M107

FINAL REPORT

ALTAMONT PASS WIND RESOURCE AREA BIRD FATALITY STUDY, MONITORING YEARS 2005–2013

PREPARED FOR:

Alameda County Community Development Agency
224 W. Winton Avenue, Room 110
Hayward, CA 94544
Contact: Sandra Rivera
510.670.6526

PREPARED BY:

ICF International
630 K Street, Suite 400
Sacramento, CA 95814
Contact: Doug Leslie
916.231.9560

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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, making the area an ideal setting for production of wind energy. Permits have been granted for 5,400 wind turbines, which together had 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 regulations.

The numbers of birds killed annually in the APWRA in turbine-related incidents led to substantial controversy, which in September 2005 resulted in the Alameda County Board of Supervisors attaching extensive conditions of approval to use permits for the continued operation of wind power projects. Aimed at achieving major reductions in avian fatalities, these conditions included the establishment of an Avian Wildlife Protection Program and Schedule (AWPPS) and the formation of a Scientific Review Committee (SRC) and a Monitoring Team (MT).

- The AWPPS consisted 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 later in this chapter under *Management Actions and Repowering*.
- The SRC provided expertise on research and monitoring related to wind energy production and avian behavior and safety. To this end, the goals of the SRC were 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. The SRC advised Alameda County and the power companies on actions to reduce turbine-related avian fatalities including the 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 implemented the avian fatality monitoring program, analyzed data collected, and reported 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 changed several times since its formation. The MT was headed by West, Inc. for the first two years of the monitoring program, then 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*). That original baseline estimate—1,300 raptors per year—was based on the work of Smallwood and Thelander (2004: Table 3-11). However, 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 was 1,130 fatalities per year.

The primary goal of the avian fatality monitoring program, which ran continuously from October 1, 2005, through September 30, 2014 (hereinafter referred to as the *current study* or *the study*), was 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 better reflect the timing of annual movements of birds through the study area and the implementation of management actions, 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. 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 projects—referred to as *operating groups* in this report—shared a common turbine type, geographic location, and owner/operator, although these relationships have changed over the years. Operating groups were later refined into 30 BLOBs (i.e., *base layer of operating group boundaries*). BLOBs provided a basis for stratification of the analysis across the variable turbine types, topographies, and geographies of the APWRA (Figure 1-2).

The number of operating turbines decreased 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. Many of the older-generation turbines in

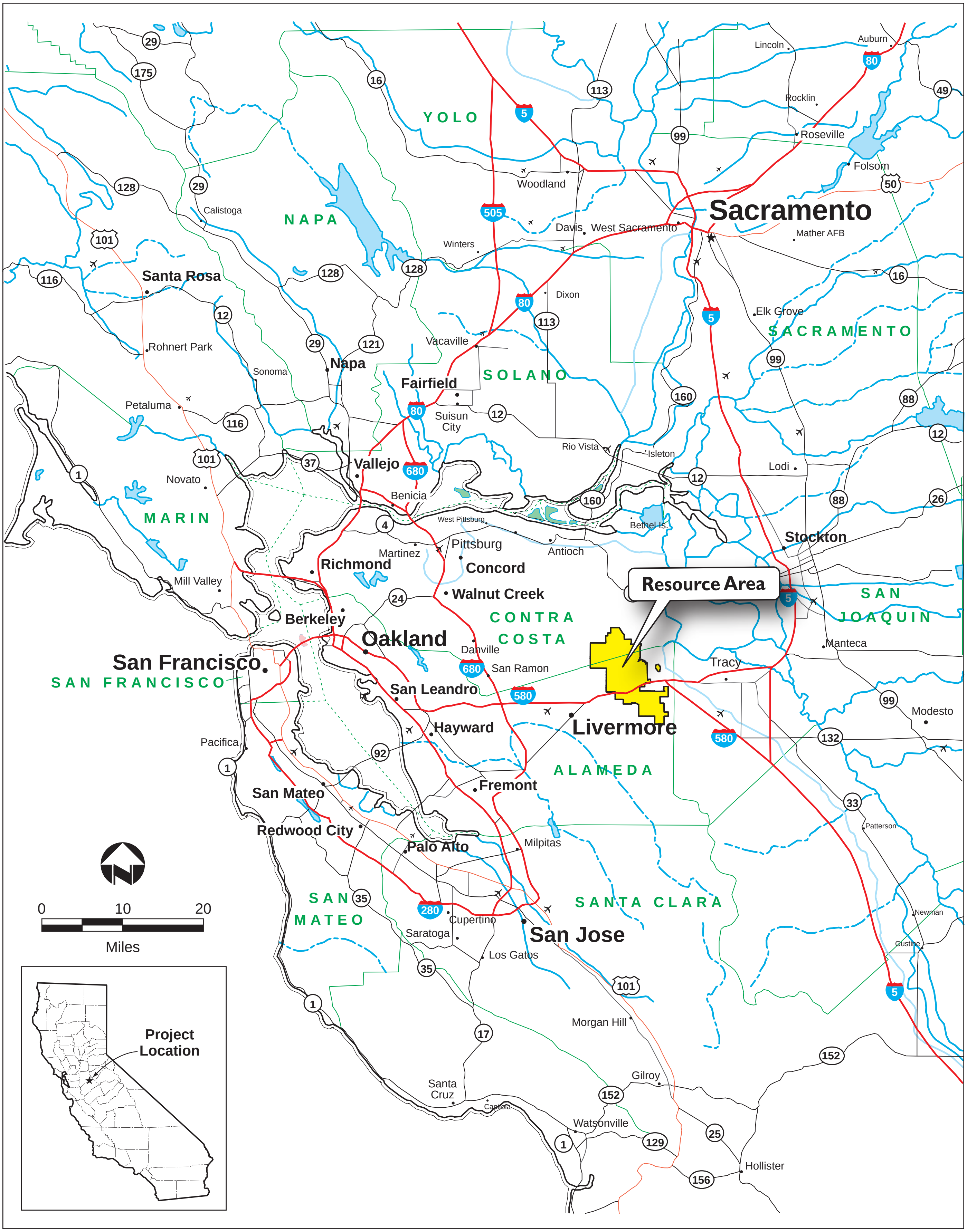

Figure 1-1
Location of the Altamont Pass Wind Resource Area (APWRA)

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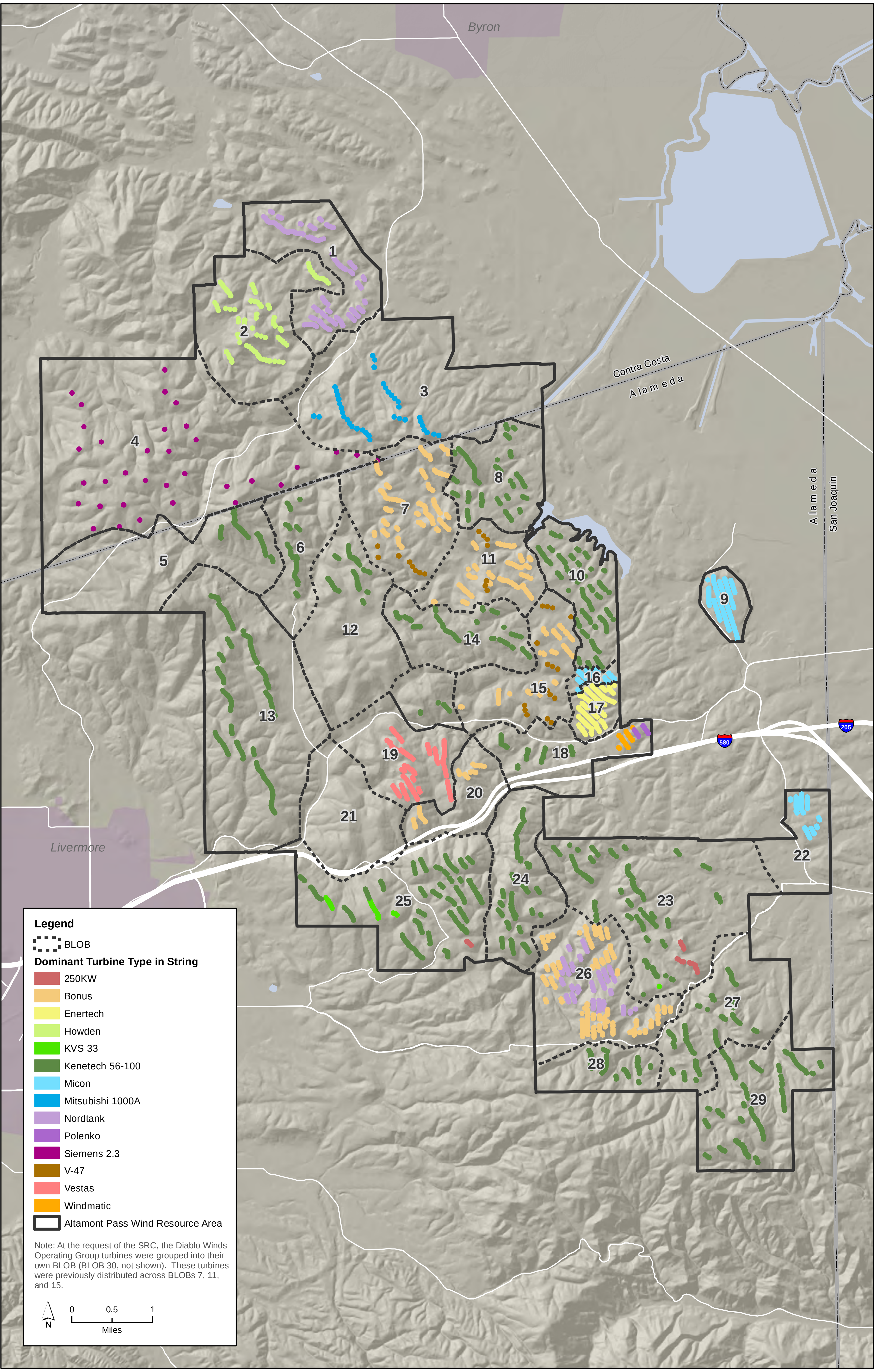

Note: At the request of the SRC, the Diablo Winds Operating Group turbines were grouped into their own BLOB (BLOB 30, not shown). These turbines were previously distributed across BLOBs 7, 11, and 15.

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

the APWRA were obsolete, so mechanical breakdowns often resulted in loss of the entire turbine. *Repowering* typically refers to the replacement of several to many older generation turbines with fewer but larger (both in physical size and megawatt capacity) turbines. Power companies with wind projects in the APWRA provided information on the total *installed capacity*—defined as the sum of the rated capacities of all of the extant (i.e., not removed) turbines—each year. Installed capacity in the APWRA changed substantially over the course of the monitoring period, ranging from a high of 525 MW in the 2006 monitoring year to 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 declined steadily over the course of the monitoring period, installed capacity of newer-generation turbines increased. By the end of the monitoring period, repowered turbines accounted for approximately 29% of the total installed capacity in the APWRA.

A wide variety of different turbine types and sizes have been installed in the APWRA since the first project was built in 1966. These turbine types varied 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 differed 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 2013 Monitoring Year	Total Operational Capacity 2013 Monitoring Year (kW)	Description
Kenetech	100	60/80/140	59	3,500	350,000	1,777	177,700	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	201	24,120	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	
Siemens 2.3	2,300	262	331	34	78,200	34	78,200	Re-powered turbines in the Vasco Winds Operating Group
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
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 2013 Monitoring Year	Total Operational Capacity 2013 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	50		54	99	4,950	0	0	Downwind, blade tip brakes, free yaw, tilt-down lattice tower
Energy Sciences	65		54	96	6,240	0	0	Downwind, blade tip brakes, free yaw, tilt-down lattice tower
Energy Sciences	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**	**3,337**	**462,190**	

Management Actions and Repowering

Two primary management actions were 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 is another measure considered by some to have 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 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 experiments 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 assigned to treatments (i.e., inside or outside the shutdown period) because the search interval was long and aging of carcasses—particularly feather piles—is often inaccurate. 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.

However, the power companies would only agree to a 2-month seasonal shutdown, which was implemented in the 2007 monitoring year. The shutdown was phased, meaning that each monitored turbine string was shut down immediately following its last search prior to the shutdown period. 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. 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 power companies agreed to extend the phased seasonal shutdown 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.

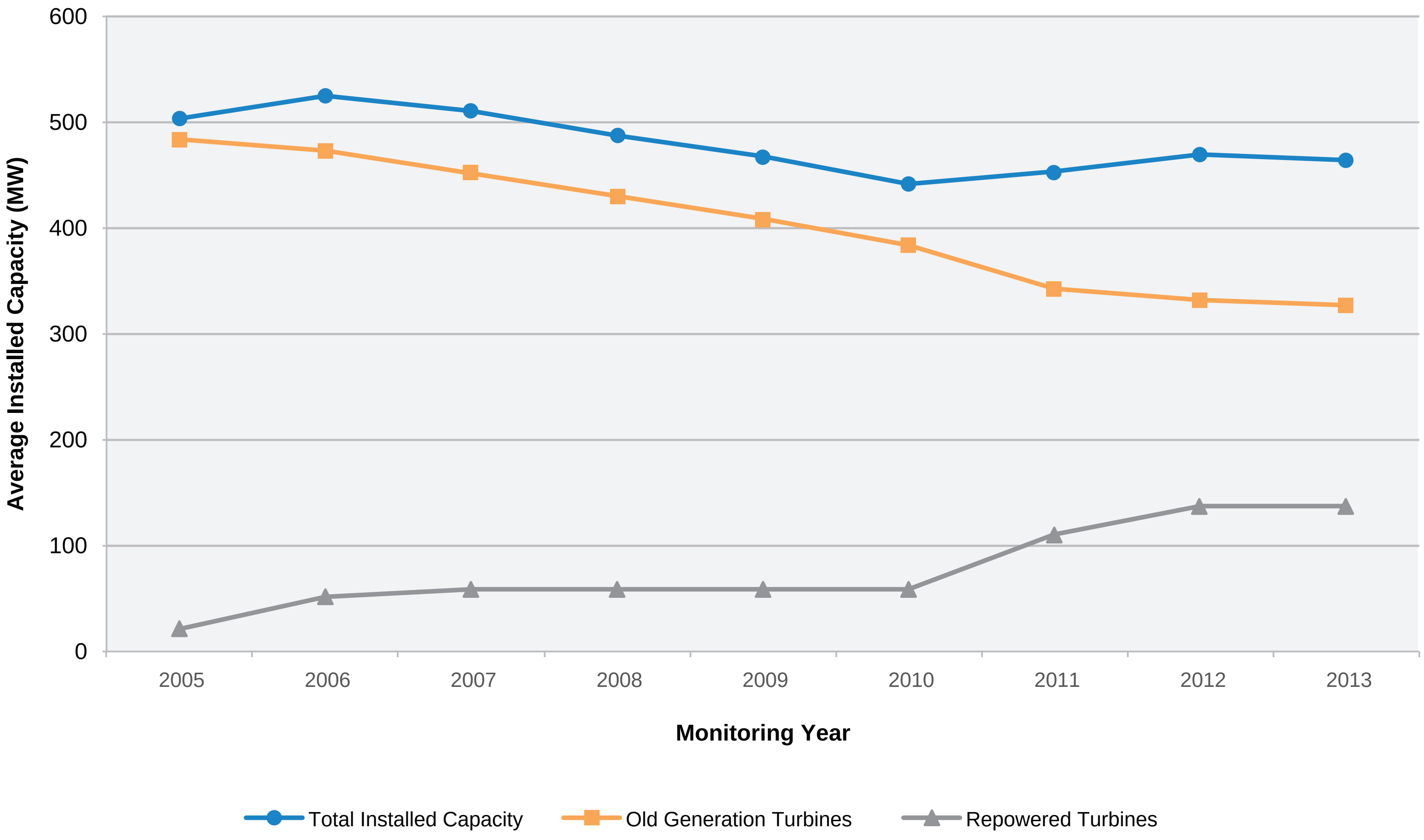

Figure 1-3
Changes in Average Installed Capacity of Turbines in the APWRA, Monitoring Years 2005–2013

In the 2009 monitoring year, the power companies agreed to extend the shutdown period 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 Seasonal 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 were 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 locations 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 substantially 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 were 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

Monitoring Year	Number of Turbines (Megawatts) Removed per Monitoring Year		Total Removed	Percentage of Annual Average Installed Capacity Removed (MW)
	Attrition	High-Risk Turbines[a]		
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

By the end of the study, three operating groups in the APWRA had 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 KCS 56 100 kW and KVS-33 400 kW 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.

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 the 2005 through 2009 monitoring years (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 the sampling unit, so in all cases all turbines within a string were searched at the same time. 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.

At the beginning of the 2010 monitoring year, resources were reallocated away from monitoring and toward directed studies, and a new sampling scheme 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 as a means to stratify the analysis to ensure that the substantial geographic variation across the APWRA in topography, geography, turbine type, and other factors could be adequately addressed.

Under the revised sampling scheme, approximately 65% 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% were *core turbines* (turbines that were monitored every year of the study), while the remaining 40% were 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 was 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 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 revised 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

Accurate estimation of fatality rates requires an assessment of the extent to which carcasses are imperfectly detected. Traditionally, detection probability has been divided into separate components that are 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).

Three separate studies conducted in the APWRA by the MT were used to derive the estimates of detection probability used in this study; 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*).

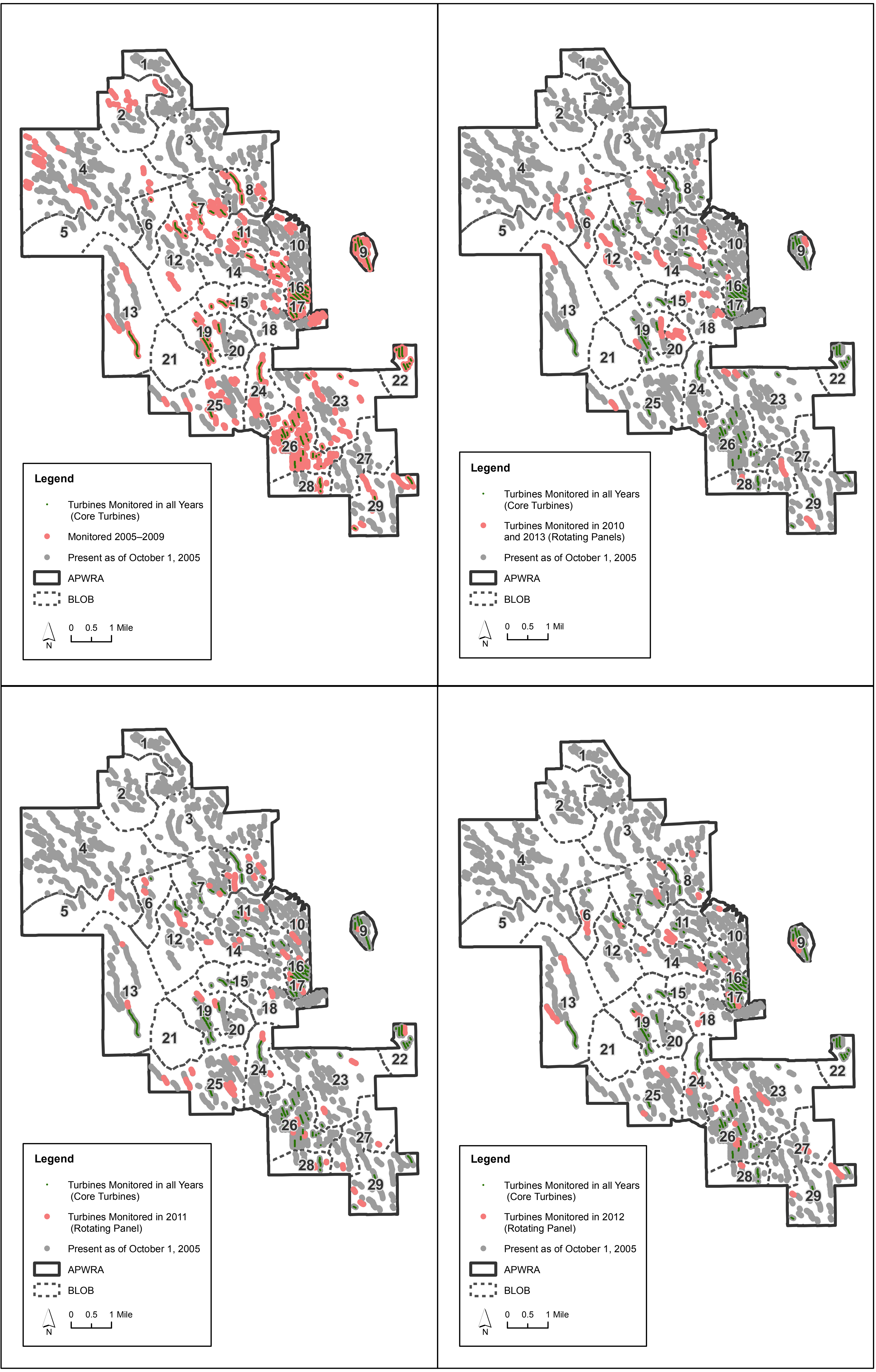

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Figure 2-1
Distribution of Turbines Monitored in the APWRA, 2005–2013 Monitoring Years

- *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.

The QAQC study was an effort to integrate detection probability monitoring into the regular fatality search protocol and 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.

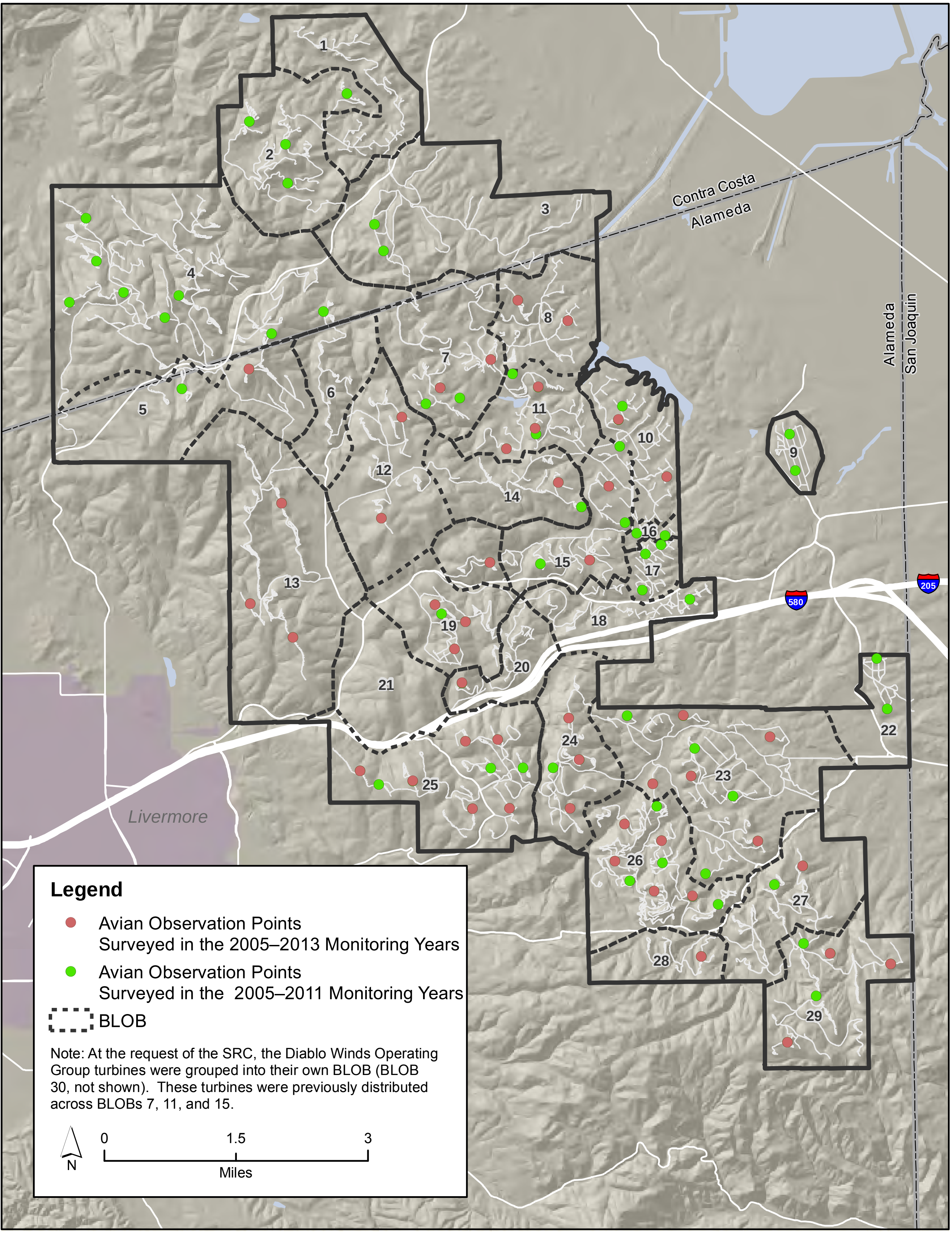
The resulting dataset constitutes a series of sequences of detections and non-detections during pre-, primary, secondary, and post-search types that were used to estimate the detection probability of a carcass. Additional details on field and analytical methods are provided in Appendix C.

Avian Use Surveys

Avian surveys were conducted to assess trends in the relative abundance of the focal species seasonally, annually, and spatially. Surveys 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 indicated that, in addition to being inefficient, the 10-minute survey duration was 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, 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.



Note: At the request of the SRC, the Diablo Winds Operating Group turbines were grouped into their own BLOB (BLOB 30, not shown). These turbines were previously distributed across BLOBs 7, 11, and 15.

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

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

In July 2014, the MT recommended—and the SRC approved—a study of avian fatalities at ridges with and without turbine strings during the period of the seasonal shutdown. The study was prompted by the finding that substantial numbers of small bird carcasses—including burrowing owls— continued to accumulate in the search area around turbines during the period of the seasonal shutdown, even though the turbines were not operating.

A matched pairs design was used with a sample of 32 matched sites. Because ridges without turbine strings are rare in the APWRA, initially the database of APWRA turbines was used to identify all ridges where turbines had been removed. Then GIS was used 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).

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 first round of searches were considered “clearing searches” and thus fatalities found during these searches were not included in the analysis. The average search interval for each matched pair was less than 11 days.

Analytical Methods

Estimating Fatality Rates and Total Fatalities

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

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

where the hat symbol (^) distinguishes the estimated total fatalities ($\widehat{N}$) 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

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

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 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 [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 as required 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 outside the standard search radius 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

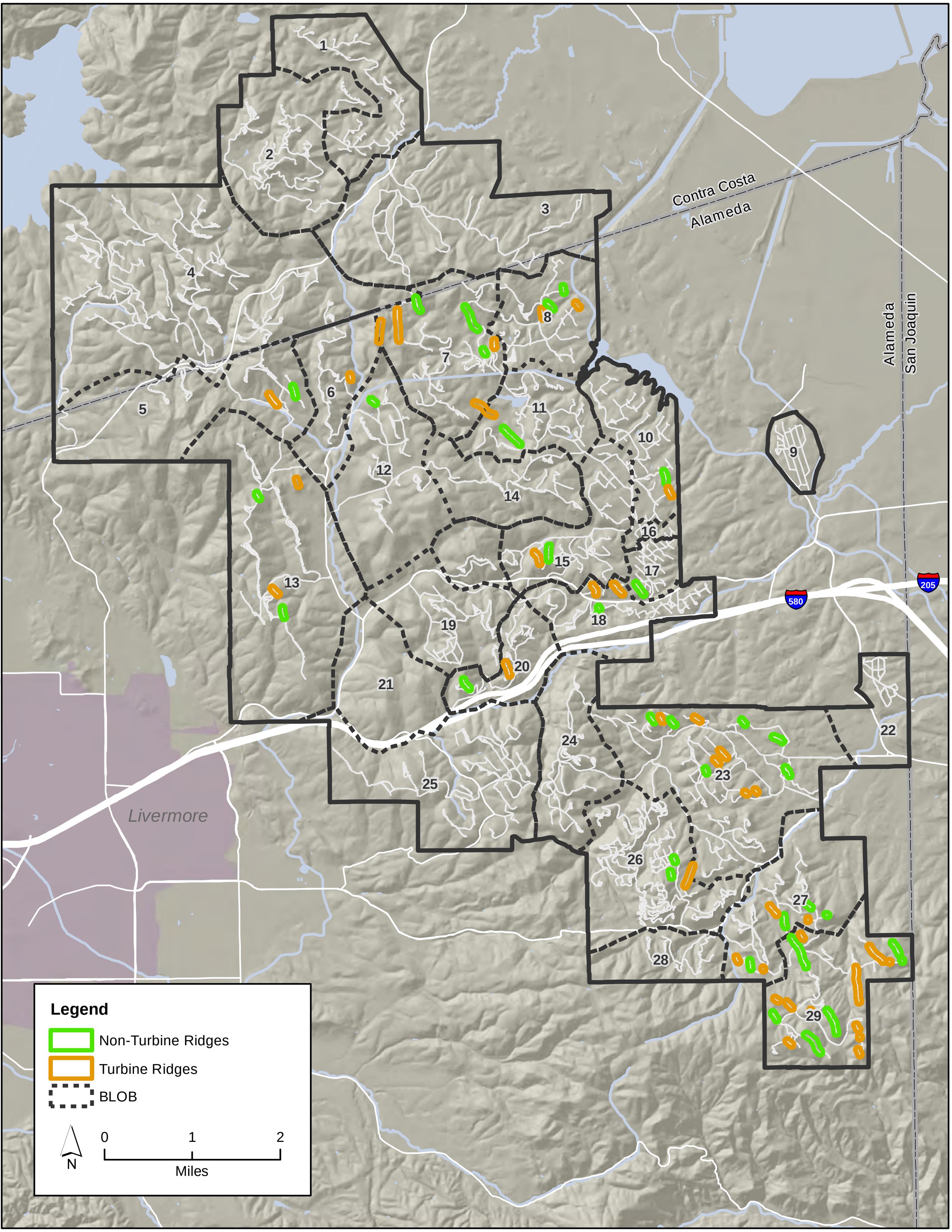

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Figure 2-3
Location of Turbine Ridges and Non-Turbine Ridges
Selected for the Background Mortality Study in the APWRA

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 already been accounted for by the adjustment of previously detected fatalities of the same species. Therefore, they were therefore excluded from the analyses.

Average Installed Capacity and Monitored Capacity

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). As noted above, the *rated capacity* of a turbine is defined as the amount of power that turbine could generate at its rated wind speed; accordingly, the rated capacity of turbine strings or wind generation facilities is the sum of the rated capacities of the individual turbines. Using the fatalities-per-megawatt metric made sense in the APWRA due to the high diversity of turbine types and rated capacities that have been installed there.

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 was 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 was not included in the installed capacity of the string for that month.

A string was 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 was 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, some searches started late or ended early in the year because of turbine removals, changes in the sampling design, and occasionally logistic constraints. To account for the relatively few cases of strings with interrupted searches due to these factors, search coverage for each string within a BLOB was estimated (Appendix D). *Search coverage* was defined as the ratio of 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

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 study.

Detection probability decreases as the search interval increases. Therefore, the average search interval for each BLOB was used to estimate detection probabilities at each BLOB. Those detection probabilities were 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.

Fatality Rates

Annual fatality rates were estimated for each BLOB 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 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. Note that this is different from taking the average of fatality rates across BLOBs. See Appendix D for details on the calculation of variance terms and confidence intervals.

Expanded Fatality Estimates

The *expanded fatality count* at each BLOB is the product of the adjusted fatality rate and the installed capacity. The estimate of annual APWRA-wide total fatalities 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. 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 were monitored each year of the study. For example, some BLOBs were repowered and monitored separately by other parties. BLOB-year combinations without monitored strings or with inadequately monitored strings were assigned fatality rates based on the best available information. The sources of estimated fatality rates 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

		Monitoring Year and Source[a]								
BLOB	Bird Group	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 older-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 Winds 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 Relative Abundance (Bird Use)

To assess trends in the relative abundance of the focal species seasonally, annually, and spatially, 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 and OPs, 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.

Evaluation of the 50% Fatality Reduction Goal

Although the settlement agreement specified a baseline point estimate of fatalities from which to measure the reduction in focal species fatalities, it did not specifically state how the reduction was to be measured—i.e., it did not specify an end point. The settlement agreement required that the 50% reduction goal be achieved within 3 years, although provisions were included should the goal not be achieved on time. Based on this fact, it was assumed that parties to the settlement agreement intended that the reduction be measured from the estimate of annual fatalities from the latest monitoring year.

Previous attempts to assess progress towards achieving the 50% reduction goal indicated problems with the baseline estimate of focal species fatalities. Analyses of the first few years of data indicated that fatality rates from the current study were *higher* than fatality rates from the baseline period, an unlikely result given the reductions in installed capacity and implementation of management measures that occurred between the two studies. Analysis of the baseline and current study datasets together also indicated that annual fatality rates were increasing and suggested the result could be due to differences between the studies in search interval, detection probability, sampling intensity, and the representativeness of the baseline study sample of turbine strings (ICF International 2011).

Consequently, the MT—in conjunction with the SRC—developed an *alternative baseline* based on the 3-year geometric mean of the annual estimates of APWRA-wide total fatalities for the first 3 years of the study. In addition, the 3-year geometric mean of the last 3 years of the study was calculated to provide an endpoint that encompassed some of the annual variation evident in fatality rates and estimates of APWRA-wide fatalities.

Based on these two baselines (i.e., the settlement agreement baseline and alternative baseline), the four following measures of the reduction in fatalities over the course of the study were derived.

- 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 geometric mean of the point estimate(s) of the last 3 years of the monitoring program (i.e., 2011–2013 monitoring years).

- Alternative (3-year geometric mean) 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 geometric mean) baseline point estimate(s) to the 3-year geometric mean of the point estimate(s) of the last 3 years of the monitoring program (i.e., 2011–2013 monitoring years).

Evaluation of the Effectiveness of Management Actions and Repowering

The monitoring program was designed to estimate annual APWRA-wide total fatalities and not specifically to evaluate the effectiveness of individual management actions—though monitoring results can be used indirectly to evaluate the effectiveness of those management actions. Relatively long search intervals, which result in low detection probabilities for some species, in combination with the rarity of fatality events (i.e., a large number of searches are required to detect each fatality), resulted in limited statistical power to detect an effect of individual management actions. Nevertheless, we evaluated the effectiveness of the various management actions taken to reduce avian fatalities in several ways.

- By comparing older-generation turbine fatality rates to fatality rates from suitable control groups.
- By comparing the proportion of annual carcasses and carcass detection rates during and outside the shutdown period, and
- By developing statistical models relating fatality rates to management measures and other potential predictor variables.

Hazardous Turbine Removal

The size of the hazardous turbine removal treatment was relatively small, never exceeding 2.5% of the installed capacity of the APWRA in any year, and accounted for a cumulative total of 56 MW removed over the course of the study. The majority of hazardous turbine removals occurred in the 2007 and 2008 monitoring years.

Two operating groups, the Santa Clara operating group (BLOB 19) and the Diablo Winds operating group (BLOB 30), were exempted from hazardous turbine removals. These operating groups were considered for use as control groups to compare with other operating groups containing older-generation turbines where hazardous turbine removals have occurred. However, the Diablo Winds operating group is composed of repowered turbines that are not arrayed in strings like older-generation turbines but are nevertheless interspersed with older-generation turbines. We therefore concluded that the Diablo Winds operating group was not a suitable control for evaluating the effectiveness of hazardous turbine removal. The Santa Clara operating group was used as a control group, and trends in fatality rates over time at these turbines were compared with those at non–Santa Clara older-generation turbines. If hazardous turbine removal were effective, one might expect fatality rates to decline over the course of the study at a greater rate at non–Santa Clara older-generation turbines than at Santa Clara turbines, all else being equal.

Seasonal Shutdown

The seasonal shutdown treatment for the first 3 years of the study was the equivalent of shutting down turbines for approximately 17% of the year, increased to 25% in the fourth year, and culminated in a shutdown for 29% of the year for the last 5 years of the study.

The Diablo Winds turbines were the only turbines monitored by the MT that were exempted from the seasonal shutdown. Despite the fact that this operating group is composed of repowered turbines, we used it as a control group and compared trends in fatality rates over time at these turbines with those at non–Diablo Winds older-generation turbines. If the seasonal shutdown of turbines were effective, one might expect fatality rates to decline over the course of the study at a greater rate at non–Diablo Winds older-generation turbines than at the Diablo Winds turbines, all else being equal.

The proportion of annual carcasses with an estimated death date during the shutdown period was compared to the proportion that might be expected under various assumptions. If shutting down turbines effectively reduced fatalities, one might expect both the number and proportion of annual fatalities occurring during the shutdown period to be near zero, especially as the duration and intensity of the shutdown increased. However, during the first 4 years of the study, the shutdown period was shorter than or nearly equal to the search interval, or the searches were phased (i.e., monitored turbines were shut down immediately following the first search in the shutdown period). These characteristics made it difficult to determine if a fatality occurred during the shutdown period because the proportion of carcasses found as feather piles was higher during the shutdown period and there was often no way of determining the age of a feather pile. Beginning in the 2009 monitoring year, a longer shutdown period (3.5 months or 29% of the year) was consistently applied across the APWRA (all older-generation turbines were shut down and restarted on the same days). This should have resulted in a reduction in errors and a relatively consistent magnitude and direction of any bias that may have occurred. Therefore, most analyses involving the proportion of annual fatalities occurring during the shutdown period included only the 2009 through 2013 monitoring years during which the universal 3.5-month shutdown occurred.

To account for any potential differences in search effort between the shutdown period and the rest of the monitoring year, carcass detection rates (i.e., the number of carcasses found per turbine string search) were compared during and outside the shutdown period.

Repowering

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

Model Development

To evaluate factors potentially influencing fatality rates at older-generation turbines, including management measures, a list of variables related to management actions, turbine characteristics, and BLOB characteristics potentially associated with fatality rates was developed (Table 2-3). For American kestrel, burrowing owl, golden eagle, and red-tailed hawk, 51%, 48%, 65%, and 37%, respectively, of the fatality rate estimates for the 222 BLOB/monitoring year combinations were zero (BLOB/monitoring year combinations using fatality rates from outside sources or substitute values were excluded from the analysis). Therefore, fatality rates were grouped into three (golden eagle) or four (American kestrel, burrowing owl, and red-tailed hawk) categories at natural breaks in the magnitude of fatality rates, with all zero estimates included in the first category. Ordered probit regression models were developed to evaluate associations between fatality rates and independent variables. Univariate tests on all independent variables were performed for each species. Only independent variables with a $P < 0.10$ were included in subsequent multivariate models.

Table 2-3. Description of parameters used to evaluate variation in fatality rates of the four focal species in the APWRA, monitoring years 2005-2013.

Parameter	Abbreviation	Description
Use	U	The mean number of detections per minute of survey per km^3 of visible airspace
Shutdown	SHUT	Variable representing the proportion of the year the APWRA was shut down (i.e., 0.17 for monitoring years 2005–2007, 0.25 for monitoring year 2008, and 0.29 for monitoring years 2009–2013)
Turbine model	TM	The model of turbine most predominant in the BLOB. Six turbine models were evaluated, including Bonus, Enertech, Howden, Kenetech 56-100, Micon, and Vestas. Variations in the size of each model were not included in the analysis.
Tower type	TT	The type of tower (Lattice or Tubular) predominant in the BLOB
Mean tower height	TH	The average height of extant turbine towers in the BLOB
Mean rotor-swept area	RSA	The average rotor swept area of extant turbines in the BLOB
Mean elevation	E	The average elevation of extant turbines in the BLOB
Mean slope	S	The mean slope of the ridge on which extant turbines in the BLOB were installed
Mean aspect	A	The mean aspect of extant turbines in the BLOB
Hazardous turbines removed	HTR	The cumulative number of hazardous turbines removed from a BLOB in a given year measured in megawatts
Installed capacity	IC	The installed capacity of turbines in a BLOB in a given monitoring year
Monitored capacity	MC	The monitored capacity of turbines in a given BLOB in a given monitoring year

Because the analysis was exploratory in nature, a P value ≤ 0.10 was considered to be marginally significant, and all combinations of independent variables were evaluated. Akaike's Information Criterion corrected for small sample sizes (AIC_c) was used to rank competing models, and AIC weights (AIC_w) were used to assess the amount of support for various models (Burnham and Anderson 2002). Bird use, monitored capacity, installed capacity, and the cumulative number of turbines (in megawatts) removed were log-transformed to better meet assumptions of normality and homoscedasticity.

Analysis

Annual variation in fatality rates and APWRA-wide total fatalities were evaluated by comparing overlap in 95% confidence intervals. Simple linear regression and two-tailed tests of the null hypothesis that $\beta = 0$ were used to evaluate annual trends in estimates of fatality rates, APWRA-wide total fatalities, and bird use. Student's t-tests and analysis of variance (ANOVA) were used to test for differences in bird use among years, seasons, BLOBs, and shutdown periods (i.e., during or outside the shutdown period). Spearman's rank correlation was used to evaluate the relationship between APWRA-wide annual fatality rates and APWRA-wide annual estimates of bird use.

We used a chi-square test to compare the proportion of annual carcasses with an estimated death date inside the shutdown period to the number expected based on the length of shutdown period using *prop.test* without correction for continuity in Program R (R version 3.0.2, www.r-project.org). We used Fisher's exact test to compare the carcass detection rates during and outside the shutdown period and between ridges with turbines and ridges without turbines using the *fisher.test* in Program R.

Chapter 3

Results

Bird Use

Over a period of 9 years, 12,304 surveys throughout the APWRA were conducted (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 (Table 3-2), 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												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Total
2005	16	16	24	61	97	0	0	32	84	55	111	16	**512**
2006	151	151	0	168	16	136	78	117	189	140	61	185	**1,392**
2007	183	0	0	153	129	196	117	133	175	177	151	140	**1,554**
2008	149	171	184	175	182	176	177	149	171	122	184	166	**2,006**
2009	202	101	186	117	185	156	161	178	142	100	211	168	**1,907**
2010	116	153	140	158	194	176	141	102	135	132	131	121	**1,699**
2011	164	126	107	100	114	140	131	97	101	96	122	92	**1,390**
2012	110	64	111	105	108	85	53	117	54	85	75	55	**1,022**
2013	63	65	60	69	65	75	79	61	77	76	83	49	**822**
Total	**1,154**	**847**	**812**	**1,106**	**1,090**	**1,140**	**937**	**986**	**1,128**	**983**	**1,129**	**992**	**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 (i.e., the 2006 and 2013 monitoring 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 (raptors in this report include the 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 second 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	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	**Total**
2005	8	8	12	31	49			16	42	28	56	8	**258**
2006	76	76	0	84	8	23	13	28	39	29	10	31	**417**
2007	31	0	0	26	22	33	20	22	29	30	25	23	**261**
2008	25	29	31	29	30	29	30	25	29	20	31	28	**336**
2009	34	17	31	20	31	26	27	30	24	17	35	28	**320**
2010	19	26	23	26	32	29	24	17	23	22	22	20	**283**
2011	27	21	18	17	19	23	22	16	17	16	20	15	**231**
2012	18	11	19	38	54	43	27	59	27	43	38	28	**405**
2013	32	33	30	35	33	38	40	31	39	38	42	25	**416**
Total	**270**	**221**	**164**	**306**	**278**	**244**	**203**	**244**	**269**	**243**	**279**	**206**	**2,909**

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 proportions of surveys with burrowing owl detections in the 2005 and 2006 monitoring years were 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]

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
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									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
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									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
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.

American kestrel use differed by monitoring year ($F_{8,\ 12295}$ = 2.35, P = 0.016), month ($F_{11,\ 12292}$ = 12.31, P < 0.001), and BLOB ($F_{12,12279}$ = 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).

Golden eagle use also differed by monitoring year ($F_{8,12295}$ = 3.85, P < 0.001), month ($F_{11,12292}$ = 6.50, P < 0.001), and BLOB ($F_{12,\ 24279}$ = 11.79, P < 0.001) (Figure 3-2). 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).

Red-tailed hawk use also differed by monitoring year ($F_{8,12295}$ = 13.1, P < 0.001), month ($F_{11,12929}$ = 46.1, P < 0.001), and BLOB ($F_{25,12279}$ = 14.8, P < 0.001) (Figure 3-3). 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). Although there was significant annual variation in red-tailed hawk use, there was no significant trend over time in use (R = -0.343, P = 0.381, 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 3-3). For the 2009–2013 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, were documented during carcass searches over the 9 years of the study (Table 3-5). 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, a trend likely associated with the completion of a new landfill 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).

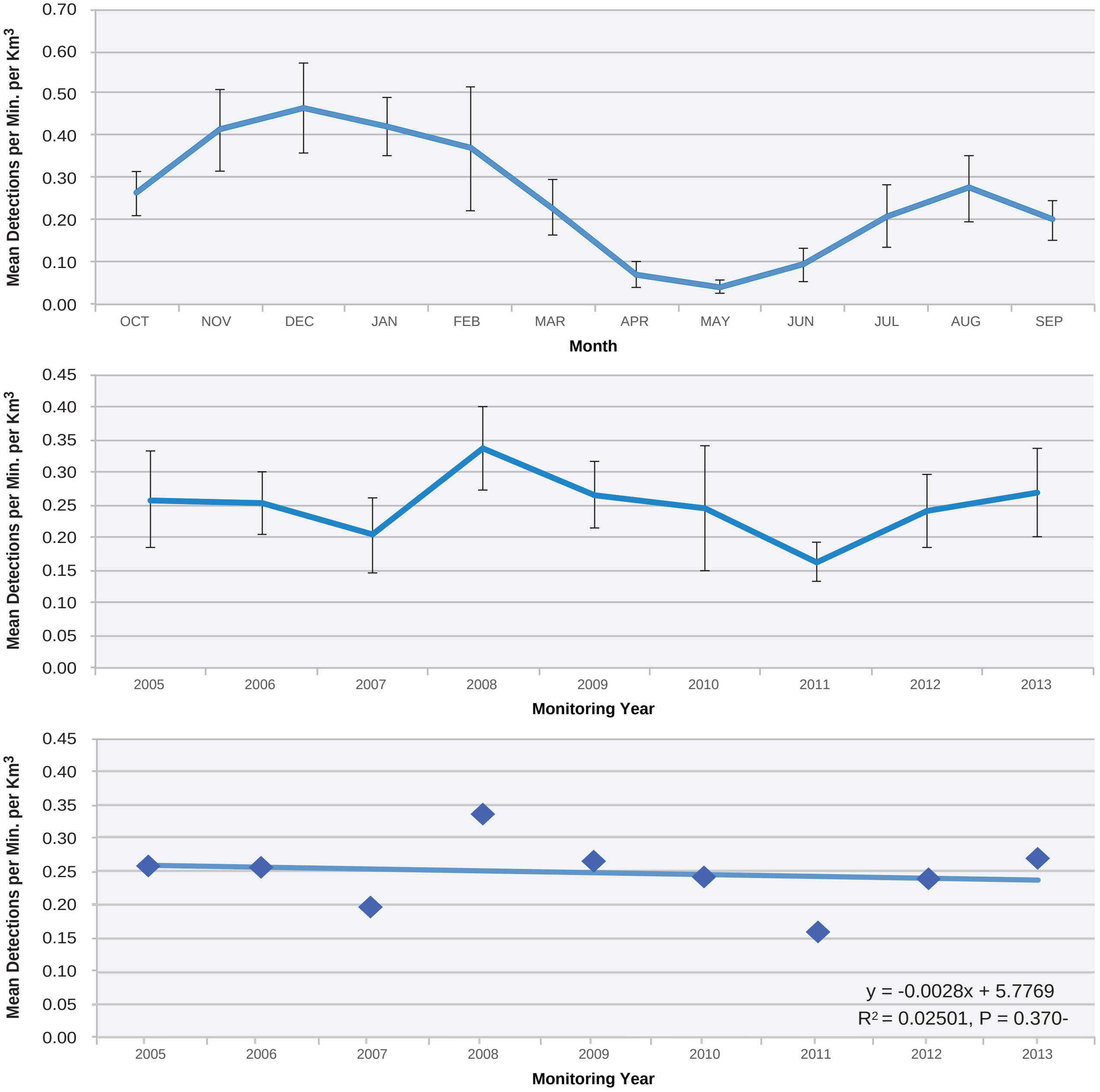

Figure 3-1
Annual and Seasonal Variation in Use (Mean Detections per Minute per Km^3 ± 95% CI) by American Kestrel in the APWRA, Monitoring Years 2005–2013

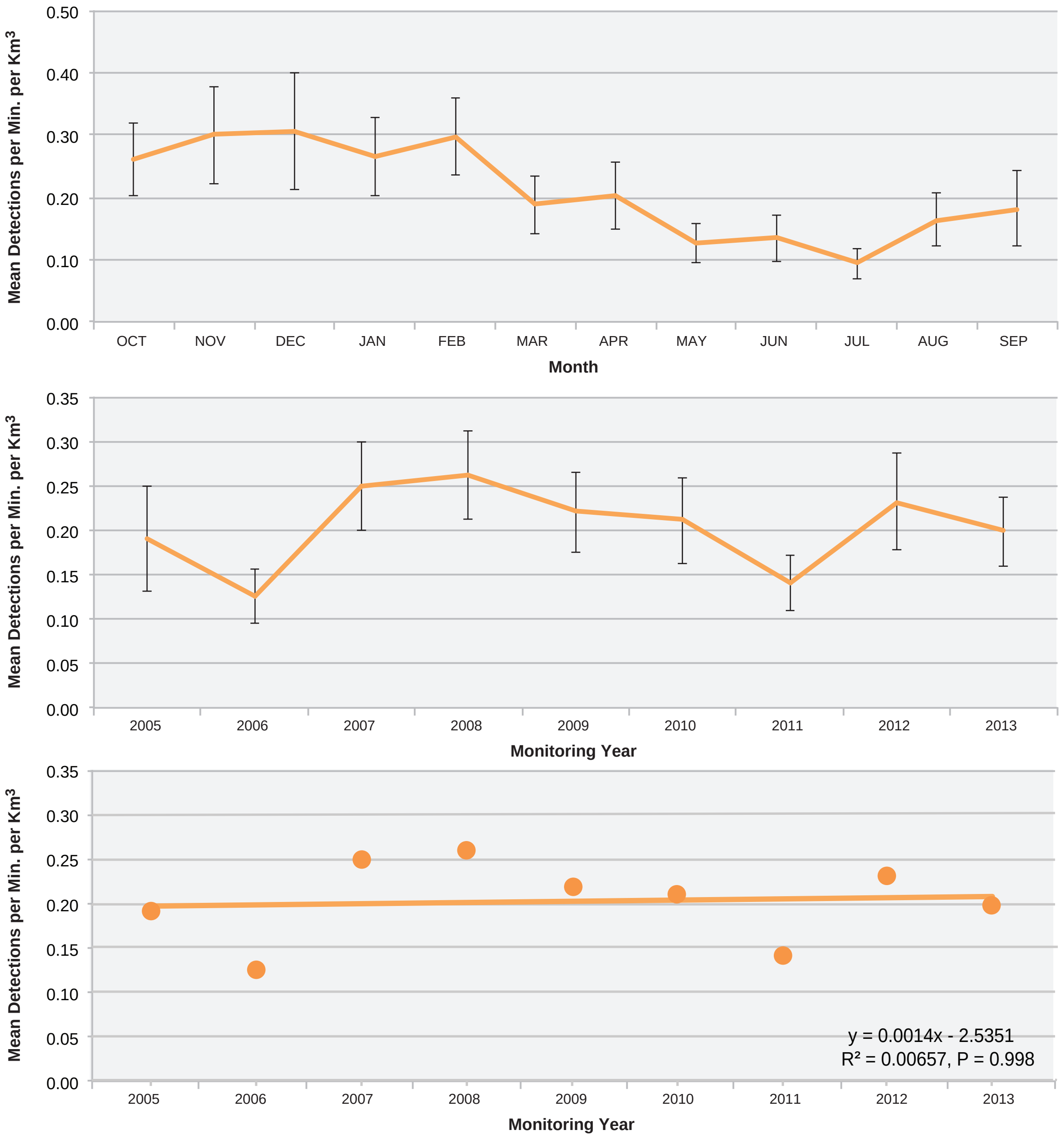

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Figure 3-2
Annual and Seasonal Variation in Use (Mean Detections per Minute per Km^3 ± 95% CI)
by Golden Eagle in the APWRA, Monitoring Years 2005–2013

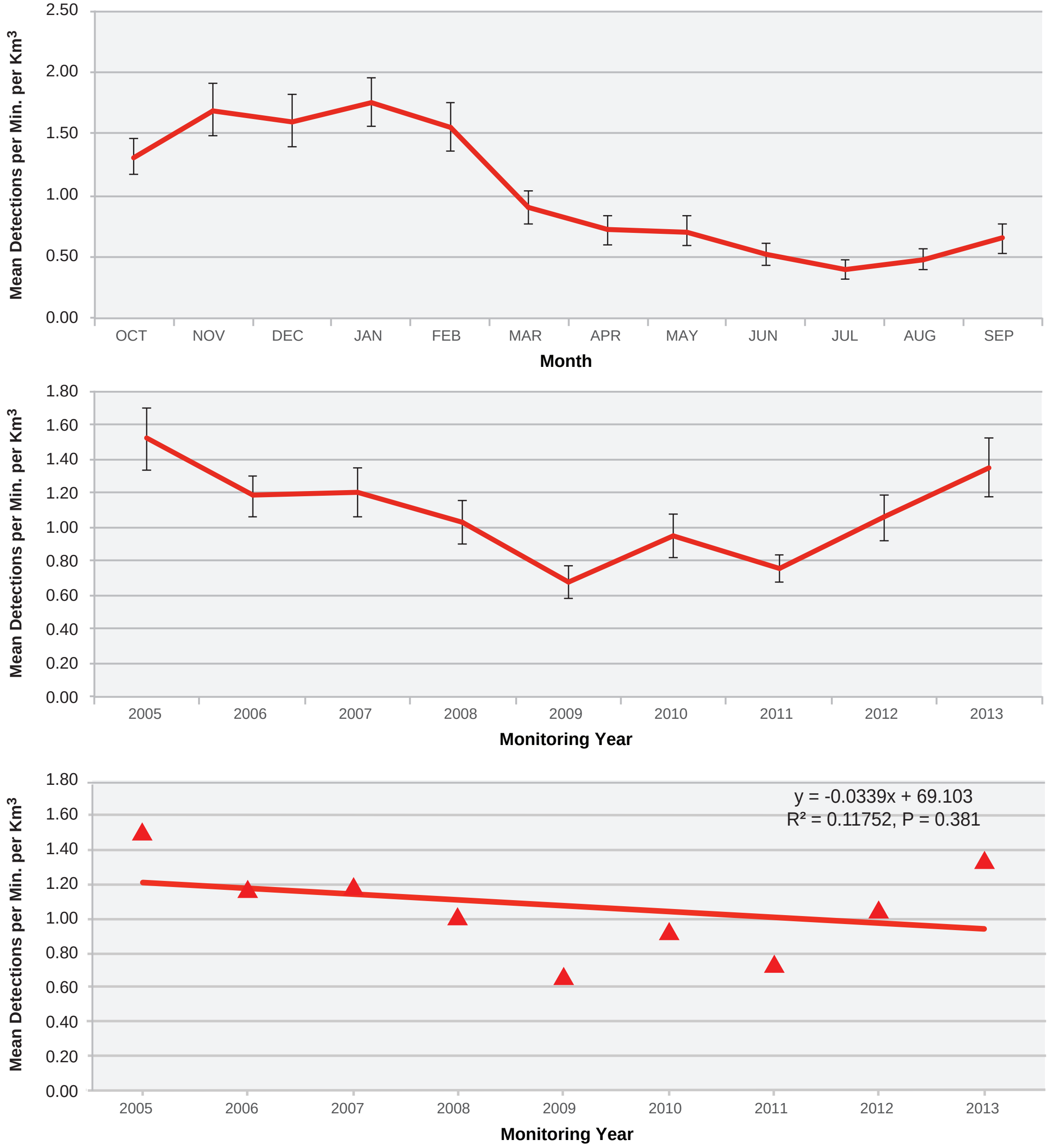

Figure 3-3
Annual and Seasonal Variation in Use (Mean Detections per Minute per Km^3 ± 95% CI)
by Red-Tailed Hawk in the APWRA, Monitoring Years 2005–2013

Over the 9 years of the study, 23 bat fatalities comprised of four species were detected during regular searches at monitored turbines (Table 3-5). Because the study was focused on measuring avian fatalities (bat fatalities have not been identified as a substantial issue at older-generation turbines in the APWRA), no attempt was made to measure detection probabilities for bats, and bat fatalities are not discussed further.

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

	Monitoring Year									
Species/Category	2005	2006	2007	2008	2009	2010[a]	2011	2012	2013	Total
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
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

	Monitoring Year									
Species/Category	2005	2006	2007	2008	2009	2010[a]	2011	2012	2013	Total
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
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 exhibited 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 as the basis for adjustment —a substantial improvement over using arbitrary size classes with significant variation in size in each class. Using a composite model of detection probability that simultaneously estimated the searcher efficiency and carcass removal components of detection probability 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 were derived from a composite data set with different information collected on different components/aspects of detection 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 in detection probability because detection probability trials were not conducted on an annual or seasonal basis.

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.

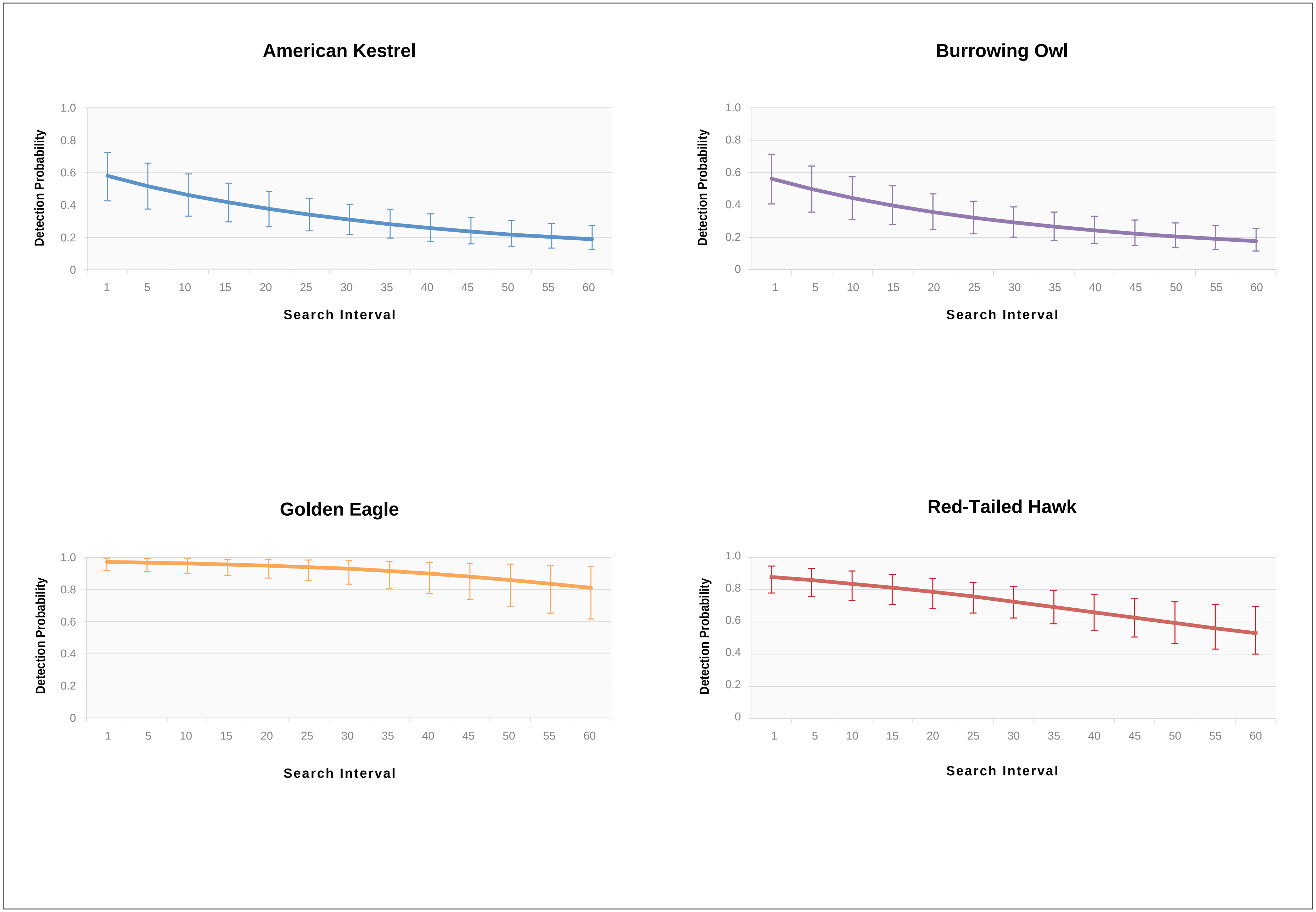

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Figure 3-4

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

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 (0.453–0.883)	0.629 (0.429–0.830)	0.440 (0.305–0.576)	0.408 (0.279–0.538)	0.482 (0.327–0.638)	0.696 (0.459–0.933)	0.829 (0.559–1.099)	0.428 (0.287–0.569)	0.558 (0.375–0.741)
Burrowing owl	0.640 (0.395–0.884)	1.778 (1.178–2.379)	0.611 (0.407–0.816)	0.266 (0.180–0.352)	0.554 (0.369–0.739)	0.386 (0.256–0.517)	0.811 (0.523–1.099)	0.562 (0.370–0.753)	0.386 (0.253–0.520)	0.666 (0.437–0.895)
Golden eagle	0.093 (0.078–0.108)	0.111 (0.101–0.122)	0.068 (0.062–0.075)	0.050 (0.046–0.054)	0.044 (0.040–0.048)	0.101 (0.091–0.111)	0.081 (0.069–0.093)	0.099 (0.089–0.110)	0.117 (0.104–0.131)	0.085 (0.075–0.095)
Red-tailed hawk	0.613 (0.468–0.757)	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 (0.456–0.622)	0.420 (0.340–0.499)	0.439 (0.367–0.510)	0.327 (0.271–0.382)	0.402 (0.332–0.471)
Total focal species	**1.790** **(1.223–2.357)**	**3.105** **(2.196–4.014)**	**1.681** **(1.213–2.149)**	**0.954** **(0.701–1.206)**	**1.168** **(0.826–1.510)**	**1.509** **(1.130–1.888)**	**2.007** **(1.390–2.624)**	**1.929** **(1.386–2.472)**	**1.258** **(0.914–1.602)**	**1.711** **(1.220–2.202)**
Turkey vulture	0.020 (0.016–0.024)	0.010 (0.009–0.012)	0.017 (0.015–0.019)	0.004 (0.004–0.005)	0.014 (0.012–0.016)	0.000 (0.000–0.000)	0.012 (0.010–0.014)	0.032 (0.028–0.036)	0.032 (0.027–0.036)	0.016 (0.013–0.018)
White-tailed kite	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)	0.030 (0.025–0.035)	0.019 (0.015–0.023)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.005 (0.004–0.006)
Northern harrier	0.000 (0.000–0.000)	0.014 (0.012–0.017)	0.018 (0.015–0.021)	0.012 (0.010–0.014)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.017 (0.013–0.021)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.007 (0.006–0.008)
Red-shouldered hawk	0.000 (0.000–0.000)	0.008 (0.006–0.009)	0.006 (0.005–0.008)	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)	0.002 (0.001–0.002)
Swainson’s hawk	0.009 (0.006–0.011)	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)	0.001 (0.001–0.001)
Ferruginous hawk	0.015 (0.012–0.019)	0.000 (0.000–0.000)	0.005 (0.004–0.005)	0.005 (0.004–0.005)	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)	0.003 (0.002–0.003)
Unidentified Buteo	0.000 (0.000–0.000)	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)	0.000 (0.000–0.000)	0.077 (0.065–0.090)	0.038 (0.032–0.045)	0.022 (0.019–0.025)
Peregrine falcon	0.000 (0.000–0.000)	0.008 (0.006–0.009)	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)	0.001 (0.001–0.001)
Prairie falcon	0.011 (0.008–0.014)	0.016 (0.013–0.018)	0.006 (0.005–0.008)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.029 (0.024–0.034)	0.072 (0.057–0.088)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.015 (0.012–0.018)
Barn owl	0.376 (0.281–0.471)	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 (0.276–0.384)	0.225 (0.181–0.270)	0.075 (0.062–0.088)	0.030 (0.025–0.036)	0.175 (0.142–0.209)
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 (0.034–0.048)	0.066 (0.054–0.079)	0.075 (0.062–0.089)	0.000 (0.000–0.000)	0.049 (0.040–0.057)
Short-eared owl	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)	0.016 (0.013–0.019)	0.000 (0.000–0.000)	0.002 (0.001–0.002)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Total raptors[a]	**2.270 (1.583–2.956)**	**3.538 (2.557–4.518)**	**1.849 (1.355–2.343)**	**1.063 (0.795–1.331)**	**1.420 (1.038–1.801)**	**1.950 (1.498–2.403)**	**2.419 (1.720–3.118)**	**2.205 (1.615–2.794)**	**1.358 (0.997–1.719)**	**2.008 (1.462–2.554)**
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)	0.000 (0.000–0.000)	0.043 (0.034–0.052)
Common goldeneye	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.009 (0.007–0.011)	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 (0.001–0.001)
Wild turkey	0.000 (0.000–0.000)	0.011 (0.010–0.013)	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)	0.001 (0.001–0.001)
Pied-billed grebe	0.000 (0.000–0.000)	0.024 (0.013–0.035)	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)	0.003 (0.001–0.004)
Eared grebe	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)	0.036 (0.023–0.048)	0.004 (0.003–0.005)
Brown pelican	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.004 (0.004–0.004)	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)
Great blue heron	0.006 (0.005–0.007)	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)	0.020 (0.018–0.023)	0.000 (0.000–0.000)	0.003 (0.003–0.003)
Great egret	0.008 (0.006–0.010)	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)	0.001 (0.001–0.001)
American coot	0.000 (0.000–0.000)	0.014 (0.010–0.018)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.030 (0.021–0.039)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.028 (0.020–0.037)	0.008 (0.006–0.010)
Sandhill crane	0.000 (0.000–0.000)	0.005 (0.004–0.005)	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)	0.001 (0.000–0.001)
Killdeer	0.000 (0.000–0.000)	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 (0.038–0.069)	0.000 (0.000–0.000)	0.058 (0.041–0.075)	0.000 (0.000–0.000)	0.024 (0.017–0.030)
Black-necked stilt	0.000 (0.000–0.000)	0.011 (0.008–0.013)	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)	0.001 (0.001–0.001)
American avocet	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.017 (0.013–0.020)	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)	0.002 (0.001–0.002)
Bonaparte’s gull	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.008 (0.006–0.010)	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)	0.001 (0.001–0.001)
Ring-billed gull	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.005 (0.005–0.006)	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 (0.001–0.001)
Western gull	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.005 (0.004–0.005)	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)	0.001 (0.000–0.001)
California gull	0.000 (0.000–0.000)	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 (0.048–0.068)	0.244 (0.203–0.286)	0.024 (0.020–0.028)	0.052 (0.043–0.060)
Glaucous-winged gull	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)	0.013 (0.010–0.016)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.001 (0.001–0.002)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
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 (0.175–0.237)	0.615 (0.500–0.730)	0.992 (0.817–1.168)	0.624 (0.517–0.732)	0.309 (0.256–0.363)
Rock pigeon	1.678 (1.153–2.203)	2.121 (1.596–2.645)	2.225 (1.684–2.766)	2.247 (1.733–2.761)	2.243 (1.706–2.779)	2.280 (1.732–2.828)	2.462 (1.816–3.107)	2.236 (1.682–2.790)	2.380 (1.768–2.992)	2.208 (1.652–2.764)
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 (0.116–0.270)	0.090 (0.053–0.127)	0.718 (0.432–1.004)	0.171 (0.102–0.240)	0.317 (0.190–0.445)
Eurasian collared dove	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)	0.033 (0.022–0.044)	0.000 (0.000–0.000)	0.004 (0.002–0.005)
Common poorwill	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.018 (0.011–0.026)	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)	0.044 (0.025–0.063)	0.007 (0.004–0.010)
White-throated swift	0.000 (0.000–0.000)	0.050 (0.027–0.074)	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)	0.006 (0.003–0.008)
Acorn woodpecker	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)	0.138 (0.079–0.196)	0.015 (0.009–0.022)
Northern flicker	0.025 (0.015–0.035)	0.000 (0.000–0.000)	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 (0.080–0.181)	0.037 (0.024–0.051)	0.036 (0.023–0.049)	0.041 (0.026–0.056)
Hammond's flycatcher	0.047 (0.013–0.080)	0.046 (0.013–0.079)	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)	0.010 (0.003–0.018)
Unidentified empidonax	0.000 (0.000–0.000)	0.007 (0.006–0.008)	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)	0.001 (0.001–0.001)
Say's phoebe	0.000 (0.000–0.000)	0.030 (0.014–0.046)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.027 (0.013–0.041)	0.000 (0.000–0.000)	0.068 (0.031–0.105)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.014 (0.006–0.021)
Loggerhead shrike	0.261 (0.104–0.418)	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 (0.066–0.260)	0.212 (0.090–0.333)	0.000 (0.000–0.000)	0.152 (0.064–0.240)
Warbling vireo	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.039 (0.011–0.068)	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)	0.004 (0.001–0.008)
Western scrub-jay	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)	0.000 (0.000–0.000)
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)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.032 (0.027–0.038)	0.032 (0.026–0.038)	0.014 (0.011–0.016)
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 (0.116–0.158)	0.104 (0.085–0.123)	0.136 (0.116–0.157)	0.197 (0.164–0.230)	0.108 (0.090–0.125)
Horned lark	0.158 (0.063–0.253)	0.373 (0.160–0.585)	0.527 (0.227–0.827)	0.156 (0.069–0.243)	0.267 (0.115–0.418)	0.385 (0.165–0.606)	0.073 (0.031–0.115)	0.068 (0.029–0.108)	0.143 (0.060–0.227)	0.239 (0.102–0.376)
Cliff swallow	0.093 (0.041–0.145)	0.000 (0.000–0.000)	0.048 (0.023–0.072)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.054 (0.026–0.082)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.022 (0.010–0.033)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Barn swallow	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.043 (0.023–0.064)	0.041 (0.022–0.059)	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)	0.009 (0.005–0.014)
Unidentified swallow	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.027 (0.011–0.043)	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)	0.003 (0.001–0.005)
Rock wren	0.146 (0.040–0.252)	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)	0.016 (0.004–0.028)
House wren	0.000 (0.000–0.000)	0.063 (0.008–0.118)	0.000 (0.000–0.000)	0.049 (0.007–0.091)	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)	0.012 (0.002–0.023)
Mountain bluebird	0.000 (0.000–0.000)	0.166 (0.083–0.250)	0.023 (0.012–0.035)	0.000 (0.000–0.000)	0.025 (0.012–0.037)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.024 (0.012–0.036)
Unidentified bluebird	0.000 (0.000–0.000)	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 (0.289–1.115)	0.000 (0.000–0.000)	0.073 (0.031–0.116)	0.156 (0.066–0.246)
Swainson’s thrush	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.026 (0.012–0.041)	0.000 (0.000–0.000)	0.030 (0.013–0.047)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.006 (0.003–0.010)
Northern mockingbird	0.083 (0.039–0.127)	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)	0.143 (0.069–0.218)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.025 (0.012–0.038)
European starling	2.127 (1.110–3.144)	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 (1.379–3.571)	2.805 (1.518–4.092)	2.044 (1.129–2.959)	1.127 (0.617–1.637)	2.143 (1.182–3.104)
American pipit	0.000 (0.000–0.000)	0.076 (0.028–0.124)	0.032 (0.012–0.052)	0.060 (0.023–0.097)	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)	0.019 (0.007–0.030)
Wilson’s warbler	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.049 (0.009–0.089)	0.043 (0.009–0.078)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.138 (0.024–0.252)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.026 (0.005–0.047)
Spotted towhee	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.031 (0.011–0.050)	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)	0.003 (0.001–0.006)
Savannah sparrow	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.045 (0.009–0.081)	0.104 (0.018–0.189)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.016 (0.003–0.030)
Lincoln’s sparrow	0.000 (0.000–0.000)	0.053 (0.012–0.094)	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)	0.006 (0.001–0.010)
Golden-crowned sparrow	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.036 (0.012–0.061)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.099 (0.031–0.167)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.015 (0.005–0.025)
Unidentified sparrow	0.067 (0.018–0.116)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.040 (0.012–0.068)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.012 (0.003–0.020)
Dark-eyed junco	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.034 (0.011–0.057)	0.040 (0.012–0.067)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.008 (0.003–0.014)
Western tanager	0.000 (0.000–0.000)	0.034 (0.014–0.054)	0.030 (0.012–0.047)	0.027 (0.011–0.043)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.081 (0.032–0.129)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.019 (0.008–0.030)
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 (0.030–0.100)	0.112 (0.051–0.172)

Species	Monitoring Year									Average
	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Tricolored blackbird	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.023 (0.012–0.035)	0.022 (0.011–0.032)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.058 (0.029–0.088)	0.000 (0.000–0.000)	0.011 (0.006–0.017)
Western meadowlark	3.027 (1.456–4.597)	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 (1.097–3.165)	1.972 (0.981–2.963)	0.968 (0.493–1.443)	0.622 (0.315–0.929)	1.904 (0.966–2.842)
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)	0.000 (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)	0.047 (0.025–0.069)
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 (0.079–0.237)	0.188 (0.091–0.284)	0.000 (0.000–0.000)	0.063 (0.031–0.095)	0.148 (0.073–0.223)
Brown-headed cowbird	0.000 (0.000–0.000)	0.034 (0.015–0.053)	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)	0.004 (0.002–0.006)
Unidentified oriole	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.028 (0.012–0.043)	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)	0.003 (0.001–0.005)
House finch	0.043 (0.014–0.073)	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)	0.097 (0.030–0.163)	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.016 (0.005–0.026)
House sparrow	0.000 (0.000–0.000)	0.000 (0.000–0.000)	0.036 (0.012–0.061)	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)	0.004 (0.001–0.007)
Total nonraptors	**8.722 (4.603–12.841)**	**9.785 (5.593–13.977)**	**8.506 (5.036–11.975)**	**8.096 (4.937–11.256)**	**7.826 (4.667–10.985)**	**8.642 (5.236–12.048)**	**10.135 (5.864–14.405)**	**7.942 (5.196–10.687)**	**5.803 (3.849–7.757)**	**8.384 (4.998–11.770)**
Total birds	**10.992 (6.186–15.798)**	**13.323 (8.150–18.495)**	**10.355 (6.391–14.319)**	**9.160 (5.732–12.588)**	**9.245 (5.705–12.786)**	**10.592 (6.734–14.450)**	**12.553 (7.584–17.523)**	**10.146 (6.811–13.481)**	**7.161 (4.847–9.476)**	**10.392 (6.460–14.324)**

[a] Includes the four focal species.

Among 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. The higher fatality rate for American kestrels relative to red-tailed hawk contrasts with the higher use rate for red-tailed hawk relative to American kestrel, indicating that American kestrel engages in more high risk behaviors than red-tailed hawk.

Each of the four focal species exhibited considerable annual variation in APWRA-wide fatality rates at older-generation turbines (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 (Figure 3-5).

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

Annual variation in golden eagle and red-tailed hawk APWRA-wide fatality rates were also significant, but there was no significant upward or downward trend in fatality rates over time ($R = 0.237$, $P = 0.554$ and $R = -0.304$, $P = 0.442$, respectively).

Factors Influencing Fatality Rates

For American kestrel, there was a significant positive association between fatality rates and use at the BLOB level (Table 3-7), while the correlation at the APWRA-wide level was moderately significant ($R = -0.588$, $P = 0.099$). The Kenetech 56-100 turbine model had a significantly higher fatality rate than other turbine models, and fatality rates decreased with increasing tower height. Fatality rates also decreased as hazardous turbine removal increased. Fatality rates were positively associated with mean elevation, mean aspect, installed capacity, and monitored capacity.

Aspect, elevation, installed capacity, monitored capacity, and hazardous turbine removal were all positively collinear, with the exception of monitored capacity and hazardous turbine removals, which were not correlated.

Each of the six top models evaluated included use and monitored capacity, and either aspect or elevation (Table 3-8). The top two models were substantially better than the remaining models based on AIC weights, and differed only in the inclusion of elevation or aspect, which were positively collinear.

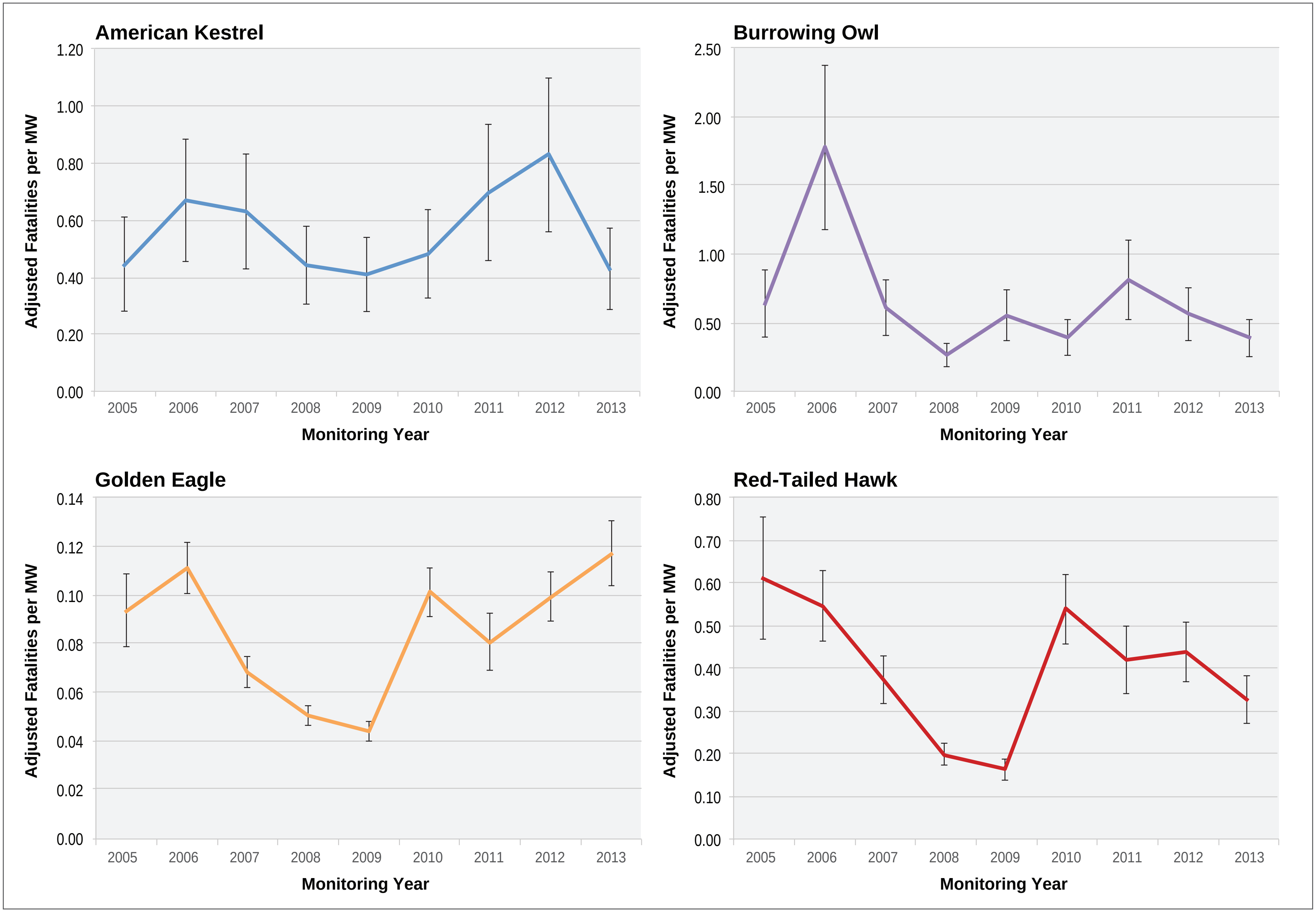

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Figure 3-5
Annual Adjusted Fatality Rates (Fatalities per MW ± 95% CI) at Old Generation Turbines for the Four Focal Species in the APWRA, Monitoring Years 2005–2013

Table 3-7. Results of Univariate Ordered-Probit Regression for Each Variable Considered Potentially Predictive of Annual Fatality Rates at Older-Generation Turbines Monitored by the Monitoring Team for the Four Focal Species in the APWRA, 2005–2013.

Variable	Coefficient ± SE	P
American Kestrel		
Use (U)	0.217 ± 0.077	**0.005**
Shutdown (SHUT)		0.542
Shutdown 0.25	-0.204 ± 0.256	
Shutdown 0.29	-0.169 ± 0.166	
Turbine model (TM)		0.131
Enertech	-0.375 ± 0.079	0.433
Howden	-0.117 ± 0.565	0.835
Kenetech 56-100	0.444 ± 0.205	**0.030**
Micon	0.370 ± 0.280	0.186
Vestas	0.601 ± 0.402	0.135
Tower type (TT)		
Lattice	0.263 ± 0.166	0.113
Mean tower height (TH)	-0.027 ± 0.011	**0.011**
Mean rotor-swept area (RSA)	-0.171E-4 ± 0.173E-4	0.323
Mean elevation (E)	0.001 ± 7.17E-4	**0.075**
Mean slope (S)	-1.763 ± 1.905	0.355
Mean aspect (A)	0.006 ± 0.002	**0.009**
Hazardous turbines removed (HTR)	-0.205 ± 0.070	**0.003**
Installed capacity (IC)	0.317 ± 0.105	**0.003**
Monitored capacity (M)	0.276 ± 0.104	**0.008**
Burrowing owl		
Use (U)	0.050 ± 0.098	0.609
Shutdown (SHUT)		**0.005**
Shutdown 0.25	-0.632 ± 0.261	
Shutdown 0.29	-0.488 ± 0.164	
Turbine model (TM)1		**< 0.001**
Enertech	1.567 ± 0.441	**< 0.001**
Howden	0.428 ± 0.485	0.378
Kenetech 56-100	-0.312 ± 0.194	0.109
Micon	0.155 ± 0.271	0.567
Vestas	-0.012 ± 0.389	0.967
Tower type (TT)		
Lattice	-0.217 ± 0.162	0.180
Mean tower height (TH)	0.012 ± 0.010	0.259
Mean rotor-swept area (RSA)	-0.364E-4 ± 0.163E-4	**0.025**
Mean elevation (E)	-0.002 ± 7.35E-4	**0.006**
Mean slope (S)	3.063 ± 1.950	0.116
Mean aspect (A)	-0.006 ± 0.002	**0.011**

Variable	Coefficient ± SE	P
Hazardous turbines removed (HTR)	-0.197 ± 0.071	**0.006**
Installed capacity (IC)	-0.160 ± 0.102	0.118
Monitored capacity (MC)	0.129 ± 0.103	0.210
Golden eagle		
Use (U)	0.181 ± 0.087	**0.037**
Shutdown (SHUT)		
Shutdown 0.25	-0.359 ± 0.285	0.208
Shutdown 0.29	-0.403 ± 0.186	**0.030**
Turbine model (TM)1		NS
Enertech	-0.748 ± 0.578	0.196
Howden	-0.597 ± 0.668	0.372
Kenetech 56-100	0.251 ± 0.222	0.258
Micon	-0.748 ± 0.369	**0.043**
Vestas	-0.410 ± 0.500	0.411
Tower type (TT)		
Lattice	0.399 ± 0.191	**0.037**
Mean tower height (TH)	-0.030 ± 0.012	**0.013**
Mean rotor-swept area (RSA)	0.585E-4 ± 0.202E-4	**0.004**
Mean elevation (E)	-9.91E-4 ± 8.41E-4	0.239
Mean slope (S)	-1.577 ± 2.269	0.487
Mean aspect (A)	0.010 ± 0.003	**<0.001**
Hazardous turbines removed (HTR)	0.158 ± 0.080	**0.047**
Installed capacity (IC)	0.405 ± 0.122	**<0.001**
Monitored capacity (MC)	0.227 ± 0.113	**0.045**
Red-tailed hawk		
Use (U)	0.324 ± 0.121	**0.007**
Shutdown (SHUT)		**0.039**
Shutdown 0.25	-0.442 ± 0.259	
Shutdown 0.29	-0.402 ± 0.166	
Turbine model (TM)1		0.216
Enertech	0.606 ± 0.401	0.131
Howden	-0.605 ± 0.573	0.291
Kenetech 56-100	-0.001 ± 0.179	0.994
Micon	0.167 ± 0.274	0.543
Vestas	0.664 ± 0.406	0.102
Tower type (TT)		
Lattice	0.019 ± 0.162	0.906
Mean tower height (TH)	-0.008 ± 0.010	0.466
Mean rotor-swept area (RSA)	-0.179E-4 ± 0.164E-4	0.275
Mean elevation (E)	-0.002 ± 7.41E-4	**0.011**
Mean slope (S)	-2.573 ± 1.962	0.190
Mean aspect (A)	-0.003 ± 0.002	0.177

Variable	Coefficient ± SE	P
Hazardous turbines removed (HTR)	0.006 ± 0.069	0.935
Installed capacity (IC)	0.137 ± 0.102	0.181
Monitored capacity (MC)	0.255 ± 0.104	**0.014**

For burrowing owls, fatality rates were significantly lower at higher shutdown intensities, primarily because fatality rates were so high in the first 2 years of the study (Table 3-7). The Enertech turbines—which are located within a single BLOB in the central-eastern portion of the APWRA—had significantly higher fatality rates than all other turbine models in all monitoring years except one. Fatality rates increased as rotor swept area decreased, a relationship currently without explanation. Fatality rates increased with decreasing elevation and aspect, relationships that held when the Enertech turbines were removed from the analysis, and which may reflect the distribution of burrowing owls within the APWRA (use by burrowing owls was negatively correlated with mean elevation). Fatality rates also decreased as hazardous turbine removal increased.

Rotor-swept area was not included in subsequent multivariate models of burrowing owl fatality rates because the relationship was contrary to predictions and likely to be spurious.

Each of the six top ranked models evaluated included turbine model and hazardous turbine removal, and either aspect or elevation (Table 3-8). The top two models were substantially better than the remaining models based on AIC weights, and differed only in the inclusion of elevation or aspect, which were positively collinear. Both aspect and elevation were also positively collinear with hazardous turbine removal.

Table 3-8. Support for Models Explaining Variation in Fatality Rates for the Four Focal Species in the APWRA

Model	N/K	AIC	AIC_c	ΔAIC	AIC_w
American kestrel					
USE,TH,MA,MC	39	436.1	436.4	0.0	0.30
USE,TH,ME,MC	39	436.5	436.8	0.4	0.24
USE,MA,MC	49	438.0	438.2	1.8	0.12
USE,ME,MC	49	438.1	438.4	2.0	0.11
USE,TH,MA,IC,MC	33	437.9	438.4	2.0	0.11
USE,TH,ME,MA,MC	33	438.1	438.5	2.1	0.11
Burrowing owl					
TM,MA,HTR	24	321.8	322.4	0.0	0.27
TM,ME,HTR	24	322.1	322.7	0.3	0.24
SHUT,TM,MA,HTR	18	322.9	323.9	1.1	0.16
TM,ME,MA,HTR	20	323.6	324.4	1.8	0.11
SHUT,TM,ME,HTR	18	323.3	324.4	1.5	0.13
SHUT,TM,ME,MA,HTR	16	324.6	326.0	2.8	0.07
Golden eagle					
USE,RSA,TH,MA	36	270.6	270.9	0.0	0.35
USE,RSA,TH,MA,MC	30	272.3	272.8	1.7	0.15
USE,TT,RSA,TH,MA	30	272.6	273.1	2.0	0.13

Model	N/K	AIC	AIC$_c$	ΔAIC	AIC$_w$
USE,RSA,MA,IC	36	272.7	273.1	2.1	0.12
USE,RSA,MA,IC	36	272.7	273.1	2.1	0.12
USE,RSA,TH,MA,IC	30	272.6	273.1	2.0	0.13
Red-tailed hawk					
USE,ME,MC	51	405.5	405.7	0.0	0.33
USE,SHUT,ME,MC	34	405.8	406.2	0.3	0.29
USE,SHUT,ME	41	406.3	406.6	0.8	0.23
USE,ME	68	407.3	407.4	1.8	0.14
USE,MC	70	413.5	413.6	8.0	0.01
USE,SHUT	52	413.9	414.1	8.4	0.00

For Golden eagle, there was a significant positive association between fatality rates and use at the BLOB level (Table 3-7), but fatality rates and use were not correlated at the APWRA-wide level (R = -0.519, P = 0.159). Fatality rates also decreased as the shutdown intensity increased. The Micon turbine model was associated with lower fatality rates relative to other turbine models, and lattice towers were associated with higher fatality rates than tubular towers. Fatality rates increased with decreasing tower height, and increased with increasing rotor swept area. Fatality rates were also positively associated with mean aspect and HTR, installed capacity, and monitored capacity.

Aspect, installed capacity, monitored capacity, and hazardous turbines removed were all positively collinear, with the exception of monitored capacity and hazardous turbines removed, which were not correlated. The inclusion of monitored capacity is notable because golden eagle carcasses have a high detection probability and companies are required to report eagle deaths, indicating that this result may be spurious.

Each of the six top ranked models evaluated included use, rotor-swept area, and aspect, and four of the six included tower height (Table 3-8). The highest ranked model was 2.3 time more likely to be the best model than the second ranked model based on AIC weights.

For red-tailed hawk, there was a significant positive association between fatality rates and use at the BLOB level (Table 3-7), but fatality rates and use were not correlated at the APWRA-wide level (R = 0.497, P = 0.181). Fatality rates also decreased as the shutdown intensity increased. Fatality rates increased with decreasing elevation, possibly because use and elevation were negatively correlated (R = -0.389, P < 0.001). Fatality rates also increased with monitored capacity.

Each of the six top ranked models evaluated included use, and the top four ranked models included elevation (Table 3-8). There was a significant jump in ΔAIC$_c$ values from the third- to the fourth-ranked model. Elevation and monitored capacity are positively correlated, so it is notable that both variables are included in the two top models. The inclusion of monitored capacity is also notable considering that red-tailed hawks have a relatively high detection probability and the total numbers of fatality detections were higher than any other focal species, indicating that this may be a spurious result as well. In this case, the model incorporating use, shutdown, and mean elevation may be the most meaningful.

Estimates of APWRA-Wide Total Fatalities

The estimates of APWRA-wide total fatalities are provided in Table 3-9 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, trends over time in annual estimates of total fatalities are similar to trends over time in annual adjusted fatality rates for all focal species except golden eagle (Figures 3-5 and 3-6).

Table 3-9. 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 (148–323)	369 (249–488)	298 (202–394)	201 (139–264)	196 (133–260)	185 (126–244)	264 (164–364)	304 (190–418)	144 (82–207)	244 (159–329)
Burrowing owl	225 (139–312)	783 (519–1047)	272 (181–363)	130 (88–173)	231 (154–308)	158 (109–208)	296 (190–403)	187 (120–254)	109 (68–149)	266 (174–357)
Golden eagle	70 (59–81)	68 (60–76)	38 (33–44)	28 (24–32)	31 (26–36)	35 (30–41)	38 (29–47)	42 (33–51)	35 (26–43)	43 (36–50)
Red-tailed hawk	304 (233–376)	247 (208–287)	180 (150–209)	94 (79–108)	81 (67–95)	168 (140–196)	176 (129–223)	156 (111–202)	118 (78–158)	169 (133–206)
Total focal species	**836 (579–1092)**	**1468 (1037–1899)**	**788 (566–1010)**	**453 (329–577)**	**540 (381–699)**	**547 (404–689)**	**774 (511–1037)**	**690 (455–925)**	**406 (255–557)**	**722 (502–943)**
Turkey vulture	11 (9–13)	6 (5–6)	10 (8–11)	3 (3–3)	6 (5–7)	1 (1–1)	5 (4–5)	11 (10–13)	15 (13–17)	7 (6–8)
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 (5–7)	6 (5–7)	5 (4–6)	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 (4–7)	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 (0–1)
Ferruginous hawk	7 (5–9)	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 (1–2)
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 (8–12)	5 (4–5)	0 (0–0)	0 (0–0)	13 (11–15)	22 (17–27)	0 (0–0)	0 (0–0)	6 (5–8)
Barn owl	240 (179–301)	124 (103–144)	22 (19–26)	24 (20–27)	44 (37–51)	73 (61–85)	91 (71–111)	22 (15–30)	12 (6–17)	72 (57–88)
Great-horned owl	38 (29–48)	40 (33–46)	18 (15–21)	4 (3–4)	40 (34–47)	21 (18–24)	14 (11–16)	19 (15–22)	0 (0–0)	22 (18–25)
Short-eared owl	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	10 (8–12)	0 (0–0)	1 (1–1)
Total raptors[a]	**1144 (810–1478)**	**1660 (1197–2123)**	**852 (620–1084)**	**492 (362–622)**	**630 (457–803)**	**664 (502–825)**	**927 (632–1223)**	**753 (504–1002)**	**434 (275–593)**	**840 (595–1084)**

	Monitoring Year									
Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Mallard	25 (18–32)	16 (13–19)	20 (16–24)	11 (9–13)	23 (19–27)	31 (25–37)	34 (26–41)	9 (7–11)	1 (1–1)	19 (15–23)
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 (7–10)	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 (8–21)	0 (0–0)	0 (0–0)	0 (0–0)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–4)
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)	7 (4–9)	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 (0–3)	1 (0–4)	1 (0–4)	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 (0–50)	14 (0–75)	14 (0–75)	4 (0–22)
American coot	0 (0–0)	8 (6–11)	0 (0–0)	0 (0–0)	0 (0–0)	5 (4–7)	1 (1–2)	1 (1–2)	5 (4–7)	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 (14–27)	15 (11–19)	4 (3–5)	12 (9–16)	11 (7–14)	0 (0–0)	8 (6–11)	0 (0–0)	8 (6–10)
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 (7–11)	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)
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 (17–22)	24 (21–27)	11 (10–13)	22 (19–26)	15 (13–18)	89 (75–104)	12 (10–14)	23 (19–26)

	Monitoring Year									
Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
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 (12–19)	62 (53–72)	53 (45–61)	56 (48–63)	26 (22–30)	79 (68–91)	208 (163–253)	352 (284–420)	250 (200–300)	122 (99–146)
Rock pigeon	624 (429–819)	826 (622–1030)	862 (652–1072)	852 (657–1047)	774 (589–959)	529 (403–656)	529 (389–670)	472 (355–589)	534 (397–672)	667 (499–835)
Mourning dove	108 (60–156)	160 (97–224)	145 (88–202)	148 (91–205)	145 (88–201)	64 (42–86)	49 (24–73)	202 (114–290)	74 (36–111)	122 (71–172)
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 (3–9)	1 (1–2)
White-throated swift	0 (0–0)	33 (18–49)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (2–5)
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)	47 (27–67)	5 (3–7)
Northern flicker	10 (6–14)	0 (0–0)	21 (13–28)	13 (9–18)	10 (7–14)	9 (6–13)	69 (42–95)	5 (3–7)	5 (3–7)	16 (10–22)
Hammond's flycatcher	11 (3–19)	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 (1–9)
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 (48–195)	170 (73–267)	44 (19–68)	65 (29–102)	8 (3–12)	37 (16–58)	54 (22–86)	63 (27–99)	0 (0–0)	62 (26–99)
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)
American crow	5 (4–6)	6 (4–7)	14 (11–16)	8 (7–9)	3 (2–3)	0 (0–0)	0 (0–0)	8 (6–9)	16 (13–19)	6 (5–8)
Common raven	51 (39–62)	39 (34–45)	63 (54–73)	41 (35–46)	32 (27–37)	52 (44–60)	32 (26–37)	42 (36–48)	74 (62–87)	47 (40–55)
Horned lark	73 (29–116)	154 (66–242)	272 (117–427)	77 (34–120)	107 (46–168)	167 (72–262)	21 (9–34)	18 (8–29)	42 (17–66)	103 (44–163)
Tree swallow	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	8 (0–24)	12 (0–36)	12 (0–36)	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 (0–26)	13 (0–39)	13 (0–39)	4 (0–11)

	Monitoring Year									
Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Cliff swallow	22 (10–34)	0 (0–0)	25 (12–38)	0 (0–0)	0 (0–0)	14 (7–21)	2 (1–4)	2 (1–4)	2 (1–4)	8 (4–12)
Barn swallow	0 (0–0)	0 (0–0)	31 (16–45)	19 (10–28)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	6 (3–8)
Unidentified Swallow	0 (0–0)	0 (0–0)	0 (0–0)	7 (3–12)	0 (0–0)	0 (0–0)	8 (0–24)	12 (0–35)	12 (0–35)	4 (0–12)
Rock wren	35 (10–61)	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 (4–51)	0 (0–0)	25 (4–47)	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 (0–28)	14 (0–42)	14 (0–42)	4 (0–12)
Mountain bluebird	0 (0–0)	126 (63–189)	14 (7–21)	0 (0–0)	12 (6–18)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	17 (8–25)
Unidentified bluebird	0 (0–0)	40 (17–63)	10 (4–16)	74 (33–115)	89 (39–140)	59 (26–92)	272 (112–433)	0 (0–0)	17 (7–26)	62 (26–98)
Swainson's thrush	0 (0–0)	0 (0–0)	21 (9–33)	0 (0–0)	10 (4–16)	3 (1–4)	3 (1–4)	3 (1–4)	3 (1–4)	5 (2–7)
Northern mockingbird	34 (16–52)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	43 (21–65)	0 (0–0)	0 (0–0)	9 (4–13)
European starling	1,209 (629–1789)	977 (542–1412)	1,146 (639–1653)	1,306 (741–1870)	1,059 (592–1525)	981 (564–1399)	902 (490–1313)	678 (378–977)	353 (197–509)	957 (530–1383)
American pipit	0 (0–0)	63 (23–102)	20 (8–33)	29 (11–46)	0 (0–0)	2 (1–4)	0 (0–0)	0 (0–0)	0 (0–0)	13 (5–21)
Wilson's warbler	0 (0–0)	0 (0–0)	22 (4–39)	12 (2–21)	0 (0–0)	0 (0–0)	48 (8–88)	0 (0–0)	0 (0–0)	9 (2–16)
Spotted towhee	0 (0–0)	0 (0–0)	24 (9–39)	0 (0–0)	0 (0–0)	3 (1–5)	3 (1–5)	3 (1–5)	3 (1–5)	4 (2–7)
Savannah sparrow	0 (0–0)	0 (0–0)	0 (0–0)	12 (2–22)	27 (5–50)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–8)
Lincoln's sparrow	0 (0–0)	23 (5–41)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	3 (1–5)
Golden-crowned sparrow	0 (0–0)	0 (0–0)	26 (8–43)	0 (0–0)	0 (0–0)	0 (0–0)	69 (21–117)	0 (0–0)	0 (0–0)	11 (3–18)
Unidentified Sparrow	39 (10–67)	0 (0–0)	0 (0–0)	0 (0–0)	22 (7–38)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	7 (2–12)
Dark-eyed junco	0 (0–0)	0 (0–0)	0 (0–0)	20 (6–33)	14 (4–23)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–6)

	Monitoring Year									
Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Western tanager	0 (0–0)	20 (8–31)	19 (8–30)	11 (5–17)	0 (0–0)	0 (0–0)	56 (22–90)	0 (0–0)	0 (0–0)	12 (5–19)
Red-winged blackbird	62 (27–97)	123 (57–188)	46 (22–71)	52 (25–80)	13 (6–20)	23 (11–34)	37 (17–56)	25 (12–37)	21 (11–32)	45 (21–68)
Tricolored blackbird	0 (0–0)	0 (0–0)	16 (8–24)	6 (3–9)	0 (0–0)	0 (0–0)	0 (0–0)	8 (4–13)	0 (0–0)	3 (2–5)
Western meadowlark	1,693 (809–2,576)	1,440 (737–2,142)	1,035 (534–1,537)	853 (448–1,257)	963 (498–1,427)	873 (496–1,249)	863 452–1,273)	424 (232–616)	432 (235–629)	953 (494–1,412)
Brewer's blackbird	113 (57–169)	82 (44–120)	13 (7–19)	15 (8–21)	0 (0–0)	2 (1–2)	5 (0–15)	7 (0–22)	7 (0–22)	27 (11–43)
Unidentified blackbird	120 (55–184)	131 (65–196)	154 (77–231)	71 (36–106)	63 (31–94)	85 (46–124)	81 (39–123)	5 (2–7)	44 (21–66)	84 (42–126)
Brown-headed cowbird	0 (0–0)	8 (3–13)	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 (4–16)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–2)
House finch	10 (3–17)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	4 (1–6)	21 (7–35)	4 (1–6)	4 (1–6)	5 (1–8)
House sparrow	0 (0–0)	0 (0–0)	10 (3–17)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–2)
Total nonraptors	**4,385 (2,279–6,491)**	**4,632 (2,613–6,650)**	**4198 (2,436–5,960)**	**3,828 (2,296–5,361)**	**3,430 (2,018–4,843)**	**3,061 (1,864–4,258)**	**3,516 (1,864–5,167)**	**2,516 (1,462–3,570)**	**2,028 (1,147–2,910)**	**3,510 (1,998–5,023)**
Total birds	**5,529 (3,089–7,969)**	**6,292 (3,810–8,773)**	**5,050 (3,057–7,044)**	**4,321 (2,658–5,983)**	**4,060 (2,474–5,646)**	**3,724 (2,366–5,083)**	**4,443 (2,496–6,389)**	**3,269 (1,966–4,573)**	**2,462 (1,421–3,503)**	**4,350 (2,593–6,107)**

[a] Includes the four focal species.

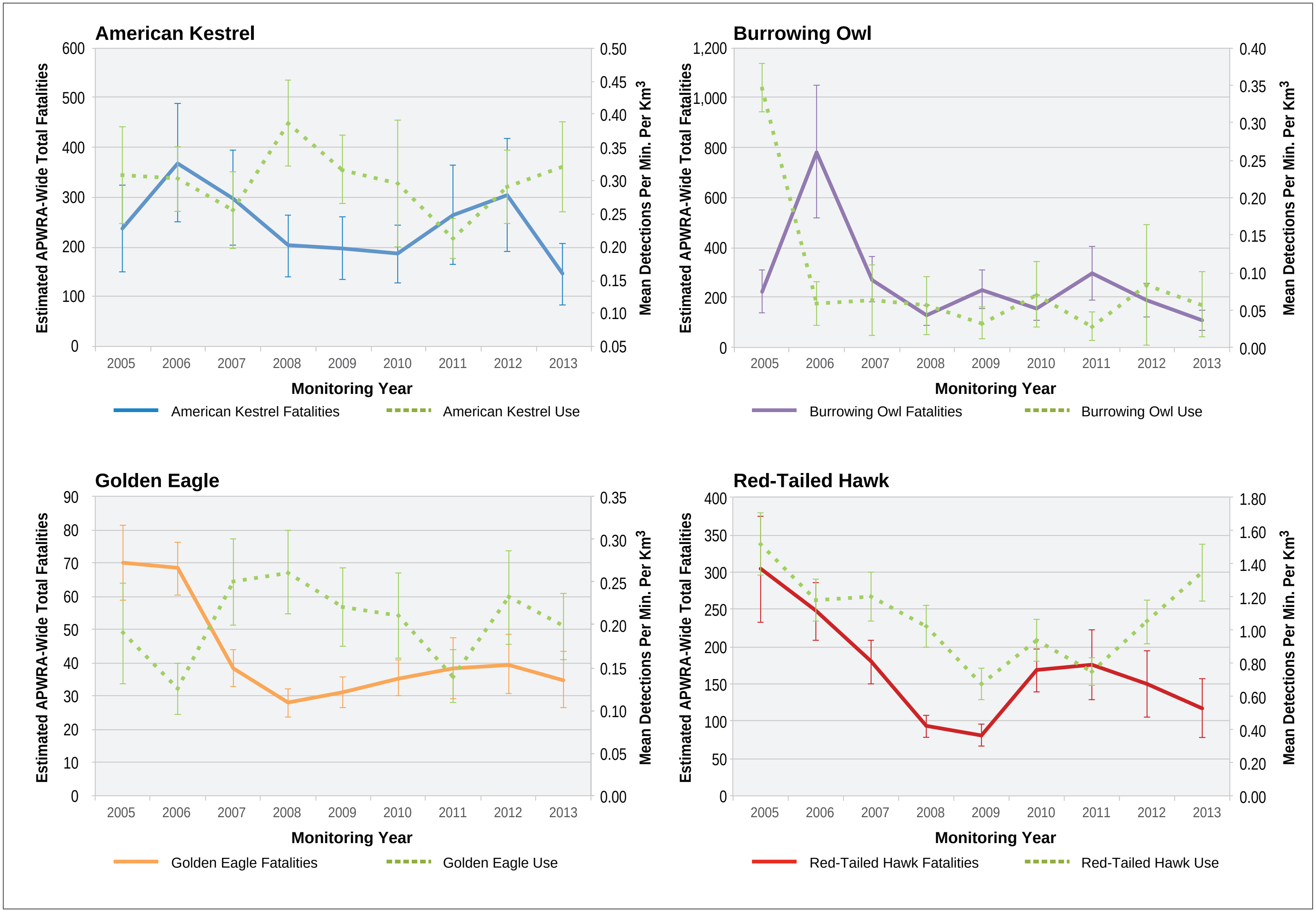

Figure 3-6
Annual Estimated Total APWRA-Wide Fatalities (±95% CI)
and Average Annual Bird Use (±95% CI) for the Four Focal Species,
Monitoring Years 2005–2013

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, Figure 3-7). 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, Figure 3-7), despite the spike in fatalities in the 2006 monitoring year.

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) (Figure 3-7).

Evaluation of the 50% Reduction

The four measures of the reduction in focal species fatalities are presented in Table 3-10.

Table 3-10. Various Measures of the Reduction in Total Annual Fatalities of the Four Focal Species

					Percent Reduction from:			
Species	Settlement Agreement Baseline	3-Year Geometric Mean Baseline	3-Year Geometric Mean 2011–2013	2013 Monitoring Year Estimate	3-Year Geometric Mean Baseline to 3-Year Geometric Mean	3-Year Geometric Mean Baseline to 2013 Monitoring Year Estimate	Settlement Agreement Baseline to 3-Year Geometric Mean	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%**

The 50% reduction goal was achieved for each focal species and for the group as a whole by the criteria specified in the settlement agreement (settlement agreement baseline compared to the 2013 monitoring year point estimate). In fact, using estimates derived under the revised stratified analytical framework, the 50% reduction goal was also achieved in the 2008 and 2010 monitoring years. Comparison of the 2013 monitoring year estimate to the SRC-adopted 3-year geometric mean baseline indicates that the 50% reduction goal was achieved for three of the four focal species (the exception being golden eagle) and for the group as a whole (Table 3-10).

Conversely, by the two measures that attempt to include annual variation in the endpoint measurements, the 50% reduction goal was not achieved for the focal species as a group.

None of the measures outlined above includes an assessment of sampling variation in the evaluation of the reduction over time in focal species fatalities.

Evaluation of the Effectiveness of Management Actions and Repowering

Hazardous Turbine Removal

The effect of hazardous turbine removals was assessed by using the Santa Clara turbines as a control group and comparing the annual adjusted fatality rates of the Santa Clara turbines to the APWRA-wide annual fatality rates at older-generation turbines excluding the Santa Clara turbines. Sampling intensity was 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 half of the study, one might expect fatality rates to decrease over time disproportionately at older-generation non–Santa Clara turbines relative to Santa Clara turbines, and for the average annual fatality rates at Santa Clara turbines to be higher than the non–Santa Clara older-generation turbines.

American kestrel fatality rates at older-generation non–Santa Clara turbines decreased slightly over time at a moderately significant level ($R = -0.637$, $P = 0.065$), while rates at the Santa Clara turbines increased significantly over time ($R = 0.730$, $P = 0.023$), indicating a beneficial effect of hazardous turbine removal for this species (Figure 3-8). However, the mean annual fatality rates between the two groups over the course of the study were not significantly different ($t_{16} = 1.019$, $P = 0.323$). There was no significant trend over time in fatality rates for burrowing owls in either group and no difference in mean fatality rate over the course of the study ($t_{16} = 0.588$, $P = 0.565$). Fatality rates for golden eagle were significantly lower at Santa Clara turbines than non–Santa Clara turbines. There was no significant trend over time in fatality rates for red-tailed hawk in either group. However, for red-tailed hawk the mean annual fatality rate over the course of the study was significantly higher at the Santa Clara turbines than at non–Santa Clara turbines ($t_{16} = 4.125$, $P < 0.001$) (Figure 3-8), indicating a potential beneficial effect of hazardous turbine removals for this species.

Seasonal Shutdown

We examined several 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 declines in golden eagle and red-tailed hawk fatalities but not in apparent declines in American kestrel and burrowing owl fatalities.

Comparison of Diablo and Non–Diablo Winds Fatality Rates

The effectiveness of the seasonal shutdown in reducing avian fatalities was evaluated by using the Diablo Winds turbines as a control group and comparing annual fatality rates at Diablo Winds turbines with the annual fatality rates from non–Diablo Winds turbines. The Diablo Winds turbines were monitored in monitoring years 2005–2009. If the seasonal shutdown were effective, one might expect fatality rates at older-generation (non–Diablo Winds) turbines to exhibit a greater decrease over time relative to fatality rates at Diablo Winds turbines, assuming all else is equal.

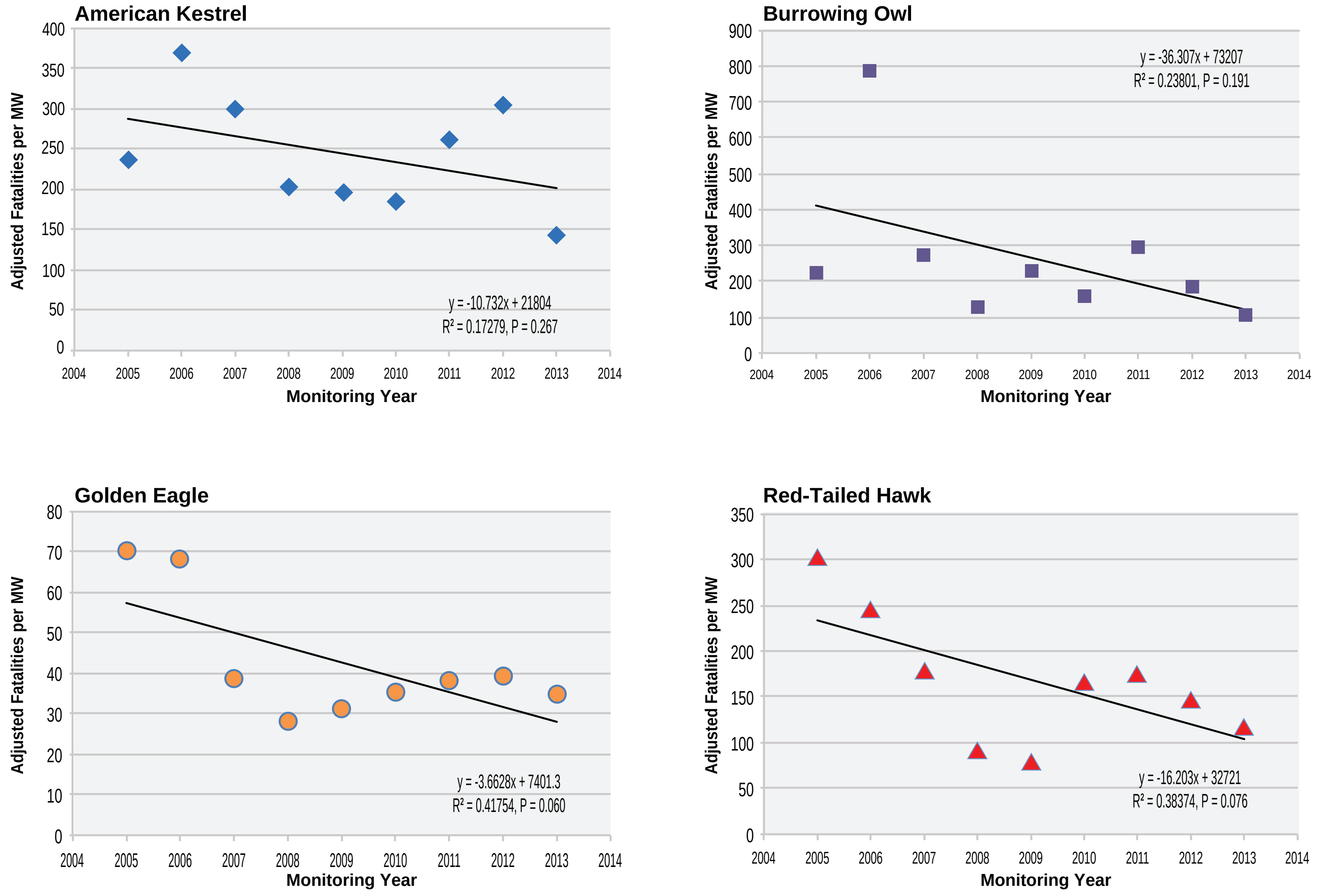

Figure 3-7
Trends in Annual APWRA-wide Total Fatalities at Older Generation Turbines for the Four Focal Species in the APWRA, Monitoring Years 2005–2013

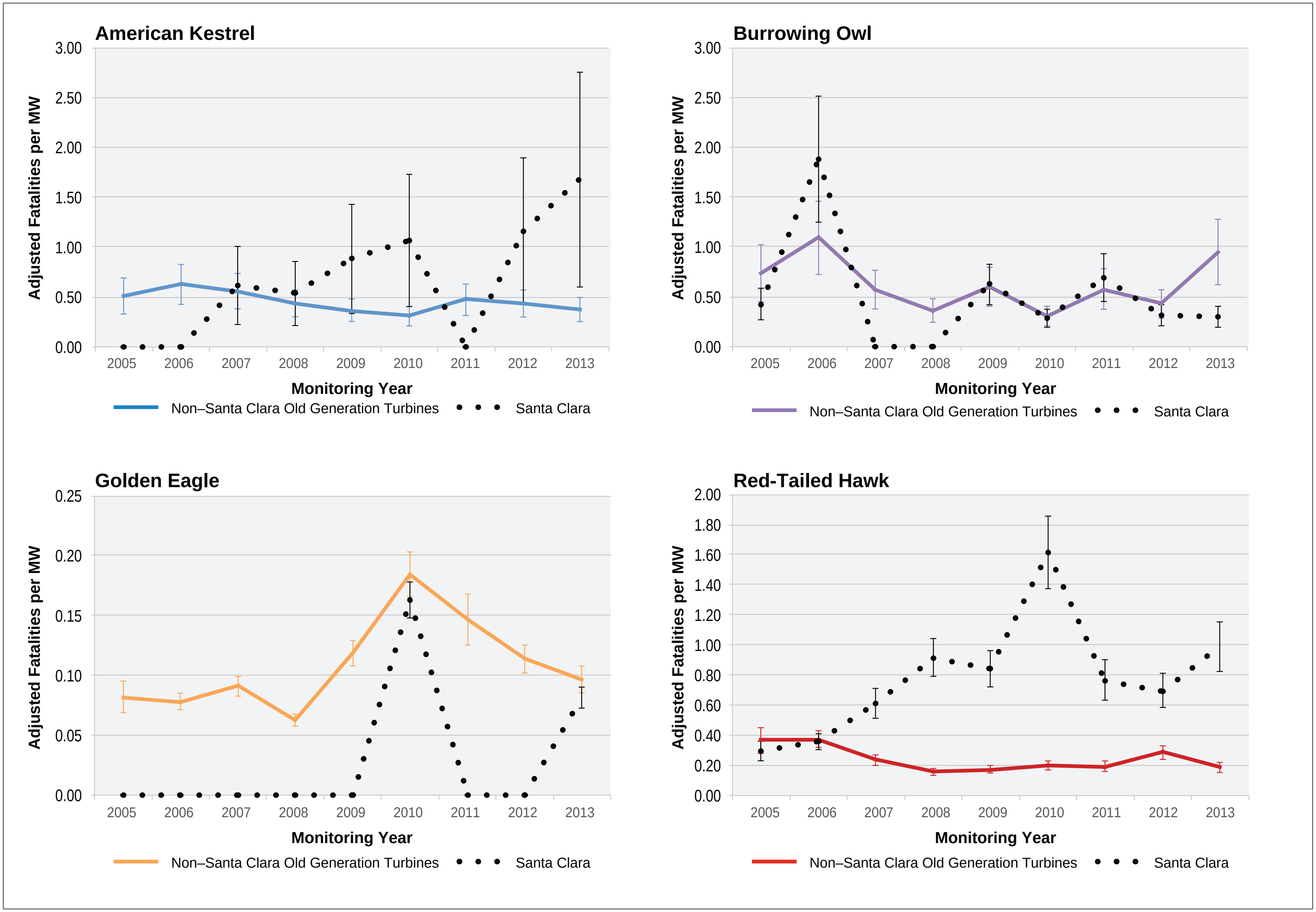

Figure 3-8

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

This comparison of Diablo Winds and non-Diablo Winds turbines differs from the analysis below (see *Repowering*) in that the non-Diablo Winds turbine fatality rates used here are averaged across the monitoring years 2005–2009, where the average used below is across all years of the study.

There were no American kestrel fatalities detected at Diablo Winds turbines in 3 of the 5 years of monitoring (Figure 3-9). The two American kestrel fatalities detected occurred in August and October, outside the seasonal shutdown period. Consequently, the average annual fatality rate at Diablo Winds turbines was significantly lower than the average annual fatality rate at older-generation non–Diablo Winds turbines based on non-overlapping 95% confidence intervals.[1] However, use rates were also significantly lower in the three geographic BLOBs containing the Diablo Winds turbines compared to the rest of the APWRA (t_{7369} = 4.77, $P < 0.001$).

There was no significant difference in average annual burrowing owl fatality rates between Diablo Winds and non–Diablo Winds turbines, and no significant trend over time for either group (R = -0.600, P = 0.327 and R = -0.448, P = 0.496, respectively) (Figure 3-9).

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) (Figure 3-9). The average annual fatality rate was significantly lower at Diablo Winds than non-Diablo Winds turbines, even though use rates at Diablo Winds turbines were significantly higher than non-Diablo Winds turbines (t_{7369} = 3.28, P = 0.001).

There was no significant difference in average annual red-tailed hawk fatality rates between Diablo Winds and non–Diablo Winds turbines. However, red-tailed hawk fatality rates at non–Diablo Winds turbines decreased significantly over time (R = -0.967, P = 0.004), while fatality rates at Diablo Winds turbines did not (R = -0.208, P = 0.765) (Figure 3-9), indicating a potential beneficial effect of the seasonal shutdown. Red-tailed hawk use rates at Diablo Winds turbines were not significantly different from use rates at non–Diablo Winds turbines (t_{7369} = 1.92, P = 0.055).

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

We examined the number and proportion of annual fatalities occurring during and outside the shutdown period for the monitoring years in which the universal 3.5-month shutdown occurred (Table 3-11). Clearly, the number of fatalities occurring during the shutdown period was greater than zero for all four focal species.

Table 3-11. 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 would theoretically be zero, was much higher for burrowing owl relative to the two larger species, and intermediate for American kestrel. This led to the hypothesis that predation may account for the continued accumulation of burrowing owl (and other small bird) carcasses in the search area around turbines even though the turbines were shut down. If true, this could explain why no decline in APWRA-wide burrowing owl fatalities was detected.

To examine this hypothesis, we calculated both the proportion and number of fatalities one might expect to find during the shutdown period if collision risk and relative abundance remained constant across the year, despite the shutdown of turbines. Expected values were calculated based on the proportion of the year the turbines were shut down (i.e., 0.29) (Table 3-12). For burrowing owl, a species known to be subject to predation from a wide variety of avian predators (Poulin et al. 2011), a substantially greater proportion of fatalities occurred during the shutdown period than expected ($\chi 2 = 8.60$, $P = 0.003$). For American kestrel, the proportion of fatalities occurring during the shutdown period was not significantly different from expected ($\chi 2 = 1.29$, $P = 0.256$), while significantly fewer than expected 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).

Table 3-12. 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 eliminate the possibility that the results observed were due to variation in search effort, a separate analysis was conducted of carcass detection rates (detections per search of a turbine string) during and outside the shutdown period (Table 3-13). Consistent with the previous analysis, the burrowing owl carcass detection rate was significantly higher during the shutdown period than outside the shutdown period, while the carcass detection rates for golden eagle and red-tailed hawk were significantly lower during the shutdown period than outside the shutdown period. The carcass detection rate for American kestrel was also marginally significantly lower during the shutdown period than outside the shutdown period.

This analysis was extended to three groups of birds (predatory birds, large non-predatory birds, and small birds likely to be subject to predation) for which we had an adequate sample of fatality

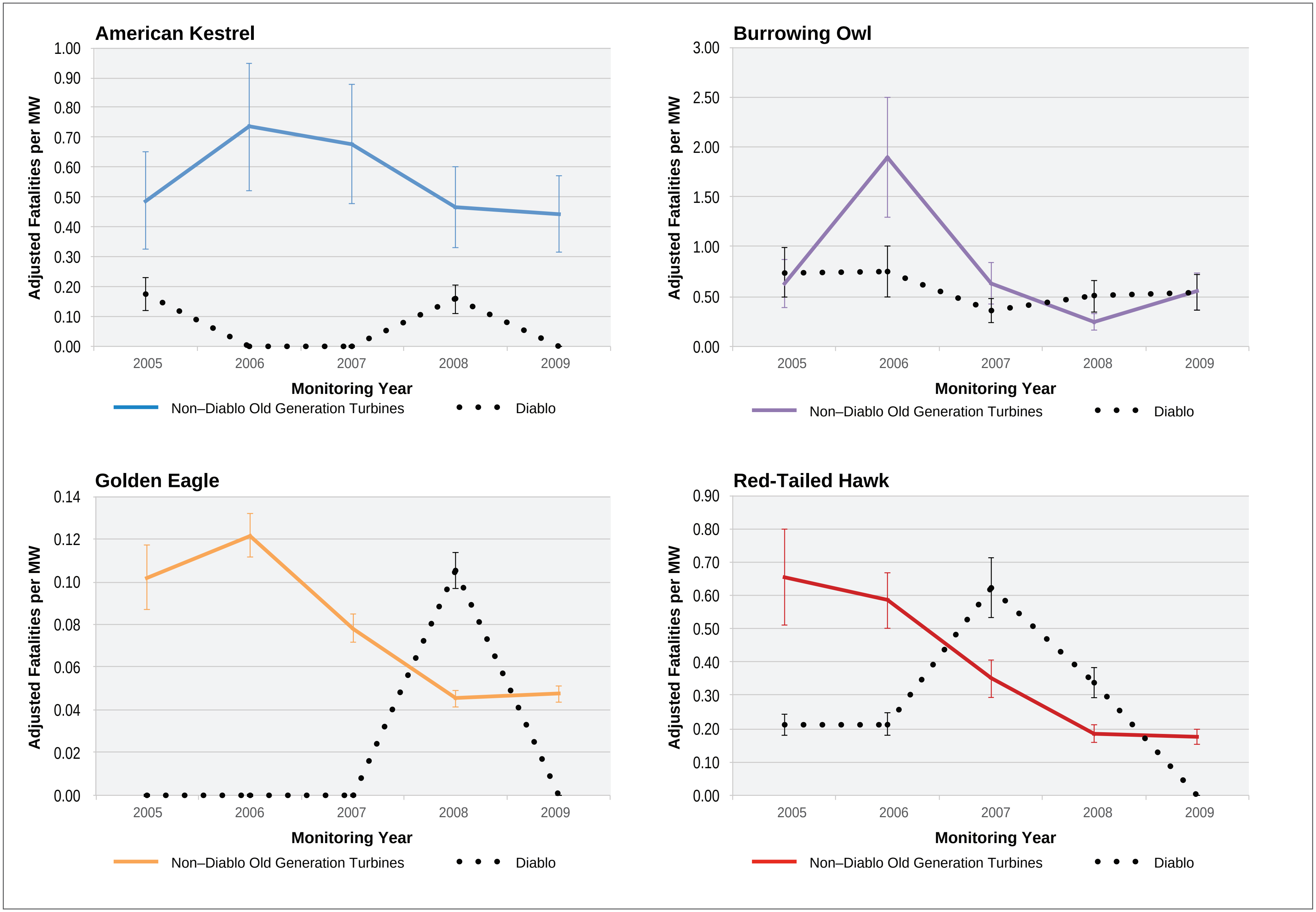

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Figure 3-9

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

detections ($n \geq 15$ carcasses) (Table 3-14). With the possible exception of American kestrel, all predatory birds had a significantly lower carcass detection rate during the shutdown period than outside the shutdown period, a pattern that also held for large, non-predatory birds. Conversely, with the exception of horned lark and European starling, the carcass detection rate of all small birds likely to be subjected to predation was significantly greater during the shutdown period than outside the shutdown period. American kestrel and European starlings are both cavity nesters that explore openings in the nacelles of older-generation turbines and have become trapped and died in these structures, which may – at least in part – explain why they did not conform to the fatality pattern outlined above.

We then examined how relative abundance (bird use) during the shutdown period relative to the rest of the year might affect the analyses outlined above for the four focal species. This was done 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 values of fatalities occurring in each period (Table 3-15).

Table 3-13. 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 3-14. Detection Rates (Detections per String Search) for Three Species Groups 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
		Prey Species		
Burrowing owl	48/3,060	50/7,263	2.2988	< 0.001
Mourning dove	21/3,060	29/7,263	1.7236	0.062
Horned lark	9/3,060	10/7,263	2.1360	0.128
Unidentified bluebird	12/3,060	8/7,263	3.5597	0.005
Starling	67/3,060	197/7,263	0.8073	0.151
Western meadowlark	84/3,060	107/7,263	1.8663	<0.001

Species	Fatalities per String Search during Shutdown Period	Fatalities per Turbine Search outside Shutdown Period	Odds Ratio	Fisher's Exact Test (2-sided) Probability
Total Prey Species	**241/3,060**	**401/7,263**	**1.4264**	**<0.000**
Predatory Species				
American kestrel	22/3,060	78/7,263	0.6671	0.099
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
Barn owl	11/3,060	56/7,263	0.4663	0.021
Great horned owl	2/3,060	25/7,263	0.1899	0.010
Total Predatory Species	**57/3,060**	**355/7,263**	**0.3811**	**< 0.000**
Other Large Birds				
California gull	1/3,060	34/7,263	0.0698	<0.000
Unidentified gull	23/3,060	173/7,263	0.3156	<0.000
Total Large Bird	**24/3,060**	**207 /7,263**	**0.2752**	**< 0.000**

Table 3-15. 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	χ^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.

Significantly fewer American kestrel fatalities occurred during the shutdown period than expected when use was accounted for ($\chi^2 = 6.10$, P < 0.014) (Table 3-15) due to the much higher average use by kestrels during the shutdown period than outside the shutdown period. This was also true for golden eagle and red-tailed hawk for the same reasons ($\chi^2 = 12.13$, *P* < 0.001, and $\chi^2 = 31.35$, *P* < 0.001, respectively).

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 for prey species but not for predatory species because there was more time available for predated carcasses to accumulate in the search area. We therefore calculated the proportion of annual fatalities occurring during the shutdown period for each of the focal species across all years of the study (Table 3-16). 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 or red-tailed hawk.

Table 3-16. 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

Three hundred and thirty-eight regular searches were conducted at matched turbine and non-turbine ridges from November 1, 2014, through February 15, 2015, the period corresponding to the seasonal shutdown. The average search interval was 10.6 days. Twenty valid carcasses were found (i.e., found during regular searches within the search area and not aged out of the search interval) at non-turbine ridges and 38 valid carcasses were found at turbine ridges. Thus, 58 valid fatalities were found over a period of 3.5 months during which time all older-generation turbines in the APWRA were shut down and all turbines included in the study were verified by search crews to not be spinning (Table 3-17). Fifty-one of 58 valid carcasses found (88%) were those of small birds. The proportion of carcasses that were small birds was not significantly different between turbine and non-turbine ridges (0.91 and 0.77, respectively, $\chi^2 = 0.846$, $P = 0.358$).

The small bird carcass detection rate was significantly higher 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, were likely to be subject to predation in the APWRA. Additional details regarding the results of the background mortality study are presented in Appendix F.

Table 3-17. 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

Species	Turbine Ridges	Non-Turbine Ridges
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

The annual fatality rates averaged across all years of the study for the four focal species at all older-generation turbines were compared to the fatality rates from the 31 Vestas V-47 660 kW repowered turbines of the Diablo Winds operating group. Those rates were also compared 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 3-18).

Table 3-18. 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

	Average Annual Adjusted Fatality Rate (95% CI)			
Species	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. American kestrel average annual fatality rates were significantly lower at Diablo Winds compared to older-generation non-Diablo Winds turbines based on non-overlapping 95% confidence intervals. However, as noted above, use rates were also significantly lower in the 3 geographic BLOBs containing the Diablo Winds turbines compared to the older generation turbines in the rest of the APWRA ($t_{12302} = 5.26$, $P < 0.001$).

There was no significant difference in burrowing owl average annual fatality rates between Diablo Winds and older-generation non-Diablo Winds turbines based on overlapping 95% confidence intervals.

Golden eagle average annual fatality rates were significantly lower at Diablo Winds turbines compared to older-generation non-Diablo Winds turbines based on non-overlapping 95% confidence intervals, despite the fact that use rates were significantly higher in the 3 geographic BLOBs containing the Diablo Winds turbines compared to the older-generation turbines in the rest of the APWRA ($t_{12302} = 4.65$, $P < 0.001$).

Red-tailed hawk average annual fatality rates were also significantly lower at Diablo Winds turbines compared to older-generation non–Diablo Winds turbines based on non-overlapping 95% confidence intervals, despite use rates being significantly higher in the three geographic BLOBs containing the Diablo Winds turbines compared to the rest of the APWRA ($t_{12302} = 5.71$, $P < 0.001$).

The average annual fatality rates for the Buena Vista turbines (BLOB 3), which are 1 MW turbines, were significantly lower for all four focal species—with the possible exception of golden eagle—than older-generation turbines based on non-overlapping 95% confidence intervals.

The average annual fatality rates for the Vasco Winds turbines (BLOB 4), which are most similar in size and capacity to the modern turbines currently being deployed throughout California, were not significantly different from fatality rates for older-generation turbines for American kestrel, golden eagle, or red-tailed hawk based on overlapping 95% confidence intervals. Conversely, the average annual burrowing owl fatality rate at the Vasco Winds turbines was significantly lower than older-generation turbines based non-overlapping 95% confidence intervals.

The Potential Influence of Predation as a Confounding Factor

Several lines of evidence associated with the seasonal shutdown of turbines suggested that a substantial proportion of small bird fatalities—in particular those occurring during the shutdown period, although the phenomenon was not necessarily restricted to the shutdown period—may have been due to predation rather than turbine collision. If this hypothesis were correct, the assessment of the reduction in focal species fatalities and effectiveness of management actions would be biased toward the conclusions of no reduction in focal species fatalities and a lack of effectiveness of management actions. Conclusions about the effectiveness of repowering in reducing burrowing owl fatalities might change, and the usefulness of predictive models to site turbines to avoid burrowing owl fatalities (Smallwood et al. 2009) might warrant re-examination.

Evidence indicative of an effect of predation is summarized below.

- There was 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. These high use rates during the winter are likely to be one of the primary reasons why the APWRA has the highest raptor fatality rates in the wind energy industry.
- Significant numbers of small bird fatalities continued to accumulate in the search area around older-generation turbines when the turbines were shut down, even though the theoretical

collision risk was reduced to near zero. A high proportion of these fatalities were composed of feather piles, for which a cause of death most often cannot be determined.

- While fatalities of many species with an estimated death date inside the shutdown period were found, significantly more small bird fatalities were found during the shutdown period than expected, while significantly fewer than expected large bird fatalities were found during the shutdown period. This pattern held across a variety of species and species groups, also applied to carcass detection rates, and became more significant when use rates were taken into account in the analysis. With respect to burrowing owl, the pattern does not appear to be related to the nocturnal habitat, as the two larger nocturnal owl species (great-horned owl and barn owl) exhibited the same pattern as all other large predatory birds.
- The proportion of annual fatalities occurring during the shutdown period increased significantly over time for burrowing owls—a species frequently subject to predation—as the duration and intensity of the shutdown period increased, but not for the two larger predatory focal species not subject to predation.
- Results of the background mortality confirmed that fatalities continued to accumulate in the search area around turbines as well as near ridges without turbines during the shutdown period. The vast majority of these carcasses were small birds at both turbine and non-turbine ridges, and the higher carcass detection rate at ridges with turbines may indicate that predatory birds may be taking their prey back to older-generation turbines for consumption.

Given the evidence summarized above, we estimated burrowing owl annual fatality rates and APWRA-wide total fatalities excluding carcasses with an estimated death date inside the shutdown period. Removing fatalities with an estimated death date inside the shutdown period resulted in a marginally significant decline in burrowing owl annual fatality rates (R = -0.653, P = 0.056) and a significant decline in estimates of annual APWRA-wide burrowing owl fatalities (R = -0.664, P = 0.050, Figure 3-10).

The removal of burrowing owl fatalities with an estimated death date during the shutdown period did not appreciably change the conclusions regarding the 50% reduction goal (Table 3-19). Three of the four measures of the reduction indicated a greater reduction in fatalities with burrowing owl fatalities with an estimated death date during the shutdown period removed. However, the size of the reduction measured by comparing the 3-year geometric mean alternative baseline to the estimate from the last year of the monitoring program decreased because the alternative baseline estimate was substantially reduced.

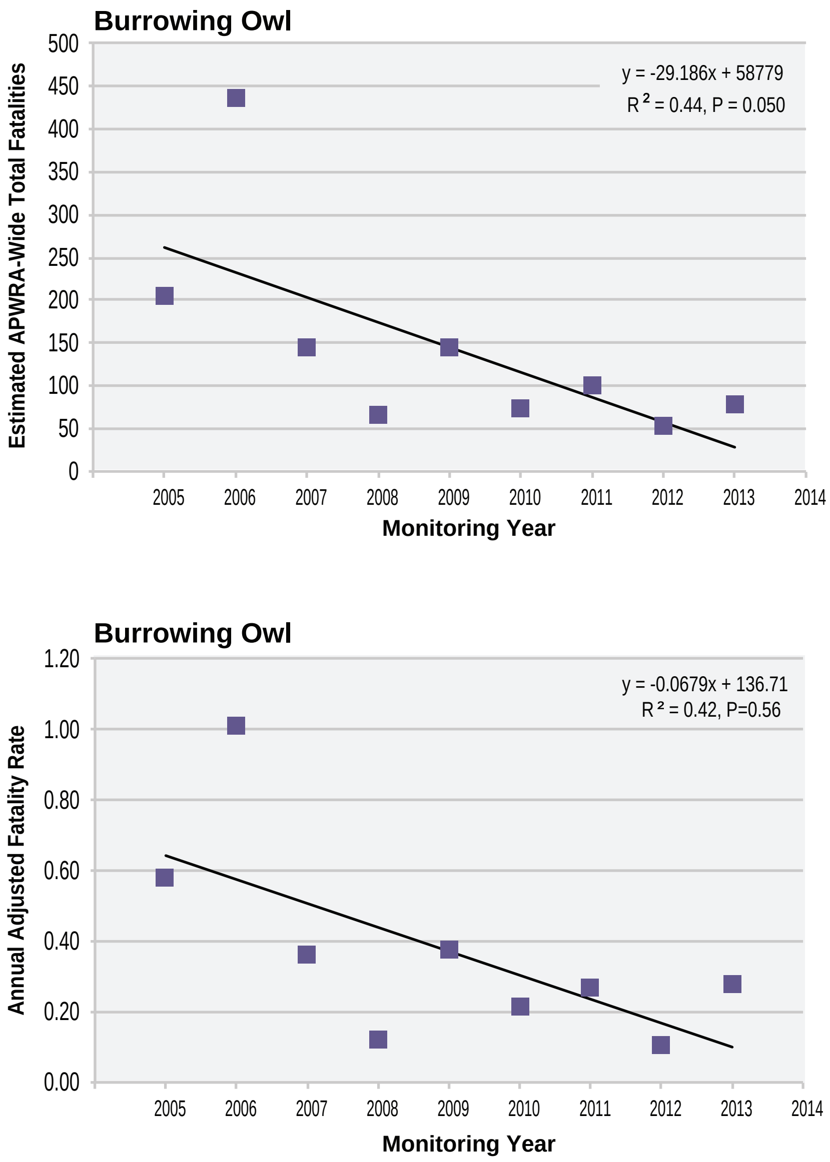

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Figure 3-10
Trends in Burrowing Owl APWRA-Wide Total Fatalities and Fatality Rates with Fatalities Occuring during the Shutdown Period Removed in the APWRA, Monitoring Years 2005–2013

Table 3-19. Various Measures of the Reduction in Total Annual Fatalities of the Four Focal Species (Excluding Burrowing Owl Fatalities with an Estimated Death Date during the Seasonal Shutdown Period)

					Percent Reduction from:			
Species	Settlement Agreement Baseline	3-Year Geometric Mean Baseline	3-Year Geometric Mean 2010–2013	2013 Monitoring Year Estimate	3-Year Geometric Mean Baseline to 3-Year Geometric Mean	3-Year Geometric Mean Baseline to 2013 Monitoring Year Estimate	Settlement Agreement Baseline to 3-Year Geometric Mean	Settlement Agreement Baseline to 2013 Monitoring Year Estimate
American kestrel	333	296	225	144	-24%	-51%	-32%	-57%
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**	**827**	**483**	**376**	**-42%**	**-55%**	**-57%**	**-67%**

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, using carcasses predominantly comprised of birds actually killed and deposited by wind turbines in the study area.

The sample size over the first 5 years of the study was approximately 58% to 87% larger than the original baseline study, with an average of 247 MW of turbines monitored. The sample of megawatts monitored was more than three times the size of the largest repowering project in the APWRA (as of September 2015). Even after the carcass search effort was reduced in 2010 to approximately 120 MW of turbines, it was still 1.5 times larger than the largest repowering project in the APWRA.

The analytical framework, which was first introduced in 2010 but not finalized until 2013, stratified the APWRA into geographically and topographically distinct units that generally shared a common turbine type and owner/operator, and presumably some degree of environmental and vegetation management similarity. This approach was clearly beneficial and necessary as evidenced by the large geographic variation in both bird use and fatality rates over time, and the relationships between them that were apparent only when analyzed at the BLOB level .

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 that were measured in the field, 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 avian fatalities in the APWRA to date.

Despite these advantages, a number of biases and uncertainties potentially influenced the estimates. These potential biases and uncertainties 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, 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 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). Longer search intervals result in lower detection probabilities and greater uncertainty. While it is clear that detection probability decreases as the search interval increases, the exact form of the relationship is unknown, particularly for longer search intervals, and is likely to be influenced by many factors. Therefore, the relatively large search intervals employed in this study could have influenced the results in not necessarily predictable ways.

Bleed through occurs when a carcass that is available to be detected is missed but then detected on a subsequent search. Such a carcass has already been accounted for in theory through the incorporation of detection probability in the estimation process, but it is now counted (and adjusted) in spite of this. While carcasses that are determined to be "aged" (i.e., determined to be older than the search interval) were 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. Numerous examples of "aged" carcasses in the APWRA exist, including a golden eagle wing that was determined to belong to a golden eagle carcass that was first detected 5 years prior. While there is no estimate of the bias in this study resulting from bleed through, the phenomenon would result in an overestimation of fatality rates and APWRA-wide total fatalities.

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), at least in part because detection probabilities estimated as part of a wide variety of population estimation processes have been documented to vary with a host of factors, including observers (or searchers), habitat, land cover, season, weather, year, and many others.

The lack of annual site-specific estimates of detection probability was a major shortcoming of this study. While carcass trials were initially conducted in the first 2 years of the study, these measurements were discarded and replaced with detection probabilities from a meta-analysis of carcass trials data from across the country under the assumption that use of detection probabilities from the meta-analysis would improve the comparability of the baseline and current studies (Smallwood 2007). Perhaps because it was never envisioned that the fatality monitoring program would last 9 years, traditional carcass placement trials to measure annual site-specific detection probabilities were never resumed, and thus trends over time in fatality rates and estimates of APWRA-wide total fatalities could not be distinguished from annual trends in detection probability.

Variation in Fatality Rates

Annual variation in fatality rates at older-generation turbines in the APWRA was significant for all four focal species, none of which showed any evidence of a decline over the course of the study. 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.

Use or relative abundance was significantly correlated with fatality rates for American kestrel, golden eagle, and red-tailed hawk, but only when the analysis was stratified, indicating substantial geographic variation in the APWRA with respect to use and collision risk. Factors influencing collision risk varied among species. Higher fatality rates were associated with shorter turbine towers for American kestrel and golden eagle, indicating that the use of taller turbine towers—

presumably with blades that at their lowest point are higher off the ground—could reduce fatality rates for these two species. Fatality rates were also higher at lower elevations for burrowing owl and red-tailed hawk, probably reflecting the distribution of burrowing owls and the distribution of use by red-tailed hawks. Monitored capacity was positively associated with fatality rates for all focal species except burrowing owl, and was included in the top ranked multivariable model for both American kestrel and red-tailed hawk. It is likely that this was a spurious result for red-tailed hawk, but the positive relationship between monitored capacity and fatality rate for American kestrel may indicate that sampling intensity was not sufficient to accurately determine American kestrel fatality rates in some BLOBs in some years. Rotor-swept area was a significant predictor of fatality rates for golden eagle, a relationship that could be used to refine the model currently used by the U.S. Fish and Wildlife Service to evaluate the impacts and take associated with future wind power projects.

Evaluation of the Effectiveness of Management Measures and Other Actions

The evaluation of the effectiveness of management actions in reducing turbine-related avian fatalities was difficult for a number of reasons. The hazardous turbine removal “treatment” was relatively small, annual variation in fatality rates (or detection probability) was large, and fatality rate estimates were imprecise, all of which combined to limit the statistical power to detect an effect, even if one were present.

Hazardous Turbine Removal

The two methods of evaluating hazardous turbine removals—the control group comparison and the models of factors influencing fatality rates—both indicated a beneficial effect of hazardous turbine removals for American kestrel, but were inconsistent with each other for the other focal species. Hazardous turbine removal was a significant predictor of burrowing owl fatalities, but there was no difference in fatality rates between the control group and parts of the APWRA subject to hazardous turbine removals. Golden eagle fatalities actually increased with increasing hazardous turbine removal, and fatality rates in the BLOB exempt from hazardous turbine removals were lower than other parts of the APWRA subject to hazardous turbine removals. Although possible, it seems unlikely that hazardous turbine removals resulted in an increase in collision risk for golden eagles. The control group comparison indicated a potential beneficial effect for red-tailed hawk, but hazardous turbine removal was not a significant predictor of red-tailed hawk fatality rates.

Based on fatality rates and use, American kestrel appears to be at greater risk of turbine collision than the other focal species, presumably due to the frequency of hover hunting in this species. Unlike burrowing owl and red-tailed hawk, American kestrel use was not inversely correlated with elevation (i.e., they occurred more often at higher elevations), and hazardous turbine removals were positively correlated with elevation. Therefore, despite a lack of consistent evidence for the other focal species, the evidence suggests that hazardous turbine removals had a beneficial effect on American kestrel fatality rates.

Seasonal Shutdown of Turbines

Four lines of evidence were examined to evaluate the effectiveness of the seasonal shutdown of turbines, the primary management action taken to reduce focal species fatalities; trends over time in annual estimates of focal species fatalities; the relationship between fatality rates and the duration and intensity of the seasonal shutdown; the comparison of fatality rates between a control group not subject to the seasonal shutdown and the portions of the APWRA that were subjected to the seasonal shutdown; and the comparison of carcass detection rates during and outside the shutdown period.

Declines in the annual estimates of APWRA-wide total focal species fatalities as measured by simple linear regression were moderately significant for golden eagle and red-tailed hawk, and significant for burrowing owl when the confounding effects of predation were accounted for. In fact, a moderately significant decline in burrowing owl fatality *rates* was evident when predation was accounted for. However, no decline was evident for American kestrel.

The comparison of the Diablo Winds control group to the rest of the APWRA where the seasonal shutdown was implemented showed a potential beneficial effect of the shutdown for red-tailed hawk, but not for any of the other focal species. However, the comparison was confounded by the potential effects of repowering in reducing focal species fatalities because the “control group” was composed of repowered turbines.

Seasonal shutdown was a significant predictor of fatality rates for all species except American kestrel, although it was not included in the top ranked models for any species except red-tailed hawk.

Finally, the comparison of carcass detection rates inside and outside the shutdown period strongly supports a beneficial effect of the seasonal shutdown in reducing fatalities for golden eagle and red-tailed hawk, and suggests an effect for American kestrel as well.

Taken together, the evidence supports a beneficial effect of the seasonal shutdown in reducing fatalities for all four focal species, with the possible exception of American kestrel.

Repowering

Comparing fatality rates at the three operating groups composed of repowered turbines with fatality rates at older-generation turbines indicated 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 have influenced these results. For example, fatality rates at older-generation turbines in the APWRA for smaller species subject to predation may have been biased high by the confounding effects of predation, especially if older-generation turbines were used as perches from which to consume prey. 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 a potential overestimate of the reduction in fatalities that is likely to occur. Methodological and analytical differences between the monitoring efforts at older-generation turbines and the monitoring efforts at two of the three repowered sites (i.e., Buena Vista and Diablo Winds) could also bias the comparison. In particular, search intervals at Buena Vista and Vasco Winds were shorter and more consistent than the search intervals at older-generation turbines, which would likely reduce the potential effects of bleed through that would bias fatality estimates at older-generation turbines high, overestimating the reduction in fatalities resulting from repowering. Also, because annual estimates of detection probability were only measured at Vasco Winds, some of the comparisons necessarily require the untenable assumption that detection probabilities were equal among sites, years, and observers.

The Influence of Predation

Circumstantial evidence has accumulated indicating that predation is a source of mortality for burrowing owls (and other smaller species), particularly during the winter, and that this has biased estimates of turbine-related fatality rates high and has confounded the assessment of the effectiveness of management actions to reduce fatalities. The extent of the bias is unknown, because in the vast majority of cases, turbine-related mortality cannot be distinguished from predation.

However, the predation hypothesis has been vigorously challenged. Therefore, a summary of the evidence and further discussion is warranted.

Significantly more burrowing owl carcasses than expected were found during the shutdown period, and carcass detection rates were significantly higher during the shutdown period relative to the rest of the year. Burrowing owls are subject to high levels of predation by a wide array of avian and mammalian predators, and use in the APWRA by potential avian predators increases significantly during the shutdown period. The pattern of significantly higher carcass detection rates during the shutdown period held for almost all small bird species that are regularly subject to predation for which we had an adequate sample size. Conversely, all large birds in general, and all large predatory birds in particular, including the two larger owl species, had significantly lower carcass detection rates during the shutdown period relative to the rest of the year. Finally, intensive searches around turbines and matched non-turbine ridges demonstrated that substantial numbers of fatalities continued to accumulate in the search areas on ridges with and without turbines during the shutdown period, and these carcasses overwhelmingly consisted of small bird species regularly subject to predation.

That significant amounts of predation occur in the APWRA during the period of the seasonal shutdown seems obvious. The APWRA has experienced the highest raptor fatality rates in the industry precisely because it is so attractive to large numbers of wintering predatory birds. Bird use data clearly demonstrate that use of the APWRA by predatory birds, including golden eagles, red-tailed hawks, peregrine falcons, prairie falcons, merlin, ferruginous hawks, rough-legged hawks, northern harriers, and Cooper's hawks, increases significantly every winter. 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).

The evidence above notwithstanding, it has been argued that the burrowing owl fatalities occurring during the shutdown period resulted from collision with non-operating turbines with stationary blades (Contra Costa Times 2015; Smallwood 2015). For this hypothesis to explain the fatality patterns observed, collision risk would have to be higher during the shutdown period (when the turbines are shut down) than outside the shutdown period (when they are operating), or large numbers of burrowing owls would have to move into the APWRA during the period of the shutdown (and only during this time), or both. The idea that the large number of burrowing owl carcasses detected during the shutdown period result from collision with non-operating turbines does not account for the fact that only smaller birds are apparently colliding with non-operating turbines while larger birds are not.

If predation accounts for most of the fatalities that occur during the shutdown period, then implementation of management actions resulted in a significant decline in turbine-related burrowing owl fatalities, previously published estimates of turbine-related burrowing owl fatalities have been biased high, and the magnitude of the reduction in burrowing owl fatalities resulting from repowering may be overestimated. In addition, collision hazard models for burrowing owls used to site new turbines might need to be revised if they are based on spatial patterns in burrowing owl fatalities (Smallwood et al. 2009).

Evaluation of the 50% Reduction

Term and condition 3 of the settlement agreement required a 50% reduction in focal species fatalities within 3 years from a baseline point estimate that took no account of sampling variation or annual variation in fatality rates. It therefore seems reasonable to conclude that the settling parties intended the reduction to be measured from a single year's point estimate. Under this assumption, the 50% reduction goal was achieved by the criteria set in the settlement agreement. The reduction in total focal species fatalities exceeded 50% as measured from both the original settlement agreement baseline and the SRC-adopted alternative (3-year geometric mean) baseline to the 2013 monitoring year point estimate.

However, from a statistical and/or biological perspective, the extent of the reduction in focal species fatalities is more difficult to assess. In fact, an objective, quantifiable, and reliable assessment of the reduction in focal species fatalities attributable to the implementation of management actions is nearly impossible, primarily due to detection probability issues with the baseline and the lack of annual detection probability estimates in this study.

The baseline study used detection probabilities derived from other studies—i.e., they were not measured (Smallwood and Thelander 2004). Unmeasured detection probabilities notwithstanding, Smallwood and Thelander (2004) concluded that their estimates were underestimates. In a subsequent paper, Smallwood and Thelander (2008) used a different set of detection probabilities from Smallwood (2007) and applied them to the same dataset from Smallwood and Thelander (2004). 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%. Because detection probabilities were never measured, there is no way to know which estimates more closely reflect the actual number of focal species fatalities that occurred during the period of the baseline study.

The comparison described above highlights the importance of actually measuring detection probabilities. It is a clear example of why using "borrowed" detection probabilities, particularly to "make studies more comparable," as advocated by Smallwood (2007), applied by Smallwood and Karas (2009), Smallwood et al. (2009), Insignia Environmental (2012), and in earlier versions of this report (ICF International 2011), is ill-advised. The inherent problems associated with using "borrowed" detection probabilities to "make studies more comparable," although logically discernable, did not become empirically evident until after the fourth year of fatality monitoring (ICF International 2011), which is why the SRC recommended adoption of the "alternative" (3-year geometric mean) baseline in 2009.

With the implementation of 5 years of almost total turbine curtailment at older-generation turbines for 29% of the year, at a time of year when use of the APWRA was demonstrably and significantly larger for at least three of the four focal species, it is reasonable to wonder why a larger reduction in focal species fatalities could not be more definitively demonstrated. There are a number of reasonable explanations. First, the baseline study estimate was not comparable to the current study estimates for the reasons outlined above, and cannot be used to assess a biologically or statistically defensible assessment of reductions in focal species fatalities. We were therefore left with evaluating the reduction—if any—in focal species fatalities from the point at which the monitoring program had already begun. However, some form of the seasonal shutdown occurred during every year of the study, so the declines observed are those that would result from a 12% increase in the shutdown period (i.e. the difference between a shutdown for 17% of the year and a shutdown for 29% of the year), not a decline that would result from shutting down turbines for 29% of the year. The last 4 years of the study occurred during a drought (arguably the most severe drought ever recorded in California), which severely limited grass growth, which would in turn very likely increase detection probabilities, thereby biasing fatality rate estimates high during that period. Finally, while there appears to be a substantial amount of annual variation in fatality rates, this could also be variation in detection probability that went undocumented, because annual detection probabilities were not measured. High levels of annual variation complicate the detection and accurate quantification of trends over time.

The issues described above notwithstanding, there was a marginally significant decline over the course of the study in golden eagle and red-tailed hawk fatalities as measured by simple linear regression, and for burrowing owls if fatalities with an estimated death date inside the shutdown period are removed from the analysis. Why the reduction in American kestrel fatality rates and estimates of APWRA-wide fatalities was so much less pronounced than reductions for the other focal species is unknown.

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 available evidence indicates that the 50% reduction goal identified in the settlement agreement was achieved. However, a biologically and/or statistically based conclusion about the *extent* of the reduction in fatalities resulting from the implementation of management measures and repowering could not be made based on the available evidence.
2. The preponderance of the evidence suggests that predation may be a substantial mortality factor in the APWRA for those species typically subject to predation during the winter, and that this potential bias should be accounted for when estimating total fatalities and drawing conclusions about the extent of the decline in turbine-related focal species fatalities and the effectiveness of management measures.
3. The available evidence suggested that repowering the APWRA with larger modern turbines would result in a reduction in the number of raptors killed per MW of power produced. However, the size of the reduction may be overestimated for a variety of reasons, including the overestimation of fatalities at older-generation turbines for species subject to predation, the lack of representativeness of the existing repowered projects, and other factors.

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

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

Siemens 2.3 MW

Howden 750 kW

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).

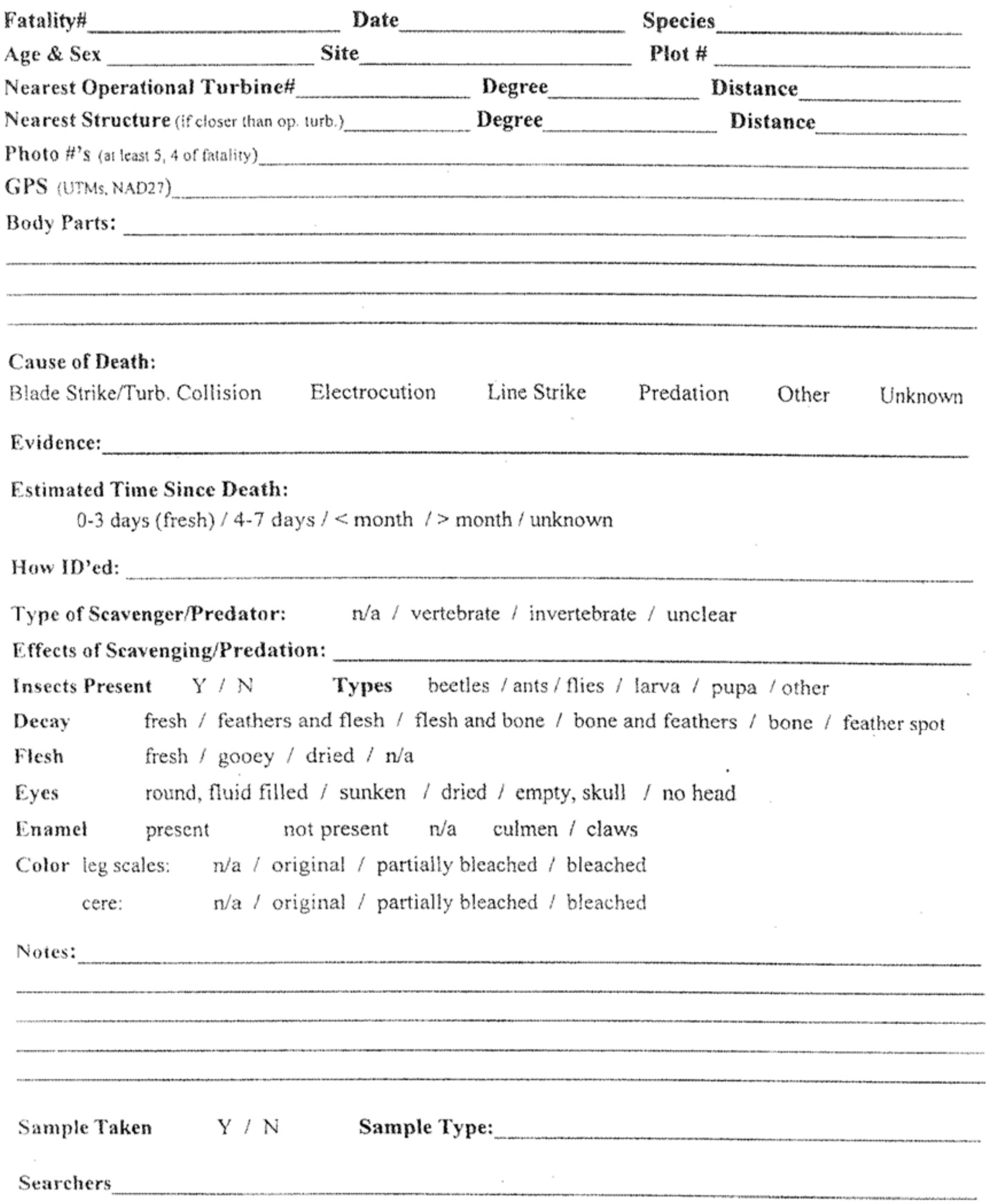
CARCASS REMOVAL/SCAVENGING TRIALS

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

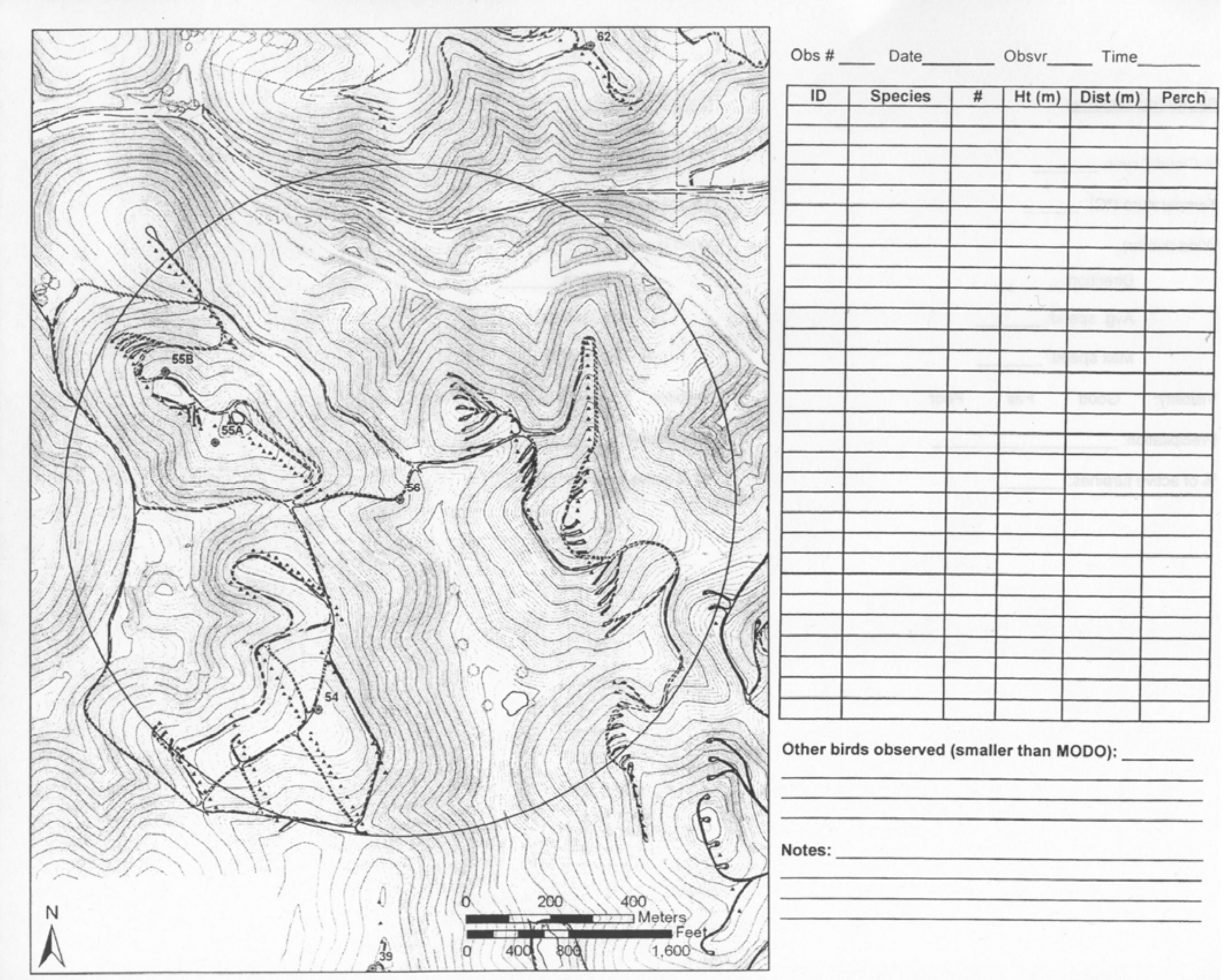
Color leg scales: n/a / original / partially bleached / bleached
cere: n/a / original / partially bleached / bleached

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

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

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

Perches

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

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)____

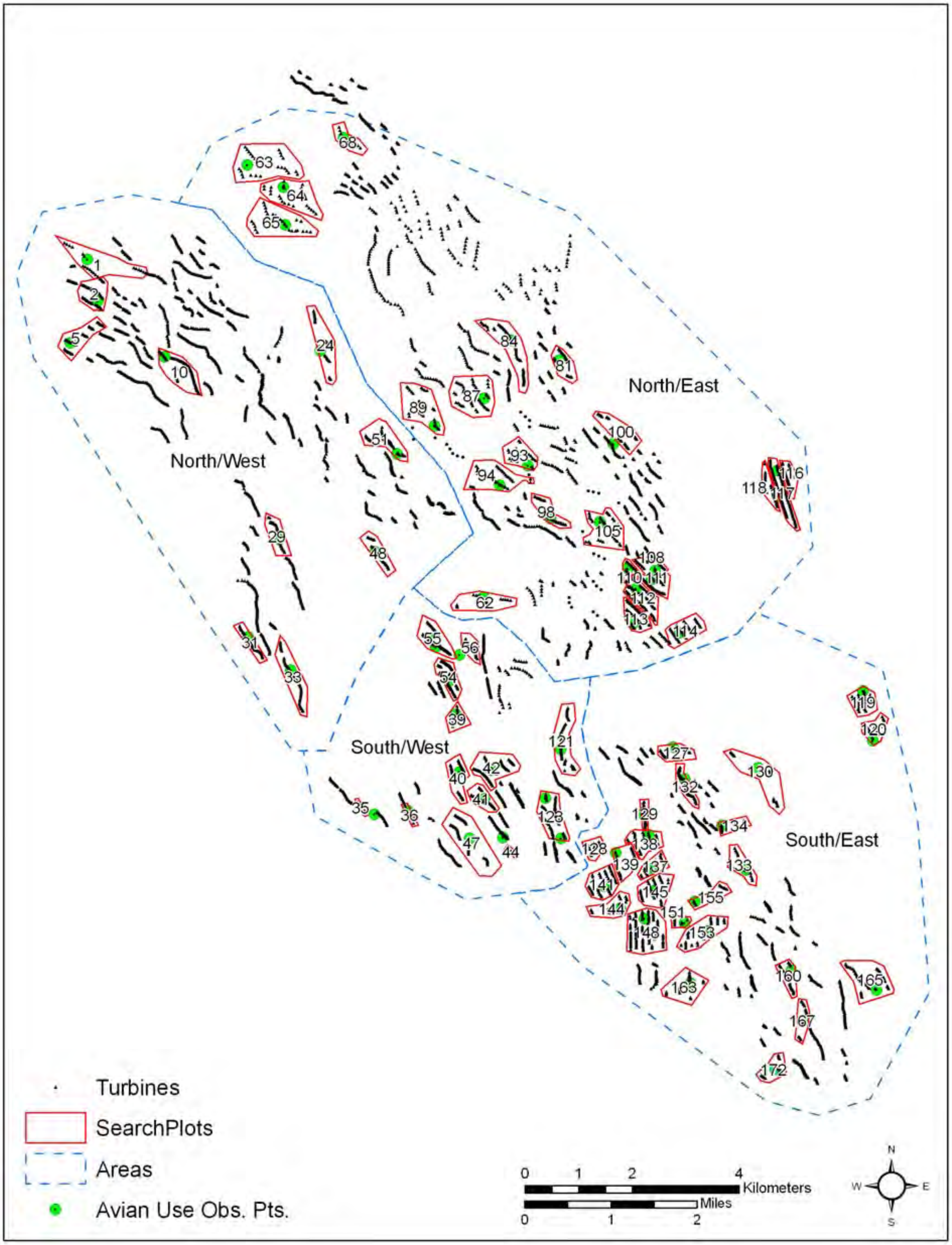


Figure 1. Fatality search plots and observation points for the APWRA Monitoring Study.

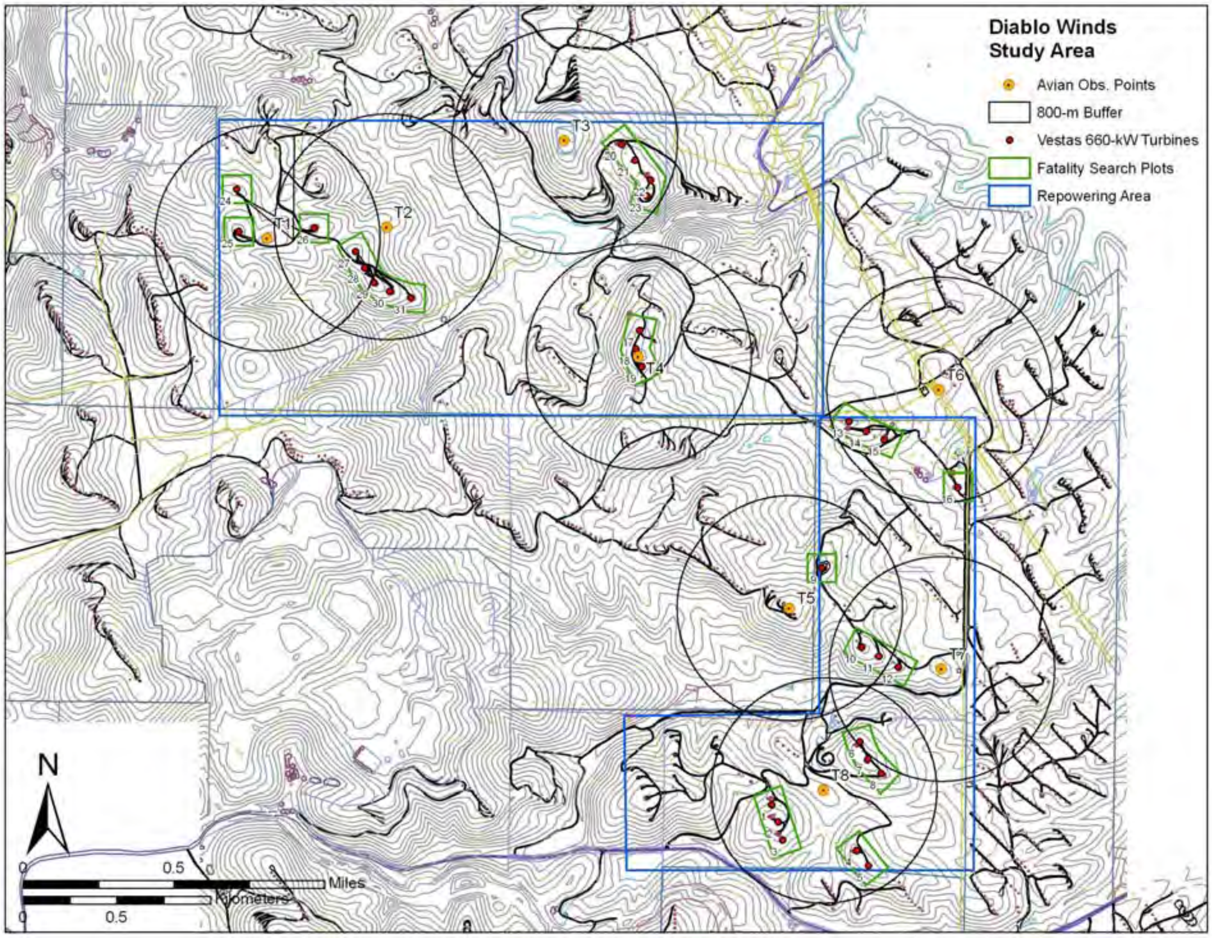


Figure 2. Fatality search areas and avian observation points in the Diablo Winds repowering area.

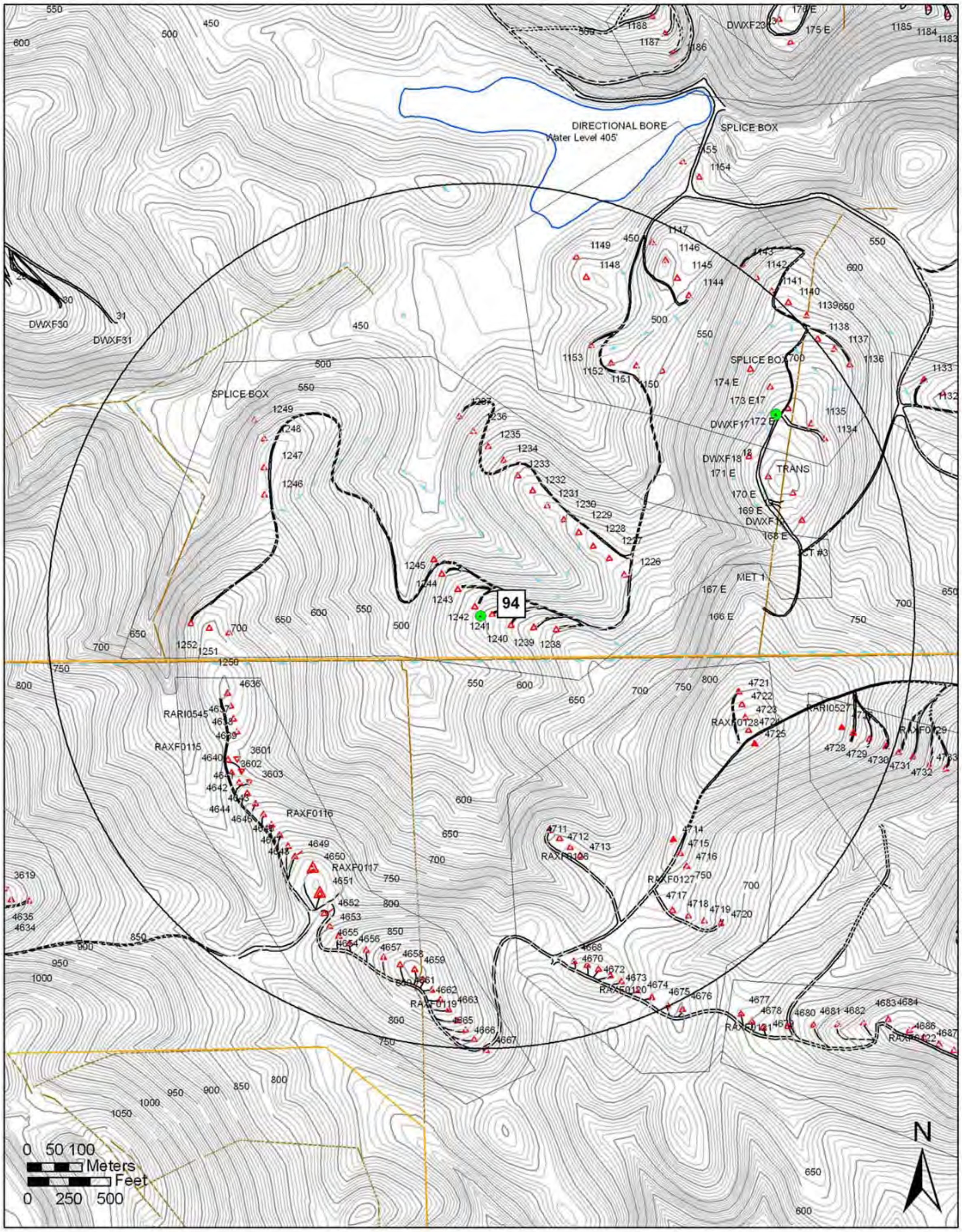


Figure 3. Topographic map with search area (800-m radius for APWRA Monitoring) used to map bird movements during 30-min observation periods.

Appendix C

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

Appendix C
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

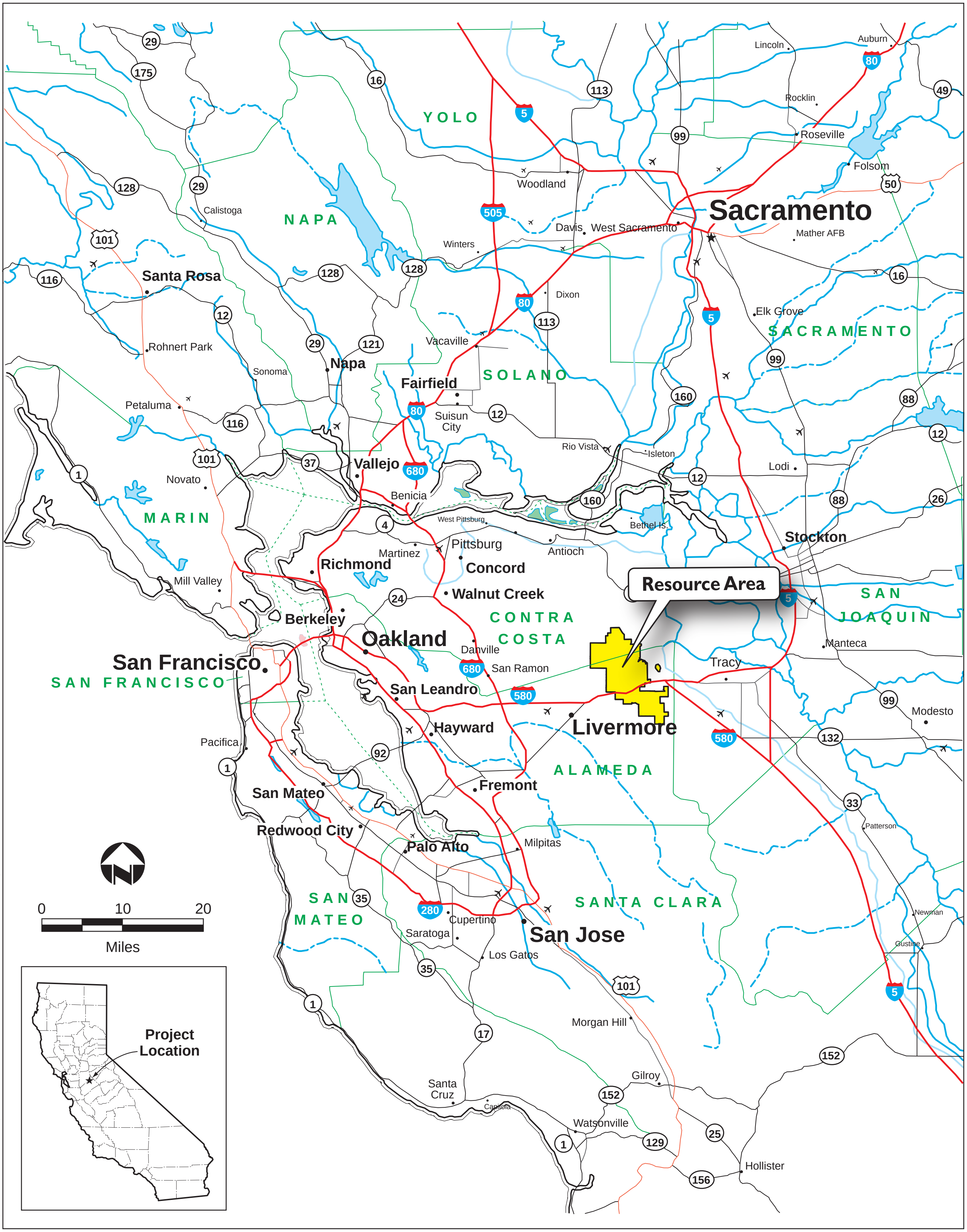


Figure C-1
Location of the Altamont Pass Wind Resource Area (APWRA)

ICF INTERNATIONAL

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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

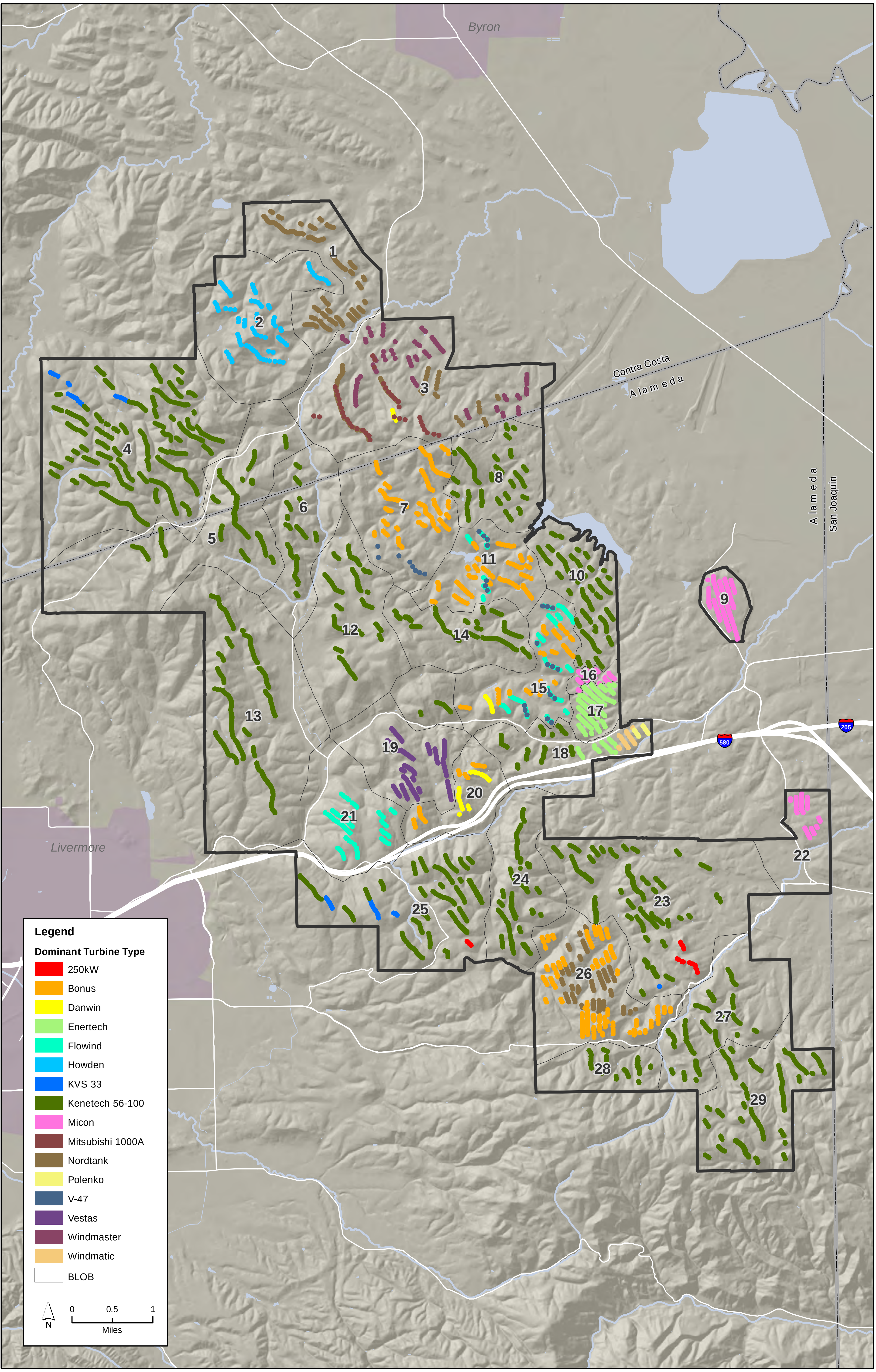

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Figure C-2
Base Layer of Operating Group Boundaries in the APWRA

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 $(0, \infty)$, 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.

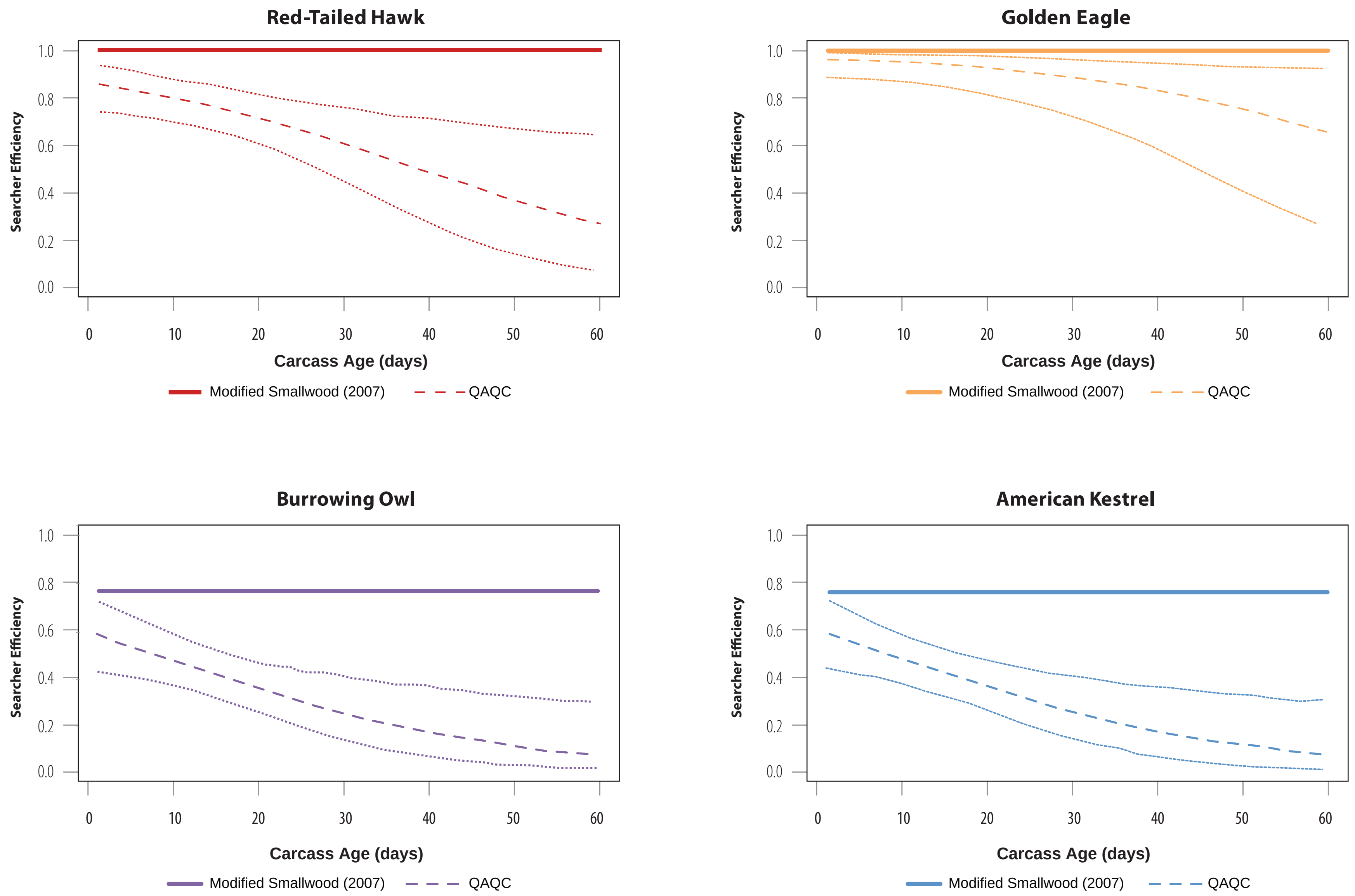
The QAQC study was implemented successfully without interfering with the primary search interval. Logistics and person-power limitations resulted in a relatively small number of the more complex search sequences. Simple repeat sampling (primary to secondary to next primary) provided a large amount of 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).



Graphics/00904.08 Altamont Pass/BY 2010 Avian Monitoring Report (11-12) SS

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

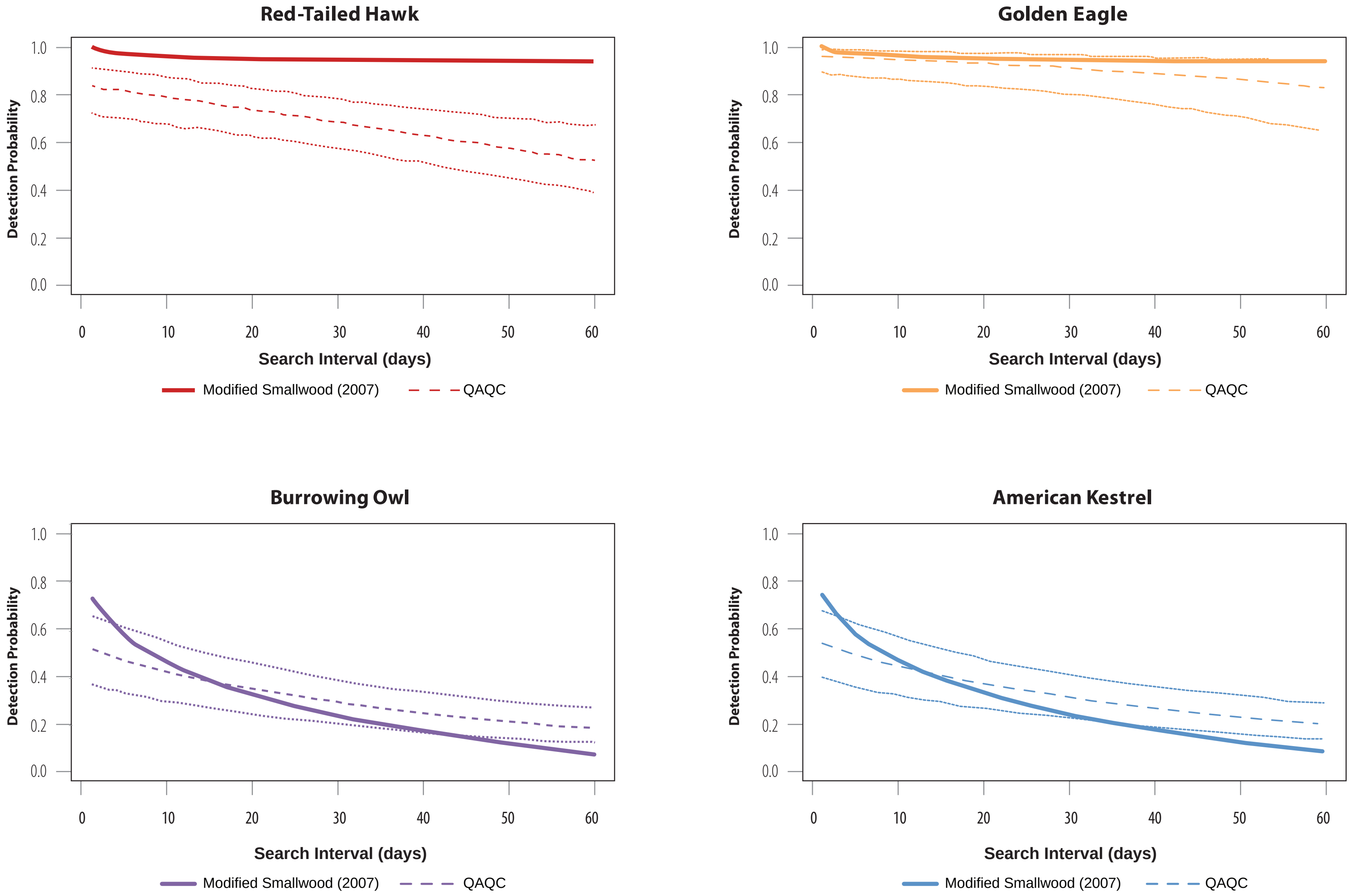


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Figure C-4
Changes in Detection Probability (and 95% Credible Interval Bands) Over Time for the Four Focal Species in the APWRA Based on Search Sequences Conducted during the QAQC Study and Information from the Carcass Removal / Scavenging Trial Study

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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Appendix D

Calculation of Fatality Rates and Estimated Total Fatalities

Appendix D
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.	
$b_M(y)$	Monitored strings		The subset of turbine strings in BLOB b that were searched 6 or more times in bird year y.	
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.6
$C_M(y)$	Monitored capacity	Bird year	The APWRA-wide amount of generating capacity that was monitored during bird year y.	Section D.6
$\hat{F}(y, s)$	Estimated fatality count	Bird year and species	The total number of fatalities estimated to have occurred APWRA-wide during bird year y.	Section D.2
$\hat{F}(y, s, b)$	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.10.1
$\hat{F}_X(y, s, b)$	Expanded fatality count	Bird year, species, and BLOB	The expanded fatality count for species s at BLOB b during bird year y.	Section D.10.3
$I(y, s_T)$	Search interval	Bird year and string	The average search interval at string s_T during bird year y.	Section D.8

Variable	Name	Level of Aggregation	Description	Definition
$I(y, b)$	Search interval	Bird year and BLOB	The average search interval at BLOB b during bird year y.	Section D.8
$K(y, s_T)$	Search coverage	Bird year and string	The search coverage of turbine string s_T during bird year y.	Section D.7
$K(y, b)$	Search coverage	Bird year and BLOB	The search coverage of BLOB b during bird year y.	Section D.7
$n_I(y, b)$	Number of installed strings		The number of turbine strings that were installed in BLOB b during bird year y.	
$n_M(y, b)$	Number of monitored strings		The number of turbine strings in BLOB b that were searched 6 or more times during bird year y.	
$\hat{P}_D(y, s, b)$	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.10.3
$\hat{R}_J(y, s)$	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.10.3
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. In general, a turbine is denoted with the variable t, a string with the variable s_T, a BLOB with the variable b, and a stratum with the variable u. 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 $\hat{F}(y,s)$ denote the APWRA-wide point estimate of the number of avian fatalities of species s during 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:

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

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

The point estimate of the number of fatalities of species s at BLOB b during bird year y 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 at least 10% of a BLOB's installed capacity 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 0).

To calculate the adjusted fatality rate, an *adjusted fatality count* must first be extrapolated from the actual number of fatalities detected, accounting for incomplete search coverage and imperfect detection probability. 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.8 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:

$$\hat{R}_J(y,s,b) = \frac{\hat{F}_J(y,s,b)}{C_M(y,b)} \qquad \textbf{Equation 4}$$

$$= \frac{F_D(y,s,b)}{C_M(y,b) \cdot K(y,b) \cdot \hat{P}_D(y,s,b)}.$$

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. Because there is likely to be significant covariance of the fatality rates between BLOBs, the standard error of $\hat{F}(y,s)$ is calculated using the simple sum of the standard errors of each BLOB. This is a conservative estimate of the standard error; for further details see Equation 56 in Section D.12.1 below:

$$SE\left(\hat{F}(y,s)\right) = \sum_{b \in B} SE\left(\hat{F}(y,s,b)\right). \qquad \textbf{Equation 5}$$

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 $C_I(y,b)$ and the fatality rate per unit of installed capacity $\hat{R}(y,s,b)$. This means that the standard error of the fatality count at a BLOB is given by the formula (as described in Section D.12.2):

$$SE\left(\hat{F}(y,s,b)\right) = \hat{F}(y,s,b) \cdot \sqrt{\left(\frac{SE\left(\hat{R}(y,s,b)\right)}{\hat{R}(y,s,b)}\right)^2 + \left(\frac{SE\left(C_I(y,b)\right)}{C_I(y,b)}\right)^2}. \qquad \textbf{Equation 6}$$

D.4 Annual Fatality Rate

D.4.1 Point Estimate

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:

$$\hat{R}_J(y,s) = \frac{\hat{F}_J(y,s)}{C_M(y)}. \qquad \textbf{Equation 7}$$

where $C_M(y)$ is the APWRA-wide monitored capacity and $\hat{F}_J(y,s,b)$ is the APWRA-wide sum of the adjusted fatality counts of that species for all monitored BLOBs:

$$\hat{F}_J(y,s) = \sum_{b \in B_M(y)} \hat{F}_J(y,s,b)\,, \qquad \textbf{Equation 8}$$

where $B_M(y)$ is the subset of BLOBs monitored during bird year y.

D.4.2 Error

The APWRA-wide adjusted fatality rate is defined in **Error! Reference source not found.** to be the quotient of the APWRA-wide adjusted fatality count $\hat{F}_J(y,s)$ and the AWPRA-wide monitored capacity. This means that the standard error of the APWRA-wide adjusted fatality rate is given by the formula (as described in Section D.12.2):

$$SE\left(\hat{R}_J(y,s)\right) = \hat{R}_J(y,s) \cdot \sqrt{\left(\frac{SE\left(\hat{F}_J(y,s)\right)}{\hat{F}_J(y,s)}\right)^2 + \left(\frac{SE\big(C_M(y)\big)}{C_M(y)}\right)^2}\,, \qquad \textbf{Equation 9}$$

where $SE\left(\hat{F}_J(y,s,)\right)$ is given by Equation 5 and $SE\big(C_M(y)\big)$ is given by Equation 21 below.

D.5 Installed Capacity

D.5.1 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:

$$C_I(m,s_T) = \sum_{t\in s_T} \begin{cases} C(t) & t \text{ was installed during month } m \\ 0 & t \text{ was not installed during all of month } m, \end{cases} \qquad \textbf{Equation 10}$$

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:

$$C_I(y,s_T) = \frac{C_I(\mathrm{Oct},s_T) + C_I(\mathrm{Nov},s_T) + \cdots + C_I(\mathrm{Sep},s_T)}{12}, \qquad \textbf{Equation 11}$$

where $C_I(m,s_T)$ is the installed capacity of string s_T during monitoring month m defined in Equation 10.

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:

$$C_I(y,b) = \sum_{s_T\in b} C_I(y,s_T)\,, \qquad \textbf{Equation 12}$$

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*:

$$C_I(y) = \sum_{b \in B} C_I(y, b)\,, \qquad \textbf{Equation 13}$$

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

D.5.2 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:

$$SE\big(C_I(y, s_T)\big) = \frac{1}{12} \cdot \sqrt{\sum_{m=1}^{12} \big(C_I(y, s_T) - C_I(m, s_T)\big)^2}\,. \qquad \textbf{Equation 14}$$

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.12.1):

$$SE\big(C_I(y, b)\big) = \sqrt{\sum_{s_T \in b} SE\big(C_I(y, s_T)\big)^2}. \qquad \textbf{Equation 15}$$

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

D.6 Monitored Capacity

D.6.1 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:

$$C_M(y, s_T) = \begin{cases} C_I(y, s_T) & \geq 6 \text{ searches of string } s_T \text{ during year } y \\ 0 & < 6 \text{ searches of string } s_T \text{ during year } y, \end{cases} \qquad \textbf{Equation 16}$$

where the capacity $C_I(y, s_T)$ is calculated using Equation 11.

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

$$C_M(y,b) = \sum_{s_T \in b} C_M(y,s_T)\,, \qquad \textbf{Equation 17}$$

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 17. Note that Equation 17 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:

$$C_M(y) = \sum_{b \in B} C_M(y,b)\,, \qquad \textbf{Equation 18}$$

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.6.2 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:

$$SE\big(C_M(y,s_T)\big) = \begin{cases} SE\big(C_I(y,s_T)\big) & s_T \text{ was monitored} \\ 0 & s_T \text{ was unmonitored} \end{cases}, \qquad \textbf{Equation 19}$$

where $SE\big(C_I(y,s_T)\big)$ is calculated by Equation 14.

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:

$$SE\big(C_M(y,b)\big) = \sqrt{\sum_{s_T \in b} SE\big(C_M(y,s_T)\big)^2}\,. \qquad \textbf{Equation 20}$$

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:

$$SE\big(C_M(y)\big) = \sqrt{\sum_{b \in B} SE\big(C_M(y,b)\big)^2}\,. \qquad \textbf{Equation 21}$$

D.7 Search Coverage

D.7.1 Point Value

Searches conducted during 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 monitored turbine strings in that BLOB during that bird year:

$$K(y,b) = \frac{1}{n_M(y,b)} \cdot \sum_{s_T \in b} K(y, s_T)\,,$$

Equation 22

where $n_M(y, b)$ is the number of strings in BLOB b monitored during bird year y 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 adjust the fatality estimates for incomplete search coverage. Regardless of coverage, strings with fewer than 6 searches in a bird year are considered inadequately sampled and are excluded from the analyses.

D.7.2 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:

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

Equation 23

D.8 Search Interval

D.8.1 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:

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

Equation 24

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:

$$I(y, b) = \frac{1}{n_M(y, b)} \cdot \sum_{s_T \in b} I(y, s_T) \,,$$

Equation 25

where $n_M(y, b)$ 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.8.2 Variance

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

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

Equation 26

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.12.3 :

$$SE\big(I(y, b)\big) = \frac{1}{n_M(y, b)} \cdot \sqrt{\sum_{s_T \in b} SE\big(I(y, s_T)\big)} \,,$$

Equation 27

where $n_M(y, b)$ is the number of monitored strings in BLOB b and each s_T is a monitored string.

D.9 Detection Probability

D.9.1 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:

$$\hat{P}_D(y,s,b) = f(I(y,b), w(s)). \qquad \textbf{Equation 28}$$

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 $f(I(y,b), w(s))$ is the detection probability for a year and BLOB associated with a wingspan model and the average search interval I.

D.9.2 Error

The variability of the search interval leads to uncertainty about the detection probability. To determine the effect of the variability of the search interval on the variability of the detection probability, the probability density function on the detection probability is estimated using a numerical procedure.

In the procedure, it is assumed that the population mean of the search interval is distributed according to normal distribution with mean $I(y,b)$ and standard deviation $SE(I(y,b))$:

$$I \sim N\left(I(y,b), SE\big(I(y,b)\big)\right). \qquad \textbf{Equation 29}$$

Let $p(i)$ be the probability that the population mean of the search interval is i as defined under the probability distribution in Equation 29. Then for any wingspan w and for all search intervals i for which a detection probability $P_D(i,w)$ is defined, the distribution of the population mean of the detection probability is approximated by the equation

$$p\big(P_D(i,w)\big) = p(i), \qquad \textbf{Equation 30}$$

where $p(i)$ is the probability that the population mean of the search interval is i under the probability distribution in Equation 29.

The distribution described in Equation 30 is approximated by the normal distribution with mean P_D. The standard error of the detection probability distribution is approximated using a Riemann sum:

$$SE\big(P_D(I^*,w)\big) \approx \sqrt{\frac{\sum_{i\in I_D} p(i)\cdot\big(i - I(y,b)\big)^2}{\sum_{i\in I_D} p(i)}}, \qquad \textbf{Equation 31}$$

where $I(y,b)$ is the search interval at BLOB b during bird year y, I_D is the set of search intervals for which detection probabilities are defined for wingspan w, I^* is the search interval in the set I_D that is closed to $I(y,b)$, and $p(i)$ is the probability that the population mean of the search interval is i under the probability distribution in Equation 29.

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.

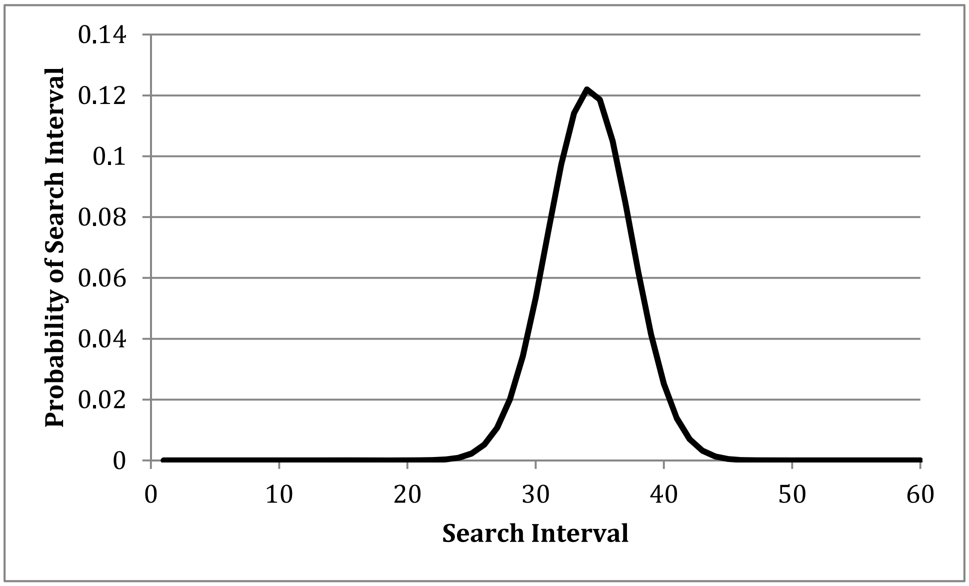

Figure 1. Implied Distribution of Population Mean of Search Interval at BLOB 10 during Bird Year 2010

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

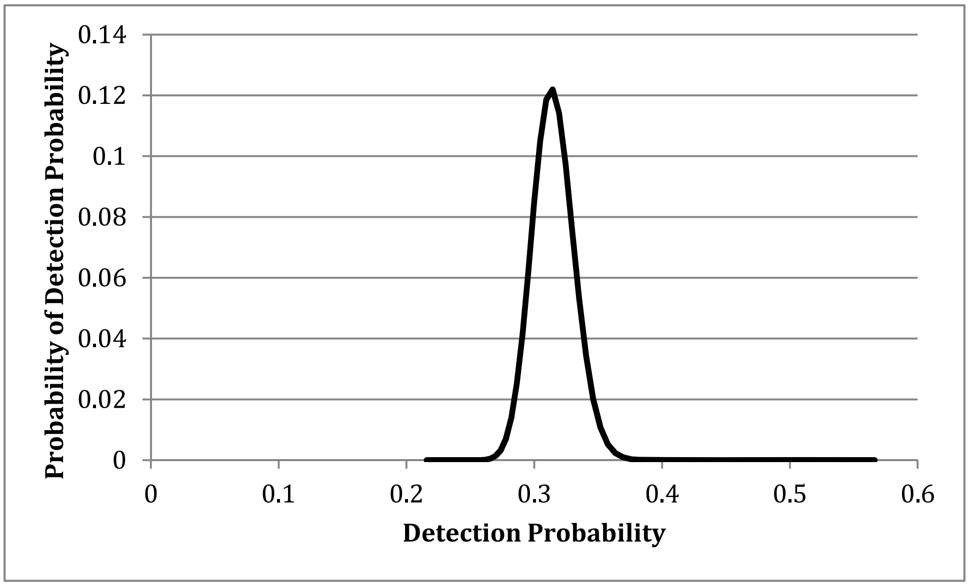

Figure 2. Distribution of the Population Mean of Detection Probability

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

$$SE\left(\hat{P}_D(y,s,b)\right) = \sqrt{SE_I\left(\hat{P}_D(y,s,b)\right)^2 + SE_0\left(\hat{P}_D(y,s,b)\right)^2}, \quad \textbf{Equation 32}$$

where $SE_I\left(\hat{P}_D(y,s,b)\right)$ is given by Equation 32.

D.10 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.10.1 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.

D.10.1.1 Point Value

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:

$$F_D(y, s, b) = \sum_{s_T \in b} F_D(y, s, s_T)\,, \qquad \textbf{Equation 33}$$

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:

$$F_M(y, s, b) = \sum_{s_T \in b_M(y)} F_D(y, s, s_T)\,, \qquad \textbf{Equation 34}$$

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 and $b_M(y)$ is the subset of strings in BLOB b that were searched 6 or more times during 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.10.1.2 Error

Because $F_M(y, s, b)$ is a sum of random variables, the standard error $SE\big(F_M(y, s, b)\big)$ is given by the equation

$$\begin{aligned} SE\big(F_M(y, s, b)\big) &= \sqrt{n_M(y, b) \cdot \mathrm{Var}\big(F_M(y, s, b)\big) \cdot \mathrm{FPC}} \\ &= \sqrt{\frac{n_M(y, b)}{n_M(y, b) - 1} \sum_{s_T \in b_M(y)} \big(F_D(y, s, s_T) - \bar{F}_M(y, s, b)\big)^2 \cdot \mathrm{FPC}}, \end{aligned} \qquad \textbf{Equation 36}$$

where $n_M(y, b)$ is the number of strings in BLOB b that were searched 6 or more times during bird year y, $b_M(y)$ is the subset of strings in BLOB b that were searched 6 or more times during bird year y, $F_D(y, s, s_T)$ is the number of valid fatalities of species s that were detected at string s_T and estimated to have died during bird year y, $\bar{F}_M(y, s, b)$ is the average number of valid fatalities detected per string, and FPC is the finite population correction factor.

The average number of valid fatalities per string is given by the equation

$$\bar{F}_M(y,s,b) = \frac{F_M(y,s,b)}{n_M(y,b)}. \qquad \textbf{Equation 37}$$

The finite population correction factor is given by the equation

$$\text{FPC} = \sqrt{\frac{n_I(y,b) - n_M(y,b)}{n_I(y,b)}}, \qquad \textbf{Equation 38}$$

where $n_I(y,b)$ is the total number of strings installed at BLOB b during bird year y.

D.10.2 Adjusted Fatality Count

The raw fatality count is then adjusted for incomplete search coverage and imperfect detection probability to get an *adjusted fatality count*.

D.10.2.1 Point Estimate

The *adjusted fatality count* $\hat{F}_J(y,s,b)$ is the raw fatality count $F_M(y,s,b)$ divided by the search coverage $K(y,b)$ and the detection probability $\hat{P}_D(y,s,b)$:

$$\hat{F}_J(y,s,b) = \frac{F_M(y,s,b)}{K(y,b)\cdot \hat{P}_D(y,s,b)} \qquad \textbf{Equation 39}$$

where $F_M(y,s,b)$ is the raw fatality count defined in Equation 33, $K(y,b)$ is the search coverage defined in Equation 22, and $\hat{P}_D(y,s,b)$ is the detection probability defined in Equation 28.

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

$$\hat{F}_J(y,s) = \sum_{b\in B_M(y)} \hat{F}_J(y,s,b)\,, \qquad \textbf{Equation 40}$$

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 Equation 39.

D.10.2.2 Error

Applying the method outlined in Section D.12.2 to the adjusted fatality count, we have the following expression for $SE\left(\hat{F}_J(y,s,b)\right)$:

$$\hat{F}_J(y,s,b)\cdot\sqrt{\left(\frac{SE\big(F_M(y,s,b)\big)}{F_M(y,s,b)}\right)^2 + \left(\frac{SE\big(K(y,b)\big)}{K(y,b)}\right)^2 + \left(\frac{SE\left(\hat{P}_D(y,s,b)\right)}{\hat{P}_D(y,s,b)}\right)^2}. \qquad \textbf{Equation 41}$$

D.10.3 Adjusted Fatality Rate

D.10.3.1 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 39, an adjusted fatality rate $\hat{R}_J(y,s,b)$ can be estimated by dividing the adjusted count by the monitored capacity:

$$\begin{aligned}\hat{R}_J(y,s,b) &= \frac{\hat{F}_J(y,s,b)}{C_M(y,b)} \\ &= \frac{F_M(y,s,b)}{C_M(y,b)\cdot K(y,b)\cdot \hat{P}_D(y,s,b)},\end{aligned} \qquad \textbf{Equation 42}$$

where $C_M(y,b)$ is the monitored capacity calculated in Equation 17.

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

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

where $\hat{F}_J(y,s)$ is calculated from Equation 40 and $C_M(y)$ is calculated from Equation 18.

D.10.3.2 Error

Applying the method outlined in Section D.12.2 to the adjusted fatality rate, we have the formula

$$SE\big(\hat{R}_J(y,s,b)\big) = \hat{R}_J(y,s,b)\cdot\sqrt{\left(\frac{SE\big(\hat{F}_J(y,s,b)\big)}{\hat{F}_J(y,s,b)}\right)^2 + \left(\frac{SE(C_M(y,b))}{C_M(y,b)}\right)^2}, \qquad \textbf{Equation 44}$$

where $SE\left(\hat{F}_J(y,s,b)\right)$ is calculated using Equation 41 and $SE\big(C_M(y,b)\big)$ is calculated using Equation 20.

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

$$SE\big(\hat{F}_X(y,s,b)\big) = \hat{F}_X(y,s,b)\cdot\sqrt{\left(\frac{SE\big(\hat{R}_J(y,s,b)\big)}{\hat{R}_J(y,s,b)}\right)^2 + \left(\frac{SE(C_I(y,b))}{C_I(y,b)}\right)^2}, \qquad \textbf{Equation 45}$$

where $\hat{F}_X(y,s,b)$ is calculated using Equation 2, $\hat{R}_J(y,s,b)$ is calculated using Equation 42, and $C_I(y,b)$ is calculated using Equation 15. 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:

$$SE\left(\hat{R}_J(y,s)\right) = \hat{R}_J(y,s) \cdot \sqrt{\left(\frac{SE\left(\hat{F}_J(y,s)\right)}{\hat{F}_J(y,s)}\right)^2 + \left(\frac{SE\left(C_M(y)\right)}{C_M(y)}\right)^2}, \qquad \textbf{Equation 46}$$

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:

$$SE\left(\hat{F}_J(y,s)\right) = \sum_{b\in B} SE\left(\hat{F}_J(y,s,b)\right), \qquad \textbf{Equation 47}$$

$$SE\left(C_M(y)\right) = \sqrt{\sum_{b\in B} SE\left(C_M(y,b)\right)^2}. \qquad \textbf{Equation 48}$$

The standard error in Equation 47 is a conservative estimate. Because there is likely to be significant covariance of the fatality rates between BLOBs, the standard error formula from Equation 55 will underestimate the standard error of the fatality count. Consequently, the more conservative standard error formula from Equation 56 is used instead.

D.11 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.

The point estimate for the fatality rate at an unmonitored BLOB is given by Equation 2. The standard error for the estimated fatality count at an unmonitored BLOB is given by the formula

$$SE\left(\hat{F}(y,s,b)\right) = \hat{F}(y,s,b) \cdot \sqrt{SE\left(\hat{R}_J(y,s,b)\right)^2 + SE\left(C_I(y,b)\right)^2}. \qquad \textbf{Equation 49}$$

where $\hat{F}(y,s,b)$ is the estimated fatality count calculated using Equation 2, $SE\left(\hat{R}_J(y,s,b)\right)$ is the standard error of the proxy fatality rate used for the unmonitored BLOB b, and $C_I(y,b)$ is the installed capacity of BLOB b calculated using Equation 15.

D.12 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 $\mathbf{V}$, the value of the entry is the variance of variable $\hat{x}_i$, $SE(\hat{x}_i)^2$.

- For all entries $v_{i,j}$ $(i \neq j, 1 \leq i, j \leq n)$ not on the northwest diagonal of $\mathbf{V}$, 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

$$SE\big(f(x_1, x_2, \cdots, x_n)\big) = \sqrt{\boldsymbol{\nabla} f \cdot \mathbf{V} \cdot (\boldsymbol{\nabla} f)^{\mathrm{T}}}, \qquad \textbf{Equation 50}$$

where $\boldsymbol{\nabla} f$ is the gradient matrix of f,

$$\boldsymbol{\nabla} f = \begin{bmatrix} \frac{\partial f}{\partial x_1} & \frac{\partial f}{\partial x_2} & \cdots & \frac{\partial f}{\partial x_n} \end{bmatrix}, \qquad \textbf{Equation 51}$$

and $(\boldsymbol{\nabla} f)^{\mathrm{T}}$ 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

$$\mathbf{V} = \begin{bmatrix} SE(\hat{x})^2 & SE(\hat{x}, \hat{y}) \\ SE(\hat{x}, \hat{y}) & SE(\hat{y})^2 \end{bmatrix} \qquad \textbf{Equation 52}$$

and gradient matrix by the formula

$$\boldsymbol{\nabla} f = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix}. \qquad \textbf{Equation 53}$$

Substituting these terms into Equation 50, it can be seen that the standard error of $f(\hat{x}, \hat{y})$ is given by the formula

$$\begin{aligned} SE\big(f(\hat{x}, \hat{y})\big) &= \sqrt{\left\| \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix} \cdot \begin{bmatrix} SE(\hat{x})^2 & SE(\hat{x}, \hat{y}) \\ SE(\hat{x}, \hat{y}) & SE(\hat{y})^2 \end{bmatrix} \cdot \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \right\|} \\ &= \sqrt{\left(\frac{\partial f}{\partial x} SE(\hat{x})\right)^2 + 2 \frac{\partial f}{\partial x} \cdot \frac{\partial f}{\partial y} SE(\hat{x}, \hat{y}) + \left(\frac{\partial f}{\partial y} SE(\hat{y})\right)^2}. \end{aligned} \qquad \textbf{Equation 54}$$

D.12.1 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:

$$SE\left(\sum_{i=1}^{n} \hat{x}_i\right) = \sqrt{\sum_{i=1}^{n} SE(\hat{x}_i)^2}. \qquad \textbf{Equation 55}$$

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

$$SE\left(\sum_{i=1}^{n} \hat{x}_i\right) = \sum_{i=1}^{n} SE(\hat{x}_i)\,. \qquad \textbf{Equation 56}$$

D.12.2 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

$$SE(\hat{X}) = \hat{X} \cdot \sqrt{\sum_{i=1}^{n} \left(\frac{SE(\hat{x}_i)}{\hat{x}_i}\right)^2}\,. \qquad \textbf{Equation 57}$$

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

$$SE(\hat{X}) = \hat{X} \cdot \sum_{i=1}^{n} \frac{SE(\hat{x}_i)}{\hat{x}_i}\,. \qquad \textbf{Equation 58}$$

D.12.3 Example: Arithmetic Mean of Estimates

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

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

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.12.4 Example: Estimated Fatality Count

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

$$\begin{aligned} \mathbf{A} &= \boldsymbol{\nabla}\hat{F} \\ &= \begin{bmatrix} \dfrac{\partial \hat{F}}{\partial \hat{P}} & \dfrac{\partial \hat{F}}{\partial \hat{E}} \end{bmatrix} \\ &= \begin{bmatrix} \dfrac{-1}{\hat{P}^2 \cdot \hat{E}} & \dfrac{-1}{\hat{P} \cdot \hat{E}^2} \end{bmatrix}. \end{aligned} \qquad \textbf{Equation 60}$$

The 2 × 2 variance matrix is constructed as follows:

$$\mathbf{V} = \begin{bmatrix} SE(\hat{P})^2 & 0 \\ 0 & SE(\hat{E})^2 \end{bmatrix}. \qquad \textbf{Equation 61}$$

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 **Error! Reference source not found.**, yielding the formula for the standard error of the fatality count:

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

Equation 62

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

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	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 km^3	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
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 km^3	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 km^3	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 km^3	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 km^3	0.752	0.998	0.763	0.375	0.331	0.570	–	–	–

	Bird Year								
BLOB	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 km^3	–	–	–	–	–	–	–	–	–
Burrowing owl									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Golden eagle									
Adjusted fatalities per MW	–	–	–	–	–	–	–	– –	
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
Red-tailed hawk									
Adjusted fatalities per MW	–	–	–	–	–	–	–	–	–
Estimated total fatalities	–	–	–	–	–	–	–	–	–
Mean observations per minute per km^3	–	–	–	–	–	–	–	–	–
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 km^3	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 km^3	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 km^3	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 km^3	0.909	0.840	1.056	0.762	0.638	0.892	–	–	–

Table E. Continued Page 3 of 14

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
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	–	–	–	–	–	–	–	–	–

Table E. Continued

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	Bird Year								
BLOB	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 km³	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 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	0.14	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 km³	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 km³	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 km³	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 km³	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 km³	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 km³	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 km³	1.099	0.628	0.377	1.066	0.692	0.442	0.369	0.414	–

Table E. Continued

	Bird Year								
BLOB	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 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	0.13	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	0.00	0.00	0.00	0.183	0.00	0.00	0.00	0.00	0.00

Table E. Continued

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	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	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 km^3	0.160	0.070	0.240	0.540	0.520	0.720	0.347	0.781	0.364

Table E. Continued

	Bird Year								
BLOB	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

Table E. Continued

	Bird Year								
BLOB	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 km³	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 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	0.00	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 km³	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 km³	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 km³	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 km³	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 km³	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 km³	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 km³	0.157	0.247	0.147	0.784	0.161	0.060	0.112	0.290	0.546

Table E. Continued Page 9 of 14

	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

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
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	–

	Bird Year								
BLOB	2005	2006	2007	2008	2009	2010	2011	2012	2013
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

Table E. Continued

	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 km^3	–	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 km^3	–	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 km^3	–	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 km^3	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 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	0.00	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 km^3	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 km^3	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 km^3	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 km^3	0.00	0.007	0.008	0.00	0.00	0.00	0.00	0.076	0.00

	Bird Year								
BLOB	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

Appendix F
A Study to Evaluate the Potential Contribution of Predation and Other Mortality Factors on Birds during the Winter in the Altamont Pass Wind Resource Area, California

Introduction

Energy production from wind has been expanding rapidly in the United States and around the world as a means of addressing global warming (Birda et al. 2005; Luderer et al. 2013). However, avian impacts from wind energy facilities are a cause for concern, and postconstruction monitoring is typically required through the permit process to assess the extent of avian impacts (California Energy Commission and California Department of Fish and Game 2007, U.S. Fish and Wildlife Service 2012). Estimating avian fatality rates is difficult in part because of the many ways in which estimates can be biased, such as crippling bias (birds are crippled but not killed and leave the search area prior to being detected), search radius bias (birds are killed but land outside the area searched), bleed through (carcasses are present, missed during a search and subsequently detected resulting in an overestimate), and others (Smallwood 2007; Strickland et al. 2011). One potential source of bias that has been little studied is the degree to which other sources of mortality – including predation - may bias the estimation of turbine-related fatality rates. Predation and other mortality factors are often difficult to parse from turbine-related fatality incidents, particularly for small birds subject to predation, because carcasses are often scavenged, leaving feather piles and/or a few bones as the only evidence that a fatality occurred.

Only two studies have addressed the issue of background mortality factors at wind energy facilities: one at Buffalo Ridge in Minnesota (Johnson et al. 2000) and one in the San Gorgonio Wind Resource Area in southern California (Anderson et al. 2000). At Buffalo Ridge, searches were conducted in "reference plots" and "turbine plots". In some cases, reference plots and turbine plots coincided, with searches conducted prior to turbine installation counting as reference plots. Thus, reference plots and turbine plots were not always searched in the same year. While the overall carcass detection rate was 1.4 times higher at turbine plots than reference plots, the total number of fatalities detected at both plot types was too low to draw conclusions about the influence of background mortality factors on estimates of turbine-related fatality rates. In addition, reference plots included areas near busy roads and other potentially substantial sources of mortality not likely to occur near turbine sites. At the San Gorgonio Wind Resource Area, researchers conducted fatality searches in areas "away from turbines" in conjunction with searches "near turbines" (Anderson et al. 2000). Fatality rates both near and away from turbine areas were very low, and no conclusions about the influence of background mortality factors on turbine-related fatality rates could be drawn.

The issue of non-turbine-related mortality sources as a potentially significant source of bias in estimates of turbine-related mortality at wind energy facilities became an issue in the Altamont Pass Wind Resource Area (APWRA) in central California. The APWRA has been a subject of significant controversy due to the large numbers of raptors, including golden eagles, red-tailed hawks, American kestrels, burrowing owls, barn owls, and other species killed each year in turbine-related incidents (Howell and DiDonato 1991; Orloff and Flannery 1992; Smallwood and Thelander 2004). The controversy led to the implementation of management measures aimed at reducing American kestrel, burrowing owl, golden eagle, and red-tailed hawk fatalities, and the establishment of a monitoring program to meaure that reduction. One of the two primary management measures implelented was the shutdown of turbines (hereafter referred to as the *seasonal shutdown*) during the winter when use of the facility by wintering raptors increased signficantly.

During the first 2 years of the monitoring program, the APWRA was divided into north and south treatment units, with each treatment unit shut down in turn for 2 months, from November 1 to December 31 in the north, and January 1 to February 28, in the south, with the order reversed in the next year. In the two subsequent years, the shutdown period was extended to 2 months, then 3 months. Durng the last 5 years of the monitorng program, all older generation turbines in the APWRA were shut down for 3.5 months (29% of the year), from November 1 through February 15 of each year.

By the end of the monitoring program, there was evidence of a decline in golden eagle and red-tailed hawk fatalities, but evidence of a decline in burrowing owl fatalities was less clear (ICF International 2016). However, several paterns in the number and timing of fatality incidents, along with other factors, indicated that predation might be responsible for some of the burrowing owls fatalities that were being used to estimate turbine-related fatality rates. In addition to the lack of evidence of a decline in burrowing owl fatalities despite shutting down turbines for 29% of the year, evidence indicating a possible role for predation included the following.

- Forty eight percent of all annual burrowing owl fatalities occuring during the shutdown period even though the shutdown period lasted for only 29% of the year and the turbines were not operating during the shutdown period.
- Significantly higher burrowing owl carcass detection rates during the shutdown period than during the rest of the year.
- Significantly lower carcass detection rats for golden eagle and red-tailed hawk during the shutdown period than during the rest of the year.
- Significantly higher carcass detection rates during the shutdown period for almost all small bird species potentially subject to predation for which we had a large enough sample size.
- Significantly lower carcass detection rates during the shutdown period for almost all large bird species in general, and all large predatory birds in particular, including barn owl and great-horned owl, than during the rest of the year.
- A significant increase over time in the proportion of annual burrowing owl fatalities occurring during the shutdown period as the duration and intensity of the shutdown period increased, a pattern that did not hold for larger predatory species not subject to predation.
- A significant and substantial increase in use during the shutdown period by large avian predators including red-tailed hawk, golden eagle, peregrine falcon, prairie falcon, ferruginous hawk, rough-legged hawk, and Cooper’s hawk.

The implications of a significant bias in estimates of turbine-related fatalities, particularly for burrowing owls, included drawing erroneous conclusions concerning the effectiveness of turbine curtailment, repowering, and other management actions to reduce fatalities. We therefore implemented a study of background mortality in the APWRA during the seasonal shutdown.

Our objective was to determine if a substantial number of fatalities continue to be found during the shutdown period if a shorter search interval was used and if those fatalities occur in areas without turbines as well as in areas with turbines.

Study Area

The APWRA is located in the Diablo Range of central California approximately 90 kilometers (56 miles) east of San Francisco (Figure 1). Elevations range from 256 to 1,542 feet (78 to 470 meters) above sea level. The area contains a highly variable and complex topography and is composed primarily of nonnative annual grasslands that receive limited precipitation. Cattle grazing is the predominant land use. Winters are mild with moderate rainfall, but summers are very dry and hot.

The wind farm is comprised of a mix of older generation and modern turbines with a combined capacity of approximately 469 megawatts (MW), distributed over 37,000 acres (150 square kilometers) of rolling grassland hills and valleys. The older-generation turbines in the APWRA are arrayed in *strings* along ridgelines and other geographic features. At least 13 different turbine types have been installed in the APWRA that 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.

Methods

To investigate the issue of background mortality we conducted carcass searches during the seasonal shutdown at sites with turbines strings (turbine ridges) and site without turbines (non-turbine ridges). The study was conducted during the winter of 2014–2015. Searches began on November 1, 2014 (the first day of the seasonal shutdown) and ended on February 15, 2015 (the last day of the seasonal shutdown). The focus of the study was on burrowing owls, but all fatalities were documented.

We used a matched pairs design, ensuring that equal areas were searched at turbine ridges and non-turbine ridges. In the fatality monitoring program, the turbine string was the sampling unit, and strings were typically arrayed along ridges. Because non-turbine ridges are rare in the APWRA, we focused our attention initially on finding suitable non-turbine ridges. We began by identifying all ridges where turbines had been previously removed. We then used GIS to model the characteristics of ridges with extant turbines in order to identify additional suitable sites without turbines that had similar characteristics.

Once all suitable ridges without turbines had been identified, proximity, slope, and elevation were used to match non-turbine ridges with 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 (n=26), equivalent search areas composed of more than two ridges was the sample unit in the six cases outlined above. In total, 39 non-turbine ridges were matched with 34 turbine ridges based on elevation, slope, aspect, size, proximity, and habitat (Figure 2). Although it was not possible to randomly select sample sites, in the end the sample sites were well-distributed throughout the APWRA.

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.

The first round of searches began on November 1 and were considered clearing searches. A two-person crew searched each treatment and control site together, typically on the same day. The average search interval for each matched pair was less than 11 days. The search radius was 50 meters from the center of the ridge. All other aspects of the carcass searches and treatment of carcasses found were identical to those followed in the regular monitoring program (ICF International 2016).

Results

We conducted 338 searches at matched turbine and non-turbine ridges. 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 not spinning as verified by search crews (Table 1). Three burrowing owl fatalities were found at turbine sites, and none at non-turbine sites. 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 57 (not valid) carcasses were located during the study, of which 22 were found during clearing searches, 9 were incidental finds, and 17 were determined to be older than the search interval (i.e., aged), 6 were backdated out of the shutdown period, and one was injured. In addition to these, one red-tailed hawk that was electrocuted was detected and one western meadowlark was initially found alive and hidden beneath a rock, but which died within the next few hours from what appeared to be natural causes.

There were significantly more small bird fatalities 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.

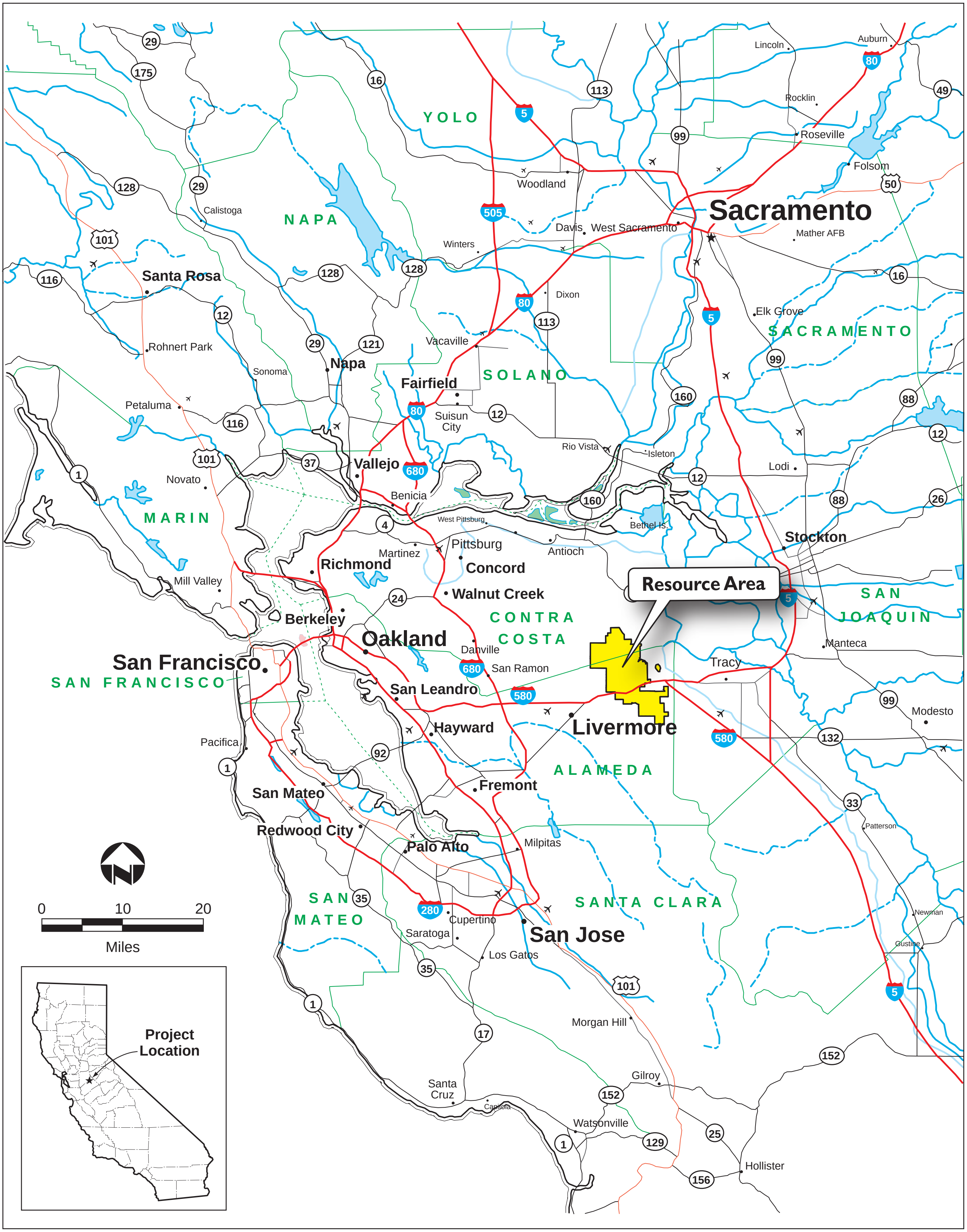

Figure 1
Location of the Altamont Pass Wind Resource Area (APWRA)

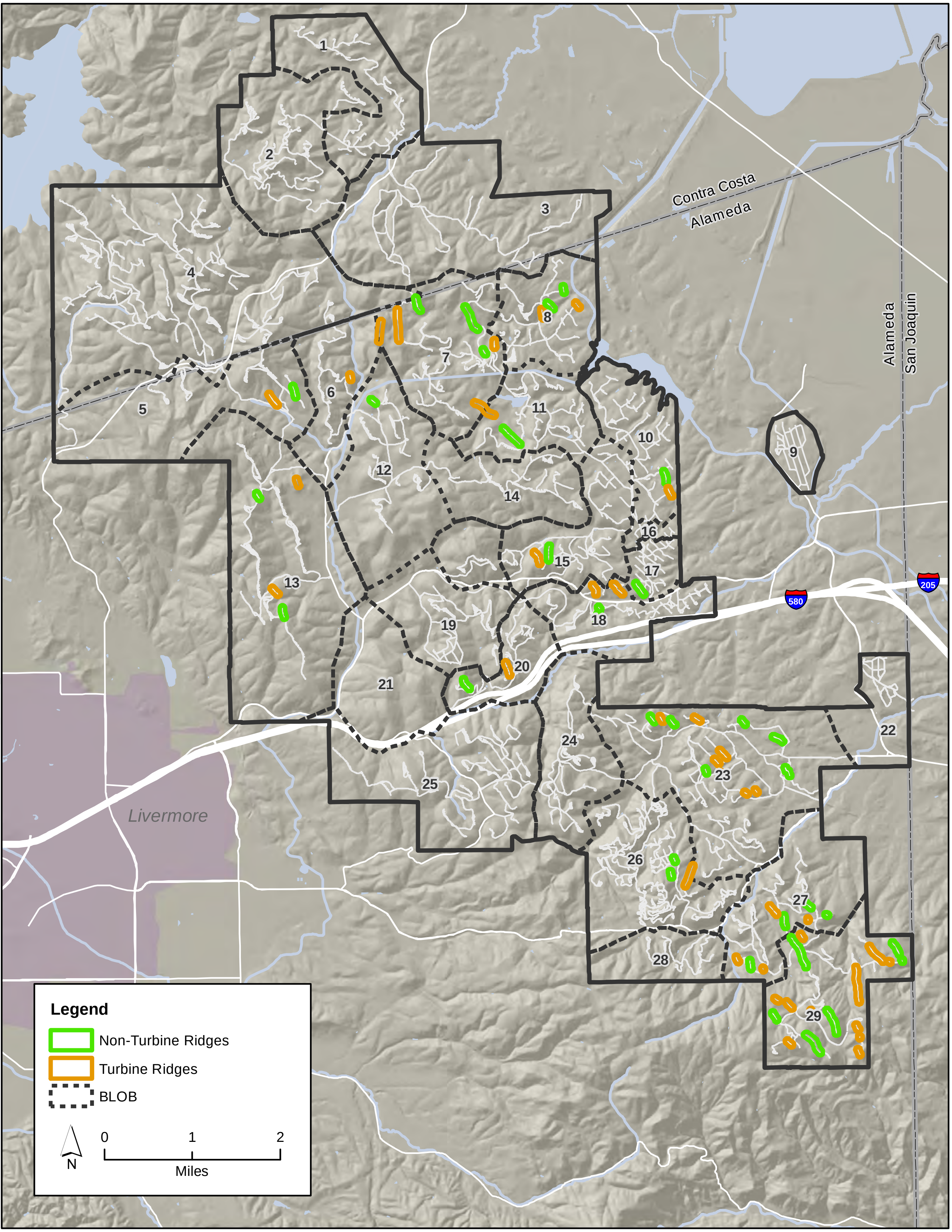

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Figure 2
Location of Turbine Ridges and Non-Turbine Ridges Selected for the Background Mortality Study in the APWRA

Table 1. Fatality Incidents Detected at Turbine Ridges and Non-Turbine Ridges during the Seasonal Shutdown Period, November 1, 2014, through February 15, 2015

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**

Discussion

Given the numerous difficulties associated with accurately and precisely estimating avian fatalities at wind energy facilities, it is perhaps obvious that accounting for background mortality factors is extremely difficult. Especially when turbine-related fatalities are low, estimating the rate of background mortality events—which by definition should be lower than estimates of total turbine-related fatality rates in the absence of correction for bias—is almost impossible, which is perhaps why it has been so little studied.

However, fatality rates in the APWRA are among the highest fatality rates ever documented in the wind energy industry. Nevertheless, management actions implemented to reduce avian fatalities over a period of 9 years resulted in no appreciable decline in burrowing owl fatality rates or APWRA-wide estimates of total annual burrowing owl fatalities. How could this be? For the last 5 years of the study, all of the older-generation turbines in the APWRA were shut down for 29% of the year. Several possible explanations have been proffered, including the attribution of fatality patterns to carcass aging errors, changes in detection probability, and collision with stationary turbines. While these ideas can potentially account for some of the fatality patterns observed, none of them accounts for all the fatality patterns observed with more parsimony than the predation hypothesis (ICF International 2016). With the exception of the predation hypothesis, none of the explanations proffered so far accounts for the large number of fatalities found during the course of this study, particularly at non-turbine ridges. Results of this study clearly demonstrate that significant numbers of small bird carcasses continue to accumulate around turbines during the winter when the turbines are shut down, and also at similar matched sites without turbines.

The detection rate of 0.086 valid fatality per search is approximately six times higher than the detection rate reported at Buffalo (0.0134 valid fatality per search) at operational turbine sites, and 8.9 times higher than the detection rate (0.0097) at reference plot sites (Johnson et al. 2000).

The higher carcass detection rate at turbine sites than non-turbine sites cannot be addressed with the data available. It may indicate that turbine sites are used by birds of prey as plucking posts, that predators use the turbines as perches from which to hunt, or that bird use (of either predators or prey) varies with some unmeasured attribute of turbine ridges.

Although the patterns are relatively clear for small birds potentially subject to predation, only three burrowing owl carcasses were detected during the study. This is lower than the number of carcasses we expected to find based upon the carcass detection rate of burrowing owls in the APWRA fatality monitoring program. California was in the fourth year of the worst drought in history during the study, and anecdotal information suggests that the burrowing owl population was rapidly declining. Therefore, extrapolations from small birds in general to burrowing owls in particular should be done cautiously.

The implications of predation being a confounding factor in the analysis of mortality in the APWRA are substantial. The effects of predation were not accounted for when predictions of the effectiveness of hazardous turbine removals and shutting down turbines in the fall and winter were calculated (Smallwood and Spiegel 2005a, 2005b, 2005c). And because burrowing owl predation has gone unmeasured and unrecognized, this omission has adversely affected the ability to detect changes in turbine-related fatalities over time and assess the effectiveness of turbine curtailment as a management action to reduce turbine-related fatalities.

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