)	10 (4–15)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–2)
House finch	10 (4–17)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–6)	21 (9–32)	4 (1–6)	4 (1–6)	5 (2–7)
House sparrow	0 (0–0)	0 (0–0)	10 (4–17)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–2)
Total nonraptors	**4,346 (3,648–5,045)**	**4,632 (3,960–5,304)**	**4,198 (3,545–4,851)**	**3,821 (3,298–4,344)**	**3,408 (2,951–3,864)**	**3,061 (2,617–3,505)**	**3,508 (2,723–4,292)**	**2,505 (2,016–2,994)**	**1,990 (1,511–2,467)**	**3,493 (2,916–4,070)**

Species	Monitoring Year 2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Total birds	**5,491 (4,681–6,300)**	**6,292 (5,487–7,096)**	**5,050 (4,325–5,775)**	**4,313 (3,749–4,877)**	**4,038 (3,526–4,550)**	**3,724 (3,225–4,224)**	**4,435 (3,541–5,329)**	**3,242 (2661–3822)**	**2,396 (1,849–2,944)**	**4,331 (3,671–4,990)**

[a] Includes the four focal species.

Non-overlapping 95% confidence intervals around the estimates of annual APWRA-wide total fatalities indicate significant annual variation for American kestrel and burrowing owl. Annual estimates of APWRA-wide American kestrel fatalities trend downward, but not significantly so ($r = -0.425$, $p = 0.267$). For burrowing owl, there is likewise no significant upward or downward trend in estimates of APWRA-wide total fatalities over time ($r = -0.488$, $p = 0.191$), despite the spike in fatalities in the 2006 monitoring year. With the exception of the 2006 monitoring year, annual fatality estimates for burrowing owl appear to be relatively stable over the course of the study.

For golden eagle and red-tailed hawk, non-overlapping 95% confidence intervals around the estimates of annual APWRA-wide total fatalities also indicate significant annual variation. In contrast to the two smaller species, there were marginally significant declines in the estimates of APWRA-wide total fatalities for both red-tailed hawk and golden eagle over time ($r = -0.646$, $p = 0.060$ and $r = -0.619$, $p = 0.076$, respectively). For golden eagle, annual APWRA-wide total fatalities appear to have stabilized or to be slightly increasing after the large drop in estimates from the 2005 to the 2008 monitoring years. The pattern appears similar for red-tailed hawk, although the estimates vary substantially more than golden eagle after the 2009 monitoring year.

Fatality Estimates and Bird Use

Mean annual bird use was not correlated with estimates of APWRA-wide total fatalities for American kestrel ($r = -0.403$, $p = 0.296$). The two metrics were marginally significantly negatively correlated for golden eagle ($r = -0.603$, $p = 0.087$) and marginally significantly positively correlated for red-tailed hawk ($r = 0.603$, $p = 0.087$).

As with fatality rates, we also correlated estimates of APWRA-wide total fatalities with bird use when seasonal shutdown observations are excluded. Bird use with shutdown observations excluded were not correlated with APWRA-wide total fatalities for either American kestrel or golden eagle, but confining bird use estimates to the non-shutdown period improved the correlation with estimates of APWRA-wide total fatalities for red-tailed hawk ($r = 0.672$, $p = 0.046$).

Evaluation of the Effectiveness of Management Actions and Repowering

The monitoring program was designed to estimate APWRA-wide total fatalities—and thus to indirectly evaluate the effectiveness of management actions—but was not designed to explicitly evaluate the effectiveness of individual management actions. Cross correlations among management actions compound this problem. For example, the duration and intensity of the seasonal shutdown was cross-correlated with both hazardous and non-hazardous (attrition) turbine removals. Turbine removal was highest at the beginning of the study and decreased over time while the duration and intensity of the seasonal shutdown increased over the course of the study. In addition, the inability to accurately age carcasses—particularly feather piles—in combination with long search intervals, makes it difficult to accurately determine when individual fatality incidents occurred, rendering assignment to a treatment category (i.e., seasonal shutdown) problematic. However, we now have data for 5 years in which a universal 3.5-month turbine shutdown has occurred, alleviating this problem to some extent.

Hazardous Turbine Removal

The Santa Clara operating group (BLOB 19) is controlled by Santa Clara County, and for this reason has been exempt from the requirement to implement removal of hazardous turbines. To assess the effect of hazardous turbine removals on reducing avian fatalities, annual adjusted fatality rates of the Santa Clara turbines were compared to the APWRA-wide annual adjusted fatality rates at older-generation turbines excluding the Santa Clara turbines (Figure 3-7). Sampling intensity has been relatively high at the Santa Clara turbines, with 11 of 15 (73%) or more strings sampled in each year of the study. Of the 202 turbines in this operating group, 22 (4%) were ranked 8 or 8.5 (i.e., hazardous) by the SRC in 2010. Because hazardous turbine removals occurred primarily over the first few years of the study, we would expect fatality rates to decrease over time disproportionately at older-generation non–Santa Clara turbines relative to Santa Clara turbines.

American kestrel fatality rates appear to decrease over time at older-generation non–Santa Clara turbines more rapidly than at the Santa Clara turbines, with the average fatality rate across all years of the study lower for the non–Santa Clara turbines, indicating a potential beneficial effect of hazardous turbine removal. Fatality rates for burrowing owl are also lower for the non–Santa Clara group, although there is no consistent trend over time. The annual fatality rate across years for red-tailed hawk is substantially lower at older generation non–Santa Clara turbines than at Santa Clara turbines, and slightly decreasing while the rate at Santa Clara turbines is increasing, consistent with the hypothesis that removal of hazardous turbines may result in lower fatality rates for this species. The number of golden eagles killed at Santa Clara turbines is too small to make a valid meaningful comparison with non–Santa Clara older generation turbines.

We also looked for correlations between turbine removals (measured in both the cumulative total number of turbines and megawatts removed) and fatality rates and estimates of APWRA-wide total fatalities for the four focal species. There was no correlation between fatality rates or estimates of APWRA-wide total fatalities and any measure of turbine removal (i.e., hazardous turbine removals, turbines removed due to attrition, and total turbine removals) for either American kestrel or burrowing owl. For both golden eagle and red-tailed hawk, there was no correlation between fatality rates and any measure of turbine removal. However, for both golden eagle and red-tailed hawk, there was a significant negative correlation between estimates of annual APWRA-wide total fatalities and the cumulative number of hazardous turbines removed ($r = -0.8567$, $p = 0.002$ and $r = -0.804$, $p = 0.007$, respectively).

Seasonal Shutdown

We examined two lines of evidence to evaluate the effectiveness of the seasonal shutdown in reducing focal species fatalities and to explore why the implementation of management actions appears to result in only a minor effect for golden eagle and red-tailed hawk and no effect for American kestrel and burrowing owl. We compared fatality rates at the Diablo Winds and non–Diablo Winds operating groups because the Diablo Winds operating group was not subject to the seasonal shutdown, and thus provided a control group for comparison. We also examined the proportion of annual carcasses estimated to have died during the seasonal shutdown and the carcass detection rates during and outside the shutdown period. If the shutdown were effective, the proportion of fatalities occurring during the shutdown period should decrease to near zero as the duration and intensity of the shutdown treatment increased and the error rate of misclassifying a carcass into the wrong period diminished.

We also conducted searches at ridges without turbines that were matched with ridges with turbines during the seasonal shutdown to see if background mortality factors could be influencing our ability to detect an effect of the seasonal shutdown.

Comparison of Diablo and Non–Diablo Winds Fatality Rates

The Diablo Winds turbines are the only set of repowered turbines in the APWRA that were monitored by the MT. They are also the only repowered turbines interspersed with older-generation turbines. Because the seasonal shutdown does not occur at repowered turbines, the annual adjusted fatality rates for the four focal species at these turbines were compared with the annual adjusted fatality rates from non–Diablo Winds turbines (Figure 3-8). The Diablo Winds turbines were monitored in monitoring years 2005–2009. If the seasonal shutdown were effective, fatality rates at older-generation (non–Diablo Winds) turbines would be expected to exhibit a greater decrease over time relative to fatality rates at Diablo Winds turbines.

There were no American kestrel fatalities detected at Diablo Winds turbines in 3 of the 5 years of monitoring. The two American kestrel fatalities that were detected occurred in August and October, outside the seasonal shutdown period. Similarly, only two golden eagle fatalities occurred at Diablo Winds turbines, both in the 2008 monitoring year, one of which occurred during the period of the seasonal shutdown (estimated death date of December 27, 2008). Burrowing owl fatality rates were very similar between the two groups in all years except the 2006 monitoring year, contrary to predictions. For red-tailed hawk, fatality rates decreased substantially at both Diablo Winds and non–Diablo Winds turbines, contrary to predictions.

Assessment of Fatalities Estimated to Have Occurred during the Seasonal Shutdown Period

If shutting down turbines were effective in reducing fatalities, we would expect both the number and proportion of annual fatalities occurring during the shutdown period to decrease to zero as the duration and intensity of the shutdown increased. The number and proportion of focal species fatalities estimated to have occurred during the shutdown period for the monitoring years in which the universal 3.5-month shutdown occurred (i.e., 2009–2013 monitoring years) are presented in Table 3-8. Clearly, the number of fatalities occurring during the shutdown period is greater than zero for all four focal species. This could be due to errors in aging carcasses, which could result in carcasses being assigned to the shutdown period when in fact they occurred outside the shutdown period. However, there is no evidence to suggest—and no reason to suspect—that the errors are biased in favor of erroneously placing carcasses into the shutdown period as opposed to erroneously placing them outside the shutdown period. The non-zero values could also be due to sources of mortality not directly associated with wind turbines such as predation.

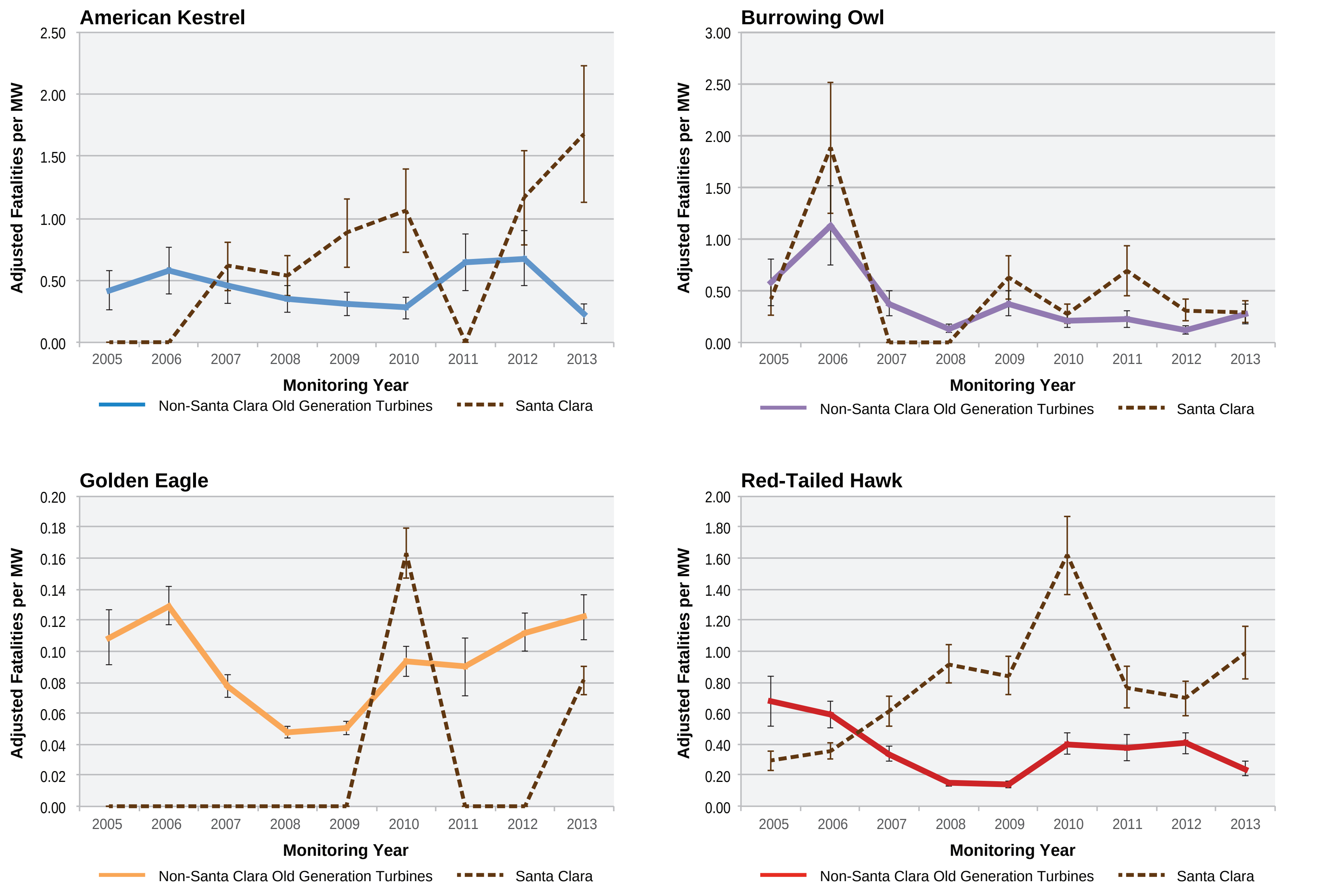

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Figure 3-7
Comparison of Annual Adjusted Fatality Rates (Fatalities per MW ± 95% CI) at Santa Clara Operating Group Turbines and Non-Santa Clara Old Generation Turbines for the Four Focal Species in the APWRA, Monitoring Years 2005–2013

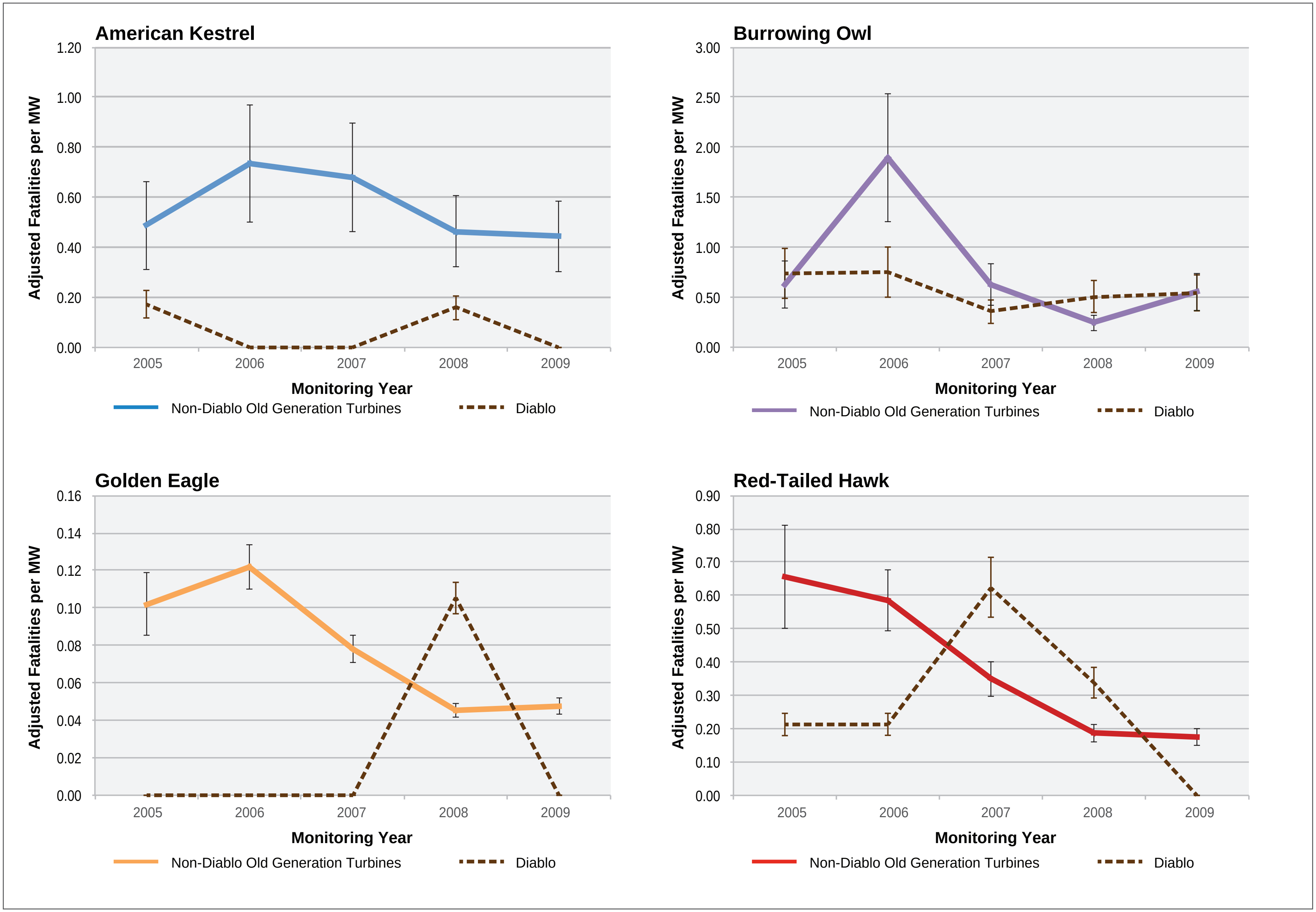

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Figure 3-8
Comparison of Annual Adjusted Fatality Rates (Fatalities per MW ± 95% CI) at Diablo Winds and non-Diablo Winds Older-Generation Turbines for the Four Focal Species in the APWRA, Monitoring Years 2005–2009

Table 3-8. Total Fatalities Estimated to Have Occurred during and outside the Seasonal Shutdown Period for the 2009–2013 Monitoring Years

Species	During Shutdown Period	Outside Shutdown Period	Total Annual Fatalities	Proportion of Fatalities during Shutdown
American kestrel	22	78	100	0.22
Burrowing owl	48	50	98	0.49
Golden eagle	3	49	52	0.06
Red-tailed hawk	19	147	166	0.11
Total	92	324	416	0.22

The proportion of annual fatalities occurring during the shutdown period, when collision risk is theoretically zero, is much higher for the smaller species relative to the two larger species, leading us to hypothesize that predation may be confounding the analysis of the effectiveness of the seasonal shutdown in reducing focal species fatalities. To test this hypothesis, we calculated the proportion and number of fatalities one might expect to find in the shutdown period if collision risk and relative abundance remained constant across the year in spite of the seasonal shutdown. We calculated expected values for each of the four focal species based on the proportion of the year in which turbines were shut down (i.e., 0.29) (Table 3-9). For American kestrel, the proportion of fatalities occurring during the shutdown period was not significantly different from expected based on the length of the shutdown period ($\chi 2 = 1.29$, $p = 0.256$). However, for burrowing owl, a species known to be subject to predation in the APWRA, a substantially greater proportion of fatalities occurred during the shutdown period than expected ($\chi 2 = 8.60$, $p = 0.003$). Conversely, significantly fewer golden eagle and red-tailed hawk fatalities occurred during the shutdown period ($\chi 2 = 9.67$, $p = 0.002$, and $\chi 2 = 15.73$, $p < 0.001$, respectively). These results are consistent with the hypothesis that the seasonal shutdown is effective in reducing fatalities for golden eagle and red-tailed hawk, and the hypothesis that predation is confounding the analysis of the effectiveness of the shutdown in reducing fatalities for burrowing owls.

Table 3-9. Observed and Expected Values of the Total Fatalities Estimated to Have Occurred during and outside the Seasonal Shutdown Period for the 2009–2013 Monitoring Years Based on the Proportion of the Monitoring Year Occurring during the Seasonal Shutdown Period

Species	During Shutdown Period	Outside Shutdown Period	Total Annual Fatalities	Proportion of Fatalities during Shutdown	$\chi 2$ p Value
American kestrel (Observed)	22	78	100	0.22	
American kestrel (Expected)	29	71	100	0.29	0.123
Burrowing owl (Observed)	48	50	98	0.49	
Burrowing owl (Expected)	28	70	98	0.29	< 0.001
Golden eagle (Observed)	3	49	52	0.06	
Golden eagle (Expected)	15	37	52	0.29	< 0.001
Red-tailed hawk (Observed)	19	147	166	0.11	
Red-tailed hawk (Expected)	48	118	166	0.29	< 0.001

To confirm these results, we conducted a separate analysis of the carcass detection rates (detections per search of a turbine string) during and outside the shutdown period (Table 3-10). The probabilities of detecting a golden eagle or red-tailed hawk carcass during the shutdown period are significantly lower than the probabilities of detection outside the shutdown period. A similar, although only marginally significant pattern is evident for American kestrel. Conversely, the probability of detecting a burrowing owl carcass is significantly higher during the shutdown period than outside the shutdown period.

We then examined how relative abundance (bird use) during the shutdown period relative to the rest of the year might affect the results. We did this by calculating the total number of daylight hours occurring during and outside the shutdown period. We then multiplied the total daylight hour values by the average number of detections per minute per cubic kilometer during and outside the shutdown period to obtain a relative measure of the total number of hours of use that occurs for three of the four focal species during and outside the shutdown period. We used the proportion of total annual use-hours to calculate the expected numbers of fatalities occurring in each period (Table 3-11).

Table 3-10. Detection Rates (Detections per String Search) for the Four Focal Species during and outside the Seasonal Shutdown Period in Monitoring Years 2009–2013

Species	Fatalities per String Search during Shutdown Period	Fatalities per Turbine Search outside Shutdown Period	Odds Ratio	Fisher's Exact Test (2-sided) Probability
American kestrel	22/3,060	78/7,263	0.6671	0.099
Burrowing owl	48/3,060	50/7,263	2.2988	< 0.001
Golden eagle	3/3,060	49/7,263	0.1449	< 0.001
Red-tailed hawk	19/3,060	147/7,263	0.3025	< 0.001
Total	**92/3,060**	**324/7,263**	**0.6639**	**0.001**

Table 3-11. Observed and Expected Values of the Total Fatalities Estimated to Have Occurred during and outside the Seasonal Shutdown Period for the 2009–2013 Monitoring Years Based on the Total Number of Daylight Hours in Each Period and Estimates of Bird Use

Species[a]	During Shutdown Period	Outside Shutdown Period	Total Annual Fatalities	Proportion of Fatalities during Shutdown	$\chi 2$ p Value
American kestrel (Observed)	22	78	100	0.22	
American kestrel (Expected)	38	62	100	0.38	0.014
Golden eagle (Observed)	3	49	52	0.06	
Golden eagle (Expected)	17	35	52	0.33	< 0.001
Red-tailed hawk (Observed)	19	147	166	0.11	
Red-tailed hawk (Expected)	63	103	166	0.38	< 0.001

[a] Use surveys were not designed to assess use for burrowing owls and are therefore not reported.

When taking use into account, there were significantly fewer American kestrel fatalities during the shutdown period than expected based on relative abundance and the length of the shutdown period ($\chi 2 = 6.10$, $p < 0.014$) (Table 3-11). This is due to the much higher average use by kestrels during the shutdown period than outside the shutdown period, and indicates that the seasonal shutdown is effective in reducing American kestrel fatalities. For golden eagle and red-tailed hawk, there were significantly fewer fatalities during the shutdown period than expected based on relative abundance and the length of the shutdown period, also because mean use was substantially higher during the shutdown period than during the rest of the year ($\chi 2 = 12.13$, $p < 0.001$, and $\chi 2 = 31.35$, $p < 0.001$, respectively).

In addition to the disproportionate numbers of fatalities occurring during the shutdown period, there is a disproportionately high number of fatalities occurring during the shutdown period that consist of feather piles for three of the four focal species (Table 3-12). For American kestrel and burrowing owl, the proportion of fatalities consisting of feather piles is significantly higher than the proportion of fatalities consisting of feather piles during the rest of the year ($\chi 2 = 9.02$, $p = 0.003$, and $\chi 2 = 34.70$, $p < 0.001$, respectively). This was also true for red-tailed hawks ($\chi 2 = 13.44$, $p < 0.001$), but not for golden eagles ($\chi 2 = 1.27$, $p = 0.721$). Assuming that carcasses resulting from predation become feather piles more quickly than carcasses resulting from other sources of mortality, this result is also consistent with the hypothesis that fatalities that occur during the shutdown period are not directly turbine-related, especially for those species subject to predation. The significantly higher proportion of feather piles during the shutdown period for red-tailed hawk may also indicate that higher scavenging rates or some other factor is responsible for the observed pattern of carcasses consisting of feather piles.

Table 3-12. Fatality Incidents of the Four Focal Species Occurring during and outside the Seasonal Shutdown at Older-Generation Turbines in the APWRA, Monitoring Years 2009–2013

	During Shutdown Period			Outside Shutdown Period		
Species	Feather Pile	Total Fatalities	Proportion Feather Pile	Feather Pile	Total Fatalities	Proportion Feather Pile
American kestrel	17	22	0.77	32	78	0.41
Burrowing owl	44	48	0.92	17	50	0.34
Golden eagle	0	3	0.00	2	49	0.04
Red-tailed hawk	5	19	0.26	6	147	0.04

Finally, we calculated the proportion of fatalities occurring during the shutdown period for each year of the study to see if there were any discernable patterns (Table 3-13). As noted above, the duration and intensity of the shutdown period increased over the course of the study. If predation were responsible for fatalities found near non-operational turbines, an increase over time in the proportion of annual fatalities occurring during the shutdown period might reasonably be expected because there is more time available for predated carcasses to accumulate and errors in death date estimation decrease. Conversely, for species not subject to predation (or other non-turbine related sources of mortality), one could reasonably expect the proportion of annual fatalities to exhibit no trend over time because fatalities are unlikely to accumulate when the turbines are shut down.

In fact, the proportion of annual fatalities occurring during the shutdown period increased significantly over time for burrowing owls ($r = 0.679$, $p = 0.042$), and tended to increase over time for American kestrel ($r = 0.602$, $p = 0.088$). Conversely, there was no apparent trend over time for golden eagle and red-tailed hawk.

Table 3-13. Proportion of Annual Fatality Incidents of the Four Focal Species Occurring during the Seasonal Shutdown at Older-Generation Turbines, Monitoring Years 2005–2013

Species	2005	2006	2007	2008	2009	2010	2011	2012	2013
American kestrel	0.00	0.09	0.27	0.14	0.24	0.25	0.17	0.15	0.29
Burrowing owl	0.04	0.23	0.34	0.30	0.32	0.46	0.67	0.81	0.27
Golden eagle	0.00	0.00	0.11	0.08	0.09	0.09	0.00	0.00	0.09
Red-tailed hawk	0.17	0.16	0.09	0.08	0.14	0.04	0.21	0.11	0.11

Background Mortality

We conducted 338 regular searches at matched turbine and non-turbine ridges from November 1, 2014, through February 15, 2015. The average search interval was 10.6 days. We found a total of 20 valid (i.e., found during regular searches within the search area and not aged out of the search interval) carcasses at non-turbine ridges and 38 valid carcasses at turbine ridges, for a total of 58 valid carcasses over a period of 3.5 months during which the turbines were shut down and verified to not be spinning by search crews (Table 3-14). Unidentified carcasses typically consisted of bones only with small pieces of fresh flesh still attached. The majority of carcasses were those of small birds.

An additional 42 (not valid) carcasses were located during the study, most of which were found during clearing searches, as incidental finds, or during regular searches but were determined to be aged.

There were significantly more small birds found at turbine ridges than at non-turbine ridges (Fisher's exact test, $p = 0.013$). All the small bird species, with the possible exception of American kestrel, are likely to be predated upon in the APWRA.

Table 3-14. Fatality Incidents Detected at Turbine Ridges and Non-Turbine Ridges during the Seasonal Shutdown Period, November 1, 2014 through February 15, 2016

Species	Turbine Ridges	Non-Turbine Ridges
Barn owl	1	0
Red-tailed hawk	0	2
Unknown large bird	2	2
Total large birds	3	4
American kestrel	1	1
American robin	2	2
Blackbird	1	0
Burrowing owl	3	0
European starling	6	3
Horned lark	4	3
Mourning dove	2	0
Savannah sparrow	3	0
Unknown small bird	5	2
Varied thrush	0	1
Western meadowlark	4	2
Total small birds	31	14
Unknown dove	1	0
Unknown medium bird	3	2
Total birds	**38**	**20**

Repowering

We compared the annual adjusted fatality rates averaged across all years of the study for the four focal species at all older-generation turbines to the fatality rates from the 31 Vestas V-47 660 kW repowered turbines of the Diablo Winds operating group. We also compared them to published fatality rates from the two other repowered operating groups in the APWRA—the Buena Vista operating group (Insignia Environmental 2012) and the Vasco Winds operating group (Brown et al. 2013) (Table 3-15).

Table 3-15. Average Annual Adjusted Focal Species Fatality Rates (Fatalities per MW and 95% CI) for all Monitored Older-Generation Turbines and Three Repowered Operating Groups (Diablo Winds, Buena Vista, and Vasco Winds) in the APWRA

Species	Average Annual Adjusted Fatality Rate (95% CI)			
	APWRA-Wide Older-Generation Turbines[a]	Diablo Winds Turbines[b]	Buena Vista Turbines[c]	Vasco Winds Turbines[d]
American kestrel	0.56 (0.37–0.74)	0.07 (0.05–0.09)	0.15 (0.06–0.24)	0.21 (0.00–0.45)
Burrowing owl	0.67 (0.44–0.90)	0.58 (0.39–0.77)	0.00 (0.00–0.00)	0.05 (0.01-0.13)
Golden eagle	0.09 (0.07–0.10)	0.02 (0.02–0.02)	0.04 (0.01–0.07)	0.04 (0.00-0.10)
Red-tailed hawk	0.40 (0.33–0.47)	0.28 (0.24–0.32)	0.10 (0.05–0.15)	0.44 (0.00-0.92)
Total focal species	**1.71 (1.21–2.21)**	**0.94 (0.69–1.20)**	**0.29 (0.18–0.40)**	**0.73 (0.00–1.61)**

[a] Fatality rates were calculated across all years of the study (2005–2013 monitoring years).
[b] Fatality rates were calculated using Diablo Winds turbines only for the 2005–2009 monitoring years.
[c] Fatality rates based on 3 years of monitoring conducted from February 2008 through January 2011.
[d] Fatality rates based on 2 years of monitoring conducted from May 2012 to May 2014.

The Diablo Winds turbines are the smallest and oldest of the repowered turbines in the APWRA, and are also interspersed with older-generation turbines. Nevertheless, average annual fatality rates at the Diablo Winds turbines were significantly lower for each of the four focal species except burrowing owl based on non-overlapping 95% confidence intervals. The Diablo Winds BLOB had a lower average annual fatality rate for American kestrel than any of the BLOBs with older-generation turbines, the fifth lowest for burrowing owl, the sixth lowest for golden eagle, and the fifth lowest for red-tailed hawk.

Fatality rates for the Buena Vista turbines (BLOB 3), which are 1 MW turbines, were higher than the Diablo Winds turbines for American kestrel and golden eagle, but still had significantly lower fatality rates for all four focal species—with the possible exception of golden eagle—compared to the older-generation turbines based on non-overlapping 95% confidence intervals. The Buena Vista turbines had a lower average annual fatality rate for American kestrel, burrowing owl, and red-tailed hawk than any of the BLOBs with older-generation turbines, and the second lowest for golden eagle.

The Vasco Winds turbines (BLOB 4), which are most similar in size and capacity to modern turbines currently being deployed throughout California, had a significantly lower fatality rate for burrowing owl based on non-overlapping 95% confidence intervals. Fatality rates for American kestrel and golden eagle were lower at Vasco Wind than for older-generation turbines, but not significantly so. The mean fatality rates for red-tailed hawk were similar between the Vasco Winds turbines and the older-generation turbines in the APWRA. The Vasco Winds turbines had a lower average annual fatality rate for American kestrel and burrowing owl than any of the BLOBs with older-generation turbines, and the second lowest for golden eagle. Seven BLOBs with older-generation turbines had lower fatality rates for red-tailed hawk than those reported for the Vasco Winds turbines.

Evaluation of the 50% Reduction

The primary goal of the avian fatality monitoring program was to assess progress toward achieving the 50% reduction target mandated by the 2007 settlement agreement. The settlement agreement referenced a baseline for comparison comprised of point estimates of focal species fatalities derived from Smallwood and Thelander (2004). We measured the reduction in focal species fatalities in reference to this baseline for each of the focal species individually and for the focal species as a whole by comparing this baseline estimate to the estimates of focal species fatalities from the last year of the monitoring program (i.e., the 2013 monitoring year).

However, due to biases inherent in making valid comparisons between the baseline dataset and the current study dataset, the SRC, in conjunction with the MT, derived an alternative baseline based on a 3-year rolling average, with the 3-year average from the first 3 years of the monitoring program serving as the alternative baseline. The 3-year rolling average (geometric means) of the annual estimates of APWRA-wide fatalities was approved by the SRC for use as an “alternative baseline” in June 2010 (APWRA Scientific Review Committee 2010).

Three-Year Rolling Average of the Estimates of APWRA-Wide Total Fatalities

The 3-year rolling average of the annual estimates of APWRA-wide total fatalities for the four focal species over the seven 3-year periods are presented in Table 3-16 and depicted graphically in Figure 3-9.

For American kestrel, golden eagle, and red-tailed hawk, there is no significant trend over time in the 3-year geometric means ($r = -0.629$, $p = 0.139$, $r = -0.561$, $p = 0.204$, $r = -0.434$, $p = 0.352$, respectively). However, there is a significant decline over time in the 3-year geometric means for burrowing owl ($r = -0.777$, $p = 0.038$). The trend for total focal species was also not significant ($r = -0.663$, $p = 0.110$).

Table 3-16. Three-Year Rolling Average (Geometric Mean) of Estimated APWRA-Wide Total Focal Species Fatalities (95% CI), Monitoring years 2005–2013

Species/ Category	3-Year Period and Fatalities (95% CI)						
	2005–2007	2006–2008	2007–2009	2008–2010	2009–2011	2010–2012	2011–2013
American kestrel	296 (262–329)	281 (253–308)	228 (206–249)	194 (176–212)	213 (191–234)	245 (217–273)	225 (192–259)
Burrowing owl	363 (328–399)	303 (274–332)	202 (182–221)	168 (151–186)	221 (197–246)	206 (183–229)	183 (159–205)
Golden eagle	57 (54–60)	42 (39–44)	32 (30–34)	31 (29–34)	35 (32–38)	38 (34–41)	38 (34–41)
Red-tailed hawk	238 (227–250)	161 (154–168)	111 (105–117)	108 (102–114)	134 (124–143)	164 (148–180)	146 (125–167)
Total focal species	**954 (871–1,038)**	**786 (720–852)**	**572 (523–622)**	**502 (459–546)**	**602 (543–661)**	**653 (582–724)**	**591 (510–672)**

Measures of Reduction

Based on the numbers from the settlement agreement and the 3-year rolling averages, we derived the four following measures of the reduction in fatalities over the course of the study.

- Settlement agreement baseline point estimate(s) to the point estimate(s) from the last year of the monitoring program (i.e., 2013 Monitoring Year Estimate).
- Settlement agreement baseline point estimate(s) to the 3-year rolling average of the point estimate(s) of the last 3 years of the monitoring program (i.e., 2011–2013 monitoring years).
- Alternative (3-Year Rolling Average) baseline point estimate(s) to the point estimate(s) from the last year of the monitoring program (i.e., 2013 Monitoring Year Estimate).
- Alternative (3-Year Rolling Average) baseline point estimate(s) to the 3-year rolling average of the point estimate(s) of the last 3 years of the monitoring program (i.e., 2011–2013 monitoring years).

The resulting measures are presented in Table 3-17.

Table 3-17. Various Measures of the Reduction in Total Annual Fatalities of the Four Focal Species

					Percent Reduction from:			
Species	Settlement Agreement Baseline	3-Year Rolling Average Baseline	3-Year Rolling Average 2011–2013	2013 Monitoring Year Estimate	3-Year Rolling Average to 3-Year Rolling Average	3-Year Rolling Average to 2013 Monitoring Year Estimate	Settlement Agreement Baseline to 3-Year Rolling Average	Settlement Agreement Baseline to 2013 Monitoring Year Estimate
American kestrel	333	296	225	144	-24%	-51%	-32%	-57%
Burrowing owl	380	363	182	109	-50%	-70%	-52%	-71%
Golden eagle	117	57	38	35	-34%	-39%	-68%	-70%
Red-tailed hawk	300	238	146	118	-39%	-50%	-51%	-61%
Total focal species	**1,130**	**954**	**591**	**406**	**-38%**	**-57%**	**-48%**	**-64%**

Technically, by the criteria specified in the settlement agreement, the 50% reduction goal was achieved (settlement agreement baseline compared to the 2013 monitoring year point estimate). This conclusion assumes that because the settlement agreement used a specific point estimate for the baseline without reference to any measure of variation, use of a single point estimate without incorporation of any measure of variation to measure the reduction would be legally acceptable. When the 2013 monitoring year estimate is compared to the SRC-adopted 3-year rolling average baseline, the 50% reduction goal is also technically achieved.

However, both of the measures that include annual variation in the endpoint measurements indicate that the 50% reduction goal was not achieved. The percentage decrease in total focal species fatalities averaged across all four measures of the reduction was 52%.

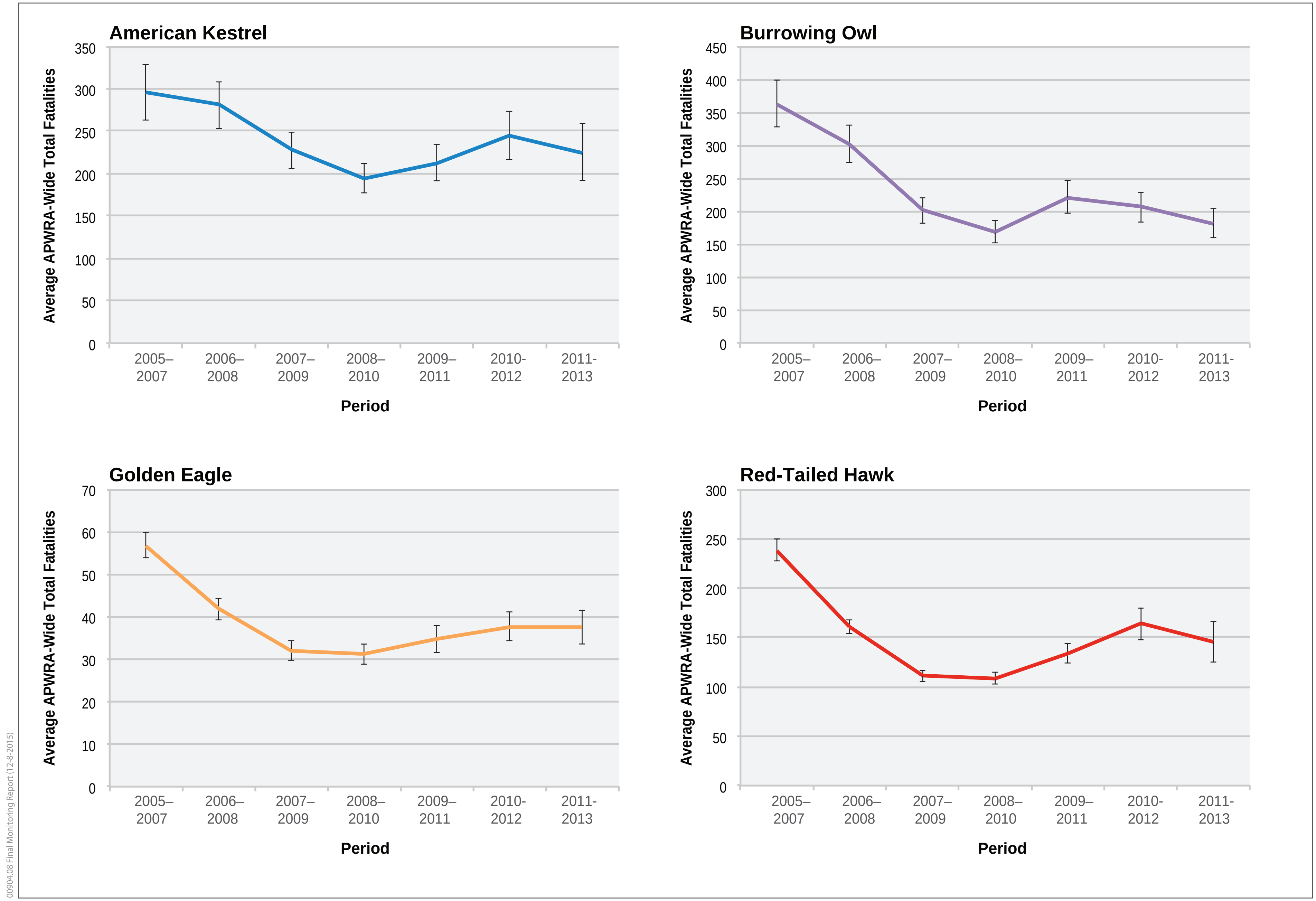

Figure 3-9
Three-year Rolling Average (Geometric Means) of the Estimated Annual Total Fatalities (± Average 95% CI) in the APWRA, Monitoring Years 2005–2013

Confounding with Predation

Several lines of evidence presented above strongly indicate that predation, particularly during the period of the seasonal shutdown, is confounding the analysis of the effectiveness of management actions and the resulting estimates of turbine-related fatalities to some degree. These are listed below.

- Significant numbers of fatalities are detected with an estimated death date during the shutdown period, even though the theoretical collision risk is reduced to near zero.
- There is a significant and substantial increase in use during the shutdown period by the two larger predatory focal species and by numerous other large predatory species, including peregrine falcon, prairie falcon, ferruginous hawk, rough-legged hawk, and others.
- A smaller proportion of annual fatalities occurs during the shutdown period for larger birds not subject to predation while a larger than expected proportion of annual fatalities occurs during the shutdown period for smaller species subject to predation.
- For burrowing owls, the carcass detection rate is significantly higher during the shutdown period, while the opposite is true for the other focal species.
- The proportion of annual fatalities occurring during the shutdown period increased over time for burrowing owls and possibly American kestrels as the duration and intensity of the shutdown period increased, but not for the larger predatory birds not subject to predation.
- A substantially larger proportion of burrowing owl carcasses are found outside the maximum 50-meter search radius than of the other focal species (73% versus 84%).
- The results of the background mortality study clearly show that some level of background mortality is occurring, and that these fatalities are detected during carcass searches. In addition, significantly more small bird carcasses are found on turbine ridges than on non-turbine ridges, suggesting that predatory birds may be taking their prey back to turbines for consumption.

To estimate the potential effect confounding with predation could have on the estimated reduction in focal species fatalities over time, we calculated the 3-year rolling averages of the annual estimates of APWRA-wide total fatalities when the fatalities with estimated death dates during the shutdown period are excluded from the analysis. The results for burrowing owl and American kestrel, the two focal species that are potentially subject to predation, are presented in Table 3-18 and depicted graphically in Figure 3-10.

Table 3-18. Three-Year Rolling Average (Geometric Mean) of Estimated APWRA-Wide Total American Kestrel and Burrowing Owl Fatalities (95% CI), Monitoring Years 2005–2013, with Shutdown Fatalities Included and Excluded

Species/ Category	3-Year Period and Fatalities (95% CI)						
	2005–2007	2006–2008	2007–2009	2008–2010	2009–2011	2010–2012	2011–2013
Fatalities with Estimated Death Dates during the Seasonal Shutdown Period Included							
American kestrel	296 (262–329)	281 (253–308)	228 (206–249)	194 (176–212)	213 (191–234)	245 (217–273)	225 (192–259)
Burrowing owl	363 (328–399)	303 (274–332)	202 (182–221)	168 (151–186)	221 (197–246)	206 (183–229)	183 (159–205)
Fatalities with Estimated Death Dates during the Seasonal Shutdown Period Excluded							
American kestrel	227 (200–253)	203 (182–224)	166 (149–184)	148 (133–164)	168 (148–187)	197 (172–221)	186 (156–216)
Burrowing owl	236 (210–262)	162 (143–181)	112 (99–125)	89 (78–100)	102 (89–115)	72 (60–84)	74 (61–88)

For American kestrel, removal of fatalities estimated to have occurred during the shutdown period resulted in an average decrease across all of the 3-year periods of approximately 23%, with a tendency for the decrease to get smaller over time. For burrowing owl, removal of fatalities estimated to have occurred during the shutdown period resulted in an average decrease across all of the 3-year periods of approximately 50%, with the size of the decrease getting larger over time.

The four metrics used to evaluate progress towards the 50% reduction goal when American kestrel and burrowing owl fatalities are removed from the analysis are presented in Table 3-19.

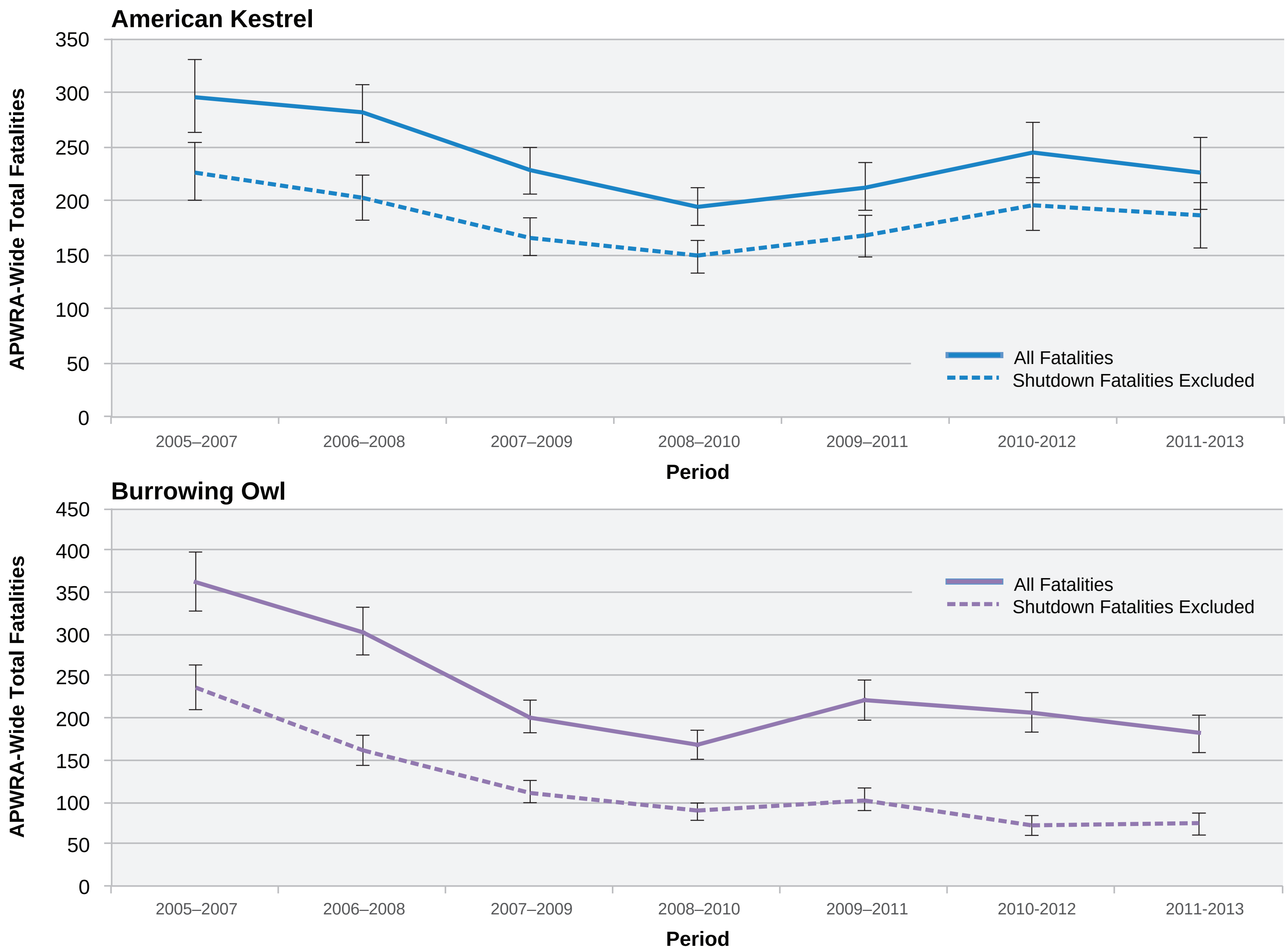

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Figure 3-10
Three-year Rolling Average (Geometric Means) of the Estimated Annual Total Fatalities (± Average 95% CI) in the APWRA with Carcasses with Estimated Death Dates Inside the Shutdown Period Excluded, Monitoring Years 2005–2013

Table 3-19. Various Measures of the Reduction in Total Annual Fatalities of the Four Focal Species if Fatalities for Small Birds Potentially Subject to Predation with an Estimated Death Date during the Seasonal Shutdown Period are Excluded from Analysis

					Percent Reduction from:			
Species	Settlement Agreement Baseline	3-Year Rolling Average Baseline	3-Year Rolling Average 2010–2013	2013 Monitoring Year Estimate	3-Year Rolling Average to 3-Year Rolling Average	3-Year Rolling Average to 2013 Monitoring Year Estimate	Settlement Agreement Baseline to 3-Year Rolling Average	Settlement Agreement Baseline to 2013 Monitoring Year Estimate
American kestrel	333	227	186	119	-18%	-47%	-44%	-64%
Burrowing owl	380	236	74	79	-69%	-67%	-80%	-79%
Golden eagle	117	57	38	35	-34%	-39%	-68%	-70%
Red-tailed hawk	300	238	146	118	-39%	-50%	-51%	-61%
Total focal species	**1,130**	**758**	**444**	**351**	**-41%**	**-54%**	**-61%**	**-69%**

Removal of fatalities estimated to have occurred during the shutdown period—at least some of which are likely to be a result of predation—changes the conclusions regarding achievement of the 50% reduction goal. With shutdown fatalities removed, three of the four measures of reduction indicate that the 50% reduction criteria was achieved. If the removal of fatalities estimated to have occurred during the shutdown period is confined to burrowing owls, the same three measures of reduction indicate that the 50% reduction goal has been achieved.

With the removal of fatalities estimated to have occurred during the shutdown period, the percentage decrease in total focal species fatalities averaged across all four measures of the reduction was 56%.

Chapter 4
Discussion

The APWRA Avian Fatality Monitoring Program has been one of the largest and longest running avian fatality monitoring programs ever conducted. Formal fatality monitoring ended in September 2015, culminating over 9 years of fatality monitoring at one of the largest wind farms in the United States. The estimates derived from this study have several advantages over previously published estimates, including a much larger sample size, a geographically stratified analytical framework, and estimates of detection probabilities derived from data collected at the study site over the course of the study.

For the first 5 years of the study, an average of 247 MW of turbines were monitored, more than three times the size of the largest individual project requiring monitoring (e.g., repowering project) in the APWRA to date. When the size of the monitoring program was reduced to approximately 120 MW of turbines sampled, it was still 1.5 times larger than the total capacity of the largest repowering project.

The analytical framework, which was first introduced in 2010 but not finalized until 2013, stratifies the APWRA into geographically and topographically distinct units that generally share a common turbine type and owner/operator, and presumably some degree of environmental and vegetation management similarity.

The estimates of fatality rates and APWRA-wide total fatalities were also, for the first time since Orloff and Flannery (1992), based on detection probabilities derived from information collected during three separate studies that were part of the overall monitoring program (the QAQC study, the carcass removal/scavenging trial, and the 48-hour search interval study). Consequently, the estimates presented here represent the best estimates of total APWRA-wide avian fatalities available to date.

Despite these advantages, there remains a number of potential biases and uncertainties that can heavily influence the point estimates, not the least of which is the state of the science of accurately and precisely estimating turbine-related avian fatalities at wind farms in general. These potential biases and uncertainties make it difficult to draw conclusions based on changes over time in the annual estimates of fatality rates and APWRA-wide total fatalities, and include issues such as the removal of carcasses by O&M personnel during the first 2 years of the study, a large and variable search interval, the persistence of carcasses beyond the duration of the search interval and their subsequent detection on a later search (bleed through), and the lack of annual estimates of detection probability.

Prior to 2007, fatalities documented by wind company O&M personnel were removed from the study area, rendering them unavailable for detection by search crews. This resulted in a possible downward bias in the 2005 monitoring year estimates and, to a limited degree, the 2006 monitoring year estimates, potentially resulting in an underestimate of the reduction in both fatality rates and APWRA-wide total fatalities over time.

The annual average search interval over the course of the study has varied from 30 to as many as 51 days, substantially greater than the maximum search interval recommended by the U.S. Fish and Wildlife Service (2012) or the California Energy Commission and California Department of Fish and

Game (2007). While this may not be a substantial issue for larger birds such as golden eagles and red-tailed hawks, it is a potentially substantial issue for smaller species that are particularly subject to predation and scavenging. While it is clear that the probability of detection decreases as the search interval increases, the exact form of the relationship is not known precisely and is likely to vary in different environments. Therefore, the relatively large search intervals employed in this study can influence the results in ways that are not necessarily predictable.

Another bias issue related to longer search intervals is "bleed through." Bleed through occurs when a carcass that is available to be detected is missed, but is detected on a subsequent search. Theoretically, such a carcass has already been accounted for through the incorporation of detection probability in the estimation process, but it is now counted (and adjusted) again. While carcasses that are determined to be "aged" (i.e., determined to be older than the search interval) are excluded from the analysis, longer search intervals make the detection of bias resulting from "bleed through" more difficult because it is more difficult to accurately age older carcasses. We have numerous examples of "aged" carcasses in the APWRA, including a golden eagle wing that was determined to belong to a golden eagle carcass that was first detected 5 years prior. While we do not have an estimate of the bias in this study resulting from bleed through, the phenomenon would result in an overestimation of fatality rates.

Finally, the importance of measuring detection probability in any population estimation process (including estimation of a population of dead animals) has long been recognized. It is important because it is known to vary with a host of factors, including observers (or searchers), habitat, land cover, season, weather, year, and many others. Recommendations made by regulatory agencies regarding the study of avian mortality at wind farms all strongly recommend estimating annual detection probabilities (U.S. Fish and Wildlife Service 2012, California Energy Commission and California Department of Fish and Game 2007). The lack of annual site-specific estimates of detection probability is a major shortcoming of this study. The apparent relative stability of annual estimates of APWRA-wide total fatalities for the four focal species may be an artifact of the estimates of detection probabilities used in this study, in that they represent a composite estimate derived from studies conducted over many years of the study but applied equally to all years of the study.

Problems with the Baseline

Throughout the current study, a heavy emphasis has been placed on ensuring that the annual point estimates of the total numbers of avian fatalities be as precise and accurate as possible, because the objective was to measure the reduction in fatalities from baseline estimates provided by Smallwood and Thelander (2004).

However, detection probabilities were not measured or estimated in the baseline study (Smallwood and Thelander 2004). Instead, detection probabilities from other studies were averaged and then applied to the fatality counts. In a subsequent paper, Smallwood and Thelander (2008) used a different set of detection probabilities and applied them to the same dataset from Smallwood and Thelander (2004). These detection probabilities were model-based average detection probabilities derived by Smallwood (2007) from searcher efficiency and carcass removal studies collected from monitoring reports throughout the country. Using this second set of detection probabilities, the estimates of total golden eagle fatalities decreased by 43% and the estimate for total red-tailed hawk fatalities decreased by 37%, while the burrowing owl estimate increased by 16% and the American kestrel estimate increased by 5%.

When evaluating the reduction in focal species fatalities, it is important to keep in mind that the SRC and the monitoring team were tasked with measuring a reduction in focal species fatalities from a baseline estimate that itself was both highly imprecise and unreliable, as evidenced by the comparison above.

Because detection probability was not measured during the baseline study, there is no way to know which set of baseline estimates more closely reflect the actual number of focal species fatalities. The comparison described above highlights the importance of actually measuring detection probability and is an example of why using model-based average detection probabilities “to make studies more comparable” in cases where detection probability was not measured or was measured inaccurately, as advocated by Smallwood (2007), is inappropriate.

The inherent problems associated with using model-based detection probabilities to make studies more comparable became evident in the results produced from the current study. Estimates of focal species fatalities over the first 5 years of the current study—using model-based average detection probabilities—were higher than estimates using data from Smallwood and Thelander (2004) and the same model-based average detection probabilities, despite the removal of hazardous turbines, seasonal shutdown of turbines, and a substantial decline in the installed capacity of the APWRA due to attrition of older-generation turbines (ICF International 2011).

A different approach to measuring the reduction in fatalities had to be developed, which resulted in the adoption of the 3-year rolling average baseline by the SRC in 2009.

Variation in Annual Fatality Rates and Estimates of APWRA-Wide Total Fatalities

There is a striking amount of annual variation in the point estimates of APWRA-wide fatality rates for the four focal species. Fatality rates show no evidence of a decline over time for any of the focal species. This is perhaps not surprising because turbine strings sampled were not selected with respect to hazardous turbine removal or any other management action, although the seasonal shutdown in some form was applied to all turbines in the APWRA in all 9 years of the study.

There is also significant annual variation evident in the estimates of APWRA-wide total fatalities for the four focal species. While no decline was evident for the two smaller focal species, American kestrel and burrowing owl, there was a marginally significant decline over time in golden eagle and red-tailed hawk fatalities. Changes in fatality estimates are influenced significantly by changes in installed capacity and by repowering, which over the course of the study resulted in lower fatality rates in parts of the APWRA subject to such modifications.

In general, the direction and magnitude of annual changes in fatality rates among the four focal species did not correspond to one another, indicating that different factor(s) were driving changes in fatality rates or that the same factor(s) were driving changes in rates in different ways among the four species. Fatality rates and estimates of APWRA-wide fatalities were not correlated with estimates of average annual bird use for either American kestrel or golden eagle. For red-tailed hawk, mean annual bird use was marginally correlated with estimates of APWRA-wide total fatalities, and significantly correlated with estimates of APWRA-wide of total fatalities when use observations from the seasonal shutdown period were removed from the analysis. However, the general lack of correspondence between use and fatality rates and estimates of APWRA-wide total fatalities leaves us without an explanation for what drives the tremendous amount of variation in fatalities and fatality rates observed in the APWRA.

There is a striking lack of correspondence in trends in fatality rates from year to year among subsets of the data. For example, the comparisons of the Diablo Winds turbines with the older-generation turbines in the APWRA and the comparison of the Santa Clara operating group turbines with the non–Santa Clara older-generation turbines show little agreement in the direction of change from year to year in fatality rates, and this holds true for many comparisons among the 30 BLOBs. This geographic variation in trends in fatality rates suggests that there may be some unmeasured variables which are strongly influencing collision risk. One possibility is that geographic and temporal variation in fatality rates is driven by geographic and temporal variation in prey resources throughout the APWRA—in particular, changes in the distribution and abundance of California ground squirrels. California ground squirrels, ubiquitous throughout the APWRA, are a keystone species that drives much of the ecology in the arid grassland ecosystem of the Diablo Range. It is possible that changes in the distribution and abundance of individual colonies is playing a large role in driving the annual and geographic variation in collision risk—and thus fatality rates—than has generally been recognized.

Evaluation of the Effectiveness of Management Measures and Other Actions

Evaluation of the effectiveness of management actions in reducing turbine-related avian fatalities is difficult when the response variable of interest is an annual measure of rates or fatalities with significant amounts of annual variation, management actions are correlated or cross correlated with each other, and there are few effective controls with which to make comparisons.

Hazardous Turbine Removal

The selection of turbine strings for inclusion in the sample did not take into account the removal of hazardous turbines. Thus the ability to detect an effect of hazardous turbine removal on fatality rates was limited. Changes in the annual estimates of APWRA-wide total fatalities were not correlated with removal of hazardous turbines for American kestrel and burrowing owl, but were negatively correlated with hazardous turbine removal (and all other measures of turbine removal) for golden eagle and red-tailed hawk. Additionally, patterns evident in the comparison of Santa Clara turbines—which were not subject to hazardous turbine removal—with non–Santa Clara older–generation turbines provide some evidence for a beneficial effect of hazardous turbine removal for American kestrel, red-tailed hawk, and perhaps burrowing owl as well.

Seasonal Shutdown of Turbines

While it is intuitive that shutting down turbines during the period of highest use would result in clear reductions in turbine-related avian fatalities, the trends over time in the annual estimates of APWRA-wide focal species fatalities do not exhibit the substantial reductions that were predicted (Smallwood and Spiegel 2005a). The comparison of older-generation turbine fatality rates with fatality rates at the repowered Diablo Winds turbines showed little evidence of an effect of the seasonal shutdown. Although one eagle was killed at Diablo Winds turbines during the period of the seasonal shutdown that probably would not have been killed had the shutdown been in effect, no similar effects were apparent for the other focal species.

However, the hypothesis that the seasonal shutdown is effective in reducing avian fatalities—at least for golden eagle and red-tailed hawk—is supported by the marginally significant decline over time in fatalities for these species. In addition, the significantly lower carcass detection rate during the shutdown period for monitoring years 2009–2013—i.e., those years in which a full 3.5-month shutdown was implemented—strongly supports the hypothesis that the seasonal shutdown is effective in reducing fatalities for those species. Finally, when bird use is taken into account, significantly fewer American kestrel fatalities are found during the shutdown period than expected, indicating a positive beneficial effect of the seasonal shutdown on this species as well.

Conversely, there is no evidence of a beneficial effect of the seasonal shutdown on burrowing owls. There is no demonstrable decline in fatalities over time for burrowing owl, and the carcass detection rate is significantly higher during the shutdown period than outside the shutdown period. However, there is now strong evidence indicating that—at least for burrowing owl—predation has been a significant factor confounding the assessment of the effectiveness of management actions in reducing turbine-related fatalities and in properly evaluating trends over time in turbine-related fatality rates and total APWRA-wide fatalities for this species. Because we cannot currently determine the cause of death for most burrowing owl fatalities, we cannot accurately determine the effectiveness of the seasonal shutdown on burrowing owls.

As noted above, the carcass detection rate for burrowing owl is significantly greater during the shutdown period—despite the actual reduction of collision risk to near zero. Although there are several hypotheses that could potentially explain this pattern, none of them fully explains the patterns in fatalities with more parsimony than the predation hypothesis.

The ability to accurately determine an approximate death date of carcasses found during searches is imprecise. It has been argued that errors in assigning a death date to carcasses—particularly carcasses consisting of feather piles—results in carcasses with a death date outside the shutdown period being erroneously included in the shutdown period. However, the analysis presented here includes only the 5 years in which the 3.5-month universal shutdown was in place. There are no data to indicate—and indeed no reason to suspect—that carcass aging errors are more likely to erroneously place carcasses inside the shutdown period than to erroneously place them outside the shutdown period.

The “collision with stationary turbines” hypothesis has been put forward by Shawn Smallwood, who has argued that the prevalence of burrowing owl carcasses during the shutdown period is a result of burrowing owls colliding with stationary turbines rather than predation, presumably because visibility can be reduced on the foggy days that are more prevalent during the period of the seasonal shutdown. For this hypothesis to be true, either collision risk during the shutdown period would have to increase substantially above the risk that occurs when the turbines are actually spinning, or burrowing owl populations would have to increase substantially during the period of the shutdown, or both. In addition, Smallwood (2007b) himself noted that during the baseline study, the Enertech turbines, which have always been shut down for the winter as standard operating procedure, recorded no fatalities during the winter period but recorded seven fatalities outside the winter period. Either way, an increase in fatalities during the shutdown period for the larger species not subject to predation was not observed, a fact that the “collision with stationary turbines” hypothesis does not account for. While collision with stationary turbines may in fact occur in rare cases, it does not explain the fatality patterns observed.

Changes in detection probability during the shutdown period could potentially explain the disproportionate number of burrowing owl carcasses detected during the shutdown period. Although it is likely that detection probability changes measurably during the shutdown period, in the absence of data one could cogently argue both that it increases and that it decreases. However, this hypothesis also does not explain why only the smaller species potentially subject to predation are detected more frequently during the shutdown period without postulating that detection probability changes only for smaller species and that it changes in the direction of a higher detection probability during the shutdown period.

Finally, it has been argued by some that turbines facilitate predation by serving as elevated perches from which to hunt, particularly during the shutdown period when the turbines are not spinning. There is no evidence to support this hypothesis in the bird use data collected during those periods when behavior data (including perching behavior) was recorded. In fact, American kestrels and red-tailed hawks hovering/kiting in the vicinity of turbines rather than perch hunting was frequently recorded. Results from the background mortality study confirm that the turbines are used by predatory birds to consume prey, the unconsumed remains of which are then dropped below the turbines. This could be interpreted as evidence that the turbines are also being used to hunt from, and thus they are indirectly responsible for facilitating predation. However, there are few places in the APWRA that are any substantial distance from a turbine tower. Nevertheless, the possibility that stationary turbines are indirectly responsible for some predation events cannot be ruled out with the information available.

That significant amounts of predation occur in the APWRA during the period of the seasonal shutdown seems obvious. Bird use data collected over the course of the study clearly demonstrate that large numbers of predatory birds regularly come into the area every winter, including golden eagles and red-tailed hawks, peregrine falcons, prairie falcons, merlin, ferruginous hawks, rough-legged hawks, northern harriers, and Cooper’s hawks. Most of these species (as well as American crows and great horned owls, both common in the APWRA) are known or suspected predators of burrowing owls (Poulin et al. 2011).

Results of the background mortality study confirm that significant numbers of small bird carcasses are found during the period when turbines are shut down, including on ridges without turbines. In fact, a total of 58 valid fatalities were found during regular searches in the shutdown period in 3.5 months of searches during which time the turbines were verified by search crews not to be spinning. By comparison, a study conducted at Buffalo Ridge in Minnesota found only 31 avian fatalities during 2,482 searches of reference plots without turbines (Johnson et al. 2000).

The implications of predation being a confounding factor in the analysis of mortality in the APWRA are substantial. Smallwood and Spiegel (2005a, 2005b, 2005c) did not account for the effects of predation when they derived their predictions of the effectiveness of hazardous turbine removals and shutting down turbines in the fall and winter. And because predation has gone unmeasured and unrecognized, this omission has adversely affected our ability to detect changes in turbine-related fatalities over time and assess the effectiveness of management actions on reducing turbine-related fatalities. That this open question has begun to be addressed is a significant achievement of this study.

Repowering

Comparison of fatality rates at the three operating groups comprised of repowered turbines with fatality rates at older-generation turbines indicates that repowering may result in a reduction in fatality rates for the four focal species. These results suggest that avian fatalities could be reduced in areas where modern, high-capacity turbines are deployed *in place of* older-generation turbines. Although the three sites now represent approximately 29% of the installed capacity in the APWRA, these three sites are not necessarily representative of the rest of the APWRA.

Several factors could be influencing these results. For example, disturbance associated with construction may cause a temporary decrease in bird use at a newly repowered site, resulting in lower fatalities for the first year at that site. Loss of prey species and/or cover and habitat for prey species may result from construction of such large facilities, tending to decrease fatality rates at newly constructed facilities for the first few years, when monitoring typically occurs. Conversely, ground disturbance can also be attractive to fossorial mammals in general, and California ground squirrels in particular.

Another possibility is that fatality rates at older-generation turbines in the APWRA—at least for the smaller species—may be biased high by predation, or at least by the tendency of large predatory birds to use old generation turbine towers to consume prey, which are then dropped below the turbines and found by search crews. By design, such perching opportunities are absent or substantially reduced on newer turbines. Consequently, the comparison of fatality rates between new and old generation turbines for smaller birds subject to predation should be viewed as an overestimate of the reduction in fatalities that is likely to occur.

Finally, there are several methodological and analytical differences between the different efforts to monitor fatalities at older generation turbines and the three repowered sites (although Diablo Winds was monitored by the MT). The larger turbines have a potentially wider spatial distribution of turbine-related carcasses. While the search radius around larger turbines is larger than the search radius around smaller turbines, it is possible that fatalities are more often deposited outside the search radius at larger turbines, resulting in the appearance of fewer fatalities at larger turbines. Search intervals at Buena Vista and Vasco Winds were shorter and more consistent than the search intervals at older generation turbines. This should lessen the potential effects of "bleed through" that could be biasing the fatality estimates at older generation turbines in unknown directions. Finally, detection probability estimates were derived using three disparate techniques for Vasco Winds, Buena Vista, and the older-generation turbines in the APWRA.

Evaluation of the 50% Reduction

By the terms set in the settlement agreement, the 50% reduction goal was achieved because the reduction in total focal species fatalities measured from both the original and the SRC-adopted 3-year rolling average baselines to the 2013 monitoring year exceeded 50%. However, in light of the substantial annual variation observed in fatality rates and estimates of total focal species fatalities, from a biological perspective these are probably not the best measures. By the two measures which incorporate annual variation through the 3-year rolling averages, the 50% reduction goal was not met. However, both of these measures have their own biases. The 3-year rolling average baseline includes years in which management measures were implemented to reduce fatalities, resulting in a potential underestimate of the reduction in fatalities, while the use of an endpoint that includes annual variation in a comparison with a baseline that does not could potentially bias the measurement in either direction.

The large annual variation in fatality estimates, lack of annual detection probability monitoring, biases associated with long search intervals and bleed through, confounding with predation, and the very imprecise estimate of fatalities that constitutes the baseline make an objective assessment of the reduction in focal species fatalities attributable to the implementation of management actions from a biological and statistical perspective nearly impossible.

It is likely that predation is a significant confounding factor in measuring the reduction in focal species fatalities, because it effects the estimates of the smaller, more numerous species and thus has a disproportionately large effect when evaluating the 50% reduction goal for focal species as a whole, as mandated by the settlement agreement. When fatalities for the smaller focal species potentially subject to predation with an estimated death date inside the shutdown period are removed from the analysis, all four measures show a substantially larger reduction in focal species fatalities, with three of the four measures indicating that the 50% reduction goal was achieved.

Conclusions

Although results of the monitoring program contain considerable uncertainty, in part because the APWRA is subject to considerable variability and site-specific annual detection probabilities were not measured, we believe the following conclusions are supported.

1. The preponderance of the evidence suggests that there has been a reduction in turbine-related focal species fatalities in the APWRA, and that the 50% reduction goal identified in the settlement agreement was achieved through removal of hazardous and non-hazardous turbines, an increase in the duration and intensity of the seasonal shutdown, and the repowering of portions of the APWRA.
2. The preponderance of the evidence suggests that predation has been a significant mortality factor in the APWRA for those species typically subject to predation during the winter. Predation during the period of the seasonal shutdown has had substantial confounding effects related to estimating turbine-related fatality rates and estimates of total APWRA-wide fatalities. This confounding has complicated the evaluation of the effects of management actions, including repowering, on turbine-related fatalities, particularly for burrowing owls.
3. The available evidence suggests that repowering the APWRA with larger modern turbines would result in a reduction in the number of raptors killed per MW of power produced, although the size of the reduction may be overestimated for those species subject to predation because fatality rates at older generation turbines in the APWRA are confounded with predation during the winter when the seasonal shutdown was in effect.

Chapter 5
Glossary

adjusted fatality rate: see *fatality rate.*

adjustment factors: factors used to adjust raw fatality counts to compensate for those that may have been missed due to scavengers (see *carcass removal*) or missed because they were not detected by searchers (see *searcher efficiency*).

Altamont Pass Wind Resource Area: a 37,000-acre site in central California where over 5,000 wind turbines have been installed since 1966; area subject of the *baseline study* and *current study*.

Avian Wildlife Protection Program and Schedule (AWPPS): a collection of management actions including strategic removal of turbines, strategic turbine shutdowns, and other actions aimed at reducing turbine-related avian fatalities; the Alameda County Board of Supervisors formed the AWPPS in 2005 as one condition of its approval to allow continued operation of wind power projects in the APWRA.

backdate: estimated date of death for a particular carcass, based on the presence of insects, brittleness of feathers, degree to which bones are bleached, and other characteristics of the carcass.

baseline study: the period of avian fatality monitoring in the APWRA spanning 1998–2003; avian fatality rates estimated from this study served as the benchmark from which to assess progress toward achieving the targeted 50% reduction in turbine-related raptor fatalities in the APWRA.

base layer of operating group boundary (BLOB): a group of turbines that generally share the same turbine type, owner/operator, and topography, and occur in a distinct geographic area.

carcass removal (R_c): a calculation of the expected cumulative number of bird carcasses remaining at the survey site after a specified time period; one of two *adjustment factors* used to adjust raw fatality counts in this report.

carcass removal curve: a mathematical model fit to estimates of persistence of evidence of a fatality that depicts the daily probability of a carcass remaining within the search area.

crossover experiment (design): a sampling approach whereby sampling units each receive treatment—in this case *seasonal shutdown*—in sequence; this experimental design is useful when a suitable comparison or control group does not exist, as each sampling unit in effect serves as its own control.

current study: the period of avian fatality monitoring in the APWRA spanning 2005–2009; avian fatality rates estimated from this study were compared against those from the baseline study to assess progress toward achieving the 50% reduction in turbine-related raptor fatalities in the APWRA.

fatality incident: recorded evidence of an individual deceased bird; in the current study, defined as at least five tail feathers, two primaries from the same wing within 5 meters of each other, or a total of 10 feathers.

fatality rate: the number of individuals killed per megawatt of installed capacity; the **unadjusted fatality rate** is the number of individual carcasses observed per megawatt of capacity; the **adjusted fatality rate** is the number of individual carcasses killed adjusted for *searcher efficiency* and *carcass removal* between searches divided by the megawatt capacity.

feather pile: a carcass that is composed entirely of feathers, with no other body parts (such as bones or flesh) remaining.

focal species: the four raptor species—American kestrel, golden eagle, red-tailed hawk, and burrowing owl—of concern in the targeted 50% reduction in turbine-related raptor fatalities in the APWRA.

high risk or hazardous turbine: turbines identified as posing an increased risk of fatality to avian species.

Horvitz–Thompson estimator: a statistical estimator of a population total in which the total population of interest is estimated by the total number of individuals detected in that population divided by the probability of detecting an individual in that population.

installed capacity: the summed rated capacities of all operational turbines in a *turbine string* each year; the metric used in this report to extrapolate fatality rates to the entire APWRA.

megawatt capacity: the amount of power an individual turbine could generate under ideal conditions.

Monitoring Team (MT): an independent consultant team retained to implement the turbine-related avian fatality monitoring program; the MT was originally comprised of three organizations and led by WEST Inc., but has been led by ICF International since 2008; the Alameda County Board of Supervisors formed the MT in 2005 as one condition of its approval to allow continued operation of wind power projects in the APWRA.

monitoring year: the period October–September used as the basis for calculating annual fatality rates because it reflects the timing of annual movement of birds through the APWRA study area.

operating group: a cluster of turbine strings that generally share a common turbine type, geographic location, and owner/operator.

power company: a public or private entity that owns and operates a wind power project in the APWRA.

rated capacity: the amount of power a wind turbine can produce at its rated wind speed, typically the wind speed at which its conversion efficiency is at its maximum.

repowering: see *turbine repowering.*

search interval: the period of time between successive searches of the same turbine string.

searcher efficiency: the proportion of carcasses available for detection that are actually detected by a search crew; one of two *adjustment factors* used to adjust raw fatality counts in this report.

seasonal shutdown: a management action involving shutting down turbines during the winter season to reduce avian fatalities.

Scientific Review Committee (SRC): a five-person committee that provides independent review of research and study related to wind energy production and avian behavior and safety; the Alameda County Board of Supervisors formed the SRC in 2005 as one condition of its approval to allow continued operation of wind power projects in the APWRA.

total installed capacity: the summed megawatt *installed capacity* at the APWRA.

transect: path surrounding a turbine followed by a searcher.

turbine repowering: replacement of older-generation turbines with newer turbines that are substantially larger with a greater rated capacity; although repowering does not add to the overall *installed capacity*, it does increases the amount of energy being generated because repowered turbines typically replace older, obsolete operating groups comprised of numerous non-functional turbines.

turbine string: a linear series of turbines arrayed along ridgelines and other geographic features; in this report, a turbine string is the basic sampling unit.

unadjusted fatality rate: see *fatality rate.*

valid fatality: a fatality that was found during a regular search within 125 meters of an older-generation turbine, that was not aged outside of the search interval, and that exhibited no clear evidence of being killed by something other than a turbine strike. Also includes carcasses found at Diablo Winds turbines. Golden eagle carcasses found at monitored turbines by O&M personnel are also valid fatalities if they were not aged out of the search interval and were found within 125 meters of a monitored turbine.

Wildlife Reporting Response System (WRRS): the power companies' fatality reporting system as documented by power company operations and maintenance (O&M) crews.

winter shutdown: see *seasonal shutdown.*

Chapter 6
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Appendix A

Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

Kenetech KCS 56-100 100 kW

Nordtank 65 kW

Figure A-1a. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

Micon 60 kW

Danregn Vind/Kraft Bonus 65, 120, 150 kW

Figure A-1b. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

Vestas 65 kW

Enertech 40 kW

Figure A-1c. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

Kenetech KVS 33 300 kW

Mitsubishi 1 MW

Figure A-1d. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

V-47 660 kW

Holec/Windmatic 65 kW

Figure A-1e. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

W.E.G. 250 kW

Holek/Polenko 100 kW

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Figure A-1f. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

Siemens 2.3 MW

Howden 750 kW

ICF INTERNATIONAL

Figure A-1g. Representative Photographs of Turbine Types in the Altamont Pass Wind Resource Area

Appendix B
Bird and Bat Mortality Monitoring Protocols

Altamont Pass Wind Resource Area
Bird and Bat Mortality Monitoring Protocols

APWRA Bird Mortality Monitoring

The APWRA Bird Mortality Monitoring Project includes approximately 2,500 turbines grouped into 84 plots located throughout the APWRA within Alameda County (and one location in Contra Costa County; Figure 1). Each plot includes one or more strings of turbines. Using Altamont Pass Road as a dividing line, these 84 plots were assigned approximately equally to either the North or South monitoring areas. Each of the 2,500 turbines is searched once every month. Searches alternate daily between North and South monitoring areas to avoid site- and time-based biases, and turbines are searched in a similar order each month.

The search area for each turbine extends 50 meters out from the turbine on all sides, except for the EnXco Tres Vaqueros site in Contra Costa County where the search radius is 60 meters. During each survey, mortality search transects are walked within the turbine search area during which the searcher scans the ground for bird and bat carcasses and/or parts of carcasses such as feathers and bones. The distance between transects within each search area averages 6 to 8 meters depending on the terrain, height of the vegetation, and the height of the individual searcher. When evidence of a fatality is found, the location of the find is marked with flagging, and the searcher then continues to search the remaining area within the plot. After completing the search of the entire plot, the searchers return to each flagged location to record data on all the finds.

To be considered a turbine-related fatality, each find must include at least 5 tail feathers or 2 primaries within at least 5 meters of each other, or a total of 10 feathers. Any evidence less than this could be remains of a previously found fatality that was dragged in from somewhere else, or in the case of feathers, could be the result of a bird molting at that location. When partial remains are detected, the data collected are cross-referenced with data collected for finds at adjacent turbines to avoid double-counting of remains from birds found during previous monthly searches.

When remains are discovered, information on the location, condition, and type of bird or bat is recorded on a standard datasheet (Table 1). The following information is collected for each bird or bat found:

- Incident number (a unique number for all birds/bats collected, regardless of cause of death, that includes the year, month, date, and a number corresponding to the number found each day. For example, the third bird found Oct. 10, 2005 would be #20051010-03).

- Species- Species is identified as accurately as possible (red-tailed hawk, unknown Buteo, unknown hawk, California myotis). If unknown, it is listed as “unknown small bird” (smaller than a mourning dove), “unknown medium bird” (between a mourning dove and raven), "unknown large bird" (red-tail hawk-sized or larger) or "unknown bat".

- Site- the site access gate at which the fatality was found, including the company that manages it. The turbines behind a particular gate may be managed by multiple companies. Typically there are multiple plots that are accessed by each gate.

- Age & Sex- if known.

- Photo Number- At least 5 photographs are taken with a digital camera: 4 of the fatality before it is disturbed and 1 of the surrounding area (such as overhead lines, turbines, fences, electrical poles, roads). The photo ID number is recorded and photos are regularly downloaded from the camera and transferred to TEAM's ftp site.

- Turbine Number- the nearest intact turbine (has a motor and blades). This information is included even if the remains are far from any turbines or appears to be an electrocution.

- Degree- the compass bearing from the nearest intact turbine to the remains.

- Distance- the distance from the nearest intact turbine to the remains in meters. An intact turbine is defined as having a motor and 3 blades.

- Nearest Structure (if closer to fatality than an intact turbine) – the nearest structure to the fatality (met tower, power pole, derelict turbine, other)

- GPS location- in UTMs (datum NAD27).

- Body parts- all body parts found (for example, "whole bird" or "right wing" or "flight feathers only" or "skull, vertebrae, and sternum"). Bone measurements are included here.

- Cause of Death – probable cause of death as determined by carcass location and condition (turbine blade collision, electrocution, predation, overhead lines, hit by car, etc.).

- Evidence--reason for determination of cause of death when cause other than unknown is circled (e.g., fatality has broken right humerus, <10 m from turbine).

- Estimated Time Since Death – age of fatality (fresh, <1 week, <1 month, >1 month.) Presence and type of insects, condition of flesh and eyes, whether or not leg scales or bones are bleached, coloration of marrow in bones, etc. are used to estimate time since death. Due to difficulty of determining age after ~1 week, categories are quite large.

- How ID'ed --how species identification was determined (e.g., plumage, bone measurements, etc.). If rare species, give details of determination in "Notes".

- Scavenger/Predator- the type of scavenger or predator (vertebrate or invertebrate), if possible to determine, and the effects of scavenging/predation.

- Insects Present – if the bird has insects on it or not at the moment.

- Types –type of insects observed. If other, state size and briefly describe.

- Decay- stage of decay of the carcass (e.g., fresh, flesh and feathers, feathers and bone, feathers only).

- Flesh- condition of the flesh of the carcass (fresh, gooey, dried).

- Eyes –condition of the eyes (round and fluid-filled, sunken, dried, empty skull)

- Enamel- if the waxy covering on the culmen and claws is present or not.

- Color- if the color of the leg scales or cere have begun to fade.

- Notes- additional information such as carcass condition and location, details for identification of rare species, band number if banded, obvious injuries, and potential cause of death if other than those listed above.

- Searchers- first and last initials of all present in case of future questions. The searcher recording the data lists his/her initials first.

If a State or Federally Threatened or Endangered species is found (i.e., golden eagle), data is collected on the find and it is then flagged to mark its location. This information is then reported to the Livermore Operations office (925-245-5555) at the end of the day. The find is then collected and processed by a designated Altamont Infrastructure Company (AIC) employee. If a non-native species such as rock pigeon, European starling, or house sparrow is found, data on the fatality is collected, and the searchers remove and dispose of the carcass off-site. All other species are individually placed in separate bags with a identifications labels that include the following information: incident number, site, turbine number, species, and date found, and placed in the TEAM freezer at the field house. If the species cannot be identified in the field, the carcass may be taken by a TEAM member to the UCD Wildlife Museum to attempt identification. When the freezer is full, carcasses are taken to the U.S. Fish & Wildlife office in Sacramento for disposal. This will be coordinated with Rene Culver, the biologist at AIC.

All suspected electrocutions are documented as usual, marked with an orange pin flag and left in the field. These fatalities are also reported to Livermore Operations office at the end of the day they are found and are subsequently picked up by an AIC employee.

Fatalities found by turbine field maintenance personnel within designated search areas are documented by Rene Culver, marked with black electrical tape on the legs, and left in place for

TEAM searchers to find. When TEAM searchers find these marked remains, standard data is collected on it and it is documented like any other remains. These finds will not be used to supplement the data on searcher efficiency.

If an injured bird or bat is found at any time on site, Operations is contacted immediately and a designated AIC employee will come to take the bird to a local rehabilitation facility.

Fatalities found incidentally outside the turbine search areas are documented and collected following the same protocol for fatalities found during searches. However, for those fatalities a note is added at the top of the datasheet indicating the find was incidental.

Diablo Winds Fatality Searches

Mortality searches of each of the 31 turbines in the Diablo Winds monitoring area are conducted monthly using the APWRA Monitoring study protocol, with the exception of the search radius. Because the Diablo Winds turbines are much larger than all other turbines in the APWRA, the search radius for each turbine was extended out to 75 meters to ensure adequate coverage (Figure 2).

AVIAN USE SURVEYS

Monitoring Observations

The primary objective of avian use surveys are to estimate the relative use of the project area by species, and to provide data on the behavior of birds relative to topography, weather and facility characteristics that can be used in resource selection analyses (Manly et al. 2003). Eighty-three observation stations have been established within the monitoring area (Figure 1.). Surveys are conducted once each month at each station. Each survey lasts for 30 minutes, with the first 20 minutes devoted to gathering behavior data, and the last 10 minutes are used to conduct a 10-minute point count. Morning and afternoon observations are generally not conducted on the same day or by the same person. As with searching, observations alternate between the North and South areas on a daily basis.

For each observation session, data on ambient environmental conditions is recorded at the beginning and end of the session. These data include: temperature (C°), average and maximum wind speeds (km/hr), wind direction, percentage cloud cover, visibility, and precipitation.

Surveys are not conducted when the average wind speed reaches more than 55 km/hr or if there is heavy rain or fog.

During the 20-minute behavior observation session the biologist surveys an area consisting of a 180-degree coverage area focused on a turbine string or strings of interest within 500 m of the observer. The location of the 20-minute behavior survey may be off-set from the 10-minute point count survey to ensure good views of the turbine strings. These coverage areas include areas within which birds are most likely to demonstrate representative behaviors in response to the presence and operation of the turbines. At every 30-second interval during the observation period, if a bird has been detected, its location, flight characteristics (type, height in m), and other relevant behavior information will be recorded on a map as well as the datasheet (Table 2).

For each bird detection during the behavior survey, the following information is recorded: alphanumeric code, species identification, number of individuals, and height above ground. Estimates of distance to the turbines in the observation area and whether the turbines closest to birds are actively turning are also recorded. Age and sex of bird is noted whenever possible. If the bird being observed is perching, the type of perching structure and height (m) is also recorded (see Table 3 for list of perching structures and heights). To ensure that all perched birds within the observation area are identified, a scan of the entire plot is conducted with binoculars immediately before and after the 30-minute survey period.

Because some of the observation areas have large numbers of gulls flying back and forth from the landfill to the reservoirs, major flight routes (i.e., gull corridors) will be indicated on the maps with one letter used to designate flocks of gulls flying in one direction, and another letter used to designate gulls flying in the other direction or along another main flight route. At the end of the observation period, the width of the corridor will be indicated on the map and an estimate of the total number of gulls that flew through each corridor will be recorded on the datasheet. Any large group of gulls observed kettling within plot boundaries will be recorded on the map and given a separate alphanumeric code to distinguish them from the gulls passing through the plot.

During the 10-minute point count survey the observer scans the entire plot (360 degree coverage) throughout the observation period. When a bird (American kestrel size and larger) is detected, data are recorded onto a datasheet. Each detection (individual bird or flock of birds) is designated by an alphanumeric coding system with the letter corresponding to the individual bird or flock and the number corresponding to the minute in which the bird was observed. For the 10-minute point count survey, a map that includes an 500-m observation buffer overlaid onto a topographical map (Figure 3) and the observer records the location of each bird using the alphanumeric code, and draws an arrow indicating direction of movement. Separate maps and datasheets will be used for the 20-minute behavior observations and 10-minute point counts.

Diablo Winds Area Observations

30-minute behavior observations will be conducted at 8 observation stations located throughout the Diablo Winds are a (Figure 1.). These observations will follow the same protocols used for the monitoring observations described above.

SEARCHER EFFICIENCY TRIALS

Searcher efficiency trials are conducted to estimate the percentage of avian and bat fatalities that are actually found by searchers compared to the total number of fatalities that occur (detected and undetected). The results of these trials are then used to adjust annual fatality estimates for detection bias.

These trials will focus on specific target raptor species (American kestrel, red-tailed hawk, and burrowing owl) and are conducted in plots used for regular carcass searches. A trial administrator secretly places trial carcasses in test search areas. On the same day, search personnel conduct normal searches without knowledge of where or how many test carcasses have been placed out in their search area. Within each search plot, carcass location is determined by randomly selecting a compass bearing and distance. Carcasses are marked with green tape on the legs and placed (by dropping from waist height) within the areas to be searched prior to the search on the same day.

Immediately after searches are conducted, the trial administrator determines how many of the efficiency trials were detected by the searcher, and returns to the search plots to recover any undetected trial carcasses. The number and location of the detection carcasses found during the carcass search are recorded, and the number of carcasses available for detection during each trial is determined immediately after the trial by the person responsible for distributing the carcasses. Carcass locations and trial results are recorded on the searcher efficiency datasheet (Table 4).

CARCASS REMOVAL/SCAVENGING TRIALS

In addition to searcher efficiency trials, carcass removal/scavenging trials, 2 per season, will occur during the project to estimate the length of time bird and bat carcasses remain in the search area. Similarly, the data from these trials is used to adjust carcass counts for removal bias in the determination of annual fatality rates. Carcass removal includes removal by predation or scavenging, or removal by other means such as being plowed into a field. Some trials have already been conducted during this study and the Diablo Winds study. Additional trials will be conducted following the protocol below.

Carcass removal trials will be conducted throughout the study period to incorporate varying weather conditions, vegetative conditions and other effects. Fresh carcasses of target raptors (with the exception of golden eagles) will be left in the field to be monitored. Carcasses will be marked with green tape hidden under the bird on the legs and left in place as a trial carcass. If fresh carcasses of target raptors or surrogates are available to supplement carcasses found during searches, these will be placed randomly throughout the wind project site. Supplemental carcasses will be placed within 50 meters of randomly selected turbines. For each of these turbines, a random compass bearing between 1 and 360, and a random distance between 1 and 50 will be selected. In the field, a flag is placed at each random location, but the actual carcass is placed 10 m north of the flag in order to help conceal the carcass. Each carcass is marked with green electrical tape on both legs for recognition by searchers and wind farm personnel, and dropped from waist height. Upon placing carcasses, the species, degree of exposure (1-3), UTM coordinates, date, and time is noted on the carcass removal datasheet (Table 5).

Experimental carcasses are checked over a period of 60 days. Carcasses are checked every day for the first 3 days after placement, twice a week for the next two weeks, then once per week for the remainder of the 60-day trial. At each visit, it is noted whether the carcass is intact (I), scavenged (S), a feather spot (FS; >10 feathers), or absent (0; <10 feathers). In addition the type and degree of scavenging, and possible scavengers are noted, and photos are taken on each day of the trial. All remaining trial carcasses and feathers will be removed after the 60-day trial is terminated. When feasible, game tracker cameras will be set up to photograph the different types of scavengers attracted to each carcass.

Table 1. Datasheet used for fatalities found during regular searches and incidentally for the APWRA Monitoring and Diablo Winds studies

Fatality#__________ **Date**__________ **Species**__________

Age & Sex __________ **Site**__________ **Plot #** __________

Nearest Operational Turbine#__________ **Degree**__________ **Distance**__________

Nearest Structure (if closer than op. turb.)__________ **Degree**__________ **Distance**__________

Photo #'s (at least 5, 4 of fatality)__________

GPS (UTMs, NAD27)__________

Body Parts: __________

Cause of Death:

Blade Strike/Turb. Collision Electrocution Line Strike Predation Other Unknown

Evidence:__________

Estimated Time Since Death:

0-3 days (fresh) / 4-7 days / < month / > month / unknown

How ID'ed: __________

Type of Scavenger/Predator: n/a / vertebrate / invertebrate / unclear

Effects of Scavenging/Predation: __________

Insects Present Y / N **Types** beetles / ants / flies / larva / pupa / other

Decay fresh / feathers and flesh / flesh and bone / bone and feathers / bone / feather spot

Flesh fresh / gooey / dried / n/a

Eyes round, fluid filled / sunken / dried / empty, skull / no head

Enamel present not present n/a culmen / claws

Color leg scales: n/a / original / partially bleached / bleached

cere: n/a / original / partially bleached / bleached

Notes:__________

Sample Taken Y / N **Sample Type:**__________

Searchers__________

Table 2. Datasheet used for avian use observations in the APWRA Monitoring Study.

Obs # ____ Date________ Obsvr_____ Time_______

ID	Species	#	Ht (m)	Dist (m)	Perch

Other birds observed (smaller than MODO): ________

Notes: ________

Table 3. Behavior and feature codes used during avian observations in the Diablo Winds and APWRA Monitoring studies.

Behaviors	Perches
1. Flying through 2. Gliding 3. Soaring 4. Column soaring 5. Flapping (buy staying in plot) 6. Contouring 7. Stilling/Kiting/Hovering 8. Diving 9. Interacting 10. Perching 11. Landing 12. Displaying 13. Copulating	1. Turbine devices 1a. Wind meter 1b. Catwalk 1c. Ladder 1d. Housing 1e. Blade 1f. Lattice 1g. Transformer box 2. Electrical Dist. Pole 2a. Wire 2b. Pole top 2c. Crossbar
Heights Wooden electrical pole = 12 m Metal electrical/communications tower = 40 m Enertech lattice turbine = 18 m Bonus, WEG, Nordtank tubular turbine = 25 m Horizontal lattice turbine (short windwall) = 20 m Horizontal lattice turbine (tall windwall) = 45 m Diablo Winds tubular turbine = 50 m	3. Metal/Electrical Tower 3a. Tower crossbar 3b. Met. tower 3c. Commun. tower 3d. Tower lattice 3e. Guy wire 4. Landscape Features 4a. Rockpile 4b. Rock outcrop 4c. Fence 4d. Ground 4e. Low vegetation 4f. Sign 4g. Tree 4h. Water 4i. Building 4j. Other

Table 4. Searcher efficiency trials datasheet.

Searcher Efficiency Trials: Carcass Placement Log

General Information: Season____________ Month____________ Other____

No.	Species/Age	Placed By	Date	Time	Plot: Location	Found? (yes/no)	Retrieved? (yes/no)	Notes
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Weather notes for days that carcasses are placed:
Date_________ Time__________ Temp__________ Wind Dir.__________ Wind Speed__________ Precip___________
Date_________ Time__________ Temp__________ Wind Dir.__________ Wind Speed__________ Precip___________
Date_________ Time__________ Temp__________ Wind Dir.__________ Wind Speed__________ Precip___________

Table 5. Datasheet for carcass removal trials.

Carcass Removal Trials Form (page 1)																			
General Information: Season____________ Month____________ Other____																			
Information Regarding Carcass When Placed							Condition[1] of Carcass on Days Checked											Possible Scavenger	Notes
No.	Species /Age	Plot & Location	Expos.[2]	Placed By	Date	Time	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day		
1																			(1)
2																			(2)
3																			(3)
4																			(4)
5																			(5)
6																			(6)
7																			(7)
8																			(8)
					Checked by:														

[1] Condition: **I** = intact, no evidence of scavenging, **S** = evidence of scavenging, **FS** = feather spot, **0** = carcass not present or <10 feathers
[2] Exposure: **1** = exposed position, **2** = hidden, **3** = partially hidden
General Comments:

Notes about location of each carcass and other carcass specific comments and photo numbers (continued on back):
(1)____
(2)____
(3)____
(4)____
(5)____
(6)____
(7)____
(8)____

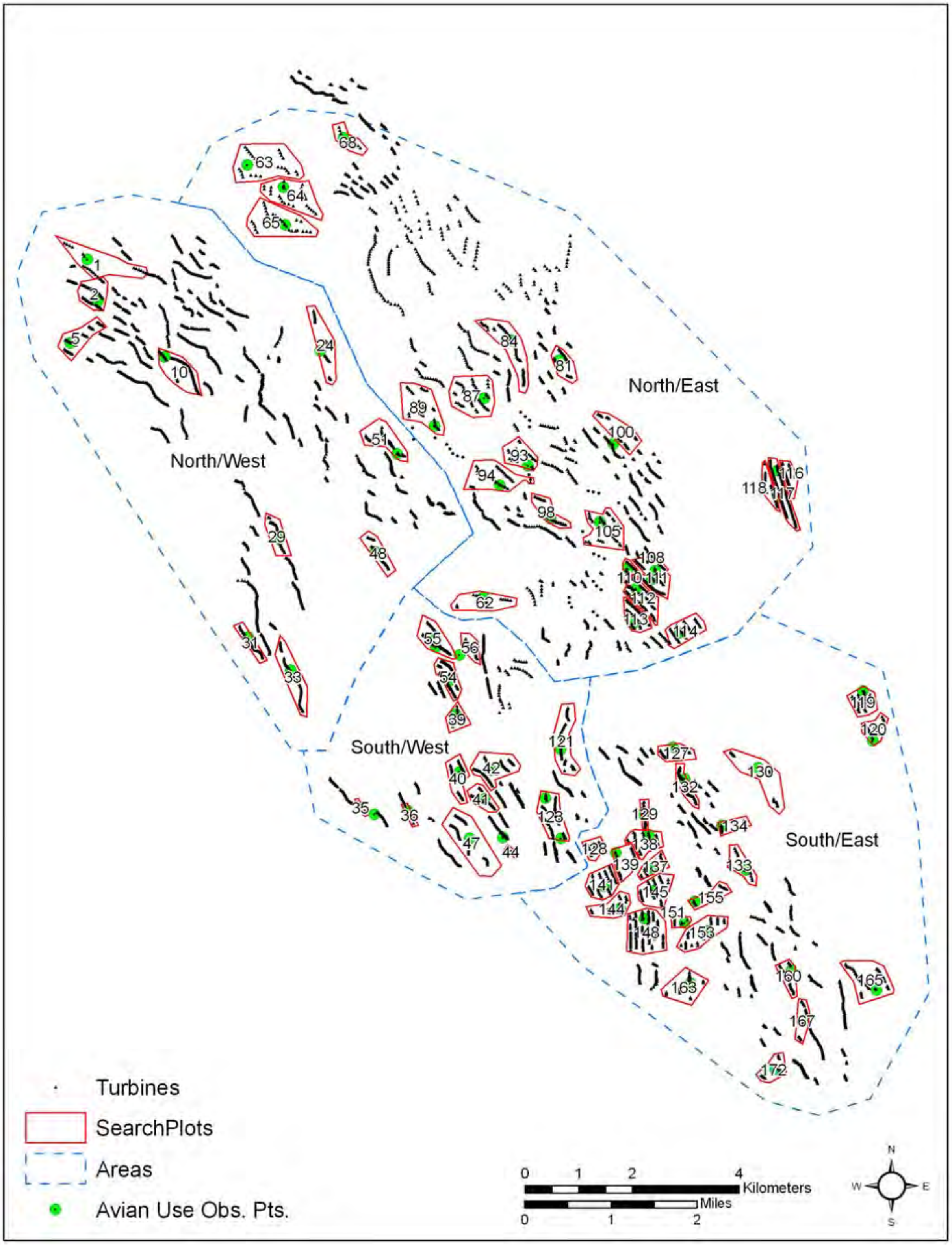

Figure 1. Fatality search plots and observation points for the APWRA Monitoring Study.

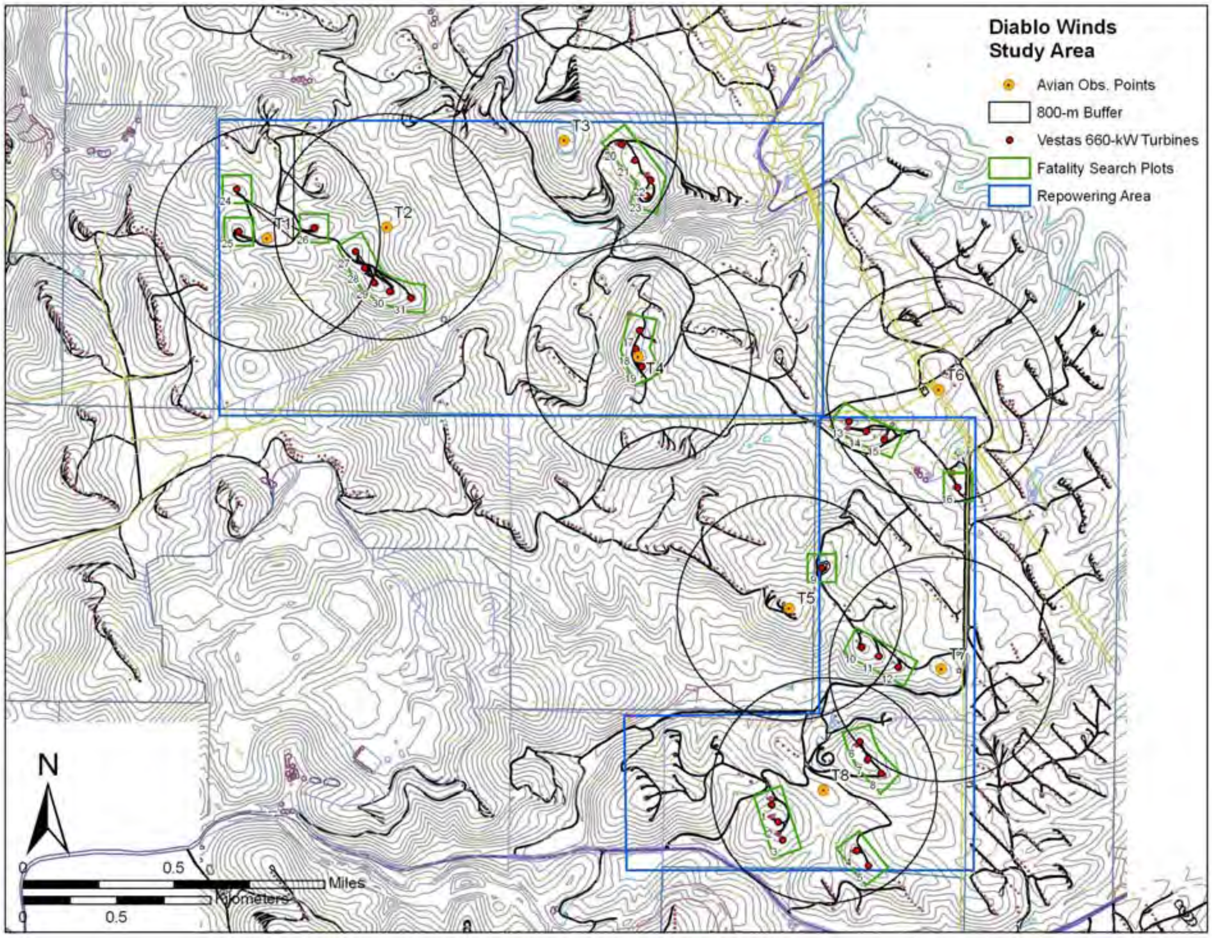

Figure 2. Fatality search areas and avian observation points in the Diablo Winds repowering area.

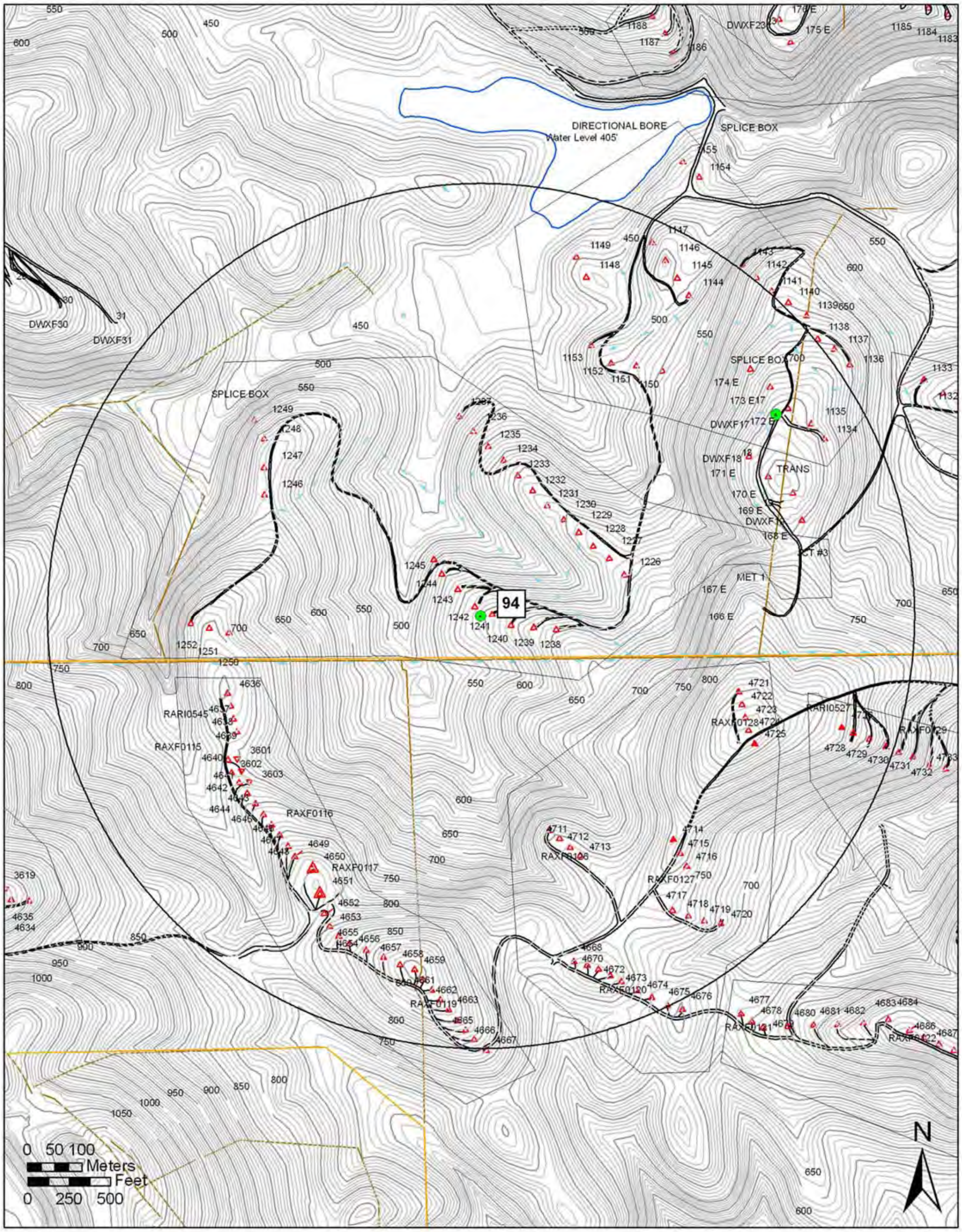

Figure 3. Topographic map with search area (800-m radius for APWRA Monitoring) used to map bird movements during 30-min observation periods.

Appendix C

Estimating Detection Probability of Carcasses Deposited by Wind Turbines in the Altamont Pass Wind Resource Area, California

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Estimating Detection Probability of Carcasses Deposited by Wind Turbines in the Altamont Pass Wind Resource Area, California

Introduction

The proliferation of wind generation facilities in the United States—and in particular in California—has led to the widespread need to monitor the effects of wind turbines on populations of birds and bats. In California, 1–3 years of post-construction monitoring is typically required by regulatory agencies and land-use authorities to determine if actual impacts are in line with impacts predicted during the environmental review process. This has most often been accomplished by regularly searching for avian and bat fatalities within a fixed search area of operating turbines.

The APWRA has received considerable public and media attention because of the large number of birds killed each in year in collisions with operating wind turbines. The APWRA supports a broad diversity of breeding, migrating, and wintering bird populations that regularly move through the wind turbine area (Orloff and Flannery 1992). In particular, diurnal raptors (eagles and hawks) use the prevailing winds and updrafts for soaring and gliding during daily movement, foraging, and migration. Birds passing through the rotor plane of operating wind turbines are often killed. Multiple studies of the avian fatality rates in the APWRA indicate that golden eagles, red-tailed hawks, American kestrels, burrowing owls, barn owls, and a diverse mix of other species are killed each year by collisions with turbines (Howell and DiDonato 1991; Orloff and Flannery 1992; Howell 1997; Smallwood and Thelander 2004).

Beginning in 2005, Alameda County implemented an avian fatality monitoring program subject to review by a scientific review committee (SRC) who also recommended management actions that could be taken to reduce avian fatalities. The Monitoring Team (MT) implementing the avian fatality monitoring program has monitored turbine-related fatalities since 2005 and reports APWRA-wide fatality rates to the SRC in support of adaptive management designed to reduce turbine-related avian fatalities. Specific field methods and results have been described elsewhere (ICF International 2012).

The number of fatalities detected during carcass surveys is not equal to the actual number of fatalities because some proportion of birds killed by turbines is never observed. Two of the largest components of detection probability are often referred to as *carcass removal* (the removal of carcasses from the search area by scavengers or abiotic forces) and *searcher efficiency* (the likelihood that a searcher will detect an available carcass). It has become common practice to conduct trials to estimate these two components of detection probability separately and then take their product as an estimate of overall or *aggregate* detection probability. There are many factors contributing to variance in these two components of detection probability, and innumerable studies have addressed habitat, time of day, season, individual skill and training, and other factors that primarily influence searcher efficiency. Carcass removal rate can also be influenced by the factors mentioned above as well as others. Detection probability must necessarily include interactions between all of these factors.

Simple nonlinear models may be sufficient to estimate detection probabilities in rare cases (e.g., Frei and Schär 2000). Similarly, a simple binomial estimate of detection probability may be useful in zero-dominated situations where distributions are assumed to be random or follow a known distribution (Guynn et al. 1985). However, these approaches may not be suitable for avian fatality modeling due to the diversity and rarity of observations and their nonrandom nature. The fundamental issue for management is that simple compound estimates of detection probabilities (Smallwood 2007; Smallwood et al. 2010) rely on the seemingly false assumption that the searcher efficiency and carcass removal estimates are independent, and unknown biases in either direction can occur as a result.

Prior to 2010, the monitoring program did not include a component to estimate detection probability of carcasses deposited by wind turbines. As a result, estimates of fatality rates and total fatalities were necessarily based on independent searcher efficiency and carcass removal probability estimates resulting from the meta-analysis presented in Smallwood (2007).

To better address these issues, we designed and implemented quality assurance / quality control (QAQC) measures in the APWRA as part of the regular monitoring program to provide *in situ* information on carcass removal, searcher efficiency, and aggregate detection probability for birds of different sizes (hereinafter referred to as the *QAQC study*). We evaluated these data using summary statistics and Monte Carlo modeling to estimate detection probabilities across the range of search intervals and bird sizes encountered in the APWRA.

Our objectives were to provide an estimate of aggregate detection probability based on local conditions using bird carcasses primarily of species found in the study area, to estimate both components of detection probability (i.e., carcass removal and searcher efficiency) simultaneously and free of the independence assumption, and to obtain a better estimate of sampling variance associated with monitoring fatalities in the APWRA with potential application to other wind energy facilities.

Study Area

The APWRA is located in central California approximately 90 kilometers (56 miles) east of San Francisco (Figure C-1). There have been as many as 5,400 wind turbines permitted within the APWRA, distributed over 150 square kilometers (37,000 acres) of rolling hills and valleys dominated by nonnative annual grassland.

Methods

We fully integrated detection probability monitoring into the overall fatality monitoring program using a blind repeated sampling approach to detect both “naturally” deposited and volitionally placed carcasses, and we supplemented this information using non-blind carcass searches.

Blind repeated sampling is similar to traditional double sampling in the sense that it consists of conducting a survey and then, for purposes of QAQC, repeating the surveys using additional observers blind to the outcomes of the previous surveys for a subsample of monitored locations (Bart and Earnst 2002). However, an important distinction is that traditional double sampling requires both observers to sample the same population (typically simultaneously), whereas our approach involves repeated sampling across multiple intervals of varying lengths, during which time the target population is continually subject to change due to a combination of new fatalities, carcass aging, and carcass removal.

As part of the overall fatality monitoring program, the APWRA was stratified into 29 distinct geographic units termed *base layer of operating group boundaries* (BLOBs) that shared a common dominant turbine type, owner/operator, geography, and topography (Figure C-2). As part of the regular fatality monitoring program, the MT conducts searches at selected turbine strings within each BLOB. Blind repeated-sampling was incorporated into a subset of these searches.

A stratified–randomized design was used to address bias in sampling location and timing. During each rotation (defined as one pass through the complete set of monitored turbines by the search crew), three monitored strings were randomly selected from within three to five randomly selected BLOBs for carcass placement. Selected BLOBs and strings are referred to here as *QAQC strings* and *QAQC BLOBs*.

Several types of searches are conducted as part of the regular monitoring program, and additional search types were defined to accommodate the QAQC study (Table 1). The first search of a QAQC string was defined as a *primary search*. The second search of a QAQC string was defined as a *secondary search*. The interval between primary and secondary searches ranged from 0 to 10 days. A *pre-search*—defined as a search by a field supervisor prior to primary search and during which a carcass might be placed—was conducted prior to a primary search at some QAQC strings. The schedule was designed to allow the field supervisor to conduct pre-searches at approximately 5% of all turbine searches and at approximately 50% of the searches that had secondary searches (hereafter called *QAQC searches*). The pre-search provides an estimate of the number of fatalities that were available for detection before the primary search and allowed the field supervisor to actively manage the volitional placement of fatalities at sites where no fatalities were detected by the pre-search. The locations chosen for pre-searches were a randomly selected sub-set of the repeat sample locations for each rotation.

Personnel were assigned to one of the two search crews at the beginning of a rotation, after which search crews remained fixed until the next rotation, when search crew assignments were changed. Each search crew would then search monitored strings within the randomly selected QAQC BLOBs at different times in the rotation. Search crews were blind to which BLOBs were part of the QAQC trials. The order of searches was randomized across BLOBs within the constraints of a 30-day search schedule and the logistical constraints of the monitoring program. During the period of the QAQC study, search crews left all carcasses in the field to provide the other search crew the opportunity to detect those fatalities.

We initially attempted to repeat sample approximately 25% of the monitored turbines. The search schedule was randomized so that a variety of intervals between the primary and secondary searches could be implemented during each rotation. However, constraints were placed on the randomization so that a disproportionately high number of secondary searches occurred within 1–2 weeks of the primary search.

A *post-search*—defined as a search by a field supervisor following a secondary search—was conducted at QAQC strings immediately following the secondary search. During the post-search, the field supervisor would attempt to locate and document any placed carcasses that had not been removed. Carcasses located during the post-search that were not located by either team were left in the field because all search crews were still blind with respect to that carcass. Carcasses that were detected by one or both teams were documented and collected during the post-search. Detections of new fatalities at QAQC strings, made by one or both teams, were also documented and collected during the post-search. The schedule was also designed to allow the field supervisor to conduct a post-search at approximately 5% of all turbine searches, after 50% of the repeat sample, and at all turbines where a fatality was available for detection after the secondary search. Post-searches were conducted approximately 1 day after the last search whenever possible.

If a fatality was detected during a pre-search or a primary search but not subsequently detected during the secondary search, the field supervisor conducted a post-search on the subsequent day to determine to the extent possible if the fatality was available for detection. In cases where a fatality was documented during the pre-search but the same fatality was not detected during subsequent searches, the field supervisor conducted a post-search to determine to the extent possible if the fatality was present and thus available for detection.

All fatalities younger than 90 days (i.e., not notably aged) that were detected during pre-searches, primary searches, and/or secondary searches were left in the field to support the blind repeated sampling design.

Table 1. Types of Searches Conducted in the APWRA QAQC Study

Search Type	Definition	Search Order
Clearing search	A search at turbines that have not been surveyed in more than 90 days. A supervisor may or may not leave a naturally found carcass or place a carcass immediately following a clearing search for detection by subsequent searches.	0
Incidental discovery	A detection outside of the standard search procedure.	0
Wildlife Response and Reporting System	A detection by owner/operators of turbines.	0
Pre-search	A search by a supervisor prior to a primary search. The supervisor may leave placed or naturally found birds immediately following a pre-search.	1
Primary search	A standard search.	2
Secondary search	A standard search that follows a primary search within the standard monitoring program search interval (approximately 3 days).	3
Post-search	A search by a supervisor after a primary or secondary search.	4
Fatality check	A search for and examination of a known fatality by a supervisor.	4

Fatality Placement

Fatalities were volitionally placed as part of the QAQC study to augment the sample of carcasses subject to the blind repeated sampling protocol. The vast majority of these carcasses were fatalities found during regular searches conducted as part of the regular monitoring program in the APWRA. The highest quality fatalities (i.e., freshest and most intact) were collected from the field, held in a freezer until used, defrosted, and placed onsite at a random set of turbines scheduled to receive searches (see below).

Whenever a placement was made the field supervisor conducted a pre-search to avoid placing carcasses at locations that might already have a naturally occurring carcass present and to minimize potential confounding. Carcasses were placed within the search area at a random distance and bearing from the turbine, and the location and condition of each carcass were documented.

The goal was to achieve 30 samples per season including feather spots and partial carcass remains. To achieve this goal, the supply of carcasses was augmented by carcasses of species that could potentially be found in the APWRA (or similar species) that were obtained from raptor rehabilitation facilities and wildlife care facilities. Placed fatalities were left in the field until they were removed by natural causes, or the sequence of planned searches was completed (see below).

To augment information on the removal rate of fresh small raptor carcasses, we volitionally placed 12 such carcasses obtained from raptor rehabilitation facilities between December 6, 2011, and January 3, 2012. These volitionally placed carcasses were located and documented by the field supervisor two to three times per week during the first month and once per week during the second month. If a carcass was not located at the point it was placed, the area around that point was searched. If a carcass was not located after five carcass check searches, it was assumed that the carcass had been removed from the area.

Ninety birds were placed during the first phase of the study. The first carcass was placed on December 27, 2010, and the last bird was placed on September 13, 2011. The last detection of a placed bird occurred on December 1, 2011.

Additional Data Included in the Analyses

We supplemented data obtained from the QAQC study with information from another study conducted in the APWRA by the MT during the course of the monitoring program: *Altamont Pass Carcass Removal/Scavenging Trial* (ICF Jones & Stokes 2008) (hereinafter referred to as the carcass removal/scavenging trial).

In the carcass removal/scavenging trial, fresh carcasses—primarily of large birds (defined as larger than a rock pigeon)—found during regular searches were left in place and their condition tracked for a period of 60 days or more. The trials began in December 2005 and continued until October 2010. A total of 57 carcasses were tracked during the trials. Carcasses were generally checked each day for the first 3 days after discovery, twice per week for the next 2 weeks, then once per week for the remainder of the trial period. At each visit, the condition of the trial carcass was noted—i.e., whether the carcass was intact (I), scavenged (S), a feather spot (FS, >10 feathers), or absent (0, <10 feathers). In addition, the type and degree of scavenging was noted, photos were taken, and pertinent notes were recorded on the physical condition and age metrics of the carcass. Upon the conclusion of each individual trial, the remaining carcass and feathers (if any) were removed from the site. This study provided detailed information on the carcass removal rate for large birds in the APWRA.

Analytical Approach

Basic Carcass Removal Model

The length of time that a carcass remains on a plot prior to removal by scavengers or other natural removal processes was modeled using a statistical modeling technique known as survival analysis. We modeled scavenger removal data cast in survival analysis terminology. For example, *survival* in this context is the persistence of the carcass (or related evidence such as feathers), and *death* represents removal. Survival is a time-dependent process expressed as a function of time since death t, or carcass age.

The survival process is basically distinguished by one or more of three functions:

1. the survival probability function $f(t)$, defined as a distribution of random survival times;
2. the cumulative probability distribution function $F(t)$, defined as the probability of "death" by time t (where "death" represents removal); note that $F(t) = \int_0^t f(u)du$ and the probability of survival to time t is $1 - F(t)$; and
3. the hazard function $h(t)$, defined as the instantaneous probability of "death" at time t for carcasses that survive to time t, or $h(t) = f(t)/(1 - F(t))$.

The functions $f(t)$, $F(t)$, and $h(t)$ are related in the sense that one function completely determines the others, and it generally suffices to determine one in order to determine the others.

The simplest survival time distribution is exponential, in which case the hazard function $h(t)$ is constant, so that the probability of surviving each subsequent day is the same regardless of the age of the carcass. A generalization of the exponential distribution is the Weibull distribution, which allows the hazard rate to increase, decrease, or remain constant over the age of the carcass. To allow the carcass removal process to vary with the changing conditions of aging carcasses, we used a Weibull distribution function to model removal times. This distribution is defined by the following distribution and hazard functions where r and b represent the shape and scale of the distribution:

$$f(t) = rbt^{r-1}\exp(-bt^r)$$

$$F(t) = 1 - \exp(-bt^r)$$

$$h(t) = rbt^{r-1}$$

To understand and interpret the shape and scale parameters, it is helpful to note some basic features. When $r = 1$, then the Weibull distribution simplifies to an exponential distribution with instantaneous removal (i.e., hazard) rate equal to a constant b. The parameter r modifies the shape of the hazard function. When $r < 1$ then the hazard of removal decreases with the age of the carcass, therefore decelerating removal for carcasses as they age. When $r > 1$ then the opposite occurs.

We modeled different removal rates for different bird species in association with body size by fitting a log-linear relationship: $\ln(b) = \beta_1 + \beta_2 x$, where x is species wing span measured in inches. The Bayesian analysis results in estimates of the unknown parameters r, β_1, and β_2 which best describe the scavenger removal data. However, previous studies indicate that $\beta_2 < 0$ due to lower rates of removal for larger bird species. Note that a negative value of β_2 indicates that the removal rate decreases by a factor of $\exp(\beta_2)$ for every 1 inch increase in wing span.

Most carcasses in the QAQC study have already aged to some degree prior to their use in a trial. We assigned an age of 2 days for carcasses classified as fresh (defined as <3 days of age), an age of 6 days for carcasses classified as 4–7 days of age, and 19 days of age for carcasses classified as 8–30 days of age. Therefore, we further modified the removal model by employing a staggered-entry survival model to prevent carcasses with older start ages from biasing the removal time distribution towards higher removal times. In this model, the distribution of removal times for the trials are not assumed Weibull per se, but rather they are assumed to be distributed according to a truncated Weibull distribution that is conditioned upon the later start age. In other words, we assume these trials were sampled from a general population of carcasses having a Weibull removal distribution with range (0, ∞), while taking into account the *a priori* knowledge that the removal times of trial carcasses are necessarily greater than their age at the start of their trial. As a result, the Weibull distribution estimated by this model reflects the distribution for removal times of general carcasses, and not the distribution of removal times of trial carcasses. The carcass removal time distribution was supplemented with data from the carcass removal/scavenging trial because carcasses followed in that study began as fresh carcasses and were checked frequently relative to the data from the QAQC trials.

Basic Searcher Efficiency Model

For carcasses not yet removed, the probability of detection p by a searcher was fit to a logistic regression model with carcass age and species size as covariates:

$$\ln(p/1-p) = a_{det} + b_{det}\text{age} + c_{det}\text{wingspan},$$

i.e., $$p = \frac{\exp\{a_{det} + b_{det}\text{age} + c_{det}\text{wingspan}\}}{1+\exp\{a_{det} + b_{det}\text{age} + c_{det}\text{wingspan}\}}$$

The QAQC data includes detection and non-detection information according to three levels of blindness associated with the existence and/or location of a carcass.

1. *Blind*, in which searchers are a priori unaware of the existence of a trial—i.e., primary and secondary searchers during the first search rotation after a trial begins.
2. *Partially blind*, in which searchers may or may not already be aware of the carcass from a previous search—i.e., primary and secondary searchers during a subsequent rotation after a trial begins where a carcass has been left in the field but one member of the search crew may have participated in the search on a previous rotation that initially located the carcass.
3. *Not blind*, or status checks in which a supervisor checks for a known carcass but could potentially miss detection.

Blind searches are the only type directly relevant to our estimate of searcher efficiency; therefore, the blind repeat sampling searches contributed the most information on searcher efficiency. However the other two types of searcher efficiency are useful for inferring removal time distribution and are therefore indirectly relevant to the estimation of overall detection probability. For example, if the probability of detecting a carcass on a status check is high but less than 1, then a non-detection outcome for a status check at time t informs the model of a high probability of removal for that carcass before time t and a low probability of removal after time t. A detection outcome for any search, regardless of the level of searcher efficiency, further informs the model with absolute certainty that the removal time is > t. The probability of false positives, i.e., the apparent detection of a carcass that was not actually present, was assumed to be negligible. However, false negatives—i.e., the non-detection of a carcass that was present—is assumed to be a very real possibility even for status checks.

The three searcher efficiency models, and their corresponding three coefficients, are indexed according to a blindness index (3=most blind, 2=partially blind, and 1=not blind), and the Bayesian model estimates the resulting nine unknown parameters $a_{det,1}$, $b_{det,1}$, $c_{det,1}$, $a_{det,2}$, $b_{det,2}$, $c_{det,2}$, $a_{det,3}$, $b_{det,3}$, and $c_{det,3}$ most likely to result in the observed sequences of detection and non-detection data.

Bayesian Modeling

The basic carcass removal model would be straightforward to fit if time to removal is directly observed. However, the exact time to removal is never known because of intermittent status checks and the possibility of false negatives. Similarly, the basic searcher efficiency model would be simple to estimate from detection and non-detection outcomes for carcasses when they are already known to be present. The lack of confirmed removal status is a substantial obstacle to the direct fitting of these models. Fortunately, as described above, the detection sequences provide likelihood information for removal times despite the lack of direct observation. This likelihood can theoretically be analyzed from either Bayesian or non-Bayesian (i.e., frequentist) perspectives, however, a Bayesian solution using Gibbs sampling is arguably the most tractable and is therefore the implementation we chose. We describe the sampler in more detail in the next section.

A defining feature of the Bayesian framework is that the likelihoods of all parameters (i.e., r, β_1, and β_2, and $a_{det,1}$, $b_{det,1}$, $c_{det,1}$, $a_{det,2}$, $b_{det,2}$, $c_{det,2}$, $a_{det,3}$, $b_{det,3}$, and $c_{det,3}$) are expressed in terms of probability distributions. For example, within this framework, we can ultimately make statements like "there is a 90% probability that the detection probability of species A is between 0.75 and 0.85." According to Bayes rule, no variable (including parameters) can have a probability distribution after data analysis unless it starts with a probability distribution prior to data analysis. Therefore, in a Bayesian analysis, each parameter has two types of probability distributions: a prior distribution which reflects what we know prior to data analysis, and a posterior distribution which reflects what we know after data analysis.

We utilized diffuse prior distributions, also known as non-informative priors, characterized by large standard deviations and variances, to reflect minimal prior assumptions. We used a normal prior distribution with mean=0 and variance=1,000 (range of $-\infty$ to ∞) for β_1, β_2, $a_{det,i}$, $b_{det,i}$, $c_{det,i}$, for $i = 1,\ldots,3$. Because r must be positive, we used an exponential prior distribution (range = 0 to ∞) with mean=1,000 and standard deviation=1,000.

We derived our final inferences from the posterior distributions resulting from the Bayesian analysis. Parameter estimates were defined by the posterior median. The Bayesian analogue of the standard error is the posterior standard deviation. Similarly, the Bayesian analogue of the 95% confidence interval, called the 95% credible interval, is determined as the lower and upper 2.5% percentile of the posterior distribution.

Composite Carcass Removal and Searcher Detection Model

The carcass removal and searcher detection processes are modeled simultaneously using Gibbs sampling. Let $\tilde{S}_i$ denote the latent removal time (i.e., survival time) for a carcass i, where $i=1,\ldots,n_{trials}$. The Gibbs sampler starts with initial estimates of the removal times ($\tilde{S}_i$) and all other parameters ($i=1,\ldots,n_{trials}$; r, β_1, β_2, $a_{det,1}$, $b_{det,1}$, $c_{det,1}$, $a_{det,2}$, $b_{det,2}$, $c_{det,2}$, $a_{det,3}$, $b_{det,3}$, $c_{det,3}$), and then performs a Markov Chain Monte Carlo (MCMC) simulation to iteratively draw new values of the parameters randomly starting from their prior distributions and ultimately converging to their posterior distributions, using the assumed values of $\tilde{S}_i$ to facilitate the analysis. Specifically, the following steps are iterated.

1. Randomly draw r, β_1, and β_2 according to the basic carcass removal time model assuming removal times $(\tilde{S}_i)$.
2. Randomly draw $a_{det,1}$, $b_{det,1}$, $c_{det,1}$, $a_{det,2}$, $b_{det,2}$, $c_{det,2}$, $a_{det,3}$, $b_{det,3}$, and $c_{det,3}$ according to the basic detection probability model using detection and non-detection outcomes for only those carcasses that were not yet removed at the time of the search, assuming removal times are $(\tilde{S}_i)$.
3. Randomly draw new estimates of $(\tilde{S}_i)$ based on the last estimates for r, β_1, and β_2 drawn in step (1), and in conjunction with the observed detection and non-detection sequences.
4. Repeat steps (1) through (3) using updated values based on the last iteration of random draws. When these steps are repeated for a large number of iterations, then the updated values follow a distribution which converges upon their true posterior distributions. Therefore histograms of the updated values demonstrate what the posterior distributions of r, β_1, β_2, $a_{det,1}$, $b_{det,1}$, $c_{det,1}$, $a_{det,2}$, $b_{det,2}$, $c_{det,2}$, $a_{det,3}$, $b_{det,3}$, and $c_{det,3}$ look like although we never precisely observe S_i.

Aggregate Detection Probability from the Composite Model

After the composite model is fit to the data, we derive detection probabilities based on different species sizes and different search intervals. For carcasses of a species-specific wingspan size w and projected to be a specific age t at the time of a search event, we define age-and-size-specific aggregate detection rate as the probability that the carcass is (A) not removed before age t and (B) detected by searchers at that age. This probability (denoted $\Pr[A \text{ and } B]_{w,t}$) is the product of $\Pr[A]_{w,t}$ and $\Pr[B \mid A]_{w,t}$, where $\Pr[A]_{w,t}$ is the probability that removal time $S > t$, and

$\Pr[B \mid A]_{w,t}$ is the searcher efficiency for a carcass at age t. In terms of the Weibull removal model and the logistic regression searcher efficiency model defined earlier, then

$$\Pr[A]_{w,t} = 1 - F(t) = \exp\{-bt^r\} = \exp\{-\exp\{\beta_1 + \beta_2 w\} t^r\}$$, and

$$\Pr[B \mid A]_{w,t} = \frac{\exp\{a_{det} + b_{det} t + c_{det} w\}}{1 + \exp\{a_{det} + b_{det} t + c_{det} w\}}.$$

These expressions are analogous to the Smallwood (2007) age-specific remaining function R_i (where in his notation i denotes age) and searcher efficiency constant p, respectively. The resulting age-and-size-specific detection rate, denoted $g(w,t)$, is the product

$$g(w,t) = \Pr[A \text{ and } B]_{w,t} = \exp\{-\exp\{\beta_1 + \beta_2 w\} t^r\} \frac{\exp\{a_{det} + b_{det} t + c_{det} w\}}{1 + \exp\{a_{det} + b_{det} t + c_{det} w\}}.$$

Following the Smallwood (2007) approach of calculating interval-based cumulative aggregate detection probabilities, we assume carcasses are evenly deposited over the span of a search interval. The proportion of carcasses deposited in that interval that are detected at the end of the interval is a cumulative average of $g(w,t)$ across $t = 1, \ldots, L$, where L is the length of the search interval. We denote this cumulative interval-based aggregate detection function $g_c(w,t)$:

$$g_c(w,L) = \frac{1}{L} \sum_{t=1}^{L} g(w,t)$$

For every species size w and search interval length L, we estimate a posterior distribution for aggregate detection probability by calculating g_c based on each iteration of the MCMC-sampled values for r, β_1, β_2, $a_{det,1}$, $b_{det,1}$, $c_{det,1}$, $a_{det,2}$, $b_{det,2}$, $c_{det,2}$, $a_{det,3}$, $b_{det,3}$, $c_{det,3}$. Finally, the posterior median and standard deviation are used to calculate adjusted fatality rates and their associated credible intervals.

This analysis relies on combining two categories of information, which we refer to as *hard* (or direct) and *soft* (indirect) data. The two components of aggregate detection probability (carcass removal and searcher efficiency) are informed by hard or soft data or a combination of both. Hard data from direct measurements are exemplified by the traditional searcher efficiency trial in which carcasses are placed just prior to a search, a blind search is conducted, and the presence of the carcass at the time of the search is subsequently verified. However, in the QAQC study design, the presence of a carcass at the time of a search is not always verified. However, because of the context of the many combinations of various types of search sequences (pre-, primary, secondary, and post-searches) it is possible to model the likelihood that the carcass was still present, and thus an indirect measurement is possible (soft data). The Bayesian modeling approach used here can leverage these indirectly measured soft pieces of data in terms of likely persistence and combine them with the directly measured hard detection information to produce a more robust estimate of aggregate detection probabilities. A series of search sequences can have a combination of hard and soft detection outcomes (Table 2). For example, in the search sequence depicted below, the results of the primary search provide hard data on searcher efficiency because the carcass placed during the pre-search was detected. However, the results of the secondary search provide soft data on searcher efficiency because the carcass was not detected, and its presence at the time of the search was not confirmed by a post-search.

Table 2. Hypothetical Search Sequence and the Resulting Data Characteristics

	Pre-Search	Primary	Secondary	Post-Search
Blindness	No	Yes	Yes	No
Detection Event	Placement	Found	Not found	No
Data type	Persistence	Persistence / search efficiency	Search efficiency	Persistence
Data firmness	Hard	Hard	Soft	Soft

The hard character and soft character of the data for both carcass removal and searcher efficiency are depicted in Table 3.

Table 3. Combinations of Blindness, Detection Outcome, and Known Positive Carcass Presence Resulting in Hard and Soft Data Points

Detection Probability Data Type	Blindness	Detection Outcome	Known Positive Carcass Presence	Data "Firmness"
Searcher efficiency	Blind	Positive	Yes	Hard
	Blind	Negative	Yes	Hard
	Blind	Negative	No	Soft
Carcass removal	Not blind	Positive	Yes	Hard
	Blind or semi-blind	Positive	Yes	Hard
	Not blind, blind, or semi-blind	Negative	Yes	Hard
	Not blind	Negative	No	Soft

Results

We used a total of 233 carcasses from 29 species in the QAQC trials, 109 (47%) of which were raptors; wingspans ranged from 6.75 inches (Savannah sparrow) to 67 inches (turkey vulture) (Table 4). Estimates of detection probability previously used in the APWRA (and in the majority of other detection probability estimators used elsewhere across the county) have used arbitrarily designated size classes to account for the recognized differences in detection and removal rates among carcasses of different sizes. Separate rates have also typically been utilized for raptors and non-raptor species. Size class and taxonomy (raptor versus non-raptor) are combined into groups referred to as *adjustment groups*. A total of 63% of carcass trials in the QAQC study were in the large size class, although the number of small carcasses was quite substantial (n=86, 32 of which were small raptors). Table 4 shows the number of QAQC trails of each species in each of the four adjustment groups.

Table 4. Number of QAQC Carcass Trials of Each Species (Wingspan) in each of Four Adjustment Groups

Species (wingspan inches)	Large Non-Raptor	Small Non-Raptor	Large Raptor	Small Raptor	**Total**
American coot (24)	1				**1**
American crow (39)	2				**2**
American kestrel (22)				15	**15**
Barn owl (42)			21		**21**
Brewer's blackbird (15.5)		1			**1**
Burrowing owl (21)				13	**13**
California gull (54)	5				**5**
Cliff swallow (13.3)		2			**2**
Cooper's hawk (31)			1		**1**
Common raven (53)	10				**10**
Dark eyed junco (9.25)		1			**1**
European starling (16)		29			**29**
Ferruginous hawk (56)			1		**1**
Great-horned owl (44)			4		**4**
Hermit thrush (11.5)		1			**1**
Horned lark (12)		2			**2**
Lesser goldfinch (8)		1			**1**
Mallard (35)	6				**6**
Mourning dove (18)		1			**1**
Rock pigeon (28)	45				**45**
Red-tailed hawk (45)			45		**45**
Red-winged blackbird (13)		1			**1**
Savannah sparrow (6.75)		1			**1**
Turkey vulture (67)			5		**5**
Violet-green swallow (13.5)		1			**1**
Western gull (58)	1				**1**
Western meadowlark (14.5)		12			**12**
Western scrub jay (15.5)		1			**1**
Western screech owl (20)				4	**4**
Total	**70**	**54**	**77**	**32**	**233**

The distribution of age classes of carcasses used in the QAQC trials in each of the four adjustment groups is provided in Table 5. A total of 59% of small raptors were in the freshest age class, followed by 49% for large raptors, 37% for large non-raptors, and 35% for small non-raptors.

Table 5. Number of QAQC Carcass Trials in Each of Four Age Classes by Adjustment Group

Size Class	Days Dead (2)	Days Dead (6)	Days Dead (19)	Total
Large non-raptor	26 (37%)	5 (7%)	39 (56%)	**70**
Small non-raptor	19 (35%)	7 (13%)	28 (52%)	**54**
Large raptor	38 (49%)	13 (17%)	26 (34%)	**77**
Small raptor	19 (59%)	5 (16%)	8 (25%)	**32**
Total	**102 (44%)**	**30 (13%)**	**101 (43%)**	**233**

There was a slight tendency for carcasses of small birds to be intact, while carcasses of larger birds were in parts (Table 6). However, this may have been due to the emphasis placed toward the end of the study on small raptor carcasses, which by necessity came primarily from raptor rehabilitation centers as whole intact carcasses.

Table 6. Number of QAQC Carcass Trials in Each of Two Carcass Condition Classes by Adjustment Group

Size Class	Carcass Intact	Carcass in Parts	Total
Large non-raptor	23 (33%)	47 (67%)	**70**
Small non-raptor	25 (46%)	29 (54%)	**54**
Large raptor	35 (45%)	42 (55%)	**77**
Small raptor	19 (59%)	13 (41%)	**32**
Total	**102 (44%)**	**131 (56%)**	**233**

The seasonal distribution of QAQC carcass trials is provided in Table 7 for each of the four adjustment groups. Carcass trials were distributed throughout the year, although a significant spike in trials occurred during April and June through August. No small non-raptor carcass trials were conducted in October and November, no large raptor carcass trials were conducted in February, and no small raptor carcass trials were conducted in May.

Table 7. Seasonal Distribution of QAQC Carcass Trials by Adjustment Group

Size Class	Large Non-Raptor	Small Non-Raptor	Large Raptor	Small Raptor	**Total**
January	1	1	4	4	**10**
February	1	3	0	1	**5**
March	2	2	9	3	**16**
April	15	8	19	8	**50**
May	1	1	1	0	**3**
June	20	16	12	1	**49**
July	11	9	7	1	**28**
August	9	9	8	3	**29**
September	5	3	8	1	**17**
October	0	0	1	2	**3**
November	3	0	4	1	**8**
December	2	2	4	7	**15**
Total	**70**	**54**	**77**	**32**	**233**

In addition to the number of carcass trials, the number of search or placement events is also of interest, because each trial can result in more than one event, and those events can be characterized as hard or soft. The number of hard and soft data points informing the basic searcher efficiency and carcass removal models from both QAQC trials and the carcass removal/scavenging trials is provided in Table 8. Although the amount of information informing the carcass removal model is substantially greater than the information informing the searcher efficiency model, the amount of information informing the searcher efficiency model is quite large, and the two models inform each other in the Bayesian modeling approach used here.

Table 8. Total Number of Hard and Soft Data Points for Each Component of Aggregate Detection Probability from the QAQC Detection Probability Study and the Carcass Removal/Scavenging Trial in the APWRA

Detection Probability Type	Hard Data Points	Soft Data Points	Total
Searcher efficiency	162 (81%)	37 (19%)	199
Carcass removal	1,464 (94%)	90 (6%)	1,554

Based on the hard searcher efficiency data points, there was more information for larger species than for smaller species, and the most information was available for carcasses of a younger age (Table 9).

Table 9. Number of Hard Searcher Efficiency Data Points for Three Categories of Wingspan Length by Carcass Age from the QAQC Study

Carcass Age (days)	Small (6–20 inches)	Medium (21–30 inches)	Large (31–67 inches)	**Total**
0–10	10	19	31	**60**
11–20	6	20	33	**59**
21–30	7	12	15	**34**
31–40		1	4	**5**
41–50		1		**1**
51–60		1	2	**3**
61–70				
71–80				
81–90				
Total	**23**	**54**	**85**	**162**

Conversely, the number of soft data points was greatest for smaller sized birds, although these data points were also distributed primarily at younger carcass ages (Table 10).

Table 10. Number of Soft Searcher Efficiency Data Points for Three Categories of Wingspan Length by Carcass Age from the QAQC Study

Carcass Age (days)	Small (6–20 inches)	Medium (21–30 inches)	Large (31–67 inches)	**Total**
0–10	5	5		**10**
11–20	10	7		**17**
21–30	3		1	**4**
31–40	1	1	1	**3**
41–50	2			**2**
51–60				
61–70	1			**1**
71–80				
81–90				
Total	**22**	**13**	**2**	**37**

There was more hard information regarding carcass removal for larger birds, but sample sizes were substantial for all size classes and were distributed over a very wide range of carcass ages (Table 11).

Table 11. Number of Hard Persistence Data Points for Three Categories of Wingspan Length by Carcass Age from the QAQC Study

Carcass Age	Small (6–20 inches)	Medium (21–30 inches)	Large (31–67 inches)	**Total**
0–10	8	20	36	**64**
11–20	17	37	43	**97**
21–30	17	37	29	**83**
31–40	8	20	13	**41**
41–50	5	13	11	**29**
51–60	4	14	21	**39**
61–70	3	4	4	**11**
71–80		1		**1**
81–90	2		4	**6**
Total	**64**	**146**	**161**	**371**

Conversely, soft data points regarding carcass removal were concentrated around medium-sized birds and were absent for younger and older carcass ages (Table 12).

Table 12. Number of Soft Persistence Data Points for Three Categories of Wingspan Length by Carcass Age from the QAQC Study

Carcass Age	Small (6–20 inches)	Medium (21–30 inches)	Large (31–67 inches)	**Total**
0–10		6		**6**
11–20		12		**12**
21–30	1	17	1	**19**
31–40	2	7	2	**11**
41–50	6	4	6	**16**
51–60		1		**1**
61–70		2		**2**
71–80				
81–90				
Total	**9**	**49**	**9**	**83**

As noted above, we supplemented information from the QAQC trials with information from 56 carcass removal trials from the carcass persistence/scavenging trial that provided information primarily informing the carcass removal model. The species of carcasses used from that study are provided in Table 13.

Table 13. Number of Carcass Trials of Each Species (Wingspan) from the Carcass Persistence/Scavenging Trial Incorporated into the QAQC Detection Probability Study in each of Four Adjustment Groups

Species (wingspan inches)	Large Non-Raptor	Small Non-Raptor	Large Raptor	Small Raptor	**Total**
American kestrel (22)				2	**2**
Barn owl (42)			3		**3**
Burrowing owl (21)				3	**3**
Cliff swallow (13.3)		1			**1**
Common raven (53)	4				**4**
European starling (16)		2			**2**
Ferruginous hawk (56)			1		**1**
Great-horned owl (44)			4		**4**
Horned lark (12)		1			**1**
Ring-billed gull (48)	1				**1**
Rock pigeon (28)	1				**1**
Red-tailed hawk (45)			28		**28**
Turkey vulture (67)			4		**4**
Western meadowlark (14.5)		1			**1**
Total	**7**	**5**	**40**	**5**	**56**

There was a substantial decline in the searcher efficiency component of detection probability with carcass age, and this decline occurred over the range of time corresponding to a typical search interval in the APWRA monitoring program (i.e., 30–35 days, Figure C-3).

As expected, both the searcher efficiency and carcass removal components of detection probability declined with carcass age and inversely with wingspan. Thus, overall detection probability also declined over time and was smaller for smaller-sized species.

Figure C-4 reflects detection probabilities for the four focal species, aggregated over a range of search interval lengths. Detection probabilities for American kestrel and burrowing owl were higher at the longer intervals used in the APWRA monitoring program than the previously used detection probabilities from Smallwood (2007). Conversely, detection probabilities of red-tailed hawk are lower than those of Smallwood (2007), while golden eagle detection probabilities are essentially the same.

Discussion

Detection probability is arguably the most important component of a program designed to estimate the number of fatalities resulting from a process—in this case the process of operating a wind farm. Changes in detection probability resulting from any of a number of factors can dramatically influence the resulting estimates and the confidence in those estimates.

The QAQC study was implemented successfully without interfering with the primary search interval. Logistics and person-power limitations resulted in a relatively small number of the more complex search sequences. Simple repeat sampling (primary to secondary to next primary) provided a large amount of information and was able to be implemented within the constraints of the ongoing monitoring program. The number of QAQC sequences and detection events was similar to plan, but the timing of events was biased toward shorter sequence intervals. That notwithstanding, the study represents one of the largest datasets ever collected on the probability of detecting carcasses deposited at a specific wind farm.

The use of wingspan as a covariate represents a substantial improvement in the estimation of detection probability, as previously used estimates of detection probability were based on size classes that do not represent the level of variation in detection probability of the species being killed. For example, prior to the QAQC study, detection probability was the same for both house finches and burrowing owls, as well as for red-tailed hawks and golden eagles.

An issue invariably raised in discussion of detection probability trials associated with estimating a moribund population is the use of carcasses that may be more than a few days of age. This has been argued strongly by Smallwood (2010:154), who argued that the removal rate for carcasses younger than 2 days was different enough from carcasses older than 2 days to warrant a substantial adjustment. However, the exclusive use of carcasses younger than 2 days is not practicable either because fresh carcasses that are widely available are typically game species with a removal rate that may not be representative of the species of management concern or carcasses are obtained from rehabilitation facilities that are rapidly coming into short supply and even when fresh must be frozen until they are ready to use. An additional concern is the use of species that may not typically be killed at a given site and have a detection probability different from species of management concern. However, one of the strengths of the analysis used in this study is the use of a truncated Weibull distribution and a staggered entry modeling technique that approximates the distribution of removal times for carcasses of all ages.

An additional strength of this analysis was the leveraging of information from two very different types of studies and search protocols which provided complementary strengths of information on the two components of detection probability. The fates of every carcass from the carcass removal/scavenging trial and the QAQC sampling protocol were subject to various degrees of uncertainty associated with carcass removal and imperfect searcher efficiency; however, the carcass removal/scavenging trial provided relatively firm information on removal rates due to the high searcher efficiency afforded to frequent status checks, and the repeat sampling of carcasses provided firm information on blind searcher efficiency due to simultaneous estimation with carcass removal rates. Furthermore, the ability to leverage both types of data in an age-structured model revealed support for the notion that the estimation of both detection components are intertwined due to their joint dependence on age. Our analysis approach can be easily generalized to include additional covariates (e.g., grass height, season, or other spatial or temporal factors) that may similarly influence the interdependence between removal and efficiency. Such an in-depth analysis was not within the objectives for this study but may be considered in future studies.

Finally, we detected a substantial decrease in searcher efficiency with carcass age over the range of carcass ages used in the current APWRA monitoring program (i.e., ages 0–45 days). The decrease in searcher efficiency (and thus overall detection probability) over the time of a typical search interval has not been documented previously in the APWRA, and may account for the inability of the current monitoring program to detect a decrease in the fatality rate from the baseline study, which typically used much longer search intervals. It is also responsible for much of the difference in detection probabilities over the average search interval used in the APWRA monitoring program between this study and the estimates from Smallwood (2007).

Another issue likely to have confounded the comparison of fatality rates between the current and baseline programs is the effect of bleed-through—i.e., the over-correction due to undetected fatalities that are later detected. Our estimates of carcass removal are lower than those estimates by Smallwood (2007), and our estimates of searcher efficiency are lower, with the magnitude of these differences dependent on the search interval length. Thus, bleed-through biases on fatality rate estimates may be much larger than previously assumed and current and baseline period fatality rates less comparable due to different average search interval lengths. For monitoring studies that have a combination of low carcass removal and low searcher efficiency, strategies that are robust to bleed-through bias should be an ongoing topic of research and development.

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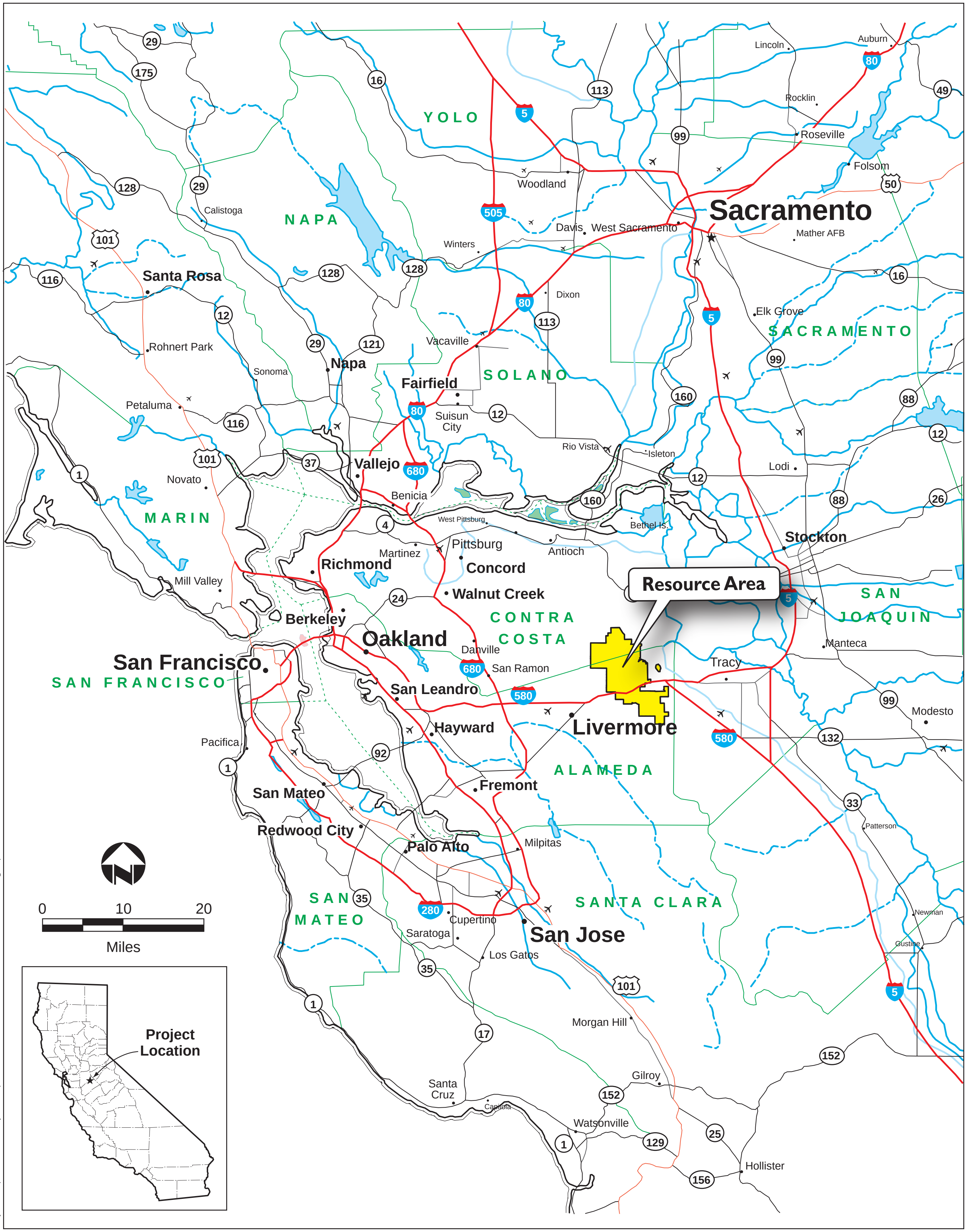

Figure C-1
Location of the Altamont Pass Wind Resource Area (APWRA)

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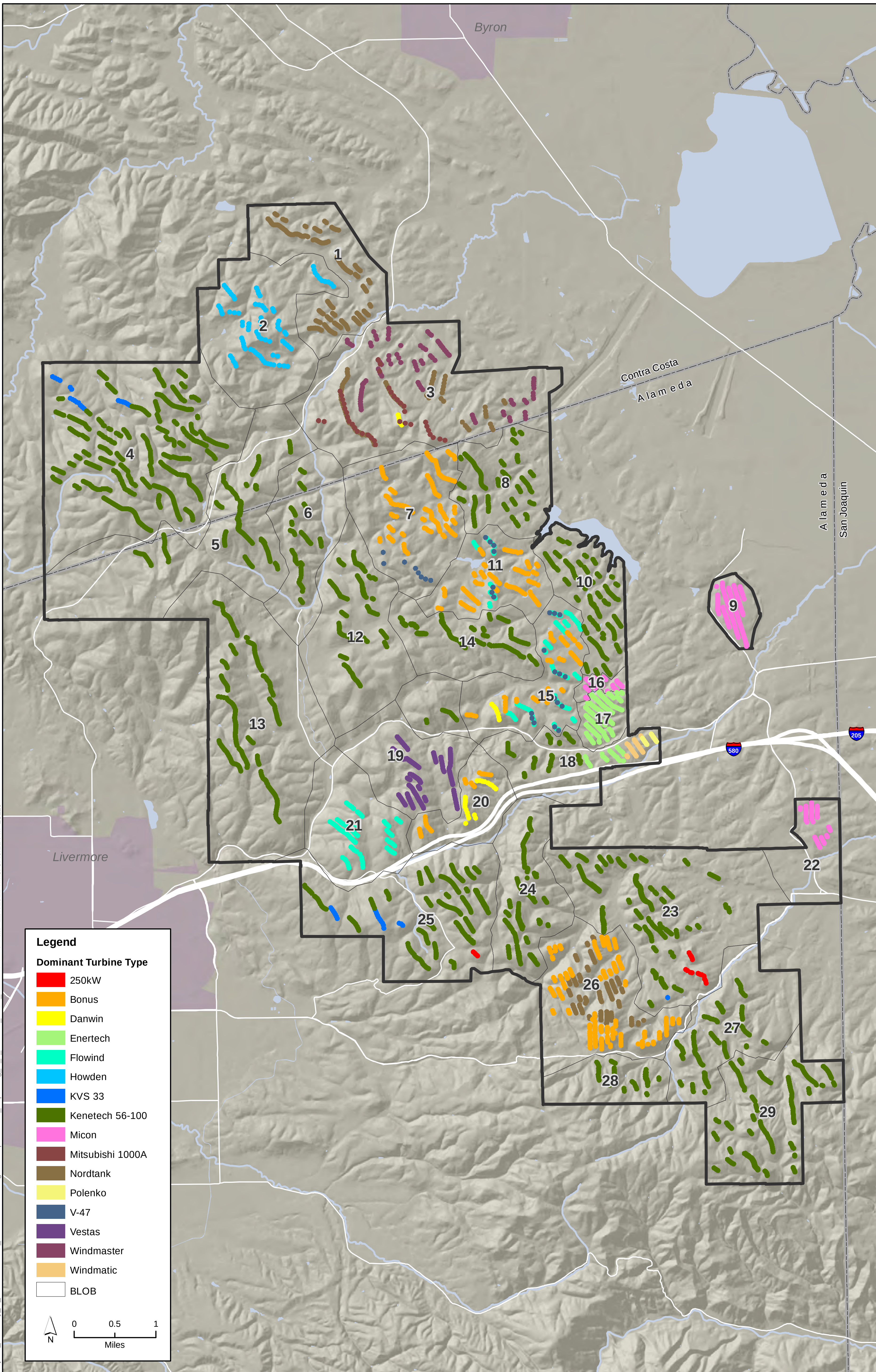

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Figure C-2
Base Layer of Operating Group Boundaries in the APWRA

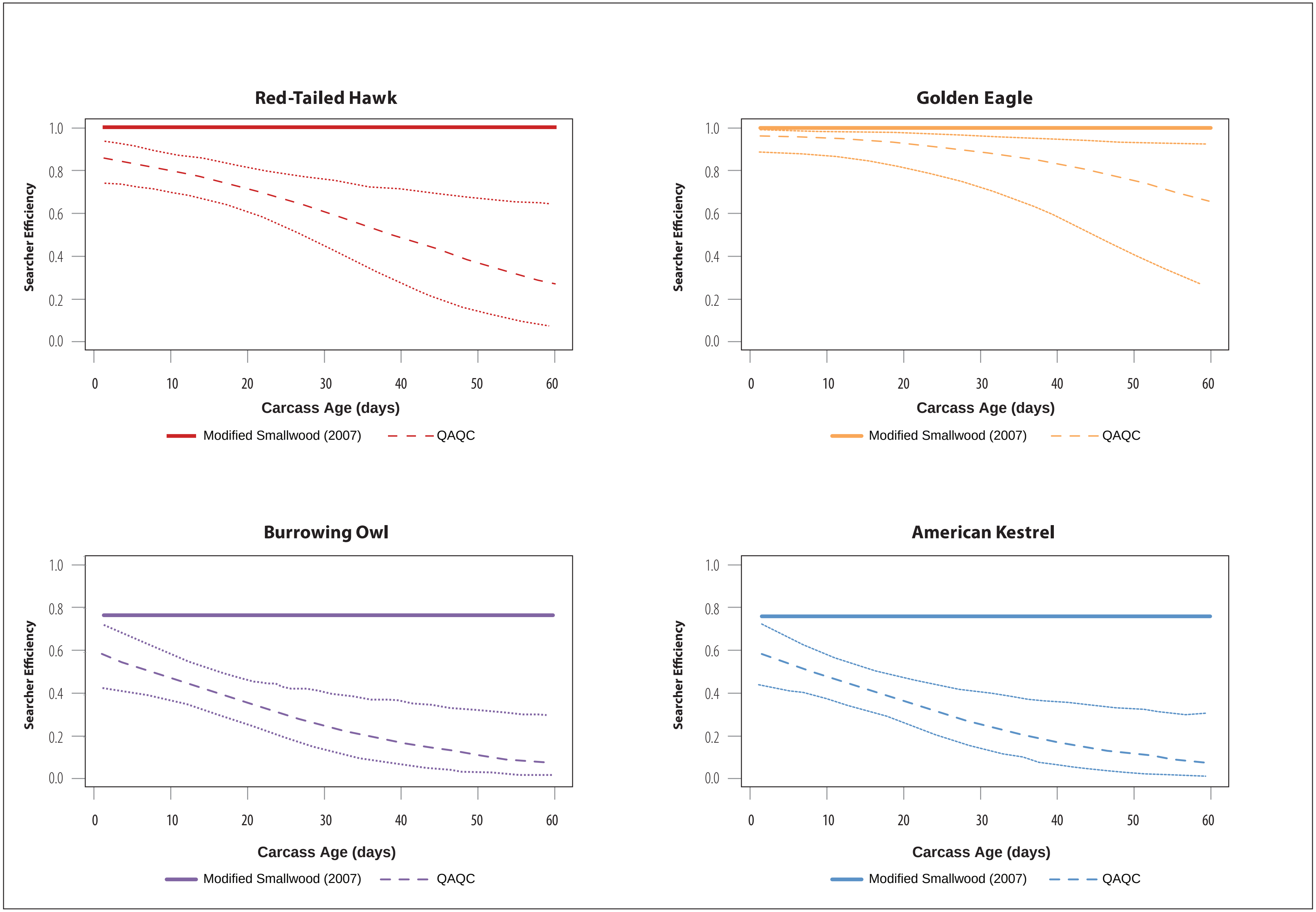

Figure C-3
Changes in Searcher Efficiency (and 95% Credible Interval Bands) as Carcasses Age Based on Blind Searches Conducted during the QAQC Study for the Four Focal Species in the APWRA

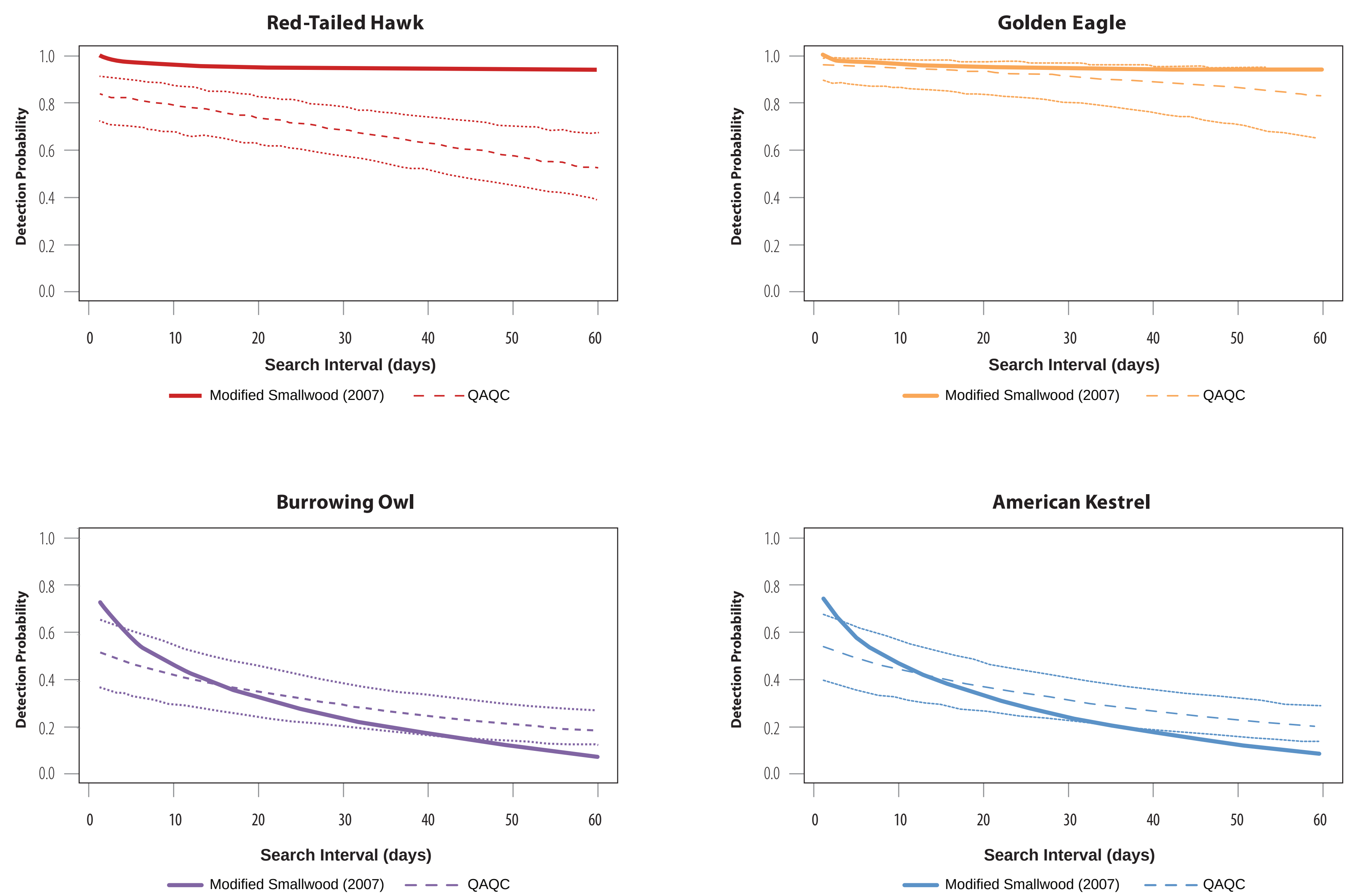

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Figure C-4
Changes in Detection Probability (and 95% Credible Interval Bands) Over Time for the Four Focal Species in the APWRA Based on Search Sequences Conducted during the QAQC Study and Information from the Carcass Removal / Scavenging Trial Study

Appendix D

Calculation of Fatality Rates and Estimated Total Fatalities

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Calculation of Fatality Rates and Estimated Total Fatalities

This appendix describes the methods used to calculate avian fatality rates and estimated total avian fatalities within the Altamont Pass Wind Resource Area (APWRA).

D.1 Variables

Several of the variables used in this document are aggregated at several different scales. For example, installed capacity C_I is aggregated temporally by month or year and spatially by turbine string or BLOB. To avoid ambiguity, the installed capacity aggregated by string and month is denoted $C_I(m, s_T)$, and the installed capacity aggregated by BLOB and bird year is denoted $C_I(y, b)$. These might be read, respectively, as "installed capacity as a function of month and string" and as "installed capacity as a function of BLOB and bird year."

Estimated values are denoted with a hat symbol: $F_D(y, s, b)$ denotes the number of fatalities F_D of species s detected by the monitoring team at BLOB b during bird year y, whereas $\hat{F}(y, s, b)$ denotes the total estimated fatalities, a value which is extrapolated from the number of fatalities detected.

Variable	Name	Level of Aggregation	Description	Definition
b	BLOB		A set of turbine strings sharing a common location, owner, turbine type, or other characteristic.	
$\|b\|$			The number of strings in BLOB b.	
B			The set of all BLOBs in the APWRA.	
$B_M(y)$	Monitored BLOBs	Bird year	The set of all BLOBs in the APWRA that were monitored during bird year y.	
$C(t)$		Turbine	The generating capacity of turbine t in megawatts.	
$C_I(m, s_T)$	Installed capacity	Month and string	The total installed (or operational) generating capacity in megawatts of string s_T during month m.	Section D.4
$C_I(y, s_T)$	Installed capacity	Bird year and string	The total installed (or operational) generating capacity in megawatts of string s_T during bird year y.	Section D.4
$C_I(y, b)$	Installed capacity	Bird year and BLOB	The total installed (or operational) generating capacity in megawatts of BLOB b during bird year y.	Section D.4
$C_I(y)$	Installed capacity	Bird year	The APWRA-wide amount of generating capacity that was installed during bird year y.	
$C_M(y, b)$	Monitored capacity	Bird year and BLOB	The generating capacity of BLOB b that was monitored during bird year y.	Section D.5
$C_M(y)$	Monitored capacity	Bird year	The APWRA-wide amount of generating capacity that was monitored during bird year y.	Section D.5
$\hat{F}(y, s)$	Estimated fatality count	Bird year and species	The total number of fatalities estimated to have occurred APWRA-wide during bird year y.	Section 0
$\hat{F}(y, s, b)$	Estimated fatality count	Bird year, species, and BLOB	The number of fatalities of species s estimated to have occurred at BLOB b during bird year y.	
$F_D(y, s, b)$	Detected fatality count	Bird year, species, and BLOB	The number of fatalities of species s detected by the monitoring team at BLOB b during bird year y.	
$\hat{F}_J(y, s, b)$	Adjusted fatality count	Bird year, species, and BLOB	The adjusted fatality count for species s at BLOB b during bird year y.	
$\hat{F}_J(y, s)$	Adjusted fatality count	Bird year and species	The APWRA-wide adjusted fatality count for species s during bird year y.	
$\hat{F}_O(y, s, b)$	Amortized fatality count	Bird year, species, and BLOB	The amortized fatality count for species s at BLOB b during bird year y.	Section D.9.1
$\hat{F}_X(y, s, b)$	Expanded fatality count	Bird year, species, and BLOB	The expanded fatality count for species s at BLOB b during bird year y.	Section D.9.6
$I(y, s_T)$	Search interval	Bird year and string	The average search interval at string s_T during bird year y.	Section D.7
$I(y, b)$	Search interval	Bird year and BLOB	The average search interval at BLOB b during bird year y.	Section D.7

Variable	Name	Level of Aggregation	Description	Definition
$K(y, s_T)$	Search coverage	Bird year and string	The search coverage of turbine string s_T during bird year y.	Section D.6
$K(y, b)$	Search coverage	Bird year and BLOB	The search coverage of BLOB b during bird year y.	Section D.6
$\hat{P}_D(y, s, b)$	Detection probability	Bird year, species, and BLOB	The estimated probability of detecting a fatality of species s during a search of BLOB b during bird year y.	
$\hat{R}(y, s, b)$	Estimated fatality rate	Bird year, species, and BLOB	The estimated number of fatalities for species s at BLOB b during bird year y per unit of generating capacity installed at BLOB b during bird year y.	
$\hat{R}_J(y, s, b)$	Adjusted fatality rate	Bird year, species, and BLOB	The adjusted rate of fatalities for species s at BLOB b during bird year y per unit of generating capacity at BLOB b during bird year y.	Section D.9.6
$\hat{R}_J(y, s)$	Adjusted fatality rate	Bird year and species	The APWRA-wide adjusted rate of fatalities for species s during bird year y per unit of monitored generating capacity.	Section D.9.6
S			The set of all species.	
s	Species			
s_T	Turbine string			
t	Turbine			
u	Stratum		A set of turbine strings; all BLOBs are strata, but not all strata are BLOBs.	
y	Bird year			

D.2 Spatial Scales

Fatality counts and rates in the APWRA are aggregated at several spatial scales. The most basic spatial scale is the individual *turbine*; every fatality discovered is assigned to the closest operational turbine. The next spatial scale is the *string*, a set of turbines arrayed in a line. Carcass searches are carried out on the spatial scale of strings rather than individual turbines. The next spatial scale is the *stratum*, which is a set of strings. A special type of stratum is a *BLOB (*i.e., *base layer of operating group boundaries)*, which is a spatial division used for search scheduling. Whereas every string in the APWRA belongs to exactly one BLOB, strings may be assigned to any number of additional non-BLOB strata. All equations below that refer to a BLOB using the variable b can be rewritten to refer to a stratum using the variable u.

D.3 Annual Fatality Count

D.3.1 Point Estimate

Let $\hat{F}(y)$ denote the APWRA-wide point estimate of the number of avian fatalities in bird year y. To arrive at this estimate, the APWRA is divided into BLOBs as described in Section D.2 . Let $\hat{F}(y,s,b)$ denote the point estimate of the number of fatalities of species s at BLOB b in bird year y. The APWRA-wide fatality estimate is simply the sum of estimated fatality counts for all species–BLOB pairs:

$$\hat{F}(y) = \sum_{b \in B} \sum_{s \in S} \hat{F}(y,s,b)\,, \qquad \textbf{Equation 1}$$

where B is the set of all BLOBs and S is the set of all species.

The fatality rate of species s at BLOB b is estimated by multiplying the installed capacity of BLOB b by the estimated rate of fatalities of species s per unit of rated generating capacity installed at BLOB b:

$$\hat{F}(y,s,b) = \hat{R}(y,s,b) \cdot C_I(y,b), \qquad \textbf{Equation 2}$$

where $\hat{R}(y,s,b)$ is the estimated fatality rate and $C_I(y,b)$ is the installed capacity (defined in Section D.4). If a BLOB is monitored during bird year y, the fatality rate is extrapolated from the actual number of fatalities detected by the monitoring team. (This extrapolated rate is referred to as the *adjusted fatality rate*.) If a BLOB is not monitored during bird year y, the fatality rate must be estimated using some other technique (as outlined in Section D.10).

To calculate the adjusted fatality rate, an *adjusted fatality count* must first be extrapolated from the actual number of fatalities detected. The adjusted fatality count $\hat{F}_J(y,s,b)$ is given by the formula

$$\hat{F}_J(y,s,b) = \frac{F_D(y,s,b)}{K(y,b) \cdot \hat{P}_D(y,s,b)}, \qquad \textbf{Equation 3}$$

where $F_D(y,s,b)$ denotes the number of fatalities actually detected, $K(y,b)$ denotes the *transect coverage*, and $\hat{P}_D(y,s,b)$ denotes the *detection probability*. This equation is explained in more detail in Section D.7 below.

The adjusted fatality rate $\hat{R}_J(y,s,b)$ for a specific BLOB b is the quotient of the adjusted fatality count and the rated generating capacity of the BLOB b monitored by the monitoring team:

$$\begin{aligned} \hat{R}_J(y,s,b) &= \frac{\hat{F}_J(y,s,b)}{C_M(y,b)} \\ &= \frac{F_D(y,s,b)}{C_M(y,b) \cdot K(y,b) \cdot \hat{P}_D(y,s,b)}. \end{aligned} \qquad \textbf{Equation 4}$$

The APWRA-wide adjusted fatality count for a species is simply the sum of the adjusted fatality counts of that species for all monitored BLOBs:

$$\hat{F}_J(y,s) = \sum_{b \in B_M(y)} \hat{F}_J(y,s,b)\,, \qquad \textbf{Equation 5}$$

where $B_M(y)$ is the subset of BLOBs monitored during bird year y. The APWRA-wide adjusted fatality rate for a species is the quotient of the APWRA-wide adjusted fatality count and the APWRA-wide monitored capacity:

$$\hat{R}_J(y,s) = \frac{\hat{F}_J(y,s)}{C_M(y)}. \qquad \textbf{Equation 6}$$

where $\hat{F}_J(y,s)$ is the APWRA-wide adjusted fatality count of species s and $C_M(y)$ is the APWRA-wide monitored capacity.

D.3.2 Error

The APWRA-wide estimated fatality count is defined in Equation 1 to be the sum of the fatality counts for each BLOB and species. The standard error of the APWRA-wide count can thus be calculated from its components as a root of sum of squares (as described in Section D.11.1):

$$SE\left(\hat{F}(y)\right) = \sqrt{\sum_{b \in B} \sum_{s \in S} SE\left(\hat{F}(y,s,b)\right)^2}\,. \qquad \textbf{Equation 7}$$

The estimated fatality count for a species s at a BLOB b, $\hat{F}(y,s,b)$, is defined in Equation 2 to be the product of the installed capacity of the BLOB and the fatality rate per unit of installed capacity. This means that the standard error of the fatality count at a BLOB is given by the formula (as described in Section D.11.2):

$$SE\left(\hat{F}(y,s,b)\right) = \hat{F}(y,s,b) \cdot \sqrt{\left(\frac{SE\left(\hat{R}(y,s,b)\right)}{\hat{R}(y,s,b)}\right)^2 + \left(\frac{SE\left(C_I(y,b)\right)}{C_I(y,b)}\right)^2}\,. \qquad \textbf{Equation 8}$$

Recall that for monitored BLOBs, the fatality rate $\hat{R}(y,s,b)$ is the adjusted fatality rate, computed using Equation 4. The standard error of the adjusted fatality rate is calculated using the formula

$$\begin{aligned} &SE\left(\hat{R}_J(y,s,b)\right) \\ &= \hat{R}_J(y,s,b)\sqrt{\left(\frac{SE\left(\hat{P}_R(y,s,b)\right)}{\hat{P}_R(y,s,b)}\right)^2 + \left(\frac{SE\left(\hat{E}(s)\right)}{\hat{E}(s)}\right)^2 + \left(\frac{SE\left(C_M(y,b)\right)}{C_M(y,b)}\right)^2}\,, \end{aligned} \qquad \textbf{Equation 9}$$

which is discussed in more detail in Section D.9.6.2 below.

For unmonitored BLOBs, the fatality rate $\hat{R}(y, s, b)$ is the APWRA-wide adjusted fatality rate, computed using Equation 6. The standard error is calculated using the formula

$$SE\left(\hat{R}_J(y,s)\right) = \hat{R}_J(y,s) \cdot \sqrt{\left(\frac{SE\left(\hat{F}_J(y,s)\right)}{\hat{F}_J(y,s)}\right)^2 + \left(\frac{SE\left(C_M(y)\right)}{C_M(y)}\right)^2}. \qquad \textbf{Equation 10}$$

Since $\hat{F}_J(y, s)$ and $C_M(y)$ represent sums across all BLOBs, their standard errors can be calculated as roots of sums of squares:

$$SE\left(\hat{F}_J(y,s)\right) = \sqrt{\sum_{b \in B} SE\left(\hat{F}_J(y,s,b)\right)^2}, \qquad \textbf{Equation 11}$$

$$SE\left(C_M(y)\right) = \sqrt{\sum_{b \in B} SE\left(C_M(y,b)\right)^2}. \qquad \textbf{Equation 12}$$

D.4 Installed Capacity

D.4.1 Point Estimate

Because the rated generating capacity of the APWRA was dynamic over the course of the study, *installed capacity*—defined as the sum of the rated capacities of all extant turbines each year—was the metric used to calculate fatality rates and extrapolate fatality rates to the entire APWRA. The power companies provided estimates of the installed capacity of each string for each year of the study along with dates of removals that occurred during a bird year.

The installed capacity of an individual turbine is prorated on a monthly basis. If a turbine was installed at any time during a particular month, its rated generating capacity is included in the installed capacity of the string for that month; if during the entire month the turbine was not installed (i.e., it had been removed or was not yet installed), its rated generating capacity is not included in the installed capacity of the string for that month:

$$C_I(m, s_T) = \sum_{t \in s_T} \begin{cases} C(t) & t \text{ was installed during month } m \\ 0 & t \text{ was not installed during all of month } m, \end{cases} \qquad \textbf{Equation 13}$$

where each t is a turbine in string s_T and $C(t)$ is the rated generating capacity of turbine t in megawatts.

The annual installed capacity $C_I(y, s_T)$ of a string s_T during a bird year y is the arithmetic mean of the installed capacity at that string during each month of the bird year:

$$C_I(y, s_T) = \frac{C_I(\text{Oct}, s_T) + C_I(\text{Nov}, s_T) + \cdots + C_I(\text{Sep}, s_T)}{12}, \qquad \textbf{Equation 14}$$

where $C_I(m, s_T)$ is the installed capacity of string s_T during monitoring month m defined in Equation 13.

The installed capacity $C_I(y, b)$ of a BLOB b during a bird year y is the sum across all strings in BLOB b of the installed capacity of each constituent string during bird year y:

$$C_I(y, b) = \sum_{s_T \in b} C_I(y, s_T)\,, \qquad \textbf{Equation 15}$$

where each s_T is a string in BLOB b and $C_I(y, s_T)$ is the installed capacity of string s_T during bird year y. The installed capacity of all BLOBs in the APWRA can then be summed to provide an *APWRA-wide installed capacity*:

$$C_I(y) = \sum_{b \in B} C_I(y, b)\,, \qquad \textbf{Equation 16}$$

where B is the set of all BLOBs in the APWRA.

D.4.2 Variance

The installed capacity of a string s_T during a month m is assumed to have a standard error of zero: $SE\big(C_I(y, s_T)\big) = 0$. The installed capacity of a string during a bird year y depends on the variation of the monthly installed capacities at that string:

$$SE\big(C_I(y, s_T)\big) = \frac{1}{12} \cdot \sqrt{\sum_{m=1}^{12} \big(C_I(y, s_T) - C_I(m, s_T)\big)^2}\,. \qquad \textbf{Equation 17}$$

Having so defined the standard error of the annual installed capacity of a string, the standard error of the annual installed capacity of a BLOB may be calculated from the standard errors for each of its constituent strings (as described in Section D.11.1):

$$SE\big(C_I(y, b)\big) = \sqrt{\sum_{s_T \in b} SE\big(C_I(y, s_T)\big)^2}. \qquad \textbf{Equation 18}$$

Note that there will be variance in a string's installed capacity only if turbines were installed or removed during the bird year.

D.5 Monitored Capacity

D.5.1 Point Estimate

A string is considered monitored during a bird year if at least 6 primary searches were conducted on that string during that bird year. The *monitored capacity* of a monitored string in a bird year is equal to the string's average installed capacity throughout the year. The monitored capacity of an unmonitored string is zero:

$$C_M(y, s_T) = \begin{cases} C_I(y, s_T) & \geq 6 \text{ searches of string } s_T \text{ during year } y \\ 0 & < 6 \text{ searches of string } s_T \text{ during year } y, \end{cases}$$ **Equation 19**

where the capacity $C_I(y, s_T)$ is calculated using Equation 14.

The monitored capacity for BLOB b during bird year y is the sum of the monitored capacity of its constituent strings:

$$C_M(y, b) = \sum_{s_T \in b} C_M(y, s_T)\,,$$ **Equation 20**

where each s_T is a string in BLOB b. A BLOB is considered monitored only if it has at least one monitored string. All unmonitored BLOBs have a monitored capacity of 0, as a consequence of Equation 20. Note that Equation 20 can also be used to calculate the monitored capacity of a non-BLOB stratum such as the set of Diablo strings.

The *APWRA-wide monitored capacity* for a bird year y is the sum of the monitored capacities of all BLOBs in the APWRA:

$$C_M(y) = \sum_{b \in B} C_M(y, b)\,,$$ **Equation 21**

where B is the set of all BLOBs.

It should be noted that the series of equations for estimating APWRA-wide counts (see below), including the estimate of monitored capacity, is carried out at the BLOB level prior to summing results at the APWRA-wide level.

D.5.2 Variance

The standard error of the monitored capacity of a monitored string is equal to the standard error that string's installed capacity; the standard error of the monitored capacity of an unmonitored string is zero:

$$SE\big(C_M(y, s_T)\big) = \begin{cases} SE\big(C_I(y, s_T)\big) & s_T \text{ was monitored} \\ 0 & s_T \text{ was unmonitored} \end{cases},$$ **Equation 22**

where $SE\big(C_I(y, s_T)\big)$ is calculated by Equation 17.

Having so defined the standard error of the annual monitored capacity of a string, the standard error of the annual monitored capacity of a BLOB may be calculated from the standard errors for each of its constituent strings:

$$SE\big(C_M(y,b)\big) = \sqrt{\sum_{s_T \in b} SE\big(C_M(y,s_T)\big)^2}\,. \qquad \textbf{Equation 23}$$

The standard error of the APWRA-wide monitored capacity can likewise be calculated from the standard errors of each of the BLOBs in the APWRA:

$$SE\big(C_M(y)\big) = \sqrt{\sum_{b \in B} SE\big(C_M(y,b)\big)^2}\,. \qquad \textbf{Equation 24}$$

D.6 Search Coverage

D.6.1 Point Value

Searches conducted through a bird year may or may not result in search intervals that completely cover the bird year calendar. Searches may start late or end early in the year because of logistic constraints, turbine removals, and changes in the sampling design. We estimated the search coverage for each string within a BLOB based on the first and last primary search dates for each bird year. The search coverage $K(y,b)$ of a BLOB b during a bird year y is the arithmetic mean search coverage for all turbine strings in that BLOB during that bird year:

$$K(y,b) = \frac{1}{|b|} \cdot \sum_{s_T \in b} K(y,s_T)\,, \qquad \textbf{Equation 25}$$

where $|b|$ is the number of monitored strings in BLOB b and $K(y,s_T)$ is the search coverage of string s_T during bird year y.

The search coverage $K(y,s_T)$ of a string s_T describes the proportion of bird year y during which string s_T can be considered to have been searched. $K(y,s_T)$ is defined as follows:

- If the last primary search on string s_T in bird year $y-1$ occurred no more than 90 days prior to the first primary search in bird year y, search coverage starts on the first day of bird year y. Otherwise coverage starts on the date of the first primary search that occurred during bird year y.
- If the first primary search on string s_T in bird year $y+1$ occurred no more than 90 days after the last search in bird year y, search coverage ends on the last day of bird year y. Otherwise coverage ends on the date of the last primary search that occurred during bird year y.

The search coverage is defined as the ratio between the length of search coverage (in days) and the length of the bird year (in days). This ratio was used to generate amortized fatality results. Regardless of coverage, strings with fewer than 6 searches in a bird year are considered inadequately sampled and are excluded from the analyses.

D.6.2 Variance

Because the search coverage is not constant within a BLOB, the standard error of the search coverage is calculated using the population standard error formula:

$$SE\big(K(y,b)\big) = \frac{1}{|b|} \cdot \sqrt{\sum_{s_T \in b} \big(K(y,b) - K(y,s_T)\big)^2}\,. \qquad \textbf{Equation 26}$$

D.7 Search Interval

D.7.1 Point Value

The interval between two searches is the difference in days between the dates of two searches. For example, if two searches were carried out on September 15 and October 15, respectively, the interval between them is thirty days. The *average search interval* $I(y, s_T)$ for a string s_T during a bird year y is the arithmetic mean of the search intervals between all adjacent pairs of primary searches. This calculation may be expressed as follows:

$$I(y, s_T) = \frac{1}{n-1} \cdot \sum_{i=1}^{n-1} S_{i+1} - S_i\,, \qquad \textbf{Equation 27}$$

where n is the number of primary searches carried out at string s_T in bird year y and S_i is the date on which the ith primary search was carried out. Note that $n - 1$ is the number of pairs of adjacent primary searches.

The average search interval $I(y, b)$ for a BLOB b during a bird year y is the arithmetic mean of the average search intervals of all monitored strings in that BLOB during that bird year:

$$I(y, b) = \frac{1}{|b|} \cdot \sum_{s_T \in b} I(y, s_T)\,, \qquad \textbf{Equation 28}$$

where $|b|$ is the number of monitored strings in BLOB b and each s_T is a monitored string (a string with 6 or more primary searches during bird year y).

D.7.2 Variance

Because the search interval is not constant throughout the year, its variance must be accounted for with the population standard error:

$$SE\big(I(y, s_T)\big) = \frac{1}{n-1} \cdot \sqrt{\sum_{i=1}^{n-1} \big(I(y, s_T) - (S_{i+1} - S_i)\big)^2}\,. \qquad \textbf{Equation 29}$$

Because the search interval for a BLOB is the arithmetic mean of the search intervals for all the strings, it is calculated using the standard error formula described in Section D.11.3 :

$$SE\big(I(y,b)\big) = \frac{1}{|b|} \cdot \sqrt{\sum_{s_T \in b} SE\big(I(y,s_T)\big)}, \qquad \textbf{Equation 30}$$

where $|b|$ is the number of monitored strings in BLOB b and each s_T is a monitored string.

D.8 Detection Probability

D.8.1 Point Estimate

The *detection probability* is the probability of a carcass being detected by the search crew. Elements of the detection probability are related to search interval, such as the cumulative probability that a fatality would remain within the search area and thus be available for detection. We estimated detection probabilities for each species based on their wingspan (Appendix C). The average search interval for each BLOB was used to estimate the detection probability for each species at each BLOB:

$$\hat{\hat{P}}_D(y,s,b) = f\big(I(y,b), w(s)\big). \qquad \textbf{Equation 31}$$

Where $\hat{P}_D(y,s,b)$ is the detection probability for a year, species, and BLOB, $w(s)$ is the wingspan of species s, and $f\big(I(y,b), w(s)\text{wingspan}\big)$ is the detection probability for a year and BLOB associated with a wingspan model and the average search interval I.

D.8.2 Error

The variability of the search interval leads to uncertainty about the detection probability. The variability of the search interval is translated into variability of detection probability. For example, consider American kestrels at BLOB 10 during bird year 2010. The average search interval is 34.2 days, with a standard error of 3.26 days. Were these search intervals a sample of a larger population, they would imply the normal distribution of the sample mean shown in Figure 1.

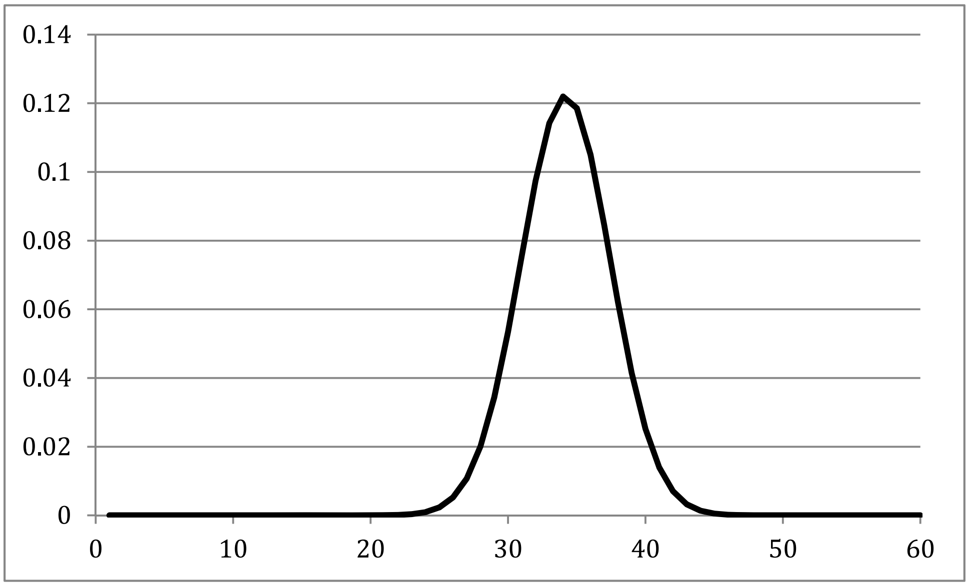

Figure 1. Implied Distribution of Population Mean of Search Interval at BLOB 10 during Bird Year 2010

Using the detection probability curve for kestrels, this distribution can be translated into a distribution around the population mean of detection probability (Figure 2).

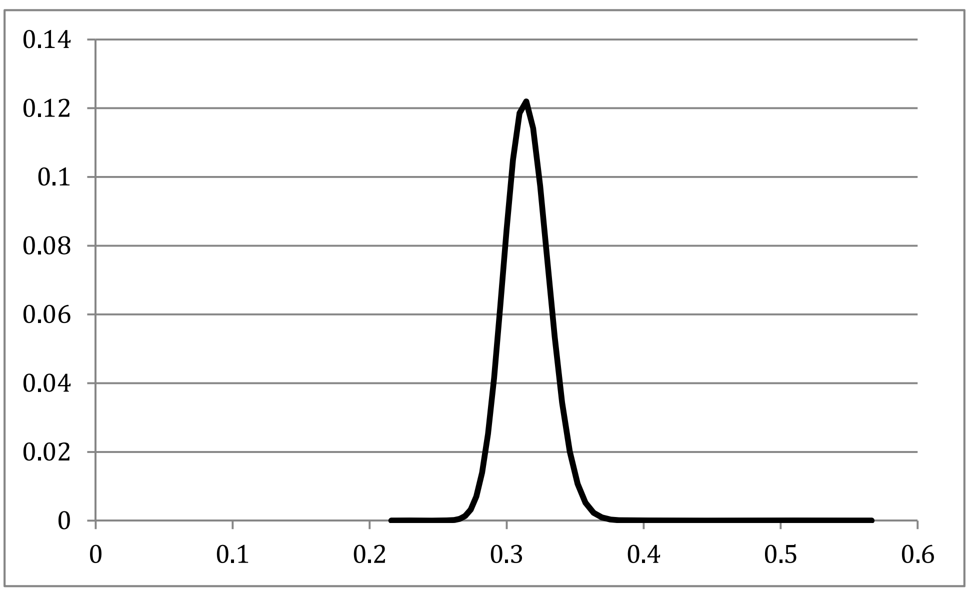

Figure 2. Distribution of the Population Mean of Detection Probability

Note: This curve was created by mapping each search interval (from the x-axis of Figure 1) to its corresponding detection probability from the American kestrel detection probability curve.

If the variation of the search interval were the only source of uncertainty about detection probability, the standard deviation of the distributions of detection probabilities so calculated would be the standard error of the detection probability. However, the detection probability curves themselves have a standard error as well. If $SE_I\left(\hat{P}_D(y,s,b)\right)$ is the standard error from the variation of the transect interval and $SE_0\left(\hat{P}_D(y,s,b)\right)$ is the standard error from the uncertainty of the detection probability curve, then the total standard error accounting for both sources of uncertainty is given by the equation

$$SE\left(\hat{P}_D(y,s,b)\right) = SE_I\left(\hat{P}_D(y,s,b)\right)^2 + SE_0\left(\hat{P}_D(y,s,b)\right)^2 .$$

Equation 32

D.9 Extrapolating from Detected Fatalities

The fatality count for any BLOB, $\hat{F}(y,s,b)$, is calculated by multiplying the estimated fatality rate $\hat{R}(y,s,b)$ by the installed capacity $C_I(y,b)$, as described in Equation 2. For monitored BLOBs, the fatality rates were calculated through a series of arithmetic adjustments on the number of fatalities actually discovered by the monitoring team.

D.9.1 Raw Fatality Count

Once invalid fatalities have been excluded from the fatality list the fatalities detected by the monitoring team are assigned to bird years according to their estimated date of death. The symbol $F_D(y,s,s_T)$ denotes the number of valid fatalities of species s that were detected at string s_T and estimated to have died during bird year y. This fatality count can then be summed across all strings in a BLOB:

$$F_D(y,s,b) = \sum_{s_T \in b} F_D(y,s,s_T) ,$$

Equation 33

where b is a BLOB, each s_T is a string in BLOB b, and $F_D(y,s,b)$ is the count of valid fatalities of species s at BLOB b during bird year y.

The mathematical adjustments for search coverage and detection probability are not defined unmonitored strings. The *raw (unadjusted) fatality count at monitored strings* for a BLOB b is the sum of the number of valid fatalities of species s that were detected at the monitored strings in BLOB b:

$$F_M(y,s,b) = \sum_{s_T \in b} \begin{cases} F_D(y,s,s_T) & \geq 6 \text{ searches of string } s_T \text{ during year } y \\ 0 & < 6 \text{ searches of string } s_T \text{ during year } y, \end{cases}$$

Equation 34

where $F_D(y,s,s_T)$ is the number of valid fatalities of species s detected at string s_T that were estimated to have died in bird year y.

The APWRA-wide raw (unadjusted) fatality count at monitored strings is the sum of the number of valid fatalities in all monitored strings in the APWRA, or alternatively the sum of all the BLOB-level counts of detections at monitored strings:

$$F_M(y,s) = \sum_{b \in B} F_M(y,s,b), \qquad \textbf{Equation 35}$$

where B is the set of all BLOBs in the APWRA and $F_M(y,s,b)$ is calculated for each BLOB b using Equation 34.

D.9.2 Amortized Fatality Count

The first adjustment is an *amortization* of the actual count of discovered fatalities.

D.9.2.1 Point Value

The *amortized count* for a species s at a BLOB b is the quotient of the actual count at the BLOB and the search coverage at the BLOB:

$$\hat{F}_O(y,s,b) = \frac{F_D(y,s,b)}{K(y,b)}, \qquad \textbf{Equation 36}$$

where $F_D(y,s,b)$ is the number of fatalities actually discovered by the monitoring team.

D.9.2.2 Error

The number of fatalities discovered has a standard error of zero, so the amortized fatality count thus depends entirely on the standard error of the monitored capacity:

$$SE\left(\hat{F}_O(y,s,b)\right) = \hat{F}_O(y,s,b) \cdot \frac{SE\big(K(y,b)\big)}{K(y,b)}. \qquad \textbf{Equation 37}$$

D.9.3 Adjusted Fatality Count

The next step is to compute the *adjusted fatality count* based on the probability of a fatality being detected by the monitoring team.

D.9.3.1 Point Estimate

The *adjusted fatality count* $\hat{F}_J(y,s,b)$ is the quotient of the amortized fatality count $\hat{F}_O(y,s,b)$ and the detection probability $\hat{P}_D(y,s,b)$ calculated as:

$$\begin{aligned} \hat{F}_J(y,s,b) &= \frac{\hat{F}_O(y,s,b)}{\hat{P}_D(y,s,b)} \\ &= \frac{F_M(y,s,b)}{\hat{P}_D(y,s,b) \cdot K(y,b)}, \end{aligned} \qquad \textbf{Equation 38}$$

where $\hat{F}_O(y,s,b)$ is the amortized fatality count defined in Equation 36 and $\hat{P}_D(y,s,b)$ is the detection probability defined in Equation 31.

This count can be summed across all monitored BLOBs to give an *AWPRA-wide adjusted fatality count*:

$$\hat{F}_J(y,s) = \sum_{b \in B_M(y)} \hat{F}_J(y,s,b)\,, \qquad \textbf{Equation 39}$$

where $B_M(y)$ is the set of BLOBs monitored during bird year y and $\hat{F}_J(y,s,b)$ is calculated for each BLOB b using .

D.9.3.2 Error

Applying the method outlined in Section D.11.2 to the adjusted fatality count, we have the formula

$$SE\left(\hat{F}_J(y,s,b)\right) = \hat{F}_J(y,s,b)\sqrt{\left(\frac{SE\big(K(y,b)\big)}{K(y,b)}\right)^2 + \left(\frac{SE\left(\hat{P}_D(y,s,b)\right)}{\hat{P}_D(y,s,b)}\right)^2}\,. \qquad \textbf{Equation 40}$$

D.9.4 Raw Fatality Rate

D.9.4.1 Point Estimate

Annual unadjusted fatality rates were estimated by summing the unadjusted fatalities for all monitored strings within a BLOB for each complete bird year and dividing by the installed capacity of those monitored strings. The unadjusted fatality rates were then averaged across BLOBS to obtain estimates of the annual APWRA-wide unadjusted fatality rates. The *raw (unadjusted) fatality rate* is calculated as the quotient of the detected fatality count at the BLOB and the monitored capacity of the BLOB:

$$R_D(y,s,b) = \frac{F_M(y,s,b)}{C_M(y,b)} \qquad \textbf{Equation 41}$$

where $R_D(y,s,b)$ is the raw fatality rate of fatalities of species s during bird year y per megawatt of capacity at BLOB b, $F_M(y,s,b)$ is the raw count at monitored strings defined in Equation 34, and $C_M(y,b)$ is the monitored capacity defined in Equation 21.

The APWRA-wide raw (unadjusted) fatality rate is calculated as the quotient of the APWRA-wide fatality count at monitored strings and the APWRA-wide monitored capacity:

$$R_D(y,s) = \frac{F_M(y,s)}{C_M(y)}\,, \qquad \textbf{Equation 42}$$

where $F_M(y,s)$ is calculated from Equation 35 and $C_M(y)$ is calculated from Equation 21.

D.9.5 Amortized Fatality Rate

D.9.5.1 Point Estimate

The *amortized fatality rate* for a species s at a BLOB b is the quotient of the amortized fatality count at the BLOB and the monitored capacity of the BLOB:

$$\hat{R}_O(y,s,b) = \frac{\hat{F}_O(y,s,b)}{C_M(y,b)}. \qquad \textbf{Equation 43}$$

where $\hat{R}_O(y,s,b)$ is the amortized fatality rate of species s during bird year y per megawatt of capacity at BLOB b, $\hat{F}_O(y,s,b)$ is the amortized count defined in Equation 36 and $C_M(y,b)$ is the monitored capacity defined in Equation 21.The APWRA-wide amortized fatality rate is calculated as the quotient of the APWRA-wide amortized count and the APWRA-wide monitored capacity:

$$\hat{R}_O(y,s) = \frac{\hat{F}_O(y,s)}{C_M(y)}, \qquad \textbf{Equation 44}$$

where $\hat{F}_O(y,s)$ is the sum across all BLOBs and $C_M(y)$ is calculated from Equation 21.

D.9.5.2 Error

Applying this method to the amortized fatality rate, we have

$$SE\left(\hat{R}_O(y,s,b)\right) = \hat{R}_O(y,s,b)\sqrt{\left(\frac{SE\left(\hat{F}_O(y,s,b)\right)}{\hat{F}_O(y,s,b)}\right)^2 + \left(\frac{SE\left(C_M(y,b)\right)}{C_M(y,b)}\right)^2}, \qquad \textbf{Equation 45}$$

where $SE\left(\hat{F}_O(y,s,b)\right)$ is calculated using Equation 37 and $SE\left(C_M(y,b)\right)$ is calculated using Equation 23.

D.9.6 Adjusted Fatality Rate

D.9.6.1 Point Estimate

Annual adjusted fatality rates were estimated by summing the unadjusted fatalities for all monitored strings within a BLOB for each complete bird year, adjusting the sum, and dividing by the installed capacity of the BLOB's monitored strings. Using the adjusted fatality count from Equation 38, an adjusted fatality rate $\hat{R}_J(y,s,b)$ can be estimated by dividing the adjusted count by the monitored capacity:

$$\hat{R}_J(y,s,b) = \frac{\hat{F}_J(y,s,b)}{C_M(y,b)} = \frac{F_M(y,s,b)}{C_M(y,b)\cdot K(y,b)\cdot \hat{P}_D(y,s,b)}, \qquad \textbf{Equation 46}$$

where $C_M(y,b)$ is the monitored capacity calculated in Equation 20.

The *APWRA-wide average adjusted fatality rate* is estimated similarly, by dividing the APWRA-wide adjusted count by the APRWA-wide monitored capacity:

$$\hat{R}_J(y,s) = \frac{\hat{F}_J(y,s)}{C_M(y)}, \qquad \textbf{Equation 47}$$

where $\hat{F}_J(y,s)$ is calculated from Equation 39 and $C_M(y)$ is calculated from Equation 21.

D.9.6.2 Error

By applying Equation 61 the standard error of the adjusted fatality rate can be calculated using the following formula:

$$SE(\hat{R}_J) = \hat{R}_J \cdot \sqrt{\left(\frac{SE(K)}{K}\right)^2 + \left(\frac{SE(\hat{P}_D)}{\hat{P}_D}\right)^2 + \left(\frac{SE(C_M)}{C_M}\right)^2}, \qquad \textbf{Equation 48}$$

where $\hat{R}_J = \hat{R}_J(y,s,b)$, $K = K(y,b)$, $\hat{P}_D = \hat{P}_D(y,s,b)$, and $C_M = C_M(y,b)$.

The standard error of the expanded fatality count of a monitored BLOB can be calculated using the following formula:

$$SE(\hat{F}_X) = \hat{F}_X\sqrt{\left(\frac{SE(K)}{K}\right)^2 + \left(\frac{SE(\hat{P}_D)}{\hat{P}_D}\right)^2 + \left(\frac{SE(C_M)}{C_M}\right)^2 + \left(\frac{SE(C_I)}{C_I}\right)^2}, \qquad \textbf{Equation 49}$$

where $\hat{F}_X = \hat{F}_X(y,s,b)$ and $C_I = C_I(y,b)$. Be aware that $SE\big(C_M(y,b)\big) \neq SE\big(C_I(y,b)\big)$.

The standard error for the APWRA-wide adjusted fatality rate is calculated using the following formula:

$$SE\left(\hat{R}_J(y,s)\right) = \hat{R}_J(y,s) \cdot \sqrt{\left(\frac{SE\left(\hat{F}_J(y,s)\right)}{\hat{F}_J(y,s)}\right)^2 + \left(\frac{SE\big(C_M(y)\big)}{C_M(y)}\right)^2}, \qquad \textbf{Equation 50}$$

where $\hat{F}_J(y,s)$ is the APWRA wide sum of fatalities, $\sum_{b\in B} \hat{F}_J(y,s,b)$, and $C_M(y)$ is the APWRA-wide sum of monitored capacity, $\sum_{b\in B} C_M(y,b)$. The standard error for these two APWRA-wide sums are given by the following formulae:

$$SE\left(\hat{F}_J(y,s)\right) = \sum_{b\in B} SE\left(\hat{F}_J(y,s,b)\right), \qquad \textbf{Equation 51}$$

$$SE\big(C_M(y)\big) = \sqrt{\sum_{b\in B} SE\big(C_M(y,b)\big)^2}. \qquad \textbf{Equation 52}$$

The standard error in Equation 51 is a conservative estimate. Because there is likely to be significant covariance of the fatality rates between BLOBs, the standard error formula from Equation 59 will underestimate the standard error of the fatality count. Consequently, the more conservative standard error formula from Equation 60 is used instead.

The standard error for the fatality count at an unmonitored BLOB is thus given by the formula

$$SE\left(\hat{F}(y,s,b)\right) = \hat{F}(y,s,b) \cdot \sqrt{SE\left(\hat{R}_J(y,s)\right)^2 + SE\big(C_I(y,b)\big)^2}. \qquad \textbf{Equation 53}$$

D.10 Estimating Fatality Counts at Unmonitored BLOBs

When a BLOB is not monitored, the fatality rate must be estimated using an alternative method. This may come from a statistical model, and average of monitored rates in previous years when the BLOB was monitored, or simply the APWRA-wide monitored average. Once the rate and its error terms have been defined, the BLOB can be included in the APWRA-wide total.

D.11 Delta Method

The delta method is one way to estimate the standard error of an arbitrary function of several arguments, using a Taylor's approximation of the function and the variance matrix of the arguments. For some n-ary function $f(x_1, x_2, \cdots, x_n)$, define the variance matrix $\mathbf{V}$ of the function f as follows:

- For all entries $v_{i,i}$ $(1 \le i \le n)$ on the northwest diagonal of **V**, the value of the entry is the variance of variable $\hat{x}_i$, $SE(\hat{x}_i)^2$.
- For all entries $v_{i,j}$ $(i \ne j, 1 \le i, j \le n)$ not on the northwest diagonal of **V**, the value of the entry is the covariance of variable x_i and variable $\hat{x}_j$, $SE(\hat{x}_i, \hat{x}_j)$.

Using this variance matrix, the standard error of the n-ary function f can then be approximated by

$$SE\big(f(x_1, x_2, \cdots, x_n)\big) = \sqrt{\nabla f \cdot \mathbf{V} \cdot (\nabla f)^{\mathrm{T}}}, \qquad \textbf{Equation 54}$$

where ∇f is the gradient matrix of f,

$$\nabla f = \begin{bmatrix} \frac{\partial f}{\partial x_1} & \frac{\partial f}{\partial x_2} & \cdots & \frac{\partial f}{\partial x_n} \end{bmatrix}, \qquad \textbf{Equation 55}$$

and $(\nabla f)^{\mathrm{T}}$ is the transpose of the gradient matrix of f.

For a binary function $f(x, y)$, the variance matrix $\mathbf{V}$ will be given by the formula

$$\mathbf{V} = \begin{bmatrix} SE(\hat{x})^2 & SE(\hat{x}, \hat{y}) \\ SE(\hat{x}, \hat{y}) & SE(\hat{y})^2 \end{bmatrix} \qquad \textbf{Equation 56}$$

and gradient matrix by the formula

$$\nabla f = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix}. \qquad \textbf{Equation 57}$$

Substituting these terms into Equation 54, it can be seen that the standard error of $f(\hat{x}, \hat{y})$ is given by the formula

$$\begin{aligned} SE\big(f(\hat{x}, \hat{y})\big) &= \sqrt{\left\| \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix} \cdot \begin{bmatrix} SE(\hat{x})^2 & SE(\hat{x}, \hat{y}) \\ SE(\hat{x}, \hat{y}) & SE(\hat{y})^2 \end{bmatrix} \cdot \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \right\|} \\ &= \sqrt{\left(\frac{\partial f}{\partial x} SE(\hat{x})\right)^2 + 2\frac{\partial f}{\partial x} \cdot \frac{\partial f}{\partial y} SE(\hat{x}, \hat{y}) + \left(\frac{\partial f}{\partial y} SE(\hat{y})\right)^2}. \end{aligned} \qquad \textbf{Equation 58}$$

D.11.1 Example: Sum of Estimates

When several uncorrelated estimates are added together, the Delta method specifies that their standard errors should be combined using the *square root of sum of squares* method:

$$SE\left(\sum_{i=1}^{n} \hat{x}_i\right) = \sqrt{\sum_{i=1}^{n} SE(\hat{x}_i)^2}. \qquad \textbf{Equation 59}$$

When several perfectly correlated estimates are added together, the Delta method specifies that their standard errors should be added together using the simple sum:

$$SE\left(\sum_{i=1}^{n} \hat{x}_i\right) = \sum_{i=1}^{n} SE(\hat{x}_i). \qquad \textbf{Equation 60}$$

D.11.2 Example: Product or Quotient of Estimates

The standard error of the product or quotient of several uncorrelated estimates ($\hat{X} = \prod_{i=1}^{n} \hat{x}_i$) is given by the formula

$$SE(\hat{X}) = \hat{X} \cdot \sqrt{\sum_{i=1}^{n} \left(\frac{SE(\hat{x}_i)}{\hat{x}_i}\right)^2}. \quad \textbf{Equation 61}$$

When several perfectly correlated estimates are multiplied together, the Delta method specifies that their standard errors is given by the formula

$$SE(\hat{X}) = \hat{X} \cdot \sum_{i=1}^{n} \frac{SE(\hat{x}_i)}{\hat{x}_i}. \quad \textbf{Equation 62}$$

D.11.3 Example: Arithmetic Mean of Estimates

The standard error of the arithmetic mean of several uncorrelated estimates is given by the formula

$$SE\left(\frac{1}{n} \cdot \sum_{i=1}^{n} \hat{x}_i\right) = \frac{1}{n} \cdot \sqrt{\sum_{i=1}^{n} SE(\hat{x}_i)}. \quad \textbf{Equation 63}$$

Note that this is a combination of the sum of estimates and product of estimates.

The standard error of the arithmetic mean of several perfectly correlated estimates is the arithmetic mean of the standard errors of the estimates.

D.11.4 Example: Estimated Fatality Count

For the adjusted fatality count $\hat{F}(y, s, b)$ the 1×2 gradient vector is constructed as follows:

$$\begin{aligned} \mathbf{A} &= \boldsymbol{\nabla} \hat{F} \\ &= \begin{bmatrix} \frac{\partial \hat{F}}{\partial \hat{P}} & \frac{\partial \hat{F}}{\partial \hat{E}} \end{bmatrix} \\ &= \begin{bmatrix} \frac{-1}{\hat{P}^2 \cdot \hat{E}} & \frac{-1}{\hat{P} \cdot \hat{E}^2} \end{bmatrix}. \end{aligned} \quad \textbf{Equation 64}$$

The 2×2 variance matrix is constructed as follows:

$$\mathbf{V} = \begin{bmatrix} SE(\hat{P})^2 & 0 \\ 0 & SE(\hat{E})^2 \end{bmatrix}. \quad \textbf{Equation 65}$$

Note that the covariance of $\hat{P}$ and $\hat{E}$ is assumed to be zero, since the values were obtained independently. These two matrices can then be substituted into Equation 9, yielding the formula for the standard error of the fatality count:

$$SE\left(\hat{F}_J(y,s,b)\right) = \frac{F_D(y,s,b)}{K(y,b)} \cdot \sqrt{\left(\frac{SE(\hat{P})}{\hat{P}^2 \cdot \hat{E}}\right)^2 + \left(\frac{SE(\hat{E})}{\hat{P} \cdot \hat{E}^2}\right)^2}\,. \qquad \textbf{Equation 66}$$

Appendix E

BLOB Characteristics

Table E. Megawatt Capacities, Unadjusted and Adjusted Fatality Rates, Estimated Total Fatalities, and Bird Use by BLOB, Monitoring Years 2005–2013

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
BLOB 1									
Installed capacity (MW)	12	12	12	12	12	12	12	12	12
Monitored capacity (MW)	0	0	0	0	0	0	0	0	0
American kestrel									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
BLOB 2									
Installed capacity (MW)	29	29	28	27	26	26	26	26	26
Monitored capacity (MW)	14	14	14	14	14	0	0	0	0
American kestrel									
Adjusted fatalities per MW	0.00	0.00	0.50	0.00	0.25	–	–	–	–
Estimated total fatalities	0	0	14	0	7	–	–	–	–
Mean observations per minute per km³	0.316	0.383	0.888	0.347	0.273	0.190	–	–	–
Burrowing owl									
Adjusted fatalities per MW	0.81	1.38	0.53	0.24	1.32	–	–	–	–
Estimated total fatalities	23	40	15	6	35	–	–	–	–
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	–	–	–
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.08	0.00	0.00	–	–	–	–
Estimated total fatalities	0	0	2	0	0	–	–	–	–
Mean observations per minute per km³	0.528	0.202	0.395	0.138	0.356	0.056	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	0.27	0.00	0.10	0.00	0.00	–	–	–	–
Estimated total fatalities	8	0	3	0	0	–	–	–	–
Mean observations per minute per km³	0.752	0.998	0.763	0.375	0.331	0.570	–	–	–

BLOB	Bird Year 2005	2006	2007	2008	2009	2010	2011	2012	2013
BLOB 3									
Installed capacity (MW)	3	32	38	38	38	38	38	38	38
Monitored capacity (MW)	0	0	0	0	0	0	0	0	0
American kestrel									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	–	–	–	–	–	–	–	– –	
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
BLOB 4									
Installed capacity (MW)	58	56	53	50	47	33	52	78	78
Monitored capacity (MW)	18	19	23	21	21	0	0	0	0
American kestrel									
Adjusted fatalities per MW	0.56		0.46	0.30	0.17	–	–	–	–
Estimated total fatalities	33	0	24	15	8	–	–	– –	
Mean observations per minute per km³	0.047	0.248	0.109	0.312	0.177	0.174	–	–	–
Burrowing owl									
Adjusted fatalities per MW	0.00	0.19	0.16	0.00	0.18	–	–	–	–
Estimated total fatalities	0	11	9	0	8	–	–	–	–
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.011	0.00	–	–	–
Golden eagle									
Adjusted fatalities per MW	0.29	0.17	0.00	0.05	0.05	–	–	–	–
Estimated total fatalities	17	9	0	3	2	–	–	–	–
Mean observations per minute per km³	0.155	0.379	0.206	0.285	0.117	0.089	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	0.94	0.22	0.25	0.06	0.21	–	–	–	–
Estimated total fatalities	55	12	13	3	10	–	–	–	–
Mean observations per minute per km³	0.909	0.840	1.056	0.762	0.638	0.892	–	–	–

BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
	Bird Year								
BLOB 5									
Installed capacity (MW)	18	18	15	14	13	13	8	6	6
Monitored capacity (MW)	1	1	10	9	9	6	3	2	3
American kestrel									
Adjusted fatalities per MW	3.07	1.62	0.35	0.00	0.41	0.00	0.00	0.00	0.00
Estimated total fatalities	56	29	5	0	5	0	0	0	0
Mean observations per minute per km^3	–	0.059	0.024	0.297	0.224	0.374	0.299	0.279	0.008
Burrowing owl									
Adjusted fatalities per MW	0.12	1.40	0.00	0.38	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	2	25	0	5	0	0	0	0	0
Mean observations per minute per km^3	–	0.041	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.13	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Estimated total fatalities	2	1	0	0	0	0	0	0	3
Mean observations per minute per km^3	–	0.023	0.473	0.370	0.229	0.322	0.149	0.151	0.203
Red-tailed hawk									
Adjusted fatalities per MW	0.50	0.00	0.43	0.15	0.00	0.46	0.63	0.00	0.00
Estimated total fatalities	9	3	7	2	0	6	5	0	0
Mean observations per minute per km^3	–	0.943	0.733	1.007	0.913	0.710	0.523	0.611	0.869
BLOB 6									
Installed capacity (MW)	8	8	7	6	6	6	5	5	5
Monitored capacity (MW)	2	1	1	1	1	2	1	3	1
American kestrel									
Adjusted fatalities per MW	0.00	2.40	0.00	0.00	6.35	1.96	4.15	0.00	0.00
Estimated total fatalities	0	18	0	0	38	12	22	0	0
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	0.00	2.55	0.00	3.12	0.00	2.08	0.00	0.00	0.00
Estimated total fatalities	0	20	0	19	0	12	0	0	0
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	0.82	0.00	0.00	0.00	0.99	0.00	2.37	0.00	0.00
Estimated total fatalities	6	0	0	0	6	0	12	0	0
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	0.00
Estimated total fatalities	0	0	0	0	0	0	0	8	0
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–

BLOB	Bird Year 2005	2006	2007	2008	2009	2010	2011	2012	2013
BLOB 7									
Installed capacity (MW)	18	18	18	17	17	17	17	16	16
Monitored capacity (MW)	9	9	9	9	9	9	5	7	8
American kestrel									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.40	0.00	0.81	0.00	0.00
Estimated total fatalities	0	0	0	0	7	0	13	0	0
Mean observations per minute per km^3	0.090	0.165	0.00	0.181	0.019	0.031	0.062	0.033	0.004
Burrowing owl									
Adjusted fatalities per MW	0.62	3.33	1.68	1.18	0.42	0.89	0.86	1.24	0.00
Estimated total fatalities	11	61	30	20	7	15	14	20	0
Mean observations per minute per km^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.14	0.12	0.12	0.00	0.00	0.13	0.00	0.34	0.00
Estimated total fatalities	3	2	2	0	0	2	0	6	0
Mean observations per minute per km^3	0.122	0.050	0.149	0.070	0.264	0.226	0.118	0.273	0.432
Red-tailed hawk									
Adjusted fatalities per MW	0.42	0.79	0.64	0.00	0.65	0.17	0.00	0.46	0.00
Estimated total fatalities	8	14	12	0	11	3	0	8	0
Mean observations per minute per km^3	0.801	0.427	0.770	0.954	0.574	0.936	0.664	0.513	1.688
BLOB 8									
Installed capacity (MW)	16	15	15	15	14	14	14	14	14
Monitored capacity (MW)	7	7	7	6	6	5	9	6	9
American kestrel									
Adjusted fatalities per MW	0.00	2.14	0.00	0.51	0.00	0.67	2.20	2.57	0.00
Estimated total fatalities	0	33	0	7	0	9	30	35	0
Mean observations per minute per km^3	0.492	0.134	0.018	0.043	0.126	0.336	0.203	0.175	0.059
Burrowing owl									
Adjusted fatalities per MW	0.86	0.00	0.57	0.54	1.77	0.00	0.00	0.68	0.00
Estimated total fatalities	14	0	9	8	24	0	0	9	0
Mean observations per minute per km^3	0.00	0.037	0.00	0.00	0.194	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.20	0.16	0.00	0.00	0.00	0.21	0.16	0.19	0.27
Estimated total fatalities	3	2	0	0	0	3	2	3	4
Mean observations per minute per km^3	0.348	0.172	0.360	1.147	0.358	0.794	0.409	0.644	0.720
Red-tailed hawk									
Adjusted fatalities per MW	0.58	0.00	0.65	0.21	0.00	0.28	0.21	1.03	0.37
Estimated total fatalities	9	0	10	3	0	4	3	14	5
Mean observations per minute per km^3	1.666	1.167	1.116	0.714	1.367	0.651	0.329	1.064	1.496
BLOB 9									
Installed capacity (MW)	9	9	8	8	8	8	8	7	7
Monitored capacity (MW)	9	9	8	8	8	5	6	6	5
American kestrel									
Adjusted fatalities per MW	1.27	0.88	0.43	0.38	1.24	0.72	0.00	1.17	0.80
Estimated total fatalities	11	8	4	3	10	6	0	9	6
Mean observations per minute per km^3	1.099	0.628	0.377	1.066	0.692	0.442	0.369	0.414	–

BLOB	Bird Year 2005	2006	2007	2008	2009	2010	2011	2012	2013
Burrowing owl									
Adjusted fatalities per MW	1.35	1.41	0.00	0.00	0.44	0.00	0.00	0.00	0.00
Estimated total fatalities	12	12	0	0	4	0	0	0	0
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Golden eagle									
Adjusted fatalities per MW	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	1	0	0	0	0	0	0	0
Mean observations per minute per km³	0.00	0.004	0.151	0.198	0.020	0.350	0.00	0.104	-
Red-tailed hawk									
Adjusted fatalities per MW	0.45	0.17	0.35	0.16	0.34	0.00	0.28	0.23	0.31
Estimated total fatalities	4	1	3	1	3	0	2	2	2
Mean observations per minute per km³	1.636	3.978	2.870	2.035	0.534	0.535	0.484	0.311	-
BLOB 10									
Installed capacity (MW)	24	23	22	22	19	18	17	17	17
Monitored capacity (MW)	3	3	12	12	11	3	5	3	3
American kestrel									
Adjusted fatalities per MW	1.21	0.81	0.29	0.55	0.33	1.17	1.81	1.15	0.00
Estimated total fatalities	29	19	7	12	6	21	31	20	0
Mean observations per minute per km³	0.502	0.117	0.122	0.055	0.154	0.00	0.050	0.196	0.213
Burrowing owl									
Adjusted fatalities per MW	0.12	0.70	0.31	0.58	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	3	16	7	13	0	0	0	0	0
Mean observations per minute per km³	0.061	0.088	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.34	0.30	0.27	0.09	0.10	0.00	0.26	0.00	0.00
Estimated total fatalities	8	7	6	2	2	0	4	0	0
Mean observations per minute per km³	0.149	0.242	0.486	0.877	0.589	0.164	0.143	0.714	0.323
Red-tailed hawk									
Adjusted fatalities per MW	0.65	0.19	0.83	0.47	0.00	0.48	1.06	2.29	0.00
Estimated total fatalities	15	4	18	10	0	8	18	40	0
Mean observations per minute per km³	1.389	1.414	3.165	3.593	1.041	1.447	0.510	1.106	1.623
BLOB 11									
Installed capacity (MW)	13	13	13	11	11	10	10	10	10
Monitored capacity (MW)	7	7	8	6	6	6	5	6	5
American kestrel									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.76
Estimated total fatalities	0	0	0	0	0	0	0	7	8
Mean observations per minute per km³	0.043	0.075	0.118	0.023	0.144	0.091	0.055	0.181	0.080
Burrowing owl									
Adjusted fatalities per MW	1.56	3.88	1.47	0.00	0.00	0.00	0.99	0.00	0.00
Estimated total fatalities	21	51	19	0	0	0	10	0	0
Mean observations per minute per km³	0.00	0.00	0.00	0.183	0.00	0.00	0.00	0.00	0.00

BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
	Bird Year								
Golden eagle									
Adjusted fatalities per MW	0.00	0.16	0.43	0.17	0.37	0.00	0.27	0.00	0.00
Estimated total fatalities	0	2	5	2	4	0	3	0	0
Mean observations per minute per km³	0.075	0.215	0.842	0.516	0.391	0.395	0.315	0.355	0.469
Red-tailed hawk									
Adjusted fatalities per MW	1.61	0.64	0.94	0.00	0.00	0.27	0.00	1.34	0.00
Estimated total fatalities	21	8	12	0	0	3	0	14	0
Mean observations per minute per km³	1.150	0.870	1.319	1.124	1.115	0.991	1.414	2.201	2.474
BLOB 12									0.00
Installed capacity (MW)	16	16	16	16	13	11	10	7	7
Monitored capacity (MW)	6	6	6	6	5	5	5	3	4
American kestrel									
Adjusted fatalities per MW	0.00	0.00	1.13	1.04	0.00	0.00	1.99	0.00	0.00
Estimated total fatalities	0	0	18	17	0	0	21	0	0
Mean observations per minute per km³	0.286	0.053	0.039	0.223	0.129	0.173	0.00	0.00	0.009
Burrowing owl									
Adjusted fatalities per MW	0.00	1.16	1.80	1.10	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	19	29	18	0	0	0	0	0
Mean observations per minute per km³	0.00	0.00	0.00	0.294	0.016	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.19	0.51	0.35	0.17	0.41	1.08	0.28	0.42	0.90
Estimated total fatalities	3	8	6	3	6	12	3	3	6
Mean observations per minute per km³	0.151	0.025	0.362	0.194	0.373	0.192	0.202	0.285	0.229
Red-tailed hawk									
Adjusted fatalities per MW	0.83	0.67	0.46	0.00	0.27	0.57	0.00	0.00	0.00
Estimated total fatalities	14	11	7	0	4	6	0	0	0
Mean observations per minute per km³	0.636	0.606	1.945	1.161	0.293	0.705	0.625	0.419	1.383
BLOB 13									
Installed capacity (MW)	27	27	26	24	23	23	23	23	23
Monitored capacity (MW)	11	11	10	10	10	7	5	9	7
American kestrel									
Adjusted fatalities per MW	0.00	1.65	1.04	0.67	0.36	1.04	0.93	0.00	0.00
Estimated total fatalities	0	45	27	16	8	24	22	0	0
Mean observations per minute per km³	0.670	0.632	0.632	0.837	0.282	0.318	0.179	0.313	0.197
Burrowing owl									
Adjusted fatalities per MW	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	9	0	0	0	0	0	0	0
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	0.030	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.24	0.00	0.00	0.22	0.34	0.00	0.00	0.13	0.16
Estimated total fatalities	7	0	0	5	8	0	0	3	4
Mean observations per minute per km³	0.160	0.070	0.240	0.540	0.520	0.720	0.347	0.781	0.364

BLOB	Bird Year 2005	2006	2007	2008	2009	2010	2011	2012	2013
Red-tailed hawk									
Adjusted fatalities per MW	0.52	0.40	0.42	0.14	0.00	0.84	0.36	0.54	0.44
Estimated total fatalities	14	11	11	3	0	19	8	13	10
Mean observations per minute per km³	1.654	1.019	0.618	2.113	0.429	0.813	0.588	0.606	1.109
BLOB 14									
Installed capacity (MW)	16	16	13	11	10	9	9	8	8
Monitored capacity (MW)	3	3	2	2	2	5	2	2	3
American kestrel									
Adjusted fatalities per MW	0.00	0.00	0.00	1.54	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	0	0	17	0	0	0	0	0
Mean observations per minute per km³	0.169	0.194	0.291	0.030	0.163	0.150	0.051	0.051	0.010
Burrowing owl									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.78	7.43	0.00	0.00
Estimated total fatalities	0	0	0	0	0	7	66	0	0
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.47	0.00	0.00	0.00	1.00	0.64	0.52
Estimated total fatalities	0	0	6	0	0	0	9	5	4
Mean observations per minute per km³	0.160	0.114	0.730	0.552	0.760	0.237	0.195	0.534	0.165
Red-tailed hawk									
Adjusted fatalities per MW	0.72	1.70	0.61	1.31	0.82	0.61	2.73	0.00	1.41
Estimated total fatalities	11	27	8	15	8	6	24	0	11
Mean observations per minute per km³	1.666	1.977	2.473	1.586	1.025	0.760	2.042	2.554	2.388
BLOB 15									
Installed capacity (MW)	8	8	7	6	6	6	6	6	6
Monitored capacity (MW)	5	5	5	4	4	3	3	2	3
American kestrel									
Adjusted fatalities per MW	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	17	0	0	0	0	0	0	0	0
Mean observations per minute per km³	0.126	0.109	0.352	0.025	0.081	0.119	0.011	0.166	0.427
Burrowing owl									
Adjusted fatalities per MW	1.14	2.39	0.82	0.00	2.65	0.00	2.86	0.00	0.00
Estimated total fatalities	9	18	5	0	17	0	18	0	0
Mean observations per minute per km³	2.814	0.169	0.574	0.463	0.167	0.980	0.437	0.114	0.00
Golden eagle									
Adjusted fatalities per MW	0.27	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	2	2	0	0	0	0	0	0	0
Mean observations per minute per km³	0.084	0.082	0.252	0.461	0.727	0.317	0.231	0.157	0.174
Red-tailed hawk									
Adjusted fatalities per MW	1.57	2.49	0.32	0.32	0.00	0.00	0.53	0.00	0.90
Estimated total fatalities	12	19	2	2	0	0	3	0	5
Mean observations per minute per km³	2.372	2.167	1.549	1.847	1.250	1.876	1.401	1.987	3.651
BLOB 16									
Installed capacity (MW)	2	2	2	2	2	2	2	2	2
Monitored capacity (MW)	2	2	2	2	2	2	2	2	2

BLOB	Bird Year 2005	2006	2007	2008	2009	2010	2011	2012	2013
American kestrel									
Adjusted fatalities per MW	0.00	1.47	1.45	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	4	4	0	0	0	0	0	0
Mean observations per minute per km^3	0.00	0.043	0.117	0.130	0.095	0.099	0.221	0.00	–
Burrowing owl									
Adjusted fatalities per MW	2.24	3.12	1.54	1.43	4.63	0.00	0.00	3.45	0.00
Estimated total fatalities	6	8	4	3	11	0	0	8	0
Mean observations per minute per km^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	0	0	1	0	0	0	0	0
Mean observations per minute per km^3	1.811	0.498	0.117	0.734	0.047	0.050	0.166	0.00	–
Red-tailed hawk									
Adjusted fatalities per MW	1.51	0.59	0.00	1.15	0.59	1.26	0.65	0.00	0.67
Estimated total fatalities	4	1	0	3	1	3	2	0	2
Mean observations per minute per km^3	3.243	2.146	7.190	1.901	2.508	2.584	1.435	2.484	–
BLOB 17									
Installed capacity (MW)	6	6	6	5	5	5	5	5	5
Monitored capacity (MW)	6	6	6	5	5	4	4	4	5
American kestrel									
Adjusted fatalities per MW	0.00	0.00	1.88	0.00	0.65	0.00	0.00	0.00	0.00
Estimated total fatalities	0	0	11	0	4	0	0	0	0
Mean observations per minute per km^3	0.057	0.030	0.171	0.216	0.117	0.324	0.066	1.566	–
Burrowing owl									
Adjusted fatalities per MW	5.83	8.75	1.99	1.88	2.08	2.07	3.04	0.00	2.45
Estimated total fatalities	33	50	11	10	11	11	16	0	12
Mean observations per minute per km^3	0.00	0.085	0.210	0.216	0.510	0.076	0.00	0.00	–
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
Estimated total fatalities	0	0	0	0	0	0	0	0	1
Mean observations per minute per km^3	1.186	0.243	0.295	0.642	0.038	0.204	0.065	0.087	–
Red-tailed hawk									
Adjusted fatalities per MW	1.31	1.79	0.76	0.75	0.27	1.18	0.00	0.66	0.00
Estimated total fatalities	7	10	4	4	1	6	0	3	0
Mean observations per minute per km^3	3.281	1.783	2.256	1.172	0.928	0.895	0.522	0.957	–
BLOB 18									
Installed capacity (MW)	11	10	10	10	10	9	9	8	8
Monitored capacity (MW)	4	4	4	4	4	2	2	2	3
American kestrel									
Adjusted fatalities per MW	0.00	0.85	0.90	0.00	0.95	0.00	0.00	0.00	0.00
Estimated total fatalities	0	9	9	0	9	0	0	0	0
Mean observations per minute per km^3	0.157	0.247	0.147	0.784	0.161	0.060	0.112	0.290	0.546

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
Burrowing owl									
Adjusted fatalities per MW	2.50	5.41	1.91	0.88	4.02	0.00	0.00	1.86	1.37
Estimated total fatalities	27	57	20	9	39	0	0	14	10
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.53	0.37
Estimated total fatalities	0	0	0	0	0	6	0	4	3
Mean observations per minute per km³	0.081	0.019	0.00	0.069	0.018	0.383	0.089	0.012	0.171
Red-tailed hawk									
Adjusted fatalities per MW	0.00	0.69	0.00	0.35	0.78	0.00	2.38	0.71	1.52
Estimated total fatalities	0	7	0	4	7	0	21	5	12
Mean observations per minute per km³	1.720	1.489	0.566	0.323	1.448	0.729	0.612	1.548	2.440
BLOB 19									
Installed capacity (MW)	19	19	19	19	19	19	19	19	19
Monitored capacity (MW)	12	12	12	12	12	14	12	13	14
American kestrel									
Adjusted fatalities per MW	0.00	0.00	0.61	0.54	0.88	1.06	0.00	1.16	1.68
Estimated total fatalities	0	0	12	10	17	20	0	22	32
Mean observations per minute per km³	0.133	0.209	0.00	0.087	0.144	1.023	0.030	0.063	0.060
Burrowing owl									
Adjusted fatalities per MW	0.42	1.88	0.00	0.00	0.62	0.28	0.69	0.31	0.30
Estimated total fatalities	8	36	0	0	12	5	13	6	6
Mean observations per minute per km³	0.00	0.550	0.577	0.00	0.121	0.274	0.131	0.676	0.182
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.08
Estimated total fatalities	0	0	0	0	0	3	0	0	2
Mean observations per minute per km³	0.012	0.049	0.073	0.280	0.067	0.046	0.060	0.096	0.075
Red-tailed hawk									
Adjusted fatalities per MW	0.30	0.36	0.61	0.91	0.84	1.62	0.77	0.70	0.99
Estimated total fatalities	6	7	12	17	16	31	14	13	19
Mean observations per minute per km³	1.058	0.587	0.258	0.781	0.790	0.695	0.434	0.660	0.652
BLOB 20									
Installed capacity (MW)	5	5	3	3	3	3	3	3	3
Monitored capacity (MW)	2	2	2	2	2	3	2	2	3
American kestrel									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.00	1.21
Estimated total fatalities	0	0	0	0	7	0	0	0	4
Mean observations per minute per km³	0.116	0.694	0.085	0.737	0.455	0.231	0.526	0.077	0.541
Burrowing owl									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.28
Estimated total fatalities	0	0	0	0	0	0	0	0	4
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.038	0.00	0.00	0.00

BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
	Bird Year								
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km³	0.080	0.00	0.085	0.385	0.035	0.346	0.040	0.056	0.023
Red-tailed hawk									
Adjusted fatalities per MW	0.00	0.00	0.87	0.00	0.00	1.47	0.00	0.00	0.00
Estimated total fatalities	0	0	3	0	0	5	0	0	0
Mean observations per minute per km³	0.288	0.703	0.085	0.513	0.315	1.500	0.283	0.360	0.684
BLOB 21									
Installed capacity (MW)	0	0	0	0	0	0	0	0	0
Monitored capacity (MW)	0	0	0	0	0	0	0	0	0
American kestrel									
Adjusted fatalities per MW	NA	NA	NA	NA	NA	NA	NA	NA	NA
Estimated total fatalities	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	NA	NA	NA	NA	NA	NA	NA	NA	NA
Estimated total fatalities	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	NA	NA	NA	NA	NA	NA	NA	NA	NA
Estimated total fatalities	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	NA	NA	NA	NA	NA	NA	NA	NA	NA
Estimated total fatalities	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean observations per minute per km³	–	–	–	–	–	–	–	–	–
BLOB 22									
Installed capacity (MW)	3	3	3	3	3	3	3	3	3
Monitored capacity (MW)	3	3	3	3	3	3	3	3	3
American kestrel									
Adjusted fatalities per MW	0.00	1.07	1.07	0.98	0.00	0.00	0.00	1.36	0.00
Estimated total fatalities	0	4	4	3	0	0	0	4	0
Mean observations per minute per km³	0.808	0.378	0.720	1.484	0.764	1.183	0.919	1.050	–
Burrowing owl									
Adjusted fatalities per MW	0.00	2.28	1.14	0.00	0.00	0.00	1.30	1.44	1.30
Estimated total fatalities	0	8	4	0	0	0	4	5	4
Mean observations per minute per km³	0.00	0.007	0.00	0.00	0.00	0.00	0.00	0.00	–
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	0	1	0	0	0	0	0	0
Mean observations per minute per km³	0.997	0.409	0.349	0.223	0.436	0.00	0.025	0.00	–

BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
	Bird Year								
Red-tailed hawk									
Adjusted fatalities per MW	0.00	0.43	0.44	0.00	0.86	0.00	0.48	0.00	0.00
Estimated total fatalities	0	1	1	0	3	0	2	0	0
Mean observations per minute per km³	1.847	2.530	0.878	2.197	1.382	2.137	0.730	0.343	–
BLOB 23									
Installed capacity (MW)	34	32	30	27	25	25	24	24	24
Monitored capacity (MW)	18	17	24	21	19	5	5	6	5
American kestrel									
Adjusted fatalities per MW	0.61	1.03	0.15	0.64	0.37	0.81	0.00	0.00	0.00
Estimated total fatalities	21	33	5	17	9	20	0	0	0
Mean observations per minute per km³	0.308	0.194	0.120	0.368	0.394	0.142	0.157	0.427	0.278
Burrowing owl									
Adjusted fatalities per MW	0.65	4.17	1.29	0.17	0.79	0.86	1.69	0.64	0.00
Estimated total fatalities	22	132	39	5	20	21	41	16	0
Mean observations per minute per km³	1.961	0.147	0.150	0.00	0.00	0.016	0.010	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.23	0.13	0.09	0.05	0.00	0.00	0.00	0.55	0.00
Estimated total fatalities	8	4	3	1	0	0	0	13	0
Mean observations per minute per km³	0.324	0.060	0.200	0.138	0.114	0.136	0.130	0.132	0.169
Red-tailed hawk									
Adjusted fatalities per MW	0.44	0.67	0.12	0.14	0.08	0.00	0.62	0.00	0.33
Estimated total fatalities	15	21	4	4	2	0	15	0	8
Mean observations per minute per km³	2.822	1.297	1.223	0.668	0.366	1.105	0.768	1.153	0.946
BLOB 24									
Installed capacity (MW)	20	20	19	16	16	16	16	16	16
Monitored capacity (MW)	11	11	15	13	13	6	6	7	6
American kestrel									
Adjusted fatalities per MW	0.00	0.96	0.00	0.25	0.00	0.00	0.00	0.54	0.00
Estimated total fatalities	0	19	0	4	0	0	0	8	0
Mean observations per minute per km³	0.110	0.090	0.020	0.214	0.207	0.130	0.098	0.330	0.226
Burrowing owl									
Adjusted fatalities per MW	0.00	1.35	0.78	0.00	0.29	0.00	0.88	1.15	0.00
Estimated total fatalities	0	27	14	0	5	0	14	18	0
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.20
Estimated total fatalities	0	2	0	0	0	0	0	0	3
Mean observations per minute per km³	0.024	0.022	0.100	0.045	0.220	0.277	0.089	0.090	0.068
Red-tailed hawk									
Adjusted fatalities per MW	0.54	0.91	0.30	0.00	0.11	0.51	0.93	0.00	0.00
Estimated total fatalities	11	18	6	0	2	8	15	0	0
Mean observations per minute per km³	1.361	0.893	0.880	0.440	0.214	0.626	0.771	0.468	0.677

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
BLOB 25									
Installed capacity (MW)	40	40	39	38	37	37	37	36	36
Monitored capacity (MW)	18	21	29	27	27	6	15	6	6
American kestrel									
Adjusted fatalities per MW	0.85	0.83	1.98	0.59	0.53	0.00	0.90	1.81	0.73
Estimated total fatalities	34	33	78	22	20	0	33	66	26
Mean observations per minute per km^3	0.177	0.236	0.238	0.626	0.354	0.276	0.276	0.145	0.381
Burrowing owl									
Adjusted fatalities per MW	0.00	0.70	0.26	0.00	0.14	0.75	0.95	0.00	0.00
Estimated total fatalities	0	28	10	0	5	27	35	0	0
Mean observations per minute per km^3	0.00	0.00	0.00	0.198	0.00	0.054	0.006	0.002	0.133
Golden eagle									
Adjusted fatalities per MW	0.07	0.20	0.04	0.04	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	3	8	1	1	0	0	0	0	0
Mean observations per minute per km^3	0.029	0.051	0.078	0.083	0.120	0.051	0.157	0.209	0.067
Red-tailed hawk									
Adjusted fatalities per MW	0.63	0.61	0.20	0.05	0.11	0.57	0.12	0.00	0.28
Estimated total fatalities	25	24	8	2	4	21	4	0	10
Mean observations per minute per km^3	1.572	1.069	0.713	0.667	0.293	0.729	0.826	0.567	1.049
BLOB 26									
Installed capacity (MW)	22	22	22	21	21	21	21	20	20
Monitored capacity (MW)	22	22	22	21	21	7	8	8	8
American kestrel									
Adjusted fatalities per MW	1.00	0.83	0.82	1.07	0.50	0.55	0.54	1.46	1.59
Estimated total fatalities	22	18	18	23	10	11	11	30	33
Mean observations per minute per km^3	0.442	0.111	0.024	0.203	0.090	0.052	0.075	0.166	0.334
Burrowing owl									
Adjusted fatalities per MW	0.53	0.88	0.70	0.00	0.00	0.58	1.14	1.04	1.69
Estimated total fatalities	12	19	15	0	0	12	23	21	35
Mean observations per minute per km^3	0.00	0.040	0.00	0.00	0.00	0.104	0.00	0.293	0.263
Golden eagle									
Adjusted fatalities per MW	0.00	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	2	2	0	0	0	0	0	0
Mean observations per minute per km^3	0.125	0.066	0.204	0.021	0.023	0.069	0.112	0.099	0.066
Red-tailed hawk									
Adjusted fatalities per MW	1.09	1.07	0.33	0.19	0.00	0.22	0.21	0.00	0.00
Estimated total fatalities	24	23	7	4	0	5	4	0	0
Mean observations per minute per km^3	2.094	0.909	0.690	0.596	0.676	0.968	0.854	1.288	1.283
BLOB 27									
Installed capacity (MW)	16	16	15	15	14	13	13	12	12
Monitored capacity (MW)	0	0	4	4	3	6	4	5	6
American kestrel									
Adjusted fatalities per MW	–	–	1.69	0.00	0.00	1.80	2.03	1.63	0.00
Estimated total fatalities	–	–	26	0	0	23	25	20	0
Mean observations per minute per km^3	–	0.096	0.570	0.118	0.696	0.267	0.099	0.630	0.652

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
Burrowing owl									
Adjusted fatalities per MW	–	–	0.00	0.00	0.00	1.27	0.00	0.87	0.00
Estimated total fatalities	2	22	0	4	0	16	0	11	0
Mean observations per minute per km³	–	0.128	0.00	0.00	0.177	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	–	–	0.00	0.26	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	–	–	0	4	0	0	0	0	0
Mean observations per minute per km³	–	0.00	0.042	0.00	0.054	0.057	0.079	0.043	0.156
Red-tailed hawk									
Adjusted fatalities per MW	0.50	0.38	0.34	0.00	0.00	0.00	0.79	0.00	0.00
Estimated total fatalities	–	–	5	0	0	0	10	0	0
Mean observations per minute per km³	–	0.947	1.340	0.656	0.425	0.373	0.555	1.647	0.550
BLOB 28									
Installed capacity (MW)	7	7	6	6	6	6	6	6	6
Monitored capacity (MW)	3	3	3	3	3	5	5	4	5
American kestrel									
Adjusted fatalities per MW	0.00	1.10	1.10	0.00	1.11	0.00	0.00	0.96	0.00
Estimated total fatalities	0	7	7	0	7	0	0	6	0
Mean observations per minute per km³	0.240	0.939	0.054	0.106	1.473	0.407	0.514	0.172	0.128
Burrowing owl									
Adjusted fatalities per MW	0.00	1.17	0.00	0.00	1.18	0.00	1.04	1.02	0.95
Estimated total fatalities	0	8	0	0	7	0	6	6	6
Mean observations per minute per km³	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00
Estimated total fatalities	0	0	0	0	0	1	0	0	0
Mean observations per minute per km³	0.058	0.108	0.00	0.00	0.349	0.041	0.00	0.018	0.077
Red-tailed hawk									
Adjusted fatalities per MW	1.18	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00
Estimated total fatalities	8	0	0	0	0	2	0	0	0
Mean observations per minute per km³	0.318	1.273	1.085	0.991	1.008	0.326	0.343	1.769	1.324
BLOB 29									
Installed capacity (MW)	24	23	23	22	20	18	18	18	14
Monitored capacity (MW)	10	9	10	10	9	5	3	4	5
American kestrel									
Adjusted fatalities per MW	1.20	3.11	0.69	0.98	0.75	0.89	1.33	2.01	0.00
Estimated total fatalities	29	73	16	21	15	16	24	37	0
Mean observations per minute per km³	1.043	0.891	0.392	0.323	0.407	0.304	0.190	0.306	0.671
Burrowing owl									
Adjusted fatalities per MW	0.00	3.72	0.73	0.00	0.40	0.00	0.00	1.07	0.00
Estimated total fatalities	0	87	17	0	8	0	0	20	0
Mean observations per minute per km³	0.00	0.007	0.008	0.00	0.00	0.00	0.00	0.076	0.00

BLOB	Bird Year 2005	2006	2007	2008	2009	2010	2011	2012	2013
Golden eagle									
Adjusted fatalities per MW	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	6	0	0	0	0	0	0	0
Mean observations per minute per km^3	0.108	0.126	0.198	0.055	0.127	0.377	0.050	0.048	0.101
Red-tailed hawk									
Adjusted fatalities per MW	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.39	0.34
Estimated total fatalities	0	0	0	0	0	6	0	7	5
Mean observations per minute per km^3	1.361	0.952	0.936	0.482	0.373	0.659	0.345	0.919	1.084
BLOB 30									
Installed capacity (MW)	20	20	20	20	20	20	20	20	20
Monitored capacity (MW)	20	20	20	20	20	0	0	0	0
American kestrel									
Adjusted fatalities per MW	0.17	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	4	0	0	3	0	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	0.74	0.75	0.36	0.50	0.55	0.00	0.00	0.00	0.00
Estimated total fatalities	15	15	7	10	11	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	0	0	0	2	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	0.21	0.21	0.62	0.34	0.00	0.00	0.00	0.00	0.00
Estimated total fatalities	4	4	13	7	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–

Appendix F

Background Mortality Study (Pending)