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Western Burrowing Owl Predation in an Urban Setting in California: Do California Ground Squirrel Calls Reduce Risk?

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WESTERN BURROWING OWL PREDATION IN AN URBAN SETTING IN CALIFORNIA: DO CALIFORNIA GROUND SQUIRREL CALLS REDUCE RISK?

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ABSTRACT

WESTERN BURROWING OWL PREDATION IN AN URBAN SETTING IN CALIFORNIA: DO CALIFORNIA GROUND SQUIRREL CALLS REDUCE RISK?

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Western burrowing owls are found in ground squirrel burrows throughout the urbanized landscape of the South San Francisco bay area, where they are threatened by habitat loss and degradation, prey limitation and predation. Previous research has characterized effects of habitat loss and prey-base limitations on owls, but the interplay between ground squirrels, owls and their predators has not yet been studied. The objective of this study was to assess the rate and types of predation interactions faced by Western burrowing owls and the extent to which California ground squirrels help burrowing owls reduce risk through alarm calling at Moffett Federal Airfield in northern Santa Clara County, California. From June through August 2012 and April through June 2013, over 100 hours of direct observations and 14,540 hours of camera trapping observations yielded seven owl takes by species including red-tailed hawk, red fox, striped skunk, common raven, and snake species. Although the ratio of squirrels to owls was 74:26, ground squirrels were observed responding to predator approaches before owls 58.8% of the time, while burrowing owls responded first 28.4% of the time. Burrowing owls reacted to 65.5% of squirrel alarm calls, while squirrels responded to only 25.8% of owl alarms. This research suggests healthy ground squirrel populations may provide important predator-avoidance services in burrowing owl habitat, and that predation should be of greater concern to burrowing owl conservation. And ground squirrels are needed to determine the extent of predation protection via alarm calls.

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This research is dedicated to my dear friend Mike Hawley, who shared my love for education, science and wildlife and was taken from this Earth too soon. He made me strive for excellence and always believed in my goals knowing I would succeed at anything I put my mind to. Life is short, and I will never give up on my dreams.
He will always be in my heart.

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INTRODUCTION

Biological diversity is threatened by habitat destruction, fragmentation, pollution, global climate change, overexploitation of resources, invasive exotic species, and the spread of disease. These issues are causing massive species extinctions at the hand of expanding human population. Prairie fragmentation and rangeland deterioration are large causes of grassland bird declines (Herkert 1994; Knick and Rotenberry 1995). The fragmentation of the North American prairie by various land uses clearly has caused population declines for many grassland bird species (Knopf 1994). Replacement of native grazers with confined, exotic livestock, eradication of burrowing mammals, invasion by exotic grasses, widespread agriculture, and road building are major factors that are affecting these populations. The expansion of urban areas brings two competing scenarios that, while intense urban development of office buildings and business parks can limit resources and decrease native habitat, it can also increase the abundance and density of competing species and predators (Blair 1996; Godron and Forman 1983). Avian fecundity in urban areas is a reflection of species-specific adaptability to urban resources and to levels of nest predation and nest parasitism. Avian survivorship in urban areas is influenced by risk of collision with man-made objects, changes in the predator assemblage, food supply, and disease (Chace and Walsh 2006). The burrowing owl (*Athene cunicularia*) is one grassland bird species that is declining due to human impacts (Gervais, Rosenberg and Comrack 2008). There are two recognized subspecies in North America, *A. c. hypugaea* in the West and *A.c. floridana* in Florida and the Bahamas (Haug, Millsap and Martell 1993; Desmond *et al* 2001). Once a very prevalent subspecies in the Western United States, the Western burrowing owl has declined, especially in areas that are undergoing rapid urbanization (DeSante, Ruhlen and Rosenberg 1997; DeSante, Ruhlen and Scalf 2007).

The Western burrowing owl is unique among owl species due to its diurnal and nocturnal activities and because it is the only owl in the world that lives and nests underground (Haug, Millsap and Martell 1993). Burrowing owls use burrows to nest, retreat from enemies, store food, and for shelter (Thomsen 1971). Burrows are dug by prairie dogs (*Cynomys* spp.), ground squirrels (*Spermophilus* spp.), and other ground dwelling mammals in the West. In Northern California, the burrowing owl nests in close proximity to the California ground squirrel (*Spermophilus beecheyi*) (Thomsen 1971).

The Western burrowing owl is distributed in Western North America, west of the Mississippi river also including parts of South Canada and Northern Mexico. Burrowing owls are listed as endangered, threatened, or as a species of concern in most states and countries where they are found (Sheffield 1997). Historically, the burrowing owl was abundant in California (Grinnell and Miller 1944), but it is now listed as a species of special concern due to declining population numbers. Grinnell and Wythe (1927) reported that burrowing owls were fairly common in the drier unsettled parts of the San Francisco Bay region and were most numerous in parts of Alameda, Contra Costa, and Santa Clara counties. In the early 1990s DeSante, Ruhlen, and Scalf (2007) surveyed California's population and found that burrowing owl populations in the southern San Francisco Bay Region and in the northern and central portions of the Central Valley appeared to have declined rapidly, and populations elsewhere in the census area, including the coastal slope of Central and Southern California, had virtually disappeared. DeSante, Rulen and Scalf (2007) estimated that the entire survey area contained >9,000 pairs, with 71% of the estimated population occupying the Imperial Valley. A survey conducted in the early 2000s by Wilkerson and Seigel (2011) found approximately the same number of owl pairs found by DeSante and his colleagues and approximately 70% of those pairs were in the Imperial Valley. They also found burrowing owl numbers continuing to decline, especially in urban areas such as the San José (Figure 1) and Bakersfield areas, due to urban expansion, rodent eradication, and disruptive land uses (Wilkerson and Siegel 2011; Trulio and Chromczak 2007).

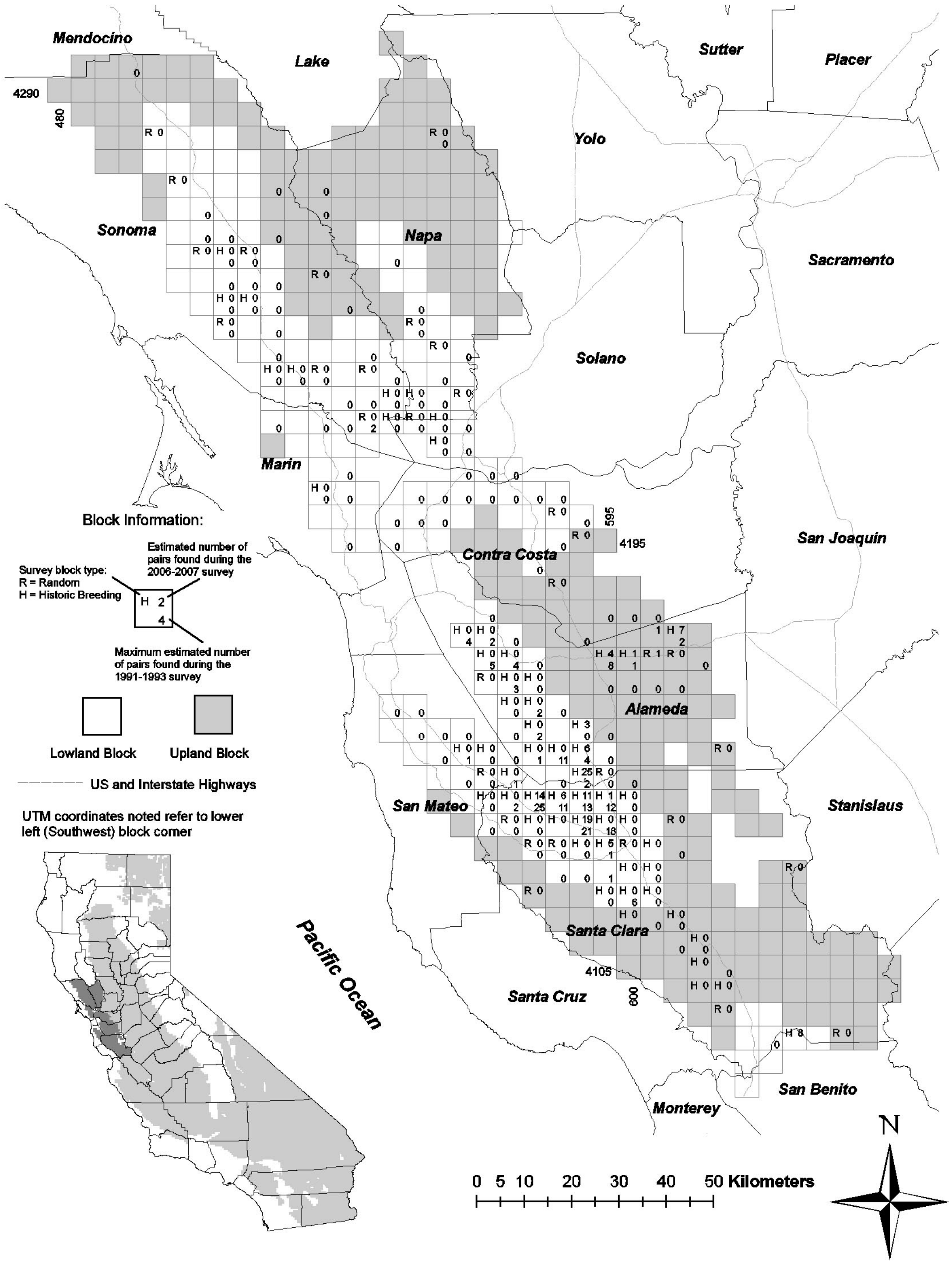

Figure 1. Burrowing owl survey results from the San Francisco Bay Area Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Source: Wilkerson and Siegel 2010

Open, short vegetative grasslands provide ideal habitat for burrowing owls (Coulombe 1971; Martin 1973). However, grasslands in many areas are threatened and these losses greatly impact bird populations. Grassland conversions to croplands, livestock grazing, and the spread of invasive species are just a few impacts that are affecting these areas; however, the largest issue is the loss of grassland due to the expanding urban and industrial boundaries (Jones and Bock 2002). Intense pressure for development of open grasslands in California has resulted in the decline of owl populations in urban areas (Wilkerson and Siegel 2011). Although burrowing owls inhabit grassland and desert communities, they are also found in human-dominated habitats such as airports, parks, golf courses, college campuses, and agricultural areas (Trulio and Higgins 2012; Haug, Millsap and Martell 1993). They can adapt to human-altered environments, but they continue to face threats including predation from urban-adapted species such as cats, crows, and ravens.

Adult burrowing owls are small, approximately 19-25cm long, and weigh about 150g. Due to their small size, adults are prime targets for many larger birds and mammals, and owl juveniles and eggs are particularly vulnerable to predation. Badgers *(Taxidea taxus),* gopher snakes *(Pituophis catenifer),* striped skunks *(Mephitis mephitus),* red-tailed hawks (*Buteo jamaicensis*), American crow (*Corvus brachyrhynchos*), common raven (*Corvus corax*), coyotes (*Canis latrans*), red fox (*Vulpes vulpes*), grey fox (*Urocyon cinereoargenteus*), rattlesnakes (*Crotalus sp*), and domestic cats (*Felis catus*) are all burrowing owl predators (Green and Anthony 1989; Coulombe 1971). Nest predation is a major source of reproductive failure in bird species and greatly reduces productivity (Ricklefs 1969; Thomsen 1971; Millsap and Bear 2000; Green and Anthony 1989; Martell 1990). However, there has been very little research on the rate of predation faced by burrowing owls and factors that may contribute or inhibit predator success. Research in urban settings, where owls habitat is restricted, is especially needed. Other research on predation of nest and birds may help future researchers and monitors of burrowing owls promote the success and longevity of this species. This study assessed the rate and sources of predation to burrowing owls and their nests at Moffett Federal Airfield, in urban Santa Clara County, California. Also quantified was whether the extent to which California ground squirrels, through alarm calls, may help to reduce predation risk to burrowing owls living in the squirrel colonies. This information may allow managers to understand predation pressures and help protect vulnerable birds during nesting season.

LITERATURE REVIEW

Burrowing Owl Natural History and Population Status

Western burrowing owls are semi-colonial nesting raptors whose densities depend on a commensal relationship with rodents that maintain complex burrow systems (Thomsen 1971; Desmond and Savidge 1996). In the prairies of the Western United States, the burrowing owl is commonly found in association with prairie dogs (Desmond, Savidge and Seibert 1995; Butts and Lewis 1982; Restaini, Rau and Flath 2001; Sidle *et al.* 2001). In the South San Francisco Bay area, burrowing owls live in burrows dug by California ground squirrels, a close relative of the prairie dog (Thomsen 1971; Rich 1986; Green and Anthony 1989). The owls do not live in the same burrows with the squirrels, but they do live in active squirrel colonies (Columbe 1971). The presence of healthy squirrel populations is a critical habitat requirement of burrowing owls (Columbe 1971; Thomsen 1971; Desmond and Savidge 1996; Green and Anthony 1989). Owls in California are generally year-round residents though some around the coast area are migrants (Haug, Millsap and Martell 1993) while elsewhere in Western North America, owls migrate south for the winter (James 1992). According to James and Ethier (1989) California is considered to be one of the most important wintering grounds for migrants.

The burrowing owl's physical features include brown and buff plumage with prominent white eyebrows and chin. They lack ear tuffs and have distinct bright yellow eyes (Haug, Millsap and Martell 1993). Males and females are similar in size and appearance and show little to no sexual dimorphism (Zarn 1974). Burrowing owl reproduction begins the year after hatching. In California, the breeding season occurs between February and August. Female owls lay between two to twelve eggs from late March to early May with clutch sizes varying from six to eleven (Zarn 1974). The female is responsible for incubation, which lasts about four weeks. The male remains near the burrow entrance by day and brings food to the female in the early morning and evening (Bent 1938; Coulombe 1971; Thomsen 1971; Martin 1973). The chicks typically emerge from the burrow at 10-14 days old. At 28-40 days old the chicks begin to fledge (Haug, Millsap and Martell 1993).

The majority of birds experience the highest mortality during the first year of life due to poor experience with flying, foraging, and predator detection (Davies and Restani 2006). A number of burrowing owl studies suggest that annual survival of fledglings is only 12%-30% (Gervais, Rosenberg, and Comrack 2008; Davies and Restani 2006; Millsap 2002; Rosenberg and Haley 2004). Predation and starvation are the primary causes of mortality in fledglings (Davies and Restani 2006). Research by Barclay, Korfanta, and Kauffman (2011) showed that in Santa Clara County burrowing owl adult survivorship is a key parameter for population persistence. Long-term studies at San José International Airport showed annual adult survival was 0.710 during 1996-2001 and 0.465 during a decline from 2002-2007 (Barclay, Korfanta, and Kauffman 2011).

Key factors in burrowing owl nest site selection are the presence of burrows, short grass conditions, and adequate foraging. Burrowing owls select flat, short grassland areas for nesting. Rich (1986) found that owls preferred flat sites with a slope of less than ten degrees 79% of the time. Burrowing owls prey primarily on arthropods and small mammals. However, they are opportunistic feeders foraging on a wide range of species in a variety of habitats including cropland, pasture, prairie dog colonies, fallow fields, sparsely vegetated areas, and urban sites (Butts 1973; MacCracken, Ursek and Hansen 1985; Haug, Millsap and Martell 1993; Trulio and Higgins 2012).

The relationship between the presence of colonial sciurid populations and the success of the burrowing owl is well known but not thoroughly understood. The rodents dig burrows that the owls rely on for nesting, shelter from predators, and refuge from harsh weather conditions, as well as a food supply and a place for social interactions (Coulombe 1971; Thomsen 1971). The availability of many burrows is extremely important for long term viability of the burrowing owl population (Zarn 1974; Desmond and Savidge 1996). Western burrowing owls rarely dig their own burrows, so the reliance on rodent species is significant. Prairie dogs and ground squirrels also clean and maintain the burrows, even those used by owls, between breeding seasons. In the absence of these mammals, unkempt burrows often collapse within approximately three years after initial abandonment (MacCracken, Uresk and Hansen 1985). The rodents eat vegetation around burrows, lowering vegetation heights and helping the burrowing owl to have better horizontal sight of its surroundings. Low vegetation and a good view are essential for helping burrowing owls quickly find prey and detect predators. Within prairie dog colonies, burrowing owls have been observed to aggregate their nests into clusters (Butts 1973; Desmond, Savidge and Eskridge 2000; Desmond and Savidge 1996). Clustered nest distributions may reduce predation risks by allowing owls to alert one another to potential predators (Hamilton 1971; Mooring and Hart 1992; Dehn 1990). In Western Nebraska, burrowing owls in larger (>35 ha) black-tailed prairie dog colonies nested in clusters with mean nearest-neighbor distances of 125 m, whereas owls in smaller (<35 ha) colonies nested with random distributions and with mean nearest-neighbor distances of 105 m, suggesting that space requirements may limit owls in smaller black-tailed prairie dog colonies (Desmond and Savidge 1996). Removal of prairie dogs from colonies is followed by rapid deterioration of burrows and encroachment of dense vegetation; owls eventually stop breeding at sites from which prairie dogs have been eliminated (Butts 1973).

Lantz, Conway and Anderson (2007) surveyed 73 prairie dog colonies in the Great Plains, and found that burrowing owl nests were located in active colonies 81% of the time. Sidle *et al* (2001) found similar results; they found 69% of burrowing owl nests in active prairie dog colonies in the National Grasslands compared to 11% of the nest occurring in inactive colonies. Burrow structure, density of prairie dog colonies, and surrounding landscape also provide features needed for burrowing owl survival. Desmond, Savidge and Seibert (1995) showed that the number of nesting burrowing owl pairs and the density of active prairie dog burrows were positively related to fledgling success within nesting clusters.

Burrowing owls are known for their site tenacity, exhibiting intraspecific territoriality, and establishing territories coinciding with pair formation. An owl's territory surrounds the burrow, with boundaries lying roughly equidistant between two adjoining burrows, and thus does not include the foraging areas (Zarn 1974). Territory defense may continue until fledging (Butts 1973; Martin 1973a; Thomsen 1971). The first stage of territorial display consists of primary song given by the defending male.

When a predator approaches a burrow, the owl on guard gives the six-note alert call when the predator is more than about 40 m away (Zarn 1974). The call is of medium pitch, of a musical quality, and has a tempo similar to "chip-chip-chi chi chip-chip." The alert call is not accompanied by a unique display or posture, though several positions may be associated with this call. If the alert call proves unsuccessful, the male presents himself to the intruder with an alarm call. The owl turns slightly and becomes erect, giving a single-noted call of a higher pitch than the alert call and of a more harsh quality: "cheed." The call is issued as the owl bobs up and down. The entire pattern is repeated about every 15 seconds until the owl flies from its perch to mob the attacker as a final attempt to ward off the trespasser. If young owls are out, or the other member of the pair is in the vicinity of the burrow entrance, these owls retreat with the first alert call (Coulombe 1971). These behaviors change during different times of the year, perhaps due to the vulnerability of eggs and young. During fall and winter months, burrowing owls will crouch down, run to a burrow or fly away silently when a predator approaches. Once the breeding season begins, owls tend to run into a burrow after an alarm call has been issued. Once chicks have fledged, either parent may give a warning call for the young to return to the burrow. Normally the male will remain outside of the burrow to mob unless the predator is a raptor (Zarn 1974; Martin 1973).

Threats to Burrowing Owls

Burrowing owls are adapted to living in open grasslands, especially prairie grasslands of the Western United States and Southern Canada (Haug, Millsap and Martell

1993). Almost 1.5 x 106 km^2 of native grasslands historically covered the continent. These Great Plains ranged from South central Saskatchewan in Canada, South to central Texas in the United States, and West towards the Central Valley of California and regions of Eastern Washington and Oregon (Knopf 1988). Now, grasslands are among the most threatened and degraded habitats in North America (Vickery and Herkert 2001). Knopf (1994) estimates that since the mid-1800s, North America has lost approximately 80% of native grassland habitat. Multiple factors contribute to the overall decline of grassland area and native species, including habitat loss to agriculture, habitat fragmentation, and the introduction of exotic species.

Another long-term threat to burrowing owls has also been the destruction of colonial rodents, such as ground squirrels (*Spermophilus* spp.) and prairie dogs (*Cynomys* spp.), upon which the owls depend (Haug, Millsap and Martell 1993). In the west, burrowing owls typically live with ground squirrels and destruction of these species negatively affects burrowing owl populations (Berardelli, Desmond, and Murray 2010). Evolutionarily, burrowing owls are often associated with prairie dogs and other fossorial mammals such as ground squirrels and badgers (Holroyd, Rodriguez-Estrella and Sheffield 2001). Prairie dogs historically occupied an estimated 404,858 km^2, compared to only 6073 km^2 in 1980 (Summers and Linder 1978). Anderson *et al* (1986) conservatively estimated a 98% decline of the five prairie dog species from historic numbers. A significant part of that reduction was the direct result of a federal and state sponsored control program intended to benefit the livestock industry (Miller, Ceballos and Reading 1994). Most agricultural, industrial and urban areas consider prairie dogs and other ground dwelling rodents to be pests and continue to target these creatures for eradication, despite the fact that semi-fossorial rodents are known to be keystone species in prairie ecosystems, making a wide range of species dependent on these rodents for survival.

Currently, one of the greatest threats to open grassland is the expansion of urban boundaries (Jones and Bock 2002). These expansion impacts to open grasslands are affecting bird species and their communities which are dependent on these specific habitats (Jones and Bock 2002); the Western burrowing owl is one such species. Burrowing owls are experiencing population declines and challenging habitat conditions throughout its range (Holroyd, Rodriguez-Estrella, and Sheffield 2001).

Rapid human population growth in the United States is resulting in urban expansion. According to the 2010 Census, California had approximately 37 million people with a projected 48 million people by year 2020 (U.S. Census Bureau 2012). The Imperial Valley and southern central valley in California are among the fastest growing regions within the state (Medvitz and Sokolow 1995). Flat grassland areas preferred by burrowing owls are the easiest areas to expand and therefore making them most sought after for new developments (Trulio and Chromczak 2007). Urbanization due to human population growth directly impacts the burrowing owl because today over 85% of the burrowing owl population in California can be found in agricultural land in the Central Valley (Desante and Ruhlen 1995; Buchanan 1996).

Santa Clara County, the location of this study, was once a major agricultural center. Now, over half of the valley is covered in urban development, which continues to increase (Bell, Acevedo, and Buchanan 1994). Although burrowing owls are relatively tolerant and have been known to habituate within urban settings such as parks, airports or golf courses (Trulio and Chromzak 2007; Millsap and Bear 2000; Trulio 1997; Thomsen 1971), natural habitats for nesting and foraging are decreasing with the increase in urban settings. Other human-related impacts such as shooting and burrow destruction adversely affect this species (Zarn 1974; Haug, Millsap and Martell 1993).

Predation as a Threat

Research by Todd (2001) showed that 47% of post fledgling mortality in burrowing owls was caused by avian predators. Mortality rates between isolated and continuous habitat patches suggested that predation events were elevated in remote patches. Research suggests the probability of predation events in smaller areas is higher than in larger areas (Burger, Burger and Faaborg 1994). Habitat changes that add tall perches provide increased opportunities for red-tailed hawks *(Buteo jamaicensis)*, Swainson's hawks *(B. swainsoni)*, great horned owl *(Bubo virginianus)* and other raptors to prey on burrowing owls (Schmutz, Schmutz, and Boag 1980; Todd 2001). Terrestrial predators, such as the badger, may provide burrows for the owl but frequently return to abandoned nests and can predate owls. Domestic cats, weasels, skunks and dogs eat eggs and young (Bent 1938; Butts 1973; Haug 1985). Burrowing owl remains have also been found in Swainson's hawks and ferruginous hawks nests. Merlins, peregrine falcons, prairie falcon, great horned owls, red-tailed hawks, coopers hawks, and American crows have all been suspected as predators of adults and young burrowing owls (Konrad and

Gilmer 1984; Millsap and Bear 1988; Martell 1990). Thomsen (1971) estimated that 20% of the damaged burrows at the Oakland airport were caused by dogs and 65% of disturbance by humans.

The Corvidae family including crows, ravens, jays and magpies are one of the most successful avian groups, with populations dramatically increasing in western North America, including California (Robbins, Bystrk and Geissler 1986; Marzluff, Boone and Cox 1994). Most corvids are omnivorous and employ many foraging strategies including predation, scavenging and kleptoparasitism (Boarman and Heinrich 1999). They often affect many other species within their communities including threatened and endangered species (Liebezeit and George 2002). Many corvids possess behaviors and preferences that allow them to thrive in human dominated landscapes and fragmented habitats to which other species have trouble adapting. Although no research has been completed on corvid predation on burrowing owls, the American crow is a major nest predator of many passerines and game birds including the endangered California least tern (*Sterna antillarum browni*) (Caffrey 1993, 1994), threatened snowy plover (*Charadrius nivosus nivosus)* (Wilson 1980) and the marbled murrelet (*Brachyramphus marmoratus*) (Nelson 1997). Crows are important nest predators taking both eggs and nestlings. The common raven is also a generalist when it comes to diet, feeding on human produced food items as well as small mammals, reptiles, birds and insects (Boarman and Heinrich 1999). Ravens are documented egg and nestling predators and may even become specialized nest robbers (Stiehl 1978; Andren 1992). Burrowing owls live in both urban and agricultural habitats where corvid species have greatly increased in number. Because corvids are effective predators on nests and young of threatened species, there is a concern that increases in populations are having a negative impact on these species (Liebezeit and George 2002). Other terrestrial predators known to affect the burrowing owl and its young are snakes, weasels, skunks, coyotes, and domestic cats and dogs depending on geographic location (Moulton, Brady and Beltroff 2006; Rosenberg and Haley 2004; Dechant *et al.* 2003). Nest and nestling predators in the South Bay, including hawks, skunks (*Mephistis mephistis*), snakes, feral cats, and non-native red foxes (*Vulpes vulpes*), are common to both urban and parkland sites (Trulio and Chromczak 2007).

Burrowing owls have evolved a wide range of behaviors to avoid predation. For example burrowing owls have been known to line their nests and tunnel entrances with livestock dung to deter predators by disguising nest odors (Martin 1973). Green and Anthony (1989) found in Oregon that predation by badgers was much higher at nests that were not lined by cattle dung and that badgers accounted for 90% of the predation events.

Alarm calling is another key behavior for avoiding predation. Both burrowing owls and California ground squirrels have well developed alarm-calling behaviors and both have many of the same predators (Hoogland 1996; Leger and Owings 1978; Coulombe 1971; Zarn 1974). Burrowing owls have several calls to alert mates and chicks of approaching predators, as do California ground squirrels and prairie dogs, with whom burrowing owls share colonies. California ground squirrels have extensive alarm calling behavior in response to both aerial and terrestrial predators. The vocal alarm system of California ground squirrels (*Spermophilus beecheyi)* is useful, as the squirrels live in close proximity to one another and are preyed upon by raptors, mammals, and snakes.

Because these predators hunt in different ways, alarm call recipients could potentially benefit by being informed of the kind of predator so that the most effective course of action could be taken (Owings and Leger 1980). The chirp of the ground squirrel varies significantly in pitch, loudness, and inflection according to the situation it encounters. It is possible that the primary function of the voice is to warn familial individuals including but not limited to direct offspring in the community of an oncoming imminent danger. These unique calls in response to predators are common among both colonial birds and mammals and are used mostly to warn offspring. These anti-predator calls are risky as the individuals calling endanger themselves to increase the safety of their own offspring (Hoogland 1996). This "kin selection" hypothesis suggests that parents may increase alarm calling during breeding season (Dunford 1977).

When a squirrel detects a low flying raptor, it may emit a single whistle note (Leger and Owings 1978). A distinctive type of chirp is given in response to the sight of a hawk or other large bird flying in the vicinity. This consists of a single short syllable of unusual loudness and carrying quality; “cheesk” or "”chisk” usually given as the animal bolts for shelter (Fitch 1948). The presence of terrestrial predators often elicits a range of calls from a temporally graded selection of chatter-chat vocalizations, variants of which appear to be associated with different levels of alarm of the caller (Leger and Owings 1978). California ground squirrels emit both non-repetitive chatters and repetitive chatter-chats in the presence of terrestrial predators (Owings and Virginia 1978).

Repetitive calling usually occurs after warning chatters have been emitted and is thought to maintain vigilance in already alerted perceivers (Owings and Hennessy 1984; Loughry and McDonough 1989). These whistles and chatters have disadvantages to the caller and that they may attract predators to the caller's locality (Dunford 1977).

This collection of alarm calls is used to notify others in the squirrel colony of a predation risk, but with burrowing owls living in close proximity, they could also benefit from the different notifications. Squirrel and owl vigilance, scanning the surroundings for predators, is a widespread anti-predator behavior. Group size can influence vigilance as a larger group may decrease individual vigilance (Fairbanks and Dobson 2007). Bertram's (1978) dilution of predator effect or detection effect suggests that an individual's risk of being captured decreases with the increase of group size because the predator is more likely to capture another individual by chance alone. The detection effect posits that individuals can decrease vigilance in groups because they can obtain information about approaching predators from group mates (Pulliam 1973).

Although both species have alarm calling behavior, little is known about the importance of sciurid mammals to burrowing owls other than for the burrows they provide owls. It is possible that owls and squirrels may alert each other to predators through clustered nesting (Pulliam 1973). Grouping by animals is commonly cited as a behavioral mechanism that offers protection from predation (Mooring and Hart 1992). Hamilton's (1971) "selfish herd effect" proposes that having other individuals nearby decreases an individual's risk of capture when the predator chooses the closest prey. The closer an animal is to each other the more its domain of danger was reduced. The most common advantage of geometric position is a central location within the group. Logically, animals in the center are more protected than those on the periphery (Mooring and Hart 1992). Grouped individuals can be less vigilant for predators than solitary species because grouping increases the likelihood of predator detection (detection effect) and makes it less likely that any given individual will be preyed upon (dilution effect) (Dehn 1990).

There is a possibility that burrowing owls could have reduced predation due to these effects of large group dilution by surrounding ground squirrels as well as the possibility of benefitting from the detection alarm calls given to warn surrounding group mates of incoming predators. Little research has been done to test the hypothesis that burrowing owls might benefit from the alarm calls of these colonial mammals (Desmond, Savidge, and Eskridge 2000). Desmond, Savidge, and Eskridge (2000) predicted that rates of badger predation on burrowing owl nests should be negatively associated with prairie dog density. Their results showed that predation rates were indeed lower in high density colonies but the reason for this association was not known. Other studies of colonial nesting species have also reported reduced rates of predation with increased sciurid colony size (Nisbet 1975; Hoogland 1981). Addressing this literature gap will help managers better understand the role of burrowing mammals in predator notification for burrowing owls and whether they indeed increase reproductive success of burrowing owls.

The South San Francisco Bay region, which includes Santa Clara and Alameda Counties, supported a population of approximately 125 pairs of burrowing owls in the late 1990s (DeSante et al. 1997, Trulio 2003). Open grasslands in Santa Clara County are disappearing at a rapid rate as a result of urban development, and this is reducing the burrowing owl population. In a survey of open grasslands in Silicon Valley occupied by burrowing owls in the early to mid-1980s, almost 60% had been developed by 1996 (Trulio, 1998). A study by the Institute for Bird Populations indicated that the burrowing owl population in the San Francisco Bay Area and parts of Central California declined by 50% in 10 years between 1983 and 1993 (DeSante *et al.* 1997). A 2002 survey of 111 city-owned or privately-owned sites in the South San Francisco Bay Area where owls were recorded between 1981-1988 showed that 66% of these occupied sites had been lost to urban development (Trulio 2003). Trulio and Chromczak (2007) studied 356 nests over seven years, 257 in urban sites and 99 in parkland areas. They found a 34% decline in the number of nests in the study area during the study period, from a high of 64 in 1999 to a low of 42 in 2003. Nest success rates for the South Bay, which averaged 51% for urban sites and 45% for parklands, were low compared to other burrowing owl populations (Trulio and Chromczak 2007). For example, Barclay, Korfanta and Kauffman (2011) reported an 80% nesting success rate at the Mineta San Jose International Airport, adjacent to the study site. At the Oakland Airport, also near the study site, Thomsen (1971) found 88% and 53% of nests produced young in 1965 and 1966, respectively. A 70% success rate for nesting females in the Imperial Valley was reported by Catlin, Rosenberg and Haley (2005).

What landscape or local factors might be influencing nest success and productivity in the South Bay region is unknown, but predation as well as prey availability, abundance, and quality are likely to be central factors (Rosenberg and Haley 2004). Neither predator abundance nor rates of predator approach or success have been quantified in this region.

Problem Statement

Rates of predation and predator attempts on burrowing owls and their young have not been quantified in any setting. This information is especially important in urban settings, including Santa Clara County where the species is declining. Managers and researchers are concerned that the numerous aerial and terrestrial predators of burrowing owls are a significant source of owl mortality (L. Trulio Pers. Comm.). Quantifying predation risk can provide information for understanding owl population declines. In Santa Clara County, burrowing owls live in association with California ground squirrels, a colonial rodent that alarm calls in response to approaching predators. This notification by squirrels may allow the owls to react quickly by diving into their burrows, therefore increasing survivorship and reproductive success. An alternate hypothesis is that burrowing owls do the most alarm calling as a part of their mutualistic relationship with squirrels. No research has attempted to assess the importance of sciurid mammals as predator alarms for burrowing owls. This research addresses the following research questions and hypotheses at Moffett Federal Airfield in Santa Clara County, California.

Research Questions

RQ1: What species are the primary predators of burrowing owls?

RQ2: What is the rate of predator approach to burrows?

RQ 3: How do squirrel and owl behaviors change between non-predator and predator observations?

RQ 4: Do owls respond to ground squirrel alarm calls or vice versa?

RQ 5: How do camera trapping methods compare to observational methods with respect to characterizing rates of predator attacks?

Hypotheses

H_1: Predator interaction rates will not:

A) differ at night when there are no squirrels compared to during the day when squirrels are present.

B) correlate with numbers of adult ground squirrels.

C) differ before compared to after chicks emerge.

H_2: The length of time it takes for owls to return to burrows after a potential predator approach does not differ:

A) between non-predator versus a known predator.

B) before versus after chicks have emerged from the nest.

H_3: The frequency of nest abandonment does not differ by predator type.

H_4: Predator approach detection rate does not differ between cameras and direct observations.

METHODS

Study Site

The study site, Moffett Federal Airfield, is approximately 60 km southeast of San Francisco, 12 km east of San José, and bordered by the cities of Mountain View and Sunnyvale (Figure 2). The site is federally owned and operated by NASA as well as military and mixed-use military organizations.

Figure 2. Greater San Francisco Bay Area, California and Moffett Federal Airfield. Source: Google Maps

The San Francisco Bay Region has a Mediterranean climate with a mild, wet season between November and April and a warm, dry season between May and October. The large open grassland area is the environment best suited for burrowing owls. The burrowing owl habitat on site is restricted to the golf course, fragmented fields, roadside embankments, airfield edges, and ornamental landscaping (Trulio and Chromczak 2007;

Rosenberg *et al* 2007). Moffett Federal Airfield (Figure 2) contains approximately 1,000 acres of land with features including three large aircraft hangers, NASA Ames facilities, administrative buildings, and open grassland habitat. Grassland habitats are dominated by nonnative grasses (predominantly *Avena* spp. and *Hordeum* spp.) and nonnative annuals, especially *Salsola kali, Brassica* spp*., Picris echioide*s, and *Dittrichia graveolens* (Trulio and Higgins 2012). An irrigated turf golf course is located at the northeast end of the airfield as well as a pond positioned north of the site. From 1992-2000, 18-27 pairs of owls were observed to nest at Moffett each year (Nasa Ames Research Center 2002).

Study Design

Camera Trapping

Data were collected during two burrowing owl breeding seasons, from June 25 to August 18, 2012 and May 8 to July 13, 2013. In 2012, twenty one active burrows were identified by Moffett's consulting biologist, Debra Chromczak, including 20 pairs and one solitary owl. In 2013, 26 burrowing owls were located on site, consisting of 12 pairs and two solitary owls (D. Chromczak Pers. Comm.). Burrows were randomly chosen if possible, but factors such as accessibility and presence of human activity dictated which burrows were most appropriate for the observations. Observations of predator approach and attack were collected with cameras and through direct observations.

In 2012, cameras were placed at the entrance of seven burrows for approximately two months while five additional nests were viewed for direct observations only (Figure

3). During the first year of collection, to determine whether behavioral changes occurred during camera trapping, half the burrows chosen did not have cameras placed at them. Since no obvious changes were observed, the following collection year I deployed cameras at all nine burrows (the total number of cameras available).

Bushnell 8MP Trophy cameras are digital scouting cameras triggered by movement in front of the highly sensitive Passive Infra-Red (PIR) motion sensor. When movement was detected, the cameras took high quality pictures and video clips up to 8 megapixels. Cameras were placed in protective boxes that were mounted on a pole no taller than 1 m, with anti predator spikes on top to prevent perching by large predators. Each camera contained a 16 GB Sandisk memory card that could hold approximately 10,000 photographs in 8 megapixel format. During the collection time, photographs were gathered from the camera memory cards every 1-2 weeks during which time Eneloop rechargeable batteries were exchanged.

A pilot study with the cameras was conducted to determine the furthest distance away from burrows for optimal camera placement in order to collect clear photographs of all animals approaching the burrows without inhibiting owl behavior. This pilot initially involved placing cameras where no owls were present to determine how far the camera could capture images clearly. Once the distance was determined, cameras were positioned such that animals moving towards the mouth of the burrow would trip an infrared beam triggering the camera to take a photo. Once cameras were placed at the burrow entrances, those particular burrows were monitored carefully and checked twice per week to determine if the burrows were still active. If owls moved, the camera was placed at the new burrow location and monitored again.

Photos collected were examined for predator approaches and attacks. Predators were identified, and photos were analyzed to see if any owls, chicks, or eggs were taken in attacks. The cameras also provided a date and time stamp showing the timing of predator attempts.

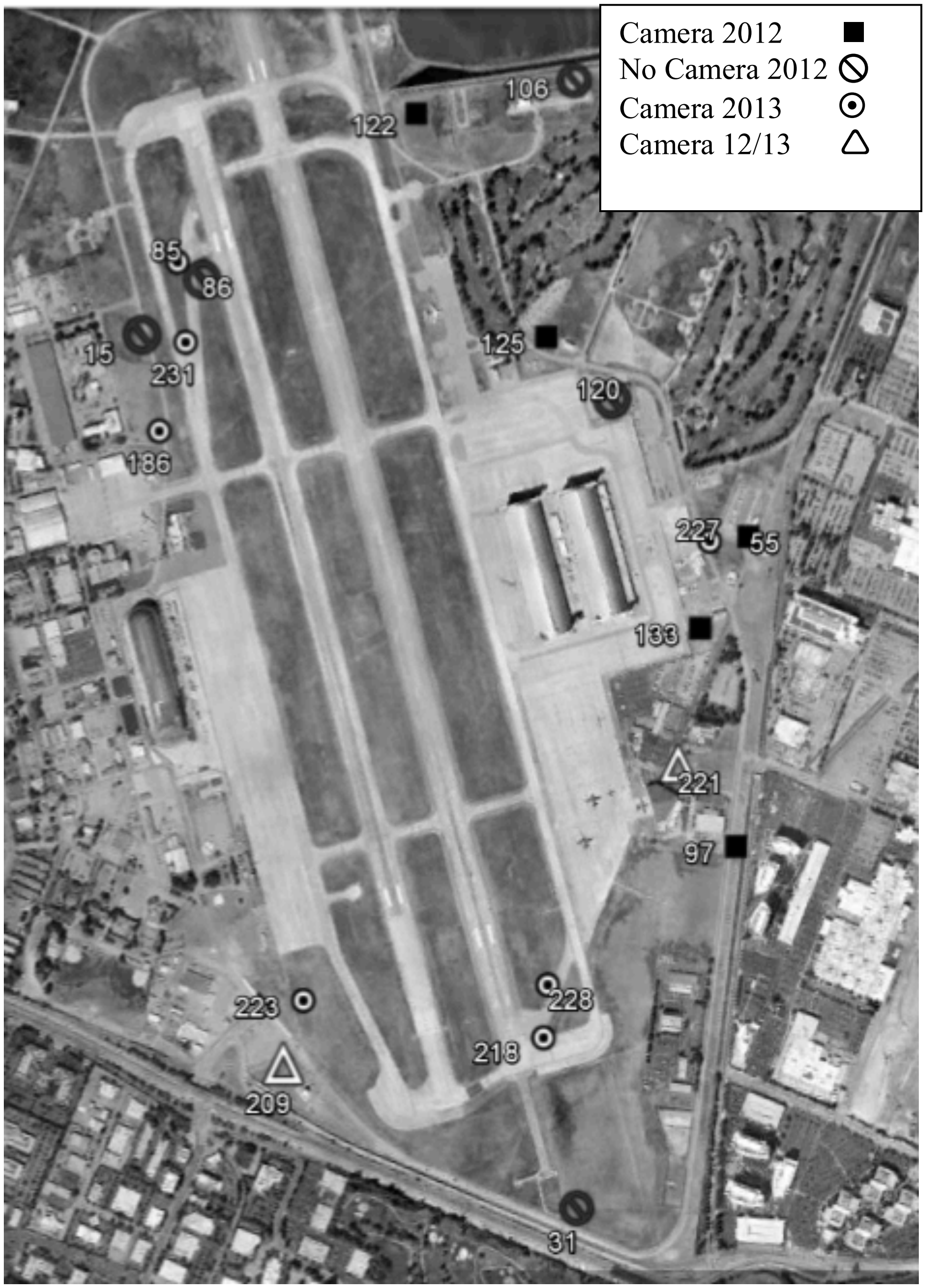

Figure 3. Burrowing owl nest locations at Moffett Federal Airfield, CA, during 2012/2013 breeding seasons. Source: Google Earth 2013.

Direct Observation Study

Burrows chosen at the beginning of each year for cameras and controls were subject of direct observation for predator approaches/attacks, as well as interactions between burrowing owls and ground squirrels. Observations were conducted from an automobile at a distance of 30-60 m that did not disturb the owls. Each nest was observed every two weeks during 2012 and 2013. Observations were conducted using Swift Reliant 10x42 binoculars and a Nikon spotting scope. Observations were performed on two nests per day, for approximately 2 hours per nest. Each nest was observed at least once during each two-week period. Times of day for viewing revolved between three time windows: 0600-1100, 1100-1600, 1600-2100. Data were collected on 1) which animal responded first to predators entering the nesting area, 2) which predators were present most frequently, 3) which times of the day had the most predation events and 4) the density of ground squirrels. I also collected information on general behaviors of both burrowing owls and ground squirrels when predators approached and when they were not present. A scan sample was taken every 15 min to identify behaviors of burrowing owls and ground squirrels when predators were not present. The number of squirrels and owls were counted, and behaviors of each were recorded.

Specific parameters for data collection included number of owls (adults and chicks), number of squirrels, time of day, temperature, predator actions, squirrel reactions, owl reactions, and first responders to predators (Appendix 1). Predators exhibited four different actions including: “transit” defined as walking/flying near but not approaching nest, “approaching the nest,” defined as a clear movement towards the nest, “hunting,” defined as trying to enter the nest for terrestrial predators and defined as a downward plunge towards the nest for aerial predators, and “take,” defined as a successful attack upon the nest resulting in owl mortality. Taken together, these predator behaviors are called “predator interactions.” Behaviors exhibited by the burrowing owl included: alarm calling, flying, mobbing, moving towards the burrow or going underground in the presence of a predator. Ground squirrel behaviors included a single note whistle or chatter alarm call, tonic calling, running towards or diving into the burrow, or standing up.

Data Analysis

SYSTAT 13™ software was used for statistical analysis. Data for all variables were tested for normality using the Shapiro/Wilk test. Regression analysis was used to examine the relationship between the numbers of ground squirrels surrounding the burrows and predator attacks. Average ground squirrel data was transformed using natural log and then a regression was run with the ln(average squirrel) data and observation predator per hour data. Mann-Whitney U tests were completed for several different hypotheses including camera versus physical observation data, day versus nighttime camera data, length of time to return to burrow after predator versus non-predator approach and length of time taken to return to nest after a predation event with or without chicks. A t-Test was used to compare predation attempts on nests with and without chicks. Frequency of nest abandonment in the face of known predator versus non-predator approach was tested with a chi-square test.

Results

Each nest during 2012 was proposed to have three observations at each burrow for a total of 36 observations. However, due to the late time frame in the breeding season many of the owls moved to wintering grounds before all 36 observations could take place. Thus, a total of 24 observations were completed. During 2013 all but two nests were observed six times each totaling 54 observations (minus two burrows that were eventually abandoned and only received two observations each). The total combined observation time was 100 hours from direct observations (which were only during daylight hours) and 14,540.87 hours from camera observations (day and night, combined) with 317,531 photographs total. There were a total of 154 predators encountered during the 2012 and 2013 collection seasons, including eight takes and eight nest abandonments (Table 1). Of the 154 predator encounters, 74 predator approaches were directly observed with 48 hunt or approaches recorded and 80 predators caught on film approaching burrows.

Red-tailed hawks were the most numerous predators seen during direct observations while ravens, skunks, and coyotes ranked highest for camera capture (Figure 4). Red-tailed hawks accounted for 62.8% of the predators observed during direct observations. Other aerial species observed included common raven (15.4%), peregrine falcon (5.1%), American kestrel (2.6%), and great blue heron (1.2%). The only terrestrial species seen during direct observations was a domestic cat (5.1%). Motion cameras caught common raven (30.5%), jack rabbits (19.4%), skunks (15.7%), coyote (12.9%), red fox (4.6%), and a rattlesnake species.

Four percent (n=8) of predator attacks resulted in take, one was an adult, five were chicks, and two other predator incidents where nests with the presence of eggs were predated and led to nest abandonment. Of the eight owl takes, only one was directly observed and the predator was a red-tailed hawk; all others were captured via camera and consisted of striped skunk, red fox, common raven, and a rattlesnake species. The take by the red-tailed hawk was a collaborative effort where four red-tailed hawks mobbed the burrow while one then took the female owl and flew away with her in its talons. The take from the red fox was an all night event, starting at midnight it spent a good portion of the evening digging up the burrow and eventually succeeded in taking four chicks present at the burrow. The striped skunk was seen entering a nest where eggs were presumed to be. The next day there were eggshells present outside of the burrow and the owl pair then abandoned the nest. A photograph was seen with a raven flying off with an egg in its mouth, although it not certain if the raven predated the nest of if the owl rejected the egg and pushed it from the burrow thus allowing the raven to take it. Lastly, the take by the snake was not seen clearly but it is assumed that a venomous snake (such as a rattlesnake) attacked and bit a chick. The chick's body was found dead near the burrow a few days later. Examples of photos captured can be found in Appendix 3-6.

Eight predator encounters lead to nest abandonment, which was defined by owls not returning to the original burrow after 24 hours had elapsed. Species that were seen prior to nest abandonment were red-tailed hawk, coyote, feral cat, and striped skunk.

Table 1. Predators seen during direct observations and camera observations at 20 nests during 2012-2013 at Moffett Federal Airfield, California.

PREDATORS	DIRECT OBSERVATION	CAMERA	TOTALS	TAKES	NEST ABANDONMENT
Red-Tailed Hawk	49	6	55	1	2
Raven	12	33	45	1	1
Striped Skunk	0	17	17	1	3
Coyote	0	14	14	0	1
Peregrine Falcon	4	0	4	0	0
Cat	4	2	6	0	0
Red Fox	0	5	5	4	1
Snake	0	1	1	1	0
American Kestrel	2	0	2	0	0
Red-Shouldered Hawk	2	0	2	0	0
Egret	1	0	1	0	0
Grey Fox	0	1	1	0	0
Great Blue Heron	1	1	2	0	0
TOTALS	74	80	154	8	8

Table 2. Non-Predator species seen during direct observations and camera observations at 20 nests during 2012-2013 at Moffett Federal Airfield, California.

NON-PREDATORS	DIRECT OBSERVATION	CAMERA	TOTALS	TAKES	NEST ABANDONMENT
Jack Rabbit	0	21	21	0	0
Goats	0	7	7	0	0
Turkey Vulture	4	0	4	0	0
California Gull	1	0	1	0	0
TOTALS	5	28	33	0	0

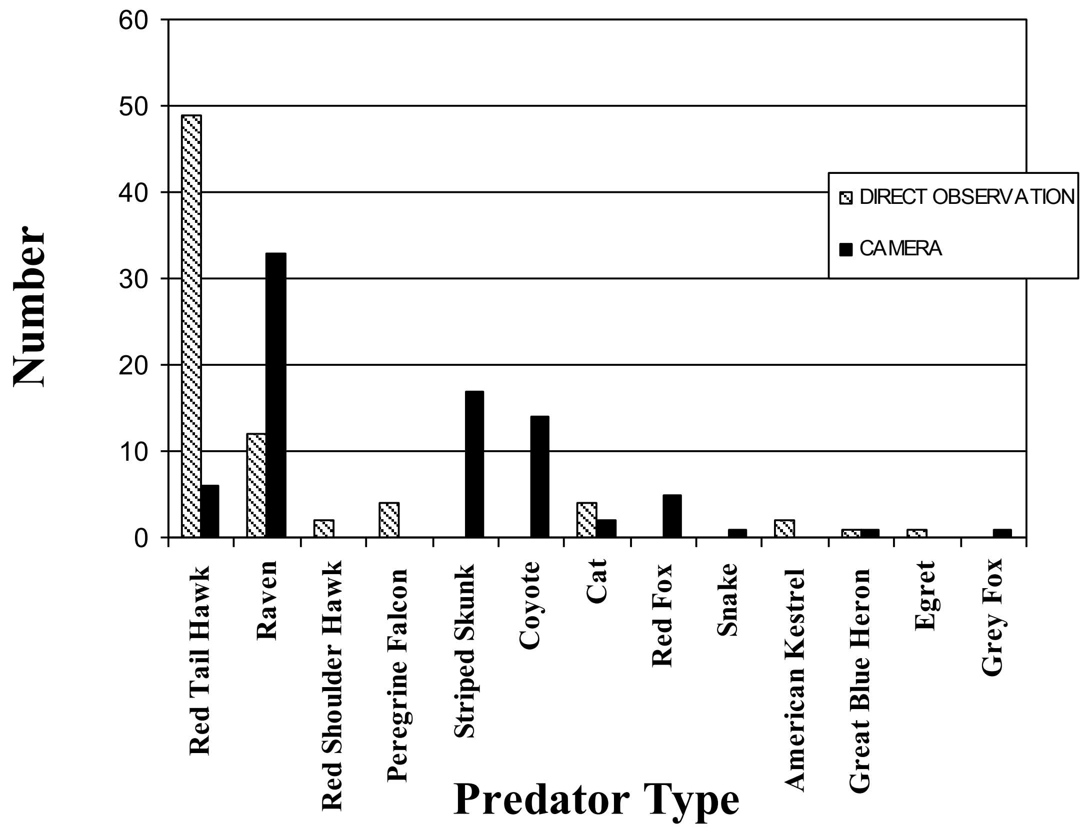

Figure 4. Numbers of predators observed through both direct observations and cameras at or around burrow during 2012-2013, Moffett Federal Airfield, California

Burrowing owl and ground squirrel behaviors showed changes between non-predator periods and predator interaction observations. Ground squirrels spent most of their time during scan samples (when there were no predator interactions) foraging, transiting from one location to another or standing stationary; during a predator encounter they would stand up erect, whistle/alarm call, or run toward their burrow (Figure 5). When predators were not present, burrowing owls spent a majority of their time standing at the burrow, but also sat underground, preened or foraged. During predator approaches owls moved underground, alarm called, or scan/watched carefully (Figure 6).

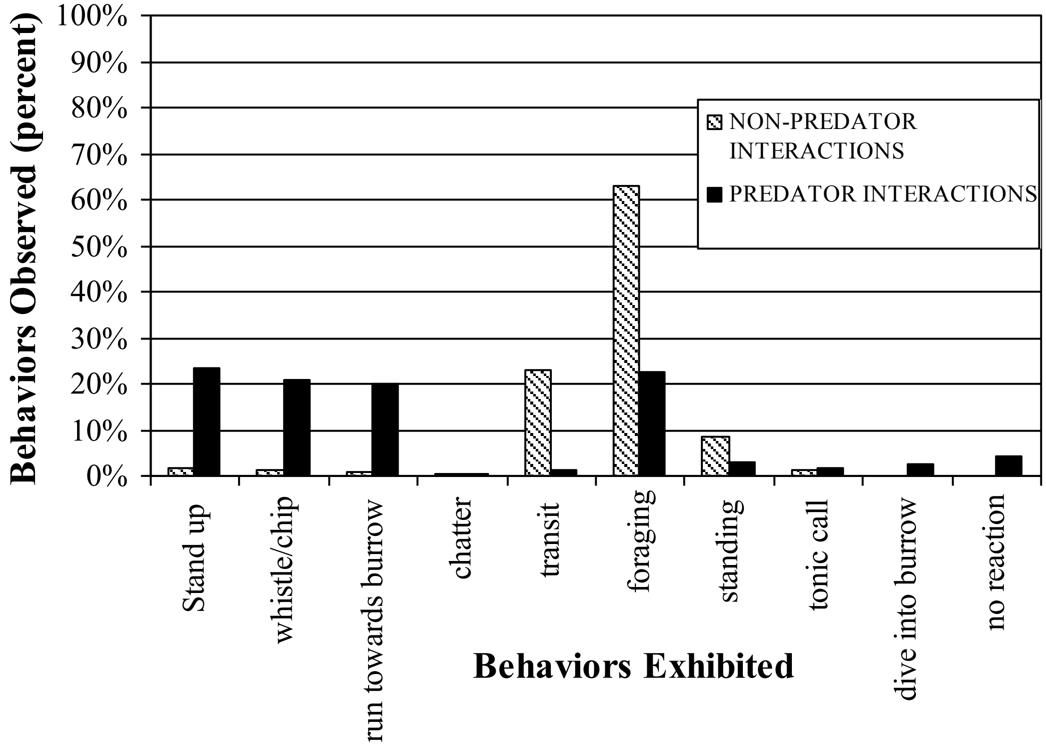

Figure 5. Percent of observations in which California ground squirrels exhibited various behaviors in response to predator and non-predator interactions.

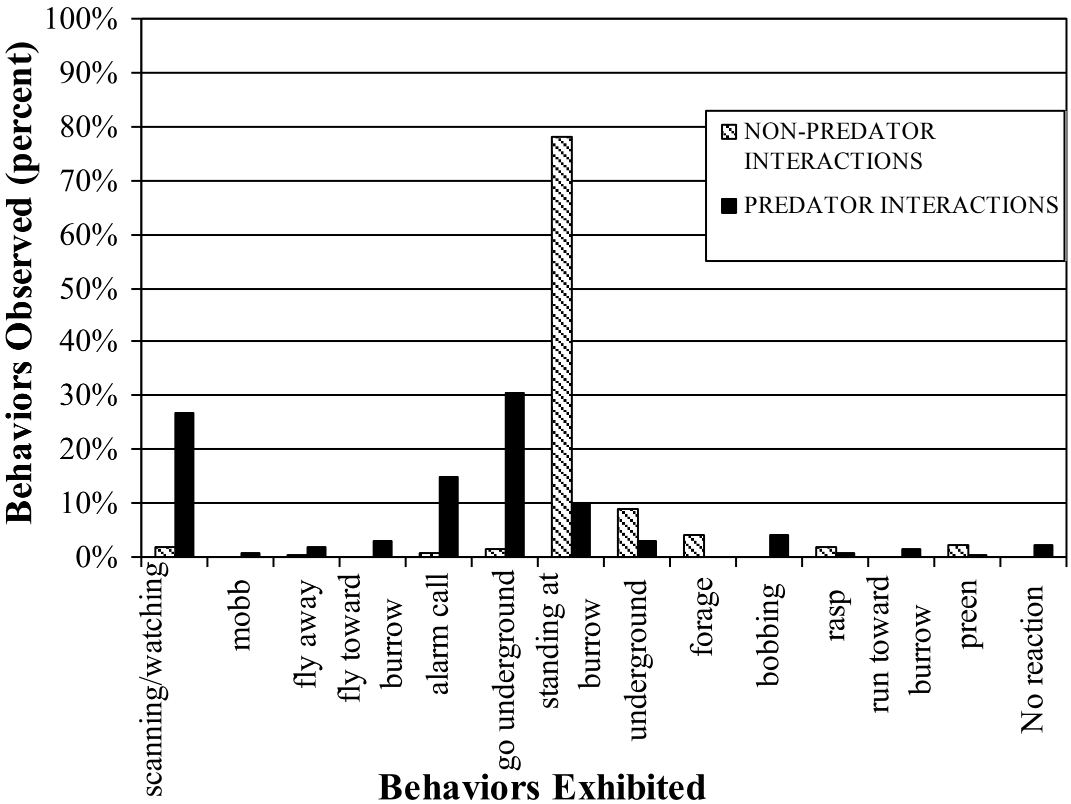

Figure 6. Percent of observations in which burrowing owls exhibited various behaviors in response to predator and non-predator interactions.

During direct observations, ground squirrels responded first to predators before owls did 58.4% of the time (60 observations) while burrowing owls responded first 28.7% of the time (29 observations). During the remaining 4.9% of responses, either both responded simultaneously or neither responded. Also 7.9% of the time (8 observations) the owls alarm called but no squirrels were present for comparison (Figure 7). Squirrel alarm call frequencies were then assessed for differences between pre and post pup emergence. In the period before squirrel pups emerged owls responded first 55% of the time. Responses were further categorized as reacting directly to the oncoming predator or reacting indirectly to each other's alarm calls. When squirrels responded first, the owls then responded to 65.5% of squirrel alarm calls while when the owls responded first, the squirrels responded to only 25.8% owl alarm calls.

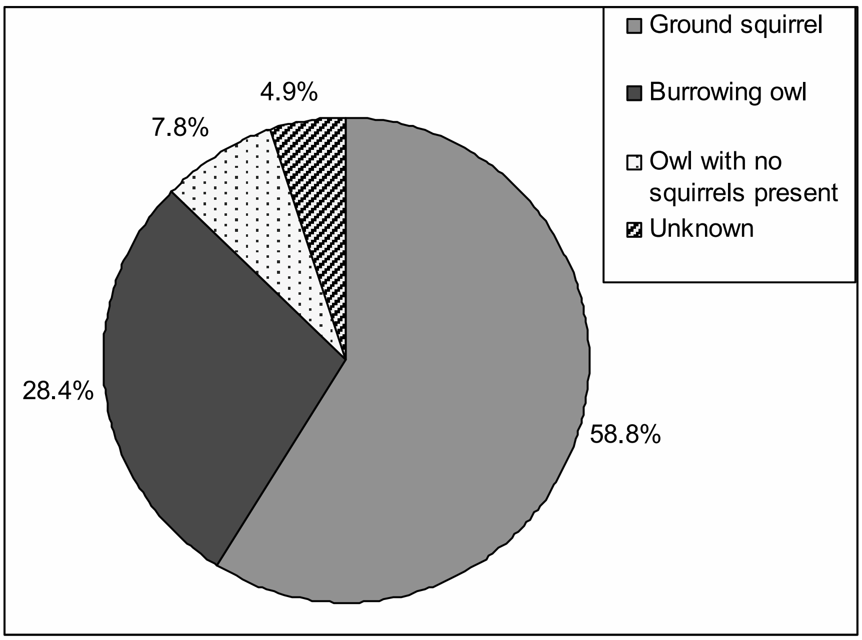

Figure 7. Ground squirrel and burrowing owl first responders during predator encounters.

Direct observational methods and camera trapping methods yielded very different results. Direct observations yielded predator interaction rates of 0.350±0.094/h, while camera observations yielded 0.005±0.001/h. AM and PM observations yielded 0.004±0.001/h and 0.007±0.002/h respectively (Figure 8). No difference was found between predation interaction rates for AM (squirrels out) and PM (squirrels not out) for camera observations (MWU= 88.00, $p= 0.131$, df=1, n=16, Figure 9).

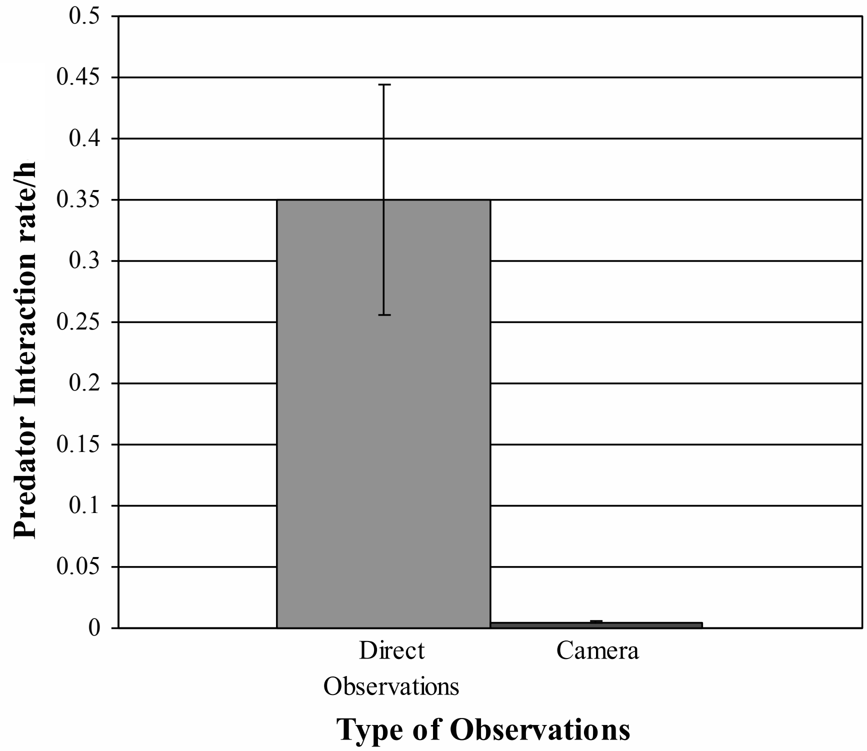

Figure 8. Camera observations versus direct observations on predator interaction rates/h.

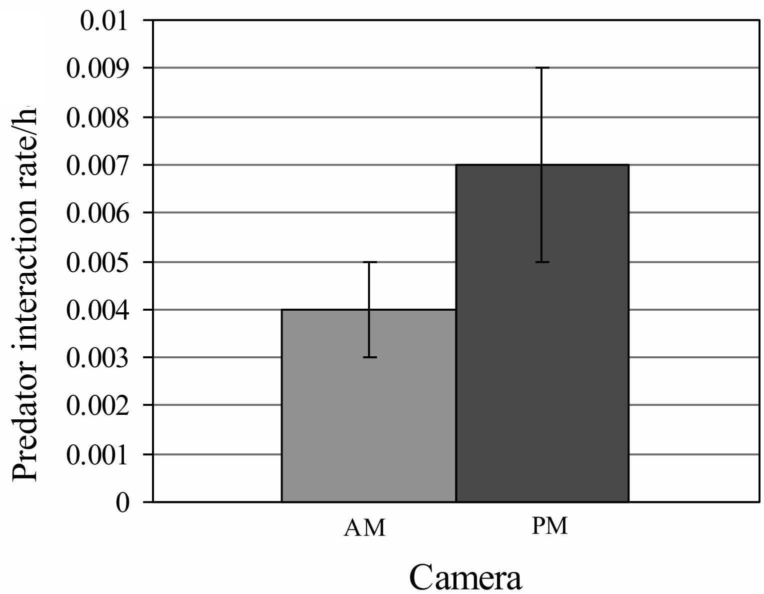

Figure 9. Mean (±SE) of predation interaction rate/h for AM camera collection versus PM camera collection.

Predator interactions went up with increasing numbers of squirrels present around burrow (R^2=0.460, p=0.055, n=18, Figure 10). The number of ground squirrels present around the burrowing owl burrow during direct observations ranged from 0 to 21 squirrels at a given time.

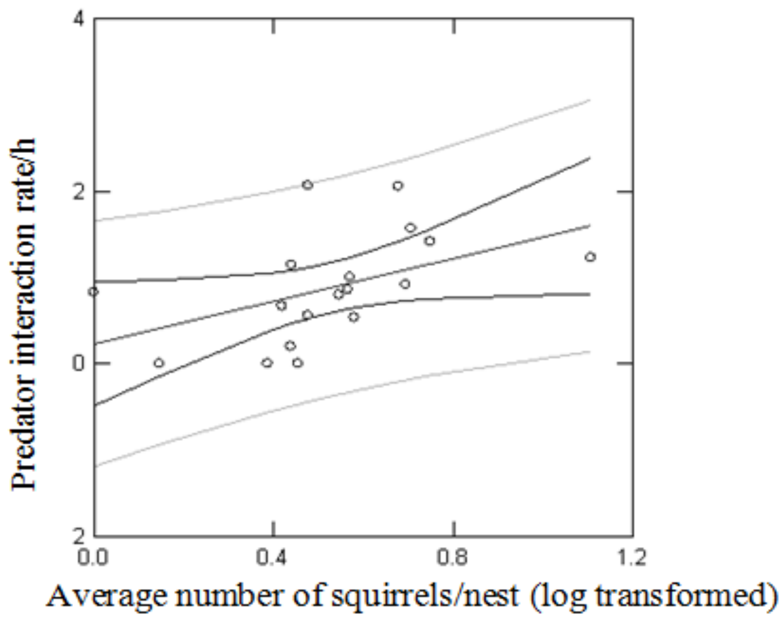

Figure 10. Relationship between the predator interaction rate on burrowing owls and the average number of ground squirrels surrounding burrows (n=18).

Over the two seasons, a total of twelve nests had chicks present, whereas six nests never produced chicks. From direct observations predator attack rates per hour for nests with chicks present was 1.02±0.17 versus 0.60±0.27 predator attack rates for nests without chicks. This difference was not significant (t=-1.378, p=0.187, df=1). Predator attack rates for nests with and without chicks as recorded by cameras at night showed no significant difference (MWU=32.00, p=0.958, df=1).

Known predator types such as striped skunks, coyotes, and foxes were compared to other species located in the vicinity of the burrow that were thought to be non-threatening such as jack rabbits, turkey vultures and goats (Table 2) to see if there was a difference in length of time to return to the burrow after an approach. Statistically significant findings stated that burrowing owls take a shorter time to return to the burrow after a non-predator type of species approaches or transits near the burrow compared to known predators. However no statistical difference was found that having chicks in the nesting burrow was a factor in their return time. The average length time for owls to return to the nest based on predator versus non-predator approaches was significantly different (MWU=171.5, p=0.000, df=1). Owls took longer to return to their nests after predator contact. Non-predator mean time to return was 19.3±8.7 minutes compared 208.6±38.0 minutes for predator approaches. Events in which owls did not return to the nest with in 24 hours were excluded from the test. Frequency of nest abandonment did not differ by predator type (X^2= 2.73, p=0.10, df=1). The length of time owls took to nest to return after predator approach did not differ significantly (MWU=302.5, p=0.309, df=1): once chicks had emerged (199 minutes) versus when they had not emerged (214 minutes).

Discussion

California Ground Squirrel and Burrowing Owl Behavior

In the urban setting at Moffett Federal Airfield in Northern California, the most common owl predators are red-tailed hawk, common raven, red fox, snake, and striped skunk. Of these species, only the red fox is not a native predator, but this species was responsible for four of six mortalities recorded or observed. Ravens were especially common in predator interactions with owls, which is of concern as this species is known to be expanding rapidly in urban areas (Marzluff, Boone and Cox 1994). The relatively frequent predator approaches from ravens supports concern that these corvids may be impacting owl populations (Liebezeit and George 2002).

California ground squirrels are an important part of the environment and may be benefitting owls with alarm-calling behavior. Squirrels called first almost 60% of the time, which is alarm calling that owls did not need to do. Since alarm calling is risky (Hoogland 1996), the owls benefit by having the squirrels do much of the calling. In addition, owls responded to squirrel calls 65% of the time; this high rate of response suggests squirrel calling is important to owls. Owls seem to be responding to the well-developed alarm-calling behavior of squirrels, which is known to reduce successful predator attacks (Hoogland 1996; Leger and Owings 1978).

However, results showed that predator interactions for owls increased with increasing numbers of squirrels. Although this finding seems to indicate that larger numbers of squirrels attract more predators, predator presence and predation rates are two different measures. In fact, Desmond, Savidge, and Eskridge (2000) found predation rates for burrowing owls were lower in high density prairie dog colonies, and Nisbet (1975) and Hoogland (1981), studying colonial nesting species reported reduced rates of predation with increasing sciurid colony size. My study did not provide adequate data on actual predation rates to test whether successful predation on owls is reduced by squirrel alarm calling. Interestingly, camera results did not indicate a difference in rate of predator approaches at night when no squirrels were present compared to daytime when squirrels are assumed to be present. Although squirrels may be attracting predators, the selfish herd/dilution theory suggests the odds of successful predation on any individual will decline with a larger group yet the rate of predation incidents was greater with greater numbers of squirrels, perhaps increasing the risk to owls. Owls may be benefitting from the "herd effect" and also from squirrel alarm calling, as squirrels alarm called first almost 60% of the time. However, the proportion of squirrels to owls was 74% squirrels to 26% owls, so, while the squirrels responded first to predators 60% of the time, the owls responded first 28% of the time suggesting that they are alarm calling a greater proportion of the time based on the ratio of ground squirrels to owls.

The presence of chicks was an important factor in predator interaction and alarm calling rates. Although not a significant difference, the mean predation interaction rate for nests with chicks was almost double the mean of predation rates without chicks. A greater rate of attacks on vulnerable young is to be expected as predation is a major source of mortality for juveniles (Davies and Restani 2006). Squirrels exhibited greater rates of calling when young were present versus when they were not, as predicted by the kin selection hypothesis (Leger and Owings, 1978).

As expected, different behaviors from the burrowing owls and California ground squirrels were elicited during non-predator observations and predator interaction observations. While the squirrels responded to predators, they responded to owl alarm calls only 25.8% of the time. Leger and Owings (1978) found that squirrels will only call once a predator has been confirmed. Thus, the squirrels may not respond until they themselves have seen the approaching predator. More data collected would be beneficial since only 20 predator approaches took place before squirrel pups emerged.

Burrowing owls reacted to 65.5% of squirrel alarm calls, while squirrels responded to only 25.8% of owl alarms. Thus, although each species benefitted from the other's alarm calling behavior, owls benefited disproportionately from the association. I detected no difference in the predation rate between AM when squirrels were present and PM without squirrels present; however, five of the six owl deaths were at night, and five of the eight nest abandonments were the result of nighttime predator approaches, when no squirrels were present. Although there was one successful take during the day by a red-tailed hawk, AM predators were generally unsuccessful regardless of the increased relationship between number of ground squirrels and predators present. No relationship was found between PM predators and squirrel numbers that could indicate an increase in danger towards the burrowing owl.

Finally, many studies have shown that animals will alarm call less frequently when the offspring are not nearby, as the risk of calling is high and benefits are low when no offspring are present. Results of this study were aligned with this prediction. Squirrels called first only 45% of the time before pups emerged versus 67 % of the time with pups. Predator attacks were nearly twice as frequent when chicks were present. Owl alarm calls pre-chick could not be addressed with this study due to chick emergence prior to collection times but is a future study question to be addressed.

Camera versus Direct Observations of Predation

Camera trapping and direct observations differ in many ways. Remote photography has some advantages over traditional research methods; it is a less invasive technique, less time consuming, and potentially less costly for long term direct observations (Culter and Swann 1999). These camera traps are also ideal to record data at night, in inaccessible locations, or for species with secretive or aggressive behaviors (Mace *et al.* 1994). Multiple photographs of nest predation events provide concrete evidence of the predator involved and may alleviate problems associated with observer bias (Culter and Swann 1999). Indeed, in this study, cameras recorded key predators and events at night that were not able to be directly observed.

Although there are advantages to remote photography, there can be disadvantages, such as mechanical problems (battery and SD card failures), programming errors by researchers and various other problems, such as possibly attracting or repelling animals (Rice 1995). Results from this research demonstrate that direct observations were able to collect predator data that would not be detected by cameras. In particular, I had a much wider field of view than the cameras. Direct observations were able to record 74 aerial predators that were not caught on camera. The cameras are stationary and focused only on the burrow and not able to scan the sky as in direct observations.

Predation attempts and takes were rare during the research collection; more time observing would be extremely beneficial, especially adding after-dark observations with the use of night vision goggles to physically observe nocturnal predators for comparison to the camera photographs. Cameras were able to capture 80 predators from 16 cameras over approximately 40 days. Some research has stated that deploying cameras can attract predators or repel focal species (Picman 1987, Major and Gowing 1994). However, during this study no changes in owl behavior were detected when cameras were deployed.

Recommendations

Many locations manage California ground squirrels, reducing their population by trapping, poisoning and other eradicating options. My research points to possible benefits for burrowing owls living in large ground squirrel populations. Eradicating the ground squirrels not only removes potential burrows for the owls but also reduces alarm calls and protection via the dilution effect.

Management suggestions:

- Allow for large ground squirrel populations so they may increase survival rates of adult and juvenile burrowing owls.
- Remove nest material from red-tailed hawks and corvid species near burrowing owl nests to reduce the number of nearby aerial predators.
- Remove nearby predator perches if possible to lessen accessibility of burrowing owl nests.
- Use camera traps to monitor burrowing owl nests for predation events, owl occupancy, and chick emergence.

Suggestions for future research include:

- Comparing data from Moffett Federal Airfield to other nearby locations such as Shoreline Park, San Jose Airport and Santa Clara/San Jose Water Control Plant burrowing owl populations.
- More time directly observing burrows for successful predation events on burrowing owls and California ground squirrels.
- More predator approach and take data on burrowing owls and ground squirrels to assess predation attack rates and successful predation rates.
- Adding nighttime direct observations with the help of night vision goggles to compare to after dark camera data.
- Collecting data during non-breeding seasons or early breeding season to allow more insight into the ground squirrel and owl alarm calls to see if there are any differences from peak breeding season.
- Continuing to assess the importance of sciurid mammals as alarm calls to prevent burrowing owl predation.
- Continuing to study predator populations and how they affect burrowing owl populations.
- Continuing to study the declining trend in burrowing owl populations to ensure the species continues to exist.

This research has provided insight into necessary steps to help manage and study predation rates and alarm call notifications.

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APPENDIX

APPENDIX 1. Predator disturbance and scan sample collection sheet.

Start time:	End time:	Date:	Nest:	Temp:	Cloud cover:	Wind Speed:	Max # of SQ		
Time	Predator Type	# of predators	Predator Action	# of SQ	SQ Rxn to pred	SQ rxn to OW	OW Rxn to SQ	OW Rxn to pred	SQ/OW rx 1st?

SCAN SAMPLES: BURROWING OWL AND GROUND SQUIRREL BEHAVIORS					
Time:	# of SQ	SQ behavior	# of OW	OW behavior	Comments

APPENDIX 2. Behavioral action codes for owl, squirrel, terrestrial and aerial predators.

Terrestrial Predator Action Code:
Tr= Transit (walking in general vicinity of nests with no visible hunting)
AP= Approaching nest (movement in general direction of colony)
A= Attack nest (attempt to enter burrow) T= Take (Successful attack)

Terrestrial Predators
Striped Skink
Red Fox
Grey Fox
Snake
Domestic Cat
Domestic Dog

Aerial Predator Action Code
Tr = Transit (flying over the colony w no visible hunting movement)
So = soaring/ circling above colony
H = hunting (downward plunge towards colony)
A= aggressive hunting (multiple hunting attempts or continual harassment of nests)

T= Take (Successful attack)

Aerial Predators
Red tail hawk
Northern Harrier
Great Horned Owl
American Crow
Peregrine Falcon
American Kestrel

BuOw Behavior Code
M = Mobbing
F = fly
AC = alarm call
R = Run towards burrow
G= Goes underground
U=Underground
Wa=Watching/Scanning
Ra=Rasp
St = Stand up
Si = silent
Fo = forage
P= Preening
S=Stationary
NC= No Change

GrSq Behavior Code
St = Stand Up
W = Whistle/chirp
Ch = Chatter
TC= Tonic call
Wa=Watching/Scanning
R = Run towards burrow
D= Dive into burrow
Fo = forage
TF = Tail flagging
NR=No reaction

APPENDIX 3. Photo from camera trap showing non-native red fox digging up burrowing owl nest burrow at Moffett Federal Airfield, CA.

APPENDIX 4. Photo from camera trap showing striped skunk family predating burrowing owl nest at Moffett Federal Airfield, CA.

APPENDIX 5. Photo from camera trap showing red-tailed hawk harassing burrowing owl nest at Moffett Federal Airfield, CA.

APPENDIX 6. Photo from camera trap showing common raven predating eggs from a burrowing owl nest at Moffett Federal Airfield, CA.