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Prey base analysis of burrowing owls in urban Santa Clara County, California

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PREY BASE ANALYSIS OF BURROWING OWLS IN URBAN SANTA CLARA COUNTY, CALIFORNIA

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by
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ABSTRACT

PREY BASE ANALYSIS OF BURROWING OWLS IN URBAN SANTA CLARA COUNTY, CALIFORNIA

by Philip Gabriel Higgins

This research evaluated the diets of burrowing owls to determine whether diet, especially presence of vertebrate prey, were associated with habitat type and nest success.

Analysis of 3,092 owl pellets and prey remains at owl burrows revealed 7,227 prey items during 2005 and 2006. Dermaptera dominated the diet, and invertebrates outnumbered vertebrates in the ratio 94:6. However, rodents accounted for 82.53% of the biomass. Dietary differences occurred among the five sites, between urban and parkland sites, between seasons, among owls with and without chicks, and between irrigated and non-irrigated areas. Most importantly, more vertebrates in pellets were associated with successful nests.

Based on these findings, the burrowing owl prey base in this urban area can be improved by maintaining a mosaic of different habitat types to support prey species, planting native perennial plants, removing feral cats, installing irrigated areas adjacent to owl habitat, and providing supplemental feeding to the owls.

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Many thanks goes to my three committee members: Dr. John Matson for teaching me small mammal trapping and the endless hours spent identifying small rodents from bone fragments and teeth, Dr. Rachel O'Malley for help in identifying invertebrate species and the relevant input in setting up invertebrate trapping, and special thanks to Dr. Lynne Trulio my committee chair and adviser since my first day at SJSU. You have been instrumental in guiding and inspiring me over the years not just with regards to burrowing owls but all aspects of environmental issues.

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INTRODUCTION

The Western burrowing owl (*Athene cunicularia hypugea*) (Figure 1) is a diminutive denizen of short grasslands, and semi-arid areas, whose life history is centered in and around an underground burrow, a unique aspect among owl species. The burrow is used for nesting, escape from predators, shelter during inclement weather, a food supply, thermoregulation, and social interaction (Coulombe 1971 and Thomsen 1971). Despite their dependence on burrows, the owls rely on fossorial mammals to provide the burrows, whereby they live in the same colony as colonial mammals, but not in the same burrow (Thomsen 1971). So great is the need for burrows that the owls are dependant on burrowing mammals, especially ground squirrels (*Spermophilus* spp.) and prairie dogs (*Cynomys* spp.) (Zarn 1974).

Burrowing owls are about 19-25cm long and weigh about 150g, they have brown and buffy-white plumage with a very distinctive bright iris of lemon-yellow (Haug, Millsap and Martell 1993). They are the only North American owl not exhibiting reversed size dimorphism (Zarn 1974).

The range of the western burrowing owl includes most of Western North America, from Southern Canada to Northern Mexico, and West of the Mississippi river. Habitat loss, alteration of existing habitat, and reduction and removal of colonial sciurid populations have resulted in the burrowing owls being listed as endangered in Canada, Minnesota and Iowa, and listed as a Species of Special Concern in most other US states, including the state of California (Sheffield 1997).

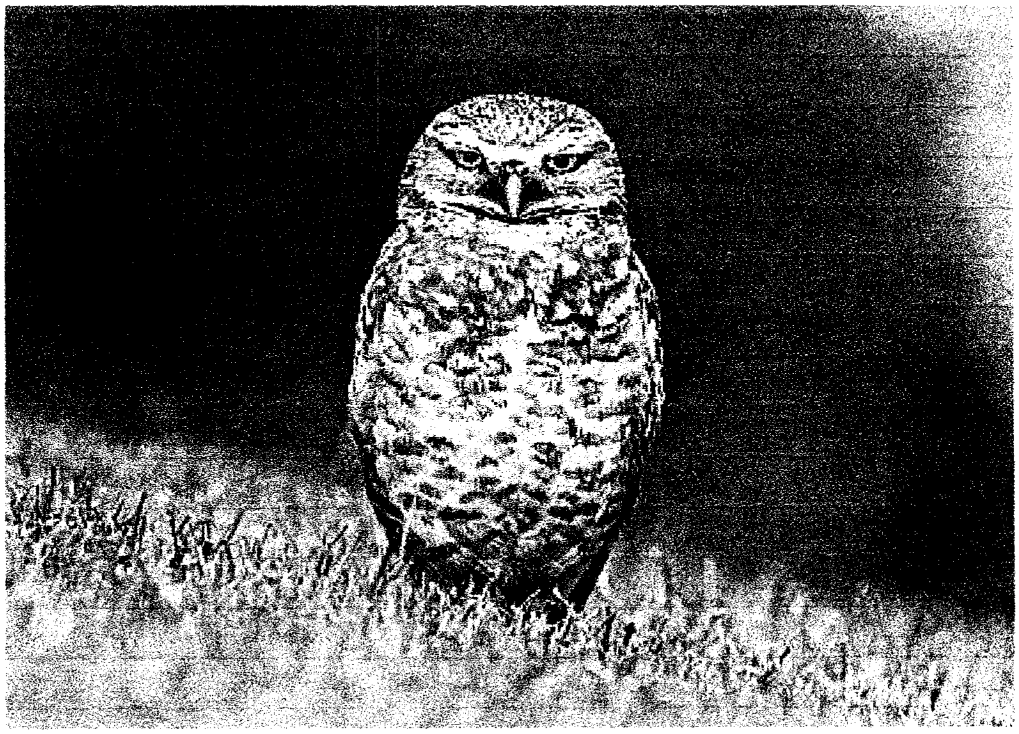

Figure 1: Western Burrowing Owl (*Athene cunicularia hypugea*)

(Photographer: Yamil Saenz; location - Shoreline Park)

Burrowing owls are opportunistic and generalists when it comes to their dietary requirements (Haug, Millsap and Martell 1993), with local conditions such as floral and faunal composition affecting both the relative proportion, and diversity of species that are preyed upon (Zarn 1974). Invertebrates were the main prey species in Southern California (99.8%; York, Rosenberg and Sturm 2001) especially Orthoptera (58.9%), Colorado (55.6%; Plumpton and Lutz 1993) especially Coleoptera (49.4%), Idaho (91%; Gleason and Craig 1979) especially Gryllacrididae (46%), Washington (82.9%; Green, Fitzner and Anthony 1992), and Oregon (91.6%; Green, Fitzner and Anthony 1992). Vertebrates were more important in the diet in Montana (74.5%; Holt, Norton and Atkinson 2001) especially rodents (72.2%), and Central Oregon (50.3%; Maser, Hammer and Anderson 1970) especially rodents (49.8%). Burrowing owls are predominantly crepuscular hunters, however, foraging has been observed nocturnally and diurnally (Thomsen 1971, Haug and Olipant 1989, Haug, Millsap and Martell 1993).

The habitat requirements of burrowing owls are very specific; short vegetation, openness, and burrow availability (Thomson 1971, Zarn 1974, Green and Anthony 1997), however, they will habituate to human altered habitats, and are often found in urban parks, golf courses, airports, agricultural areas, vacant lots in residential areas, and college campuses (Haug, Millsap and Martell 1993, Trulio 1997, Millsap 1999).

Once abundant throughout its range, this species is now experiencing a population decline as a direct result of habitat destruction, and fragmentation (Dyer 1987, Sheffield 1997). This population decline has become so severe at some locations that the burrowing owl has become extirpated in parts of its range (Holroyd, Rodriguez-Estrella and Sheffield 2001, DeSante, Ruhlen, Rosenberg 2004). Urban areas are especially prone to burrowing owl declines, as suitable habitat is replaced with urban sprawl, and no where is this more prevalent than Santa Clara County, California, where present burrowing owl populations are experiencing a severe decline (Buchanan 1996, Trulio 2004).

Grasslands across North America have declined significantly, and are one of the most threatened and degraded habitats on the continent (Jones and Bock 2002). With this reduction in grassland habitats, many grassland bird populations have also experienced a significant decline correlating to the decline in grassland ecosystems. Numerous grassland avifauna are known to be sensitive to changes in their grassland communities (Jones and Bock 2002), and many bird species, such as the burrowing owl, are indicators of the health of grassland habitats (Sheffield 1997, Trulio 2004).

Apart from degradation and fragmentation of habitat, additional factors impacting the owl's survival rate are the quality and abundance of prey species, predation rates on burrowing owls, competition for resources, and human disturbance. All of these impacts have a significant role in the decline of this bird species (Rosenberg and Haley 2004). Conservation efforts to reverse this population decline and stabilize owl populations have mainly focused on preserving suitable habitat, maintaining viable populations of ground burrowing mammals, such as prairie dogs (*Cynomys spp.*) and California ground squirrels (*Spermophilus beecheyi*), and maintaining the owls' habitat with suitable management practices, such as mowing, and artificial burrow construction (Haug et. al. 1993, Holroyd, Rodriguez-Estrella, Sheffield 2001).

However, one of the most important factors for conserving any species at a particular location is the availability of food. For avian species, resource availability is especially important in the breeding season (Strong, Rimme and McFarland 2004). Urban environments, where burrowing owls can be found, consist of a mosaic of fragmented grasslands, parks adjacent to golf courses, airports, residential and commercial premises. Management practices of these sites are often not conducive to species diversity. Maintaining short vegetation in burrowing owl habitat may be a crucial conservation technique for successful burrowing owl nesting, and adult survival (Green and Anthony 1997), but short vegetation has adverse affects on rodent and invertebrate survival. Abundance, distribution, and diversity of invertebrates are higher for extensively than intensively managed grasslands (Di Giulio, Edwards and Meister 2001, Kruess and Tscharntke 2002). Small mammal density is very low in mowed vegetation versus tall vegetation, and in one study, the author concluded that the small mammal density in a mowed area was one-half the density of an unmowed area Adams (1984).

RELATED RESEARCH

The research for this study is dependent upon several ecological principles, including the theory of bottom-up forces, impacts of limited nutritional diets, and prey base resource availability.

Theory of Bottom-Up Forces

Bottom-up forces, such as food availability, and top-down forces, such as predators are two key determining factors when analyzing population demographics (Strong 1992). For avifauna, resource availability plays a major role, especially during the breeding season (Strong, Rimme and McFarland 2004). However, most species in general, experience some population changes to increased resource availability. Yunger (2001) conducted research on the response of increased food availability to the white footed mouse (*Peromyscus leucopus*) to determine if, 1) the mouse population would increase, 2) could natural responses to the food supply be replicated using experiments, and 3) does predation interact with food to impact population demographics?

The mice did not respond numerically to increased food supply. Increases in population were a result of immigration, and not reproduction. Increased food supply did result in earlier reproduction, but a decline in numbers. Finally, food supplementation increased predators of the mice which decreased the mouse population (Yunger 2001).

Renton (2000) conducted research on food resource availability of the lilac-crowned parrot (*Amazona finschi*) in Western Mexico. The results of the study confirmed that the parrots demonstrated spatial variation in their choice of habitats as a direct result of the availability of food resources in those habitats. Analysis of the food niche breadth, and composition of the diet of the parrots showed seasonal fluctuations in abundance, and variability of the types of forest used by the parrots. The variability depended upon the rainfall in the different forests, which in turn determined the fruiting times of the forest trees (Renton 2000).

Research on Prey Base Availability

Prey availability and abundance is an area of significant importance for raptor conservation. This is especially crucial where reproductive success is concerned. According to a study by Rosenberg, Swindle, and Anthony (2003) conducted on spotted owls (*Strix occidentalis caurina*) in Oregon there was a positive correlation between the proportion of large prey availability, and reproductive success. This study analyzed the remains of regurgitated pellets during the owls' breeding season for its diet composition. Upon analysis of the pellets, the researchers found that prey biomass, and numbers of prey consumed were similar. The most common species preyed upon by the spotted owls were flying squirrels (*Glaucomys sabrinus*), and bushy-tailed wood rats (*Neotoma cinerea*). To a lesser extent, voles (*Microtus* spp.) were occasionally common in the diet, however; deer mice (*Peromyscus maniculatus*) were uncommon, despite the fact that deer mice were present in the spotted owl's habitat in greater abundance. This research concluded that, despite the similar biomass of flying squirrels and deer mice in the habitat, the spotted owl's diet was dominated by the flying squirrels in the breeding season based on both biomass (49%), and numbers (40%). Reproductive success was more than likely a combination of weather factors, and prey availability, and the life history strategy of the spotted owl (Rosenberg, Swindle and Anthony 2003).

Brown et al. (1986) conducted a comparison study of pellets of screech owls (*Otus asio*) versus burrowing owls in Southeastern Oregon. After the pellets were collected and analyzed the researchers found that, for screech owls, vertebrates represented 20.2% of the diet, and invertebrates 79.8%. For burrowing owls, vertebrates represented 14.3% of the diet, and invertebrates 85.7%. The Ord kangaroo rat (*Dipodomys ordii*) was a common prey species for both owl species, although, it was more important to the burrowing owls. The northern pocket gopher (*Thomomys talpoides*) was an important prey item for burrowing owls, but the gopher accounted for less than 1% of the diet of screech owls. For invertebrate prey, the screech owl preyed on 26 families of invertebrate, while burrowing owls preyed on 24 families, although there were major differences in quantities eaten. Beetles (Coleoptera) were more important in the burrowing owls' diet (38.6% versus 21.4% for screech owls). Orthoptera were more important for the screech owl (50.0% versus 34.3% for burrowing owls). Within Orthoptera, grasshoppers (Acrididae) were more important to the screech owl (35.2% versus 21.6% for burrowing owls). The Jerusalem cricket (*Stenopelmatus* spp.) was favored by the burrowing owl 12.7% versus 9.7% for screech owls. Finally, screech owls preyed upon the cricket (*Gryllus veletis*) while the burrowing owl did not prey upon this cricket at all. Overall flexibility in habitat by the screech owl brought it into contact with a wider prey base than the burrowing owl (Brown et al. 1986).

The spotted owl is a specialist, restricted in range to old-growth forests and focusing heavily on specific prey items. Burrowing owls, on the other hand, although denizens of short grasslands, also reside on golf courses, cemeteries, airports, agricultural areas, and vacant lots in residential areas. They are more opportunistic when it comes to feeding (Haug et al. 1993, Plumpton and Lutz 1993).

York, Rosenberg and Sturm (2002) conducted a diet analysis of burrowing owl stomachs to reduce the bias associated with pellet analysis. They were interested in the burrowing owls of the Imperial Valley, who are unique in the respect that they have the highest population density in California, yet they have a low reproductive success rate. Burrowing owls, being a 'species of special concern', are protected by the Federal Migratory Bird Treaty Act, and codes from the California Department of Fish and Game which forbid the killing, taking or disturbing of burrowing owls (Haug, Millsap and Martell 1993). To avoid any impact to burrowing owls the researchers used dead owls provided by the U.S. Fish and Wildlife Service, that were found adjacent to an electric fence that surrounds a State prison. These owls were electrocuted by the fence, which has since been modified. The Imperial Valley is a highly agricultural area. The habitat consisted of agricultural crops such as alfalfa *(Medicago sativa),* Sudan grass (*Sorghum bicolor),* onions *(Allium cepa),* and sugar beets (*Beta vulgaris*). The agricultural fields were interspersed by roads, canals, and ditches which provide ideal nesting habitat for burrowing owls, while the agricultural fields provide an abundance of prey species, especially Orthoptera. This habitat is ideal for Orthoptera: the temperature is dry and warm, there is plenty of green food available in the fields with bare ground, and sufficient water with the intensive irrigation systems associated with this type of agriculture. A total of 36 female and 17 male owl stomachs were examined.

The researchers found that the average number of prey items found in the stomach contents was 46.8 ± 3.5 items. The composition of the diet included: Araneida, Coleoptera, Dermaptera, Isopoda, Lepidoptera, Orthoptera, Rodentia, and Solpugida. The most dominant prey item based on prey numbers and frequency of occurrence was Orthoptera. The frequency of occurrence for Coleoptera, Dermaptera and Solpugida were high, but the number of individuals of each of these prey items per stomach were low. Both Rodentia and Isopoda were rare in number and frequency of occurrence; the low occurrence of rodents in this habitat is possibly due to the year-round cultivation and flood method of irrigation, making it inhospitable for rodent survival. With a diet lacking in rodents, and mainly consisting of insects, the researchers hypothesized that the burrowing owls are lacking a significant source of calcium; rodents being a high nutritional source of calcium, while insects are a poor source of calcium. This lack of calcium in the diet is a limiting factor for burrowing owl reproduction, reducing both clutch size, and reproductive success, hence, the overall low reproductive success of burrowing owls in the Imperial Valley. Consequently, the year round abundance of Orthoptera may explain the high density of burrowing owls at this location, while the lack of rodents may indicate a diet insufficient for reproduction, contributing to low reproductive success (York, Rosenberg and Sturm 2001).

Impacts of Limited Nutritional Diets

Nutritional studies conducted on other animal species have confirmed that inadequate amounts of certain nutrients limit or inhibit reproductive success in an array of animal species. Nutritional quality also influences species density, and the timing of birth to coincide when nutritional quality is at its peak. Research conducted by Batzli (1985) on California voles (*Microtus californicus*) confirmed that a lack of calcium in the diet of these animals accounted for a reduction in breeding success. The diet of California voles varies throughout the year with green forage being the staple diet during the wet season, which is also their breeding season, while the diet switches to grass seeds as the vegetation dries, while at the same time most voles discontinue breeding. Batzli conducted a number of laboratory experiments on captive bred California voles to analyze the impact of calcium and sodium on breeding success. Twenty seven female California voles and 18 male voles were fed different diets, some rich in calcium and sodium, while other diets were lacking these nutritional supplements over a 2 year period, while their reproductive success was monitored. The results of the experiments confirmed that California voles reproduced better on a nutritious diet that included calcium and sodium. Adult females on the calcium and sodium diet had significantly more litters, produced more young in these litters, and survived better on this diet (Batzli 1985).

Plumpton and Lutz (1993) conducted a study on pellets and prey remains of burrowing owls in Colorado to decipher prey selection of the owls at this location.

Pellets and prey remains were collected around active burrows in the study area, and then analyzed for species identification. The study site contained five major communities: weedy forbs, cheatgrass (*Bromus* spp.)/weedy forbs, cheatgrass/perrenial grassland, native perennial grassland, and crested wheatgrass (*Agropyron cristatum*). The researchers concluded that burrowing owls took large numbers of Coleopterans during the day, and small rodents were taken exclusively by night. Owls were never observed foraging for mammals diurnally. Both pellets and prey remains confirmed that deer mice were the single most important prey species at this location. With reference to insects, the burrowing owls preyed on *Silphidae* more than any other species. Other insects that were preyed upon were *Acrididae, Carabidae*, and *Gryllacrididae*. Pellets from the site indicated greater use of deer mice and beetles, while the prey remains indicated greater use of mammals that were larger than deer mice, toads and passerines (Plumpton and Lutz 1993).

Green et al. (1992) conducted research comparing the diets of burrowing owls in two different states: Oregon and Washington. Both sites had similar vegetation, precipitation rates, and topography. They analyzed a total of 6,328 pellets. From five nests in Washington, 769 pellets were collected from 1977-78, and 5,559 from 65 nests in Oregon from 1980-81. The pellets included 37,431 individual prey items. Of these prey items, 14 were small mammals, 3 were birds, 2 were reptiles, 1 was amphibian and 56 were arthropods. The most significant difference between the two sites was the percentage of vertebrate prey species. The Washington site had a higher percentage of vertebrate prey species (17.1%) as opposed to the Oregon site (8.4%). For small mammals, the great basin pocket mouse (*Perognathus parvus*) dominated the vertebrate prey base at both locations. Due to differences in habitat and prey species ranges at the two locations, Ord's kangaroo rat (*Dipodomys ordii*) and montane voles (*Microtus montanus*) were not found at the Washington site, while the sagebrush vole (*Lagurus curtatus*) was not found at the Oregon site. An interesting observation from the study was that over 90% of the vertebrate prey were nocturnal species, again showing the importance of nocturnal foraging to burrowing owls. At both research sites, arthropods comprised 90.4% of the prey species, yet only 12.7% of the biomass (Green et al. 1992).

Holt, Norton and Atkinson (2001) researched the diets of burrowing owls in South-central Montana. They collected 1,896 pellets from 1990 to 1992. From these pellets 2,497 prey items were identified. A total of 72.2% of the prey items were small mammals: prairie voles (*Microtus ochrogaster*) being the most dominant species with mice (*Peromyscus* spp.) being the second most dominant species. Due to the difficulty in quantifying insect remains from the pellets, it was likely that insects were under-represented in the results, according to the authors. The authors concluded that prey availability, vegetative cover, and weather all contribute to annual, and seasonal variations in the diets of burrowing owls (Holt, Norton and Atkinson 2001).

Wesemann and Rowe (1986) examined the factors influencing the distribution and abundance of burrowing owls in Cape Coral, Florida. Not only did they research prey abundance, but also percent human development of burrowing owl habitat, and soil composition. They concluded that the density of burrowing owls were highest in locations that had areas with 54-64% urbanization. Due to the fact that urban areas use artificial watering all year round, the vegetation cover in these areas was greater compared to undeveloped tracts. With greater vegetation cover, invertebrate abundance was also greater. From pellet analysis and pitfall trapping, the researchers found that the brown anole (*Anolis sagrei)* was the most common prey species consumed by the owls. The anoles were preying on the insects, which in turn were present due to the vegetation cover. However, when development surpassed 60%, burrowing owl densities dropped despite the fact that anole, and insect abundance continued to rise (Wesemann and Rowe 1986).

Types of habitat can greatly influence the diversity, and abundance of prey species available for raptors. Old growth forests provide an abundance of flying squirrels for the spotted owl, and the agricultural matrix of the Imperial Valley permitted Orthoptera to reproduce year round providing an ample prey base for burrowing owls. However, for grassland species inhabiting fragmented habitats in urban environments poses additional problems for prey availability. One study conducted by Trulio and Chromczak (in press) in the southern portion of the San Francisco Bay Area focused on urban habitats with populations of burrowing owls in two different land use types. Land use type one consisted of parkland sites; areas that were specifically managed for wildlife usage along with recreational usage. The second land use type was urban sites that were dominated by human activities, and were surrounded by development. Trulio and Chromczak (in press) conducted observational studies during the breeding season at seven sites in the southern portion of San Francisco Bay, where all owls were banded to permit ease of identification during the observational study. Active nests were observed for the emergence of owl chicks as a gauge of nest success for the owls. During the research period, 387 owls were banded: 104 males, 94 females, and 189 chicks. Nest numbers, and density along with nest success, and chick productivity were compared between the parkland sites and the urban sites.

The results of the research work showed that the maximum number of chicks per successful nest were higher for parkland nests than for urban nests (parkland mean was 3.44, while urban mean was 2.84) although not significantly so. Overall, the parkland sites were better at maintaining consistent numbers of nests. Another important finding was that no matter how many pairs of owls attempted nesting each year (range: from 64 in 1999 to 42 in 2003), the number of successful nests remained relatively constant (between 22-28, average was 24). This relative consistency in nest success could be a result of a limiting factor such as predation rates, human disturbance, or prey base (quality or quantity of food supply) (Trulio and Chromczak, in press).

This present study was conducted on the prey base of burrowing owls at the same seven sites as the Trulio Chromczak study, to access whether prey base as determined through pellets, might be a factor limiting reproductive success.

Numerous factors contribute to reproductive success in urban, parkland, agricultural, and more natural habitats. Burrowing owls that defend territories that contain abundant resources such as food and nesting sites have a far greater chance of reproducing successfully (Moulton, Brady and Belthoff 2003). Due to asynchronous hatching, burrowing owl chicks show a large variability in growth rates, and body condition, which may be due to the fact that early nestlings get a greater proportion of food, which in turn results in faster growth rates (Griebel and Savidge 2002). However, the overall factor for breeding success appears to be prey availability, abundance, and nutritional quality. These factors in turn depend on the habitat that is available for foraging, and also the climate (Haug, Millsap and Martell 1993). Numerous studies have been conducted on the diet of burrowing owls throughout their range. The results confirm that the diet of burrowing owls are site specific. However, very little detailed research has been conducted in Santa Clara County on the diet of burrowing owls, especially owls living in urbanized areas. Few studies have addressed the issue of prey availability in long vegetation versus short vegetation for burrowing owls, which is an important factor in urban environments, where habitat is limited and fragmented. Prey abundance and diversity impacts the breeding success of burrowing owls, but the literature review lacked any significant studies conducted on the relationship of breeding success and prey availability in Santa Clara County.

RESEARCH QUESTIONS

This study was designed to address the following research questions:

1. What is the diet of burrowing owls inhabiting five urban sites in Santa Clara County, California?
2. Is there a difference in prey found in pellets and remains at burrows:
    - Among the five sites?
    - Between Urban versus Parkland Sites?

  - Between the breeding season versus non-breeding season?
  - Between burrowing owl pairs with chicks versus without chicks?
  - Between burrows located on irrigated areas versus non-irrigated areas?
3. Is there a difference in prey abundance in long versus short vegetation?
4. Is there a difference in the results of the present data (2005-2006) compared to pre-study results (1999-2001) and other studies in the US?

STUDY AREAS

Trulio and Chromczak (in press) conducted a seven-year demography study at seven sites in Santa Clara County from 1998 to 2004 (Figure 2). The study sites included two different land use types: parkland sites, areas managed for recreational purposes and wildlife protection, and urban sites, which are not specifically managed for wildlife protection, and may have on-going development. By April 2005, no burrowing owls were observed at two of the seven original sites described in the Trulio and Chromczak (in press) study (Byxbee Park and Agnews Development underlined and italicized in Figure 2). Therefore, only five sites were included in the research described here.

The five study sites are all located within Santa Clara County at the south end of the San Francisco Bay Area, and covered an area of approximately 1,181 ha. The City of San Francisco is located approximately 60 km northeast of the study sites, and the City of San Jose lies approximately 12 km east of the study sites. A major highway (Route 101) is located to the south of the sites, San Francisco Bay to the north, the Guadalupe River to the east, and Adobe Creek to the west. The mean annual precipitation of the area is approximately 37 cm. During 2005, rainfall levels were higher than normal at 57 cm, and for 2006, rainfall was above average again, at 42 cm. Most of the rainfall occurs between November and April. The maximum mean temperatures for the area in January are 9.8 C and minimum temperatures are 5.8 C. June maximum mean temperatures are 19.26 C and minimum temperatures are 16.95 C (NOAA, 2007).

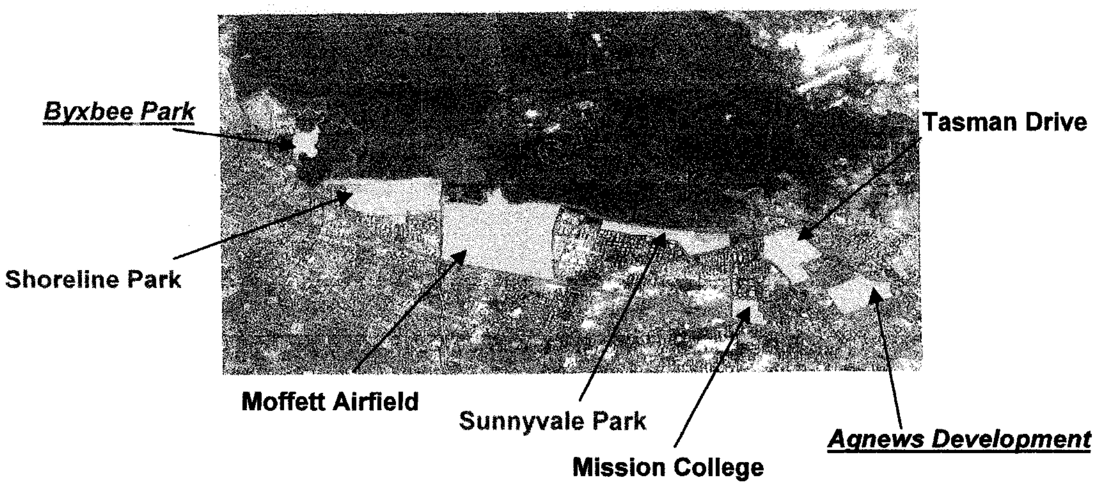

Figure 2: Burrowing Owl Study Site Locations

(Source : Trulio and Chromczak, 2004)

From east to west (Figure 2) the sites included:

Shoreline Park

Located in the City of Mountain View, this former landfill covers an area of 300 ha set aside as a recreational and wildlife area. The park includes a 20 ha salt water boating lake, an 18 hole golf course (80 ha) with five irrigation reservoirs, two tidal marshes, two sloughs, a seasonal marsh, a storm retention basin, and 38 ha of non-irrigated grassland containing predominantly non-native annual grasses. These annual grasses include such species as *Avena* and *Hordeum* spp. Other non-native species include: Russian thistle (*Salsola kali*), mustard (*Brassica spp.*), bristly ox-tongue (*Picris echoides*), curly dock (*Rumex crispus*), and Australia stinkweed (*Dittrichia graveolens*). After completion of landfill cap repairs, that are on-going, the non-irrigated grasslands are hyroseeded with a mixture of native grasses and annual flowers (*Nassella pulchra, Festuca rubra, Hordeum brachyantherum, Eschscholzia californica* and *Castelleja exerata*). However, the annual non-native grasses dominate the landscape. The topography of the site varies from 0 to 45 m mean sea level. The maximum number of adult burrowing owls observed during both breeding seasons at Shoreline Park was 10.

Moffet Federal Airfield

Also located within the City of Mountain View, this site includes approximately 683 ha of grassland habitat, and contains three large aircraft hangers, several administrative and residential buildings, and the NASA Ames facilities on the east and west side of the two runways. A golf course is located in the north east portion of the airfield, and a managed pond lies to the north of the site. The topography of the site is generally level. Vegetation at the site includes annual non-native grasses and non-native weeds including bristly ox-tongue and mustard. The maximum number of adult burrowing owls observed during both breeding seasons at Moffett Airfield was 47 adults in 2005 (Debra Chromczak, pers. comm.), and 21 adults in 2006 (Chris Alderette, pers. comm.).

Sunnyvale Baylands Park

This park is located in the City of Sunnyvale, and comprises 28 ha of parkland, and 42 ha of seasonal wetlands. The site consists of sewage treatment ponds, salt ponds, drainage channels, an active and a retired landfill, a sewage control plant, and a recycling center. Vegetation in the park includes annual non-native grasses, and non-native plants such as Australian stinkweed, mustard, and bristly ox-tongue. The topography is level to gently sloping up to 18 m above mean sea level. The maximum number of adult burrowing owls observed during both breeding seasons at Sunnyvale Park was two, both of which were females (D. Chromczak, pers. comm.).

Mission College

This site is located within the city of Santa Clara. The vast majority of this 66 ha site is comprised of the community college with two baseball fields, a soccer field and the Mercado Development Centre, a commercial and retail development on land leased from the West Valley Mission College Community District. The topography is level and the vegetation includes non-native annual grasses, yellow star thistle (Centaurea solstitialis), Australian stickweed, and curly dock. The maximum number of adult burrowing owls observed during the breeding seasons at Mission college was one adult in 2005, and two adults in 2006.

Santa Clara Golf and Tennis Club (Tasman Drive)

The golf club and the small parcel of land directly in front of the golf club are located within the city of Santa Clara. The 18-hole golf course covers an area of 62 ha with two ponds and consists of generally level topography. The small parcel of land in front of the golf course contains mainly non-native annual grasses with yellow star thistle and mustard. A maximum of four adult burrowing owls was observed during both breeding seasons.

METHODS

Active burrowing owl burrows were located at all five sites using the walk-through transect survey method, whereby all suitable habitat was visually inspected on foot using binoculars, and walking along a transect to observe burrowing owls or owl activity (droppings, pellets, feathers, prey remains or bedding material). The transects were of uniform distance apart, the distance dependant upon vegetation height. The location of all active burrows were marked on a map using the numbers assigned from the Trulio and Chromczak (in press) study.

Surveys were conducted starting in April 2005, and continued through August 2006. The time frame was divided into two seasons, the breeding season – April through August, and the non-breeding season – September through March. Hence, the study provided data for two breeding seasons and one non-breeding season.

During the 2005 breeding season, all owl pellets and prey remains found at or near burrow entrances or nearby perches were collected on a weekly basis and placed in plastic bags. The bags were identified with the date, site location, burrow number (as per Trulio and Chromczak (in press)) and the number of pellets. Additional data were recorded on a data sheet, including number of owls present, including chicks, whether the burrow was in an irrigated or non-irrigated area, vegetation height, and any other species observed at or in the burrow, whether burrow was artificial or natural, and if white wash and owl feathers were present. During the 2006 breeding season, pellets and prey remains were collected on a bi-weekly basis, and during the non-breeding season both prey remains and pellets were collected on a monthly basis. Pellets were then frozen until analysis took place.

The pellets were analyzed as groups (all those collected at or near a single burrow during one collection period) as opposed to individual pellets. Burrowing owls are known to portion single prey items over a time period, hence single pellets would create bias (Green 1983). The pellets were soaked in water and pulled apart with a forceps. Prey remains were then divided into invertebrate and vertebrate parts. With the aid of a dissecting microscope, invertebrates were identified to Order by using pincers (Dermaptera), elytra and head capsules (Coleoptera), and mandibles, head capsules and legs (Orthoptera). Vertebrate prey were identified by bones, especially the lower mandible for rodents and comparing them to specimens at the mammal collection at San Jose State University. Rodents were identified to species where possible, as were amphibians and reptiles, while birds were identified to class. Examples of all vertebrate parts were retained after positive identification to further enhance identification of new parts. Prey remains were identified in the same fashion, and recorded on a separate table to the pellet analysis. Other items found in the pellets including egg shells, pebbles, vegetation, plastic, and wood chips were also recorded.

To determine if the diet of the burrowing owls represented the range of prey items available at the sites, trapping of invertebrates and small mammals was conducted. Invertebrate trapping included ground sampling and above ground/midair sampling. Ground sampling involved the use of pitfall traps, which consisted of plastic containers placed flush in the ground with a 2-3 cm mixture of water, salt, and biodegradable laundry detergent placed inside the container. The salt acted as a preservative, and the detergent broke the water surface tension permitting invertebrates to sink. A lid was placed on top of the container supported by wooden skewers underneath to allow invertebrates to enter but prevent small mammals from entering. The trap was left in place for five days. Trapping was conducted at each site once during the breeding season (February – August) and then once per month year round at Shoreline Park to collect species to help with invertebrate identification during pellet analysis.

For above ground/midair sampling, sweep nets were used to catch invertebrates that resided on low growing vegetation or that flew just above the ground. This method was conducted on two occasions for each site, once when the pitfall traps were first installed and then again when the pitfall traps were removed. This sampling method was also conducted on a monthly basis at Shoreline Park to help with invertebrate identification.

Sherman live traps were used to capture small mammals. At each site, a randomly chosen transect line 500m long was set up consisting of 50 trapping stations. Trapping stations were located at 20m intervals down the transect line. Along the transect line at each trapping station, two Sherman traps were placed within 6m of each other. Each trap was marked with a colored marker flag. All traps were covered with vegetation to protect and insulate the captured mammals. The traps were baited with rolled oats and peanut butter, and insulated internally with polyester. The traps were removed during the day and set up and opened at sunset for a total of two to three nights per site. The traps were checked the following morning to ensure that no mammals would remain trapped for longer than 9 hours. Captured animals were identified, and the fur on a small area of their back was trimmed to identify recaptures. Then, animals were released. The total trap nights for all sites during 2005 was 1,060, while trap nights for 2006 was 600.

Invertebrate and small mammal trapping was conducted at Byxbee Park during the breeding season of 2005. However, no trapping was conducted in 2006 due to a lack of owls, and this site was not included in the final study.

All accessible burrows at the five sites were sampled. However, at Moffett, in particular, many burrows were not accessible. This military base has several off-limit locations due to security reasons, such as the large grassland area immediately adjacent to the runways. Hence, only burrows in non-restricted zones were included. The sample size at Moffett was 8 -10 individuals while the population at this site was 24. Another problem that arose here was the fact that several owls had their main burrow and satellite burrows located on both sides of the fences that divided the off-limit locations from accessible zones. Pellets were collected in the accessible areas while owls were present there. However, several owls did move to inaccessible satellite burrows at one stage or another, and pellet collection was prevented due to lack of access.

Two-way ANOVAS were used on the pellet data, which was log transformed. Two-sample t-tests were used for the invertebrate trapping data. Data from the 1999-2001 study were analyzed by Dan Rosenberg and the results were compared to the data from the present study for diet comparisons.

Biomass was only estimated for three invertebrate Orders (Dermaptera, Coleoptera and Orthoptera) which represented 92.1% of the diet, and five vertebrate species (*Microtus, Mus, Thomomys, Reithrodontomys* and *Peromyscus*) which represented 4.46% of the diet. A sample of 20 of each invertebrates from the three Orders where weighed upon capture, and their weights averaged. For the rodent species, biomass was estimated as per Jameson and Peeters 2004, and Kays and Wilson 2002 field guides.

RESULTS

Diet of Burrowing Owls

A total of 3,092 pellets yielded 7,144 prey items and an additional 83 prey remains located at the burrows (N=92), yielded a total of 7,227 individual prey items (Table 1). A total of 11 orders were recorded, and of these Orders, three represented 92.1% of all prey items: Dermaptera (48.61% of all prey items), Coleoptera (27.52% of all prey items), and Orthoptera (15.97% of all prey items). Vertebrates represented 6% of the diet and four classes were represented: Aves were only identified as birds (0.28%), Amphibia represented by one species, Pacific treefrog (*Hyla regilla*) (0.03%), Reptilia represented by one species Western fence lizard (*Sceloporus occidentalis*) (0.32%), and mammals represented by seven species (5.44%), three of which represented 4.03% of the diet. California voles (*Microtus californicus*) were the most common vertebrates representing 1.87% of the diet, while both house mice (*Mus musculus*) and Botta's pocket gopher (*Thomomys bottae*) represented 1.08% each of the diet. Other rodents included the Western harvest mouse (*Reithrodontomys megalotis*) (0.39%), the deer mouse (*Peromyscus maniculatus*) (0.04%), and unidentified rodents (0.71% of the diet). Jack rabbits (*Lepus californicus*) (0.06%), and California ground squirrels (*Spermophilus beecheyi*) (0.22%) were only found as prey remains at the burrow entrances, apart from one juvenile ground squirrel found in a pellet (Figure 3).

Biomass was estimated for the three most common invertebrate Orders, Dermaptera, Coleoptera and Orthoptera and the five species of small rodents *Microtus* *californicus, Mus musculus, Thomomys bottae, Reithrodontomys megalotis* and *Peromyscus maniculatus,* not including the unidentified small rodents. The invertebrates represented 92.1% (6,656 individuals) of the total number of prey species of the entire diet, while the rodents represented 4.46% (322 individuals), for a combined percentage of 96.56% of total individuals (Table 2). The biomass ranged from 0.05g for Dermaptera to 155.5g for *Thomomys bottae*. The total weight for the three invertebrate orders was estimated at 4,489g, representing 17.47% of total biomass, while the total weight of the rodents was estimated at 21,210g, or 82.53% of total biomass (Figure 4).

Some differences were observed in prey species found in pellets versus prey remains (Table 1). Four invertebrate Orders were only detected in prey remains, although the quantities were small. Dermaptera, although the most numerically common prey species, were only found in pellets. While two vertebrate species were only found in pellets, and another two were only found as prey remains.

Table 1

Number of Prey Items & Prey Remains for all Sites

Prey Species	Number of Prey from Pellets	Number of Prey from Remains	Total	% Total of Pellets & Remains
Invertebrates				
Dermaptera	3513	0	3513	48.61
Coleoptera	1985	4	1989	27.52
Orthoptera	1141	13	1154	15.97
Stylommatophora	53	2	55	0.76
Larvae unidentified	42	1	43	0.59
Isopoda	15	2	17	0.24
Arachnid	8	1	9	0.12
Opisthoptera	0	3	3	0.04
Hymenoptera	0	4	4	0.06
Lepidoptera	0	1	1	0.01
Decapoda	0	1	1	0.01
Sub-total Invertebrates	**6757**	**32**	**6789**	**93.94**
Vertebrates				
Mammals				
Microtus	131	4	135	1.87
Mus	77	1	78	1.08
Thomomys	74	4	78	1.08
Reithrodontomys	27	1	28	0.39
Peromyscus	3	0	3	0.04
Spermophilus	1	15	16	0.22
Lepus	0	4	4	0.06
Unidentified Rodents	44	7	51	0.71
Sub-total Mammals	**357**	**36**	**393**	**5.44**
Other Vertebrates				
Lizard	23	0	23	0.32
Unidentified Birds	7	13	20	0.28
Frog	0	2	2	0.03
Sub-total Vertebrates	**387**	**51**	**438**	**6.07**
TOTALS	**7144**	**83**	**7227**	**100**

Table 2

Estimated Biomass & Percent Biomass from Key Prey Species

Prey Species	Estimated Mean Prey Biomass (g)	Estimated Total Biomass (g)	Estimated % Biomass
Invertebrates			
Dermaptera	0.05	176.00	0.68
Coleoptera	0.2445	486.00	1.89
Orthoptera	3.316	3827.00	14.89
Sub-total Invertebrates		**4489.00**	**17.470**
Vertebrates			
Microtus	53.5	7223.00	28.1
Mus	18.0	1404.00	5.46
Thomomys	155.5	12129.00	47.2
Reithrodontomys	11.5	322.00	1.25
Peromyscus	44.0	132.00	0.51
Sub-total Mammals		**21210.00**	**82.53**
TOTALS		**25699.00**	**100**

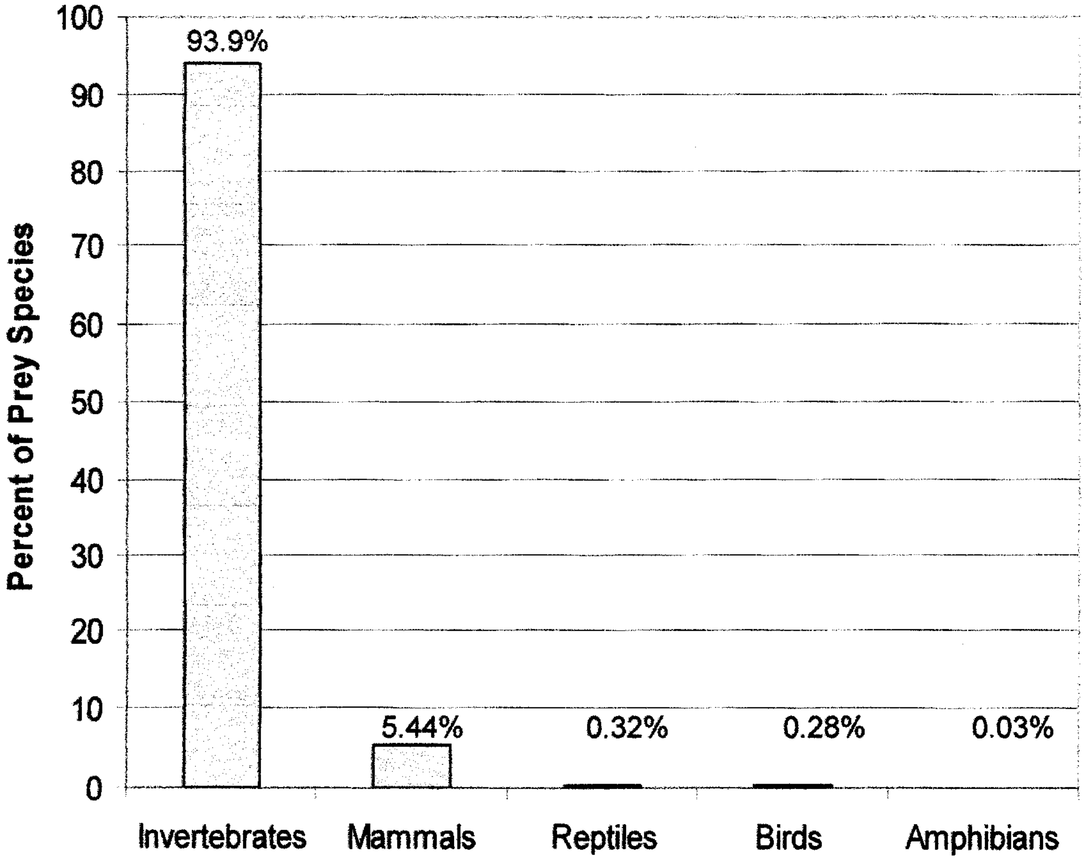

Figure 3: Percent of Prey Species from Pellets & Remains (from Table 1)

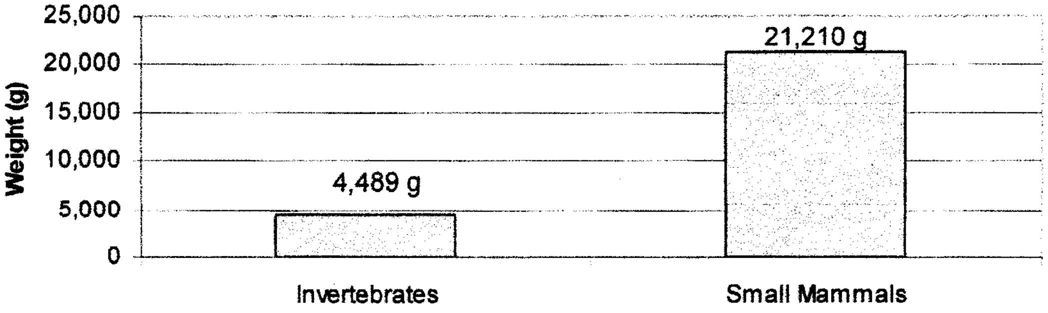

Figure 4: Estimated Biomass Comparison of Invertebrates versus Small Mammals

(from Table 2)

DIETARY DIFFERENCES

Sites and Year

The number of prey individuals from pellets and remains, and the percent representation for each of the five sites, is displayed in Table 3.

Microtus californicus were the most common vertebrate species preyed upon at all sites with the exception of Mission College, where none were found. *Thomomys bottae* were absent from Sunnyvale Park, *Peromyscus maniculatus* were only present at Shoreline Park, and Tasman Drive, *Lepus californicus* were only present at Shoreline Park, *Spermophilus beecheyi* were absent from Mission College and Sunnyvale Park, while *Sceloporus occidentalis* and *Hyla regilla* were present only at Moffett Airfield and Shoreline Park.

All burrows (N = 92) at the five sites were compared to each other over the 2-year period. A two-way ANOVA showed no major differences by year, but revealed a significant difference in the invertebrate richness driven by Moffett versus the other four sites ($F_{(1, 82)} = 3.027$, $p = 0.022$) (Table 4) and (Figure 5).

Table 3

Number of Individuals by Species and Percent of all Prey Items by Site

	Mission		Moffett		Shoreline		Sunnyvale		Tasman	
	Number of Individuals	%	Number of Individuals	%	Number of Individuals	%	Number of Individuals	%	Number of Individuals	%
Coleoptera	103	26.41	750	25.56	581	32.55	166	23.58	389	27.51
Orthoptera	107	27.44	324	11.04	463	25.94	131	18.61	129	9.12
Dermaptera	151	38.72	1663	56.68	504	28.24	383	54.40	812	57.43
Larvae	0	0.00	29	0.99	9	0.50	1	0.14	4	0.28
Isopoda	1	0.26	9	0.31	4	0.22	0	0.00	3	0.21
Lizard	0	0.00	13	0.44	10	0.56	0	0.00	0	0.00
Bird	2	0.51	7	0.24	9	0.50	1	0.14	1	0.07
Araneae	0	0.00	2	0.07	6	0.34	1	0.14	0	0.00
Stylommatophora	2	0.51	23	0.78	17	0.95	9	1.28	4	0.28
UnID rodents	2	0.51	9	0.27	31	1.57	4	0.43	5	0.35
Microtus	0	0.00	52	1.77	60	3.36	4	0.57	19	1.34
Mus	7	1.79	10	0.34	42	2.35	3	0.43	16	1.13
Reithrodontomys	3	0.77	7	0.24	7	0.39	1	0.14	10	0.71
Peromyscus	0	0.00	0	0.00	2	0.11	0	0.00	1	0.07
Thomomys	11	2.82	29	0.99	25	1.40	0	0.00	13	0.92
Spermophilus	0	0.00	2	0.07	9	0.50	0	0.00	5	0.35
Lepus	0	0.00	0	0.00	4	0.22	0	0.00	0	0.00
Frog	0	0.00	1	0.03	1	0.06	0	0.00	0	0.00
Hymenoptera	0	0.00	3	0.10	1	0.06	0	0.00	0	0.00

Opisthopora	1	0.26	0	0.00	0	0.00	0	0.00	2	0.14
Lepidoptera	0	0.00	1	0.03	0	0.00	0	0.00	0	0.00
Decapoda	0	0.00	0	0.00	0	0.00	0	0.00	1	0.07
Totals	390	100	2934	100	1785	100	704	100	1414	100

Table 4

ANOVA Results for Dietary Differences among Sites and Year

VARIABLE	SITE	YEAR	SITE*YEAR
VERTEBRATE RICHNESS	($F_{(4,82)} = 0.977$, $p = 0.425$)	($F_{(1,82)} = 0.591$, $p = 0.444$)	($F_{(4,82)} = 0.478$, $p = 0.752$)
INVERTEBRATE RICHNESS	**($F_{(4,82)} = 3.027$, $p = 0.022$)**	($F_{(1,82)} = 0.020$, $p = 0.889$)	($F_{(4,82)} = 0.154$, $p = 0.961$)
VERTEBRATE MASS	($F_{(4,82)} = 0.999$, $p = 0.413$	($F_{(1,82)} = 2.160$, $p = 0.145$	($F_{(4,82)} = 0.537$, $p = 0.709$
INVERTEBRATE MASS	($F_{(4,82)} = 0.329$, $p = 0.858$	($F_{(4,82)} = 0.166$, $p = 0.685$	($F_{(4,82)} = 0.058$, $p = 0.994$

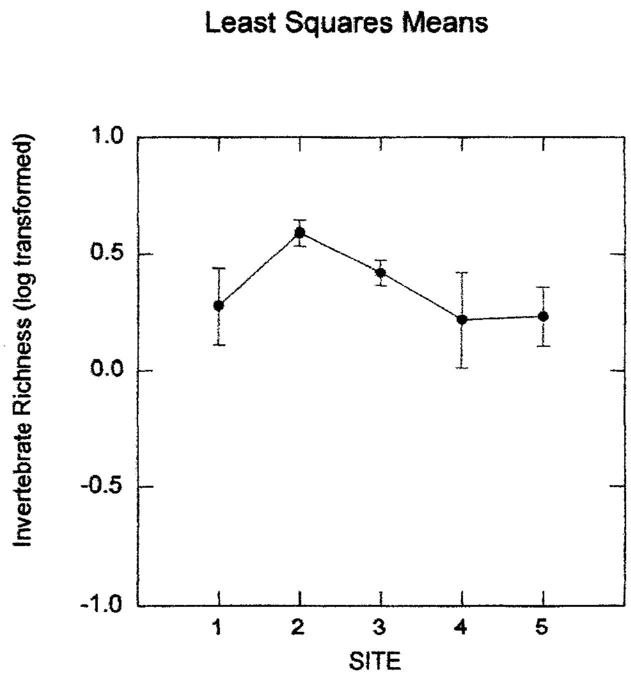

Figure 5: ANOVA Results for Invertebrate Richness among Sites

SITES: 1 = Mission College (N = 4), 2 = Moffett Airfield (N = 37), 3 = Shoreline Park (N = 41), 4 = Sunnyvale Park (N = 3), & 5 = Tasman Drive (N = 7).

Urban versus Parkland Sites and Year

Burrows (N = 26) at the two parkland sites (Shoreline Park and Sunnyvale Park) were compared to burrows (N = 39) at the 3 urban sites (Moffett Airfield, Mission College and Tasman Drive) during both breeding seasons. A two-way ANOVA showed no significant differences between parkland and urban sites for invertebrate or vertebrate species numbers or richness. There was a difference in vertebrate biomass between 2005 and 2006 ($F_{(1, 88)} = 9.350$, $p = 0.003$), driven by urban sites versus parkland sites (Table 5) (Figure 6); specifically the mass of vertebrates in pellets was significantly greater at urban sites in year 1 than in year 2 (Figure 7).

Table 5

ANOVA results for Dietary Difference between Urban versus Parkland Sites and Year

VARIABLE	YEAR	SITE TYPE	YEAR*SITE TYPE
VERTEBRATE RICHNESS	($F_{(1, 882)} = 0.029$, $p = 0.865$)	($F_{(1, 88)} = 1.764$, $p = 0.188$)	($F_{(1,88)} = 1.347$, $p = 0.249$)
INVERTEBRATE RICHNESS	($F_{(1, 88)} = 0.205$, $p = 0.652$)	($F_{(1,88)} = 1.988$, $p = 0.162$)	($F_{(1,88)} = 0.130$, $p = 0.719$)
VERTEBRATE MASS	**($F_{(1,88)} = 9.350$, $p = 0.003$)**	($F_{(1,88)} = 1.023$, $p = 0.315$)	($F_{(1, 88)} = 1.960$, $p = 0.165$)
INVERTEBRATE MASS	($F_{(1, 88)} = 0.052$, $p = 0.819$)	($F_{(1, 88)} = 0.576$, $p = 0.450$)	($F_{(1, 88)} = 0.021$, $p = 0.886$)

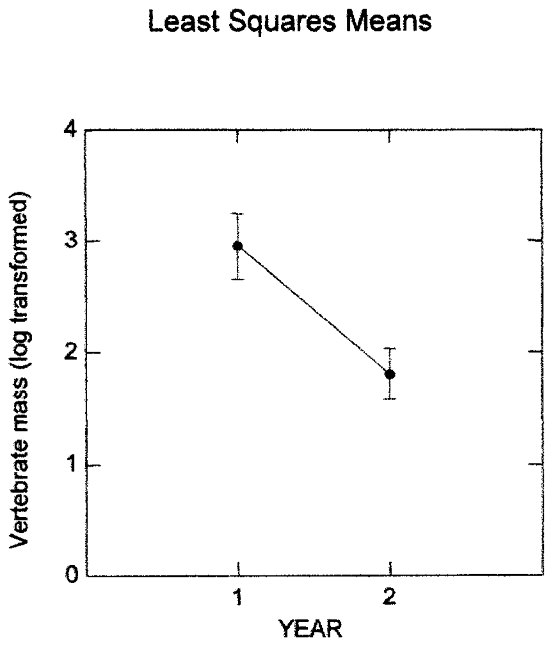

Figure 6: Vertebrate Mass between Years at Urban and Parkland Sites

1 = 2005 (N = 19), 2 = 2006 (N = 29)

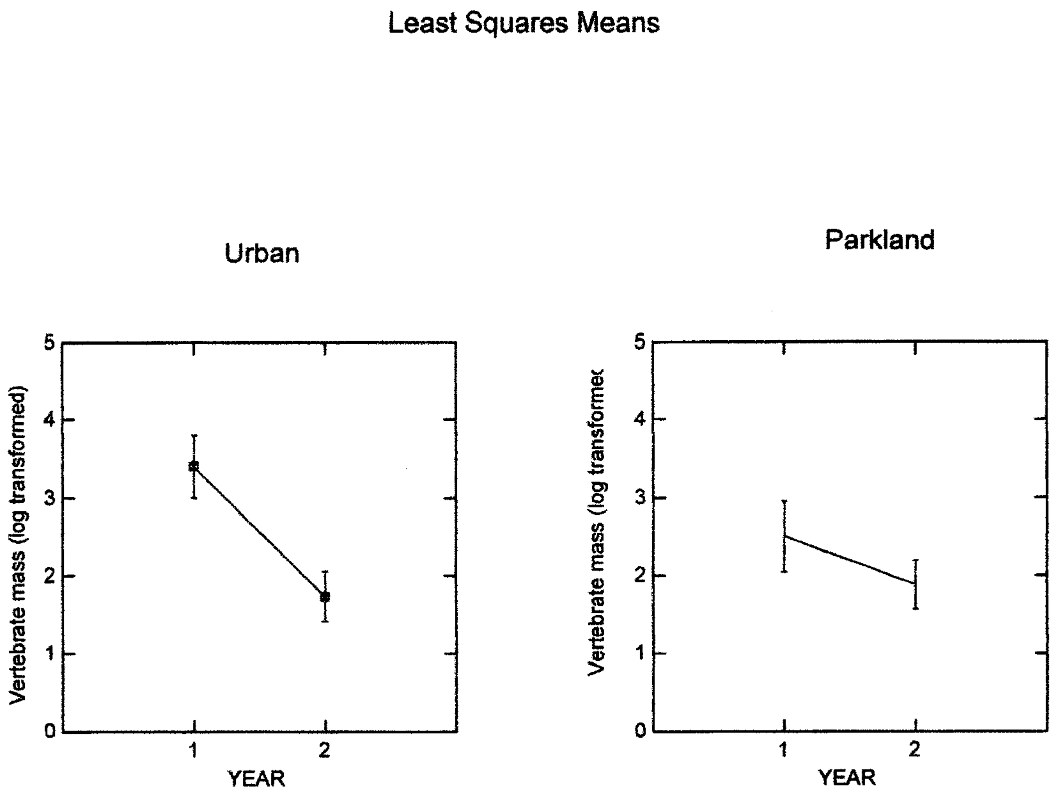

Figure 7: Vertebrate Mass between Urban versus Parkland Sites and Year

Urban Sites: 1 = 2005 (N = 19), 2 = 2006 (N = 29)

Parkland Sites: 1 = 2005 (N = 14), 2 = 2006 (N = 30)

Breeding and Non-breeding Season

Prey in pellets from burrows in the breeding seasons from April to August (N = 65) were compared to pellet results at burrows during one non-breeding season September 2005 to March 2006 (N = 27). Figure 8 shows the percent of vertebrate and invertebrate biomass in the breeding season was much greater than in the non-breeding season. And, percent of Orthoptera was much greater for the breeding season versus non-breeding season (Figure 9). Large differences in the percent ratio of *Thomomys* and *Microtus* was found for breeding versus non-breeding season (Figure 10).

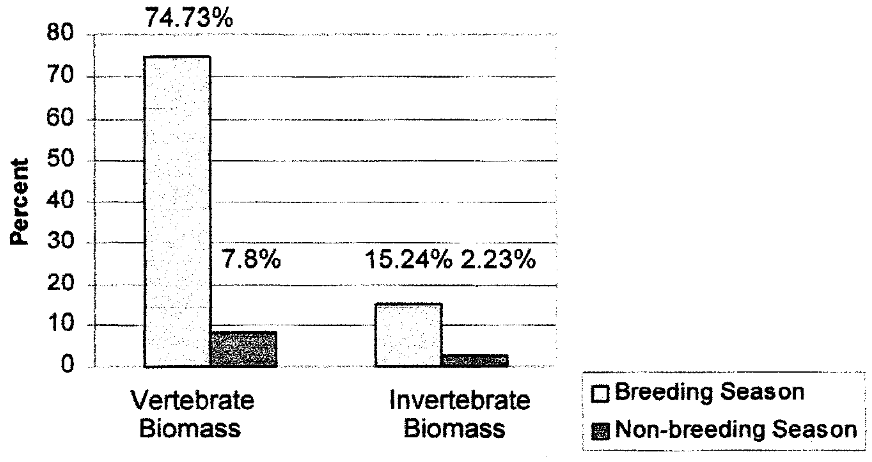

Figure 8: Percent of Vertebrate and Invertebrates by Biomass for Breeding versus Non-breeding Seasons

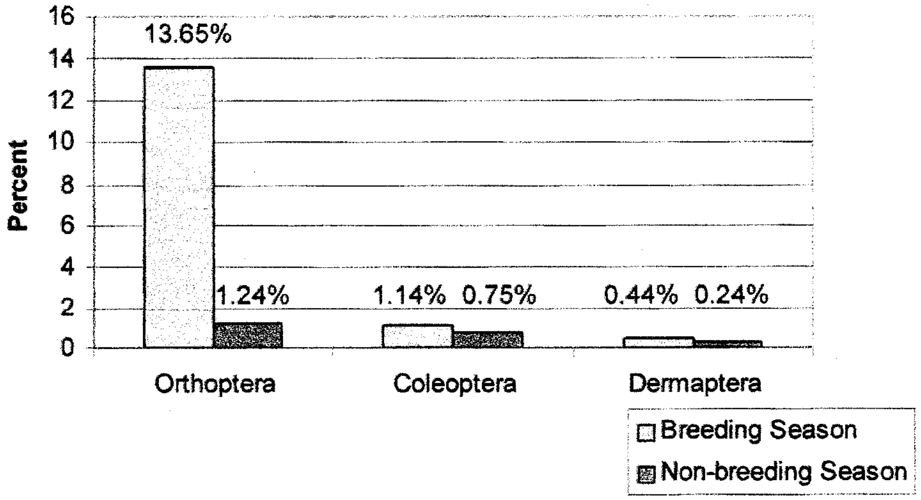

Figure 9: Percent of Invertebrate Orders for Breeding versus Non-breeding Season

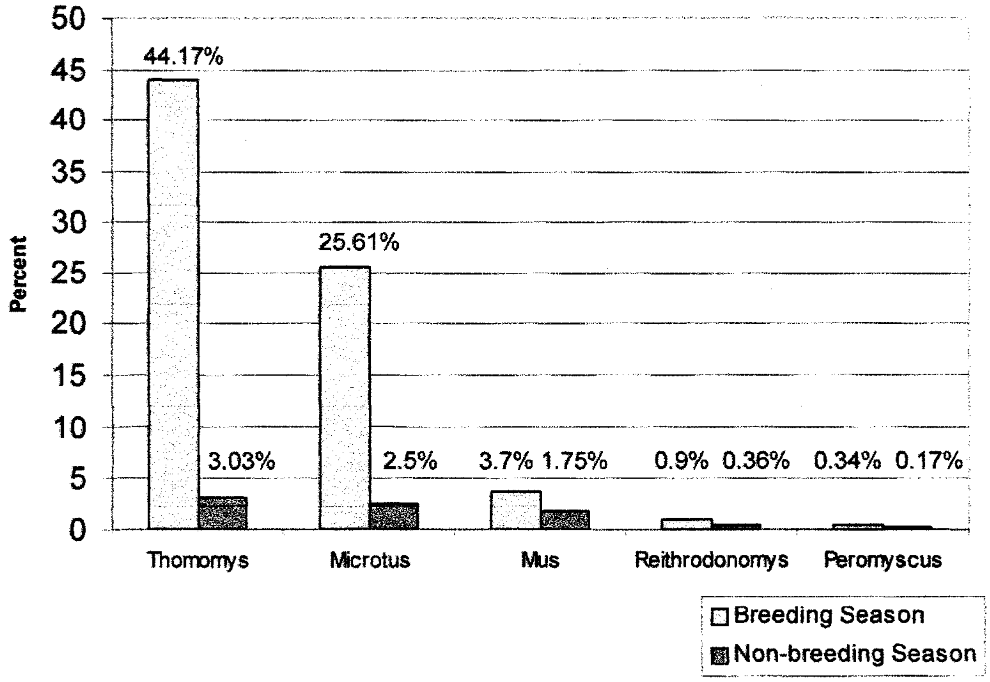

Figure 10: Percent of Vertebrates for Breeding versus Non-breeding Season

Two-way ANOVAS revealed significant differences for all variables for the breeding season versus the non-breeding season (Table 6), with the breeding season always exceeding the non-breeding season numbers.

Table 6

AVOVA results for Dietary Difference between Breeding

and Non-breeding Season and Year

VARIABLE	YEAR	SEASON	YEAR*SEASON
NUMBER OF VERTEBRATES	($F_{(1, 88)} = 0.000$, $p = 0.983$)	**($F_{(1, 88)} = 21.804$, $p = 0.000$)**	($F_{(1, 88)} = 0.316$, $p = 0.575$)
VERTEBRATE RICHNESS	($F_{(1, 88)} = 0.049$, $p = 0.826$)	**($F_{(1, 88)} = 11.888$, $p = 0.001$)**	($F_{(1,88)} = 1.380$, $p = 0.243$)
INVERTEBRATE RICHNESS	($F_{(1, 88)} = 0.150$, $p = 0.700$)	**($F_{(1,88)} = 4.826$, $p = 0.031$)**	($F_{(1,88)} = 0.040$, $p = 0.842$)
VERTEBRATE MASS	($F_{(1,88)} = 1.983$, $p = 0.163$)	**($F_{(1,88)} = 4.900$, $p = 0.029$)**	($F_{(1, 88)} = 0.043$, $p = 0.836$)
INVERTEBRATE MASS	($F_{(1, 88)} = 1.248$, $p = 0.267$)	**($F_{(1, 88)} = 25.847$, $p = 0.000$)**	($F_{(1, 88)} = 1.633$, $p = 0.205$)

Pairs with and without Chicks by Year

During the 2005 breeding season, a total of 6 pairs produced 23 chicks: Moffett (N = 2) produced 8 chicks, Shoreline (N = 2) produced 9 chicks, and Tasman (N= 2) produced 6 chicks. A total of 15 chicks were produced during 2006 by 6 pairs: Mission (N = 1) produced 2 chicks, Moffett (N = 1) produced 1 chick, Shoreline (N = 3) produced 8 chicks and Tasman (N = 1) produced 2 chicks.

A t-test was used to analyze the number of chicks per pair between the 2005 and 2006 breeding seasons. The number of chicks per successful nest was greater in 2005 (mean = 3.83, N = 6) than in 2006 (mean = 2.50, N = 6), but not significantly so (t = 1.372, df = 9.0, p = 0.200).

A two-way ANOVAS for diet of pairs with and without chicks showed that nests that produced chicks had a lower diversity of invertebrates in pellets (Figure 11), but a greater biomass of vertebrates (estimated mean biomass/sample of vertebrates for pairs with chicks was 49.42g), compared to nests that did not produce chicks (estimated mean biomass/sample of vertebrates for pairs without chicks was 36.53g) (Table 7) and (Figure 12).

Table 7

ANOVA Results for Dietary Differences between Pairs with/without Chicks and Year

VARIABLE	YEAR	CHICKS	YEAR*CHICKS
NUMBER OF VERTEBRATES	($F_{(1, 61)} = 0.497$, $p = 0.483$)	($F_{(1, 61)} = 407$, $p = 0.526$)	($F_{(1, 61)} = 0.066$, $p = 0.798$)
VERTEBRATE RICHNESS	($F_{(1, 61)} = 1.942$, $p = 0.169$)	($F_{(1, 61)} = 0.346$, $p = 0.558$)	($F_{(1,61)} = 067$, $p = 0.797$)
INVERTEBRATE RICHNESS	($F_{(1, 61)} = 0.192$, $p = 0.663$)	**($F_{(1,61)} = 5.186$, $p = 0.026$)**	($F_{(1,61)} = 0.264$, $p = 0.609$)
VERTEBRATE MASS	($F_{(1,61)} = 0.675$, $p = 0.415$)	**($F_{(1,61)} = 4.257$, $p = 0.043$)**	($F_{(1, 61)} = 1.231$, $p = 0.272$)
INVERTEBRATE MASS	**($F_{(1, 61)} = 7.925$, $p = 0.007$)**	($F_{(1, 61)} = 1.592$, $p = 0.212$)	($F_{(1, 61)} = 0.971$, $p = 0.328$)

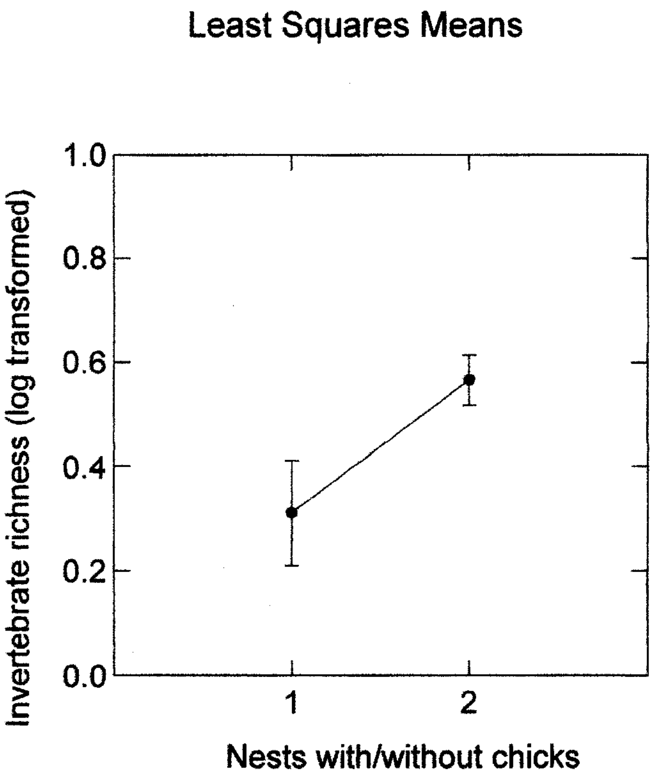

Figure 11: Invertebrate Richness among Pairs with/without Chicks

1 = Nests with chicks (N = 12)

2 = Nests without chicks (N = 53)

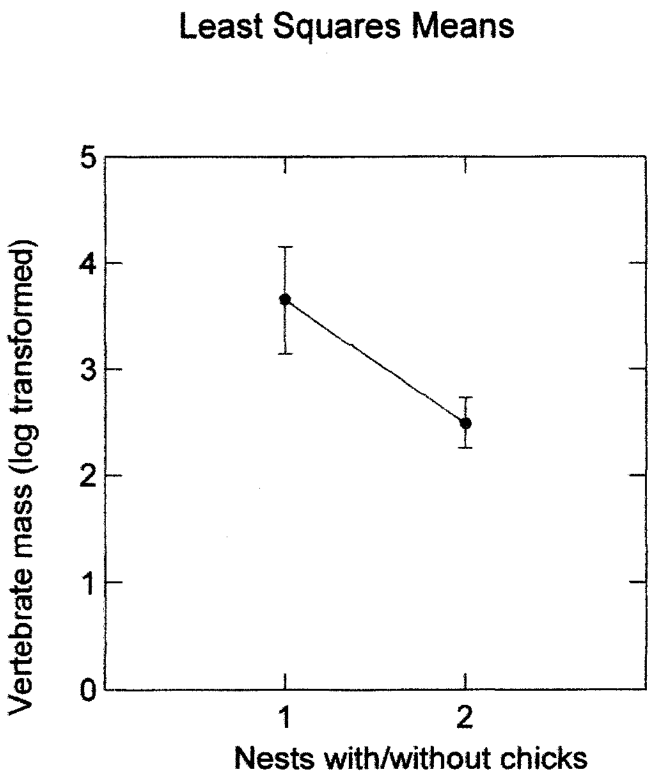

Figure 12: Vertebrate Mass among Pairs with/without Chicks

1 = Nests with chicks (N = 12)

2 = Nests without chicks (N = 53)

Irrigated versus Non-irrigated Sites and Year

Burrows located on irrigated areas (N = 19) were analyzed for a dietary difference versus burrows on non-irrigated areas (N = 46). Two-way ANOVAS for year and irrigated/non-irrigated sites showed that neither habitat site provided significantly greater invertebrate or vertebrate resources than the other. The number and richness of vertebrates was up in year 2 at irrigated sites, but vertebrate mass was down in year 2 at non-irrigated sites. Invertebrate mass and richness was up in year 2 driven by non-irrigated sites (Table 8) (Figures 13 & 14).

Table 8

Dietary Difference between Irrigated versus Non-irrigated Areas

VARIABLE	YEAR	IRRIGATED	YEAR*IRRIGATED
NUMBER OF VERTEBRATES	(F$_{(1, 61)}$ = 1.932, p = 0.170)	(F$_{(1, 61)}$ = 164, p = 0.687)	(F$_{(1, 61)}$ = 3.701, p = 0.059)
VERTEBRATE RICHNESS	**(F$_{(1, 61)}$ = 4.643, p = 0.035)**	(F$_{(1, 61)}$ = 0.077, p = 0.783)	(F$_{(1,61)}$ = 2.521, p = 0.118)
INVERTEBRATE RICHNESS	(F$_{(1, 61)}$ = 0.190, p = 0.664)	**(F$_{(1,61)}$ = 3.989, p = 0.050)**	(F$_{(1,61)}$ = 0.001, p = 0.978)
VERTEBRATE MASS	(F$_{(1,61)}$ = 1.361, p = 0.248)	(F$_{(1,61)}$ = 1.212, p = 0.275)	(F$_{(1, 61)}$ = 3.174, p = 0.080)
INVERTEBRATE MASS	**(F$_{(1, 61)}$ = 4.575, p = 0.036)**	(F$_{(1, 61)}$ = 1.123, p = 0.293)	(F$_{(1, 61)}$ = 1.128, p = 0.292)

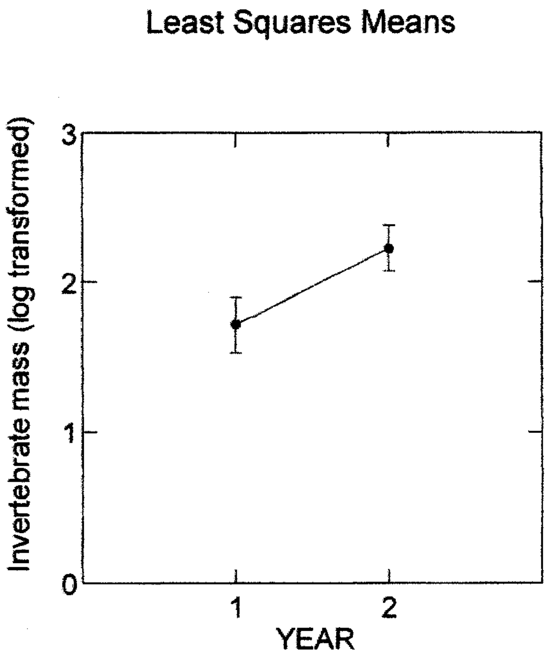

Figure 13: Invertebrate Mass between Irrigated versus Non-irrigated Areas and Year

1 = 2005 (N = 23), 2 = 2006 (N = 23)

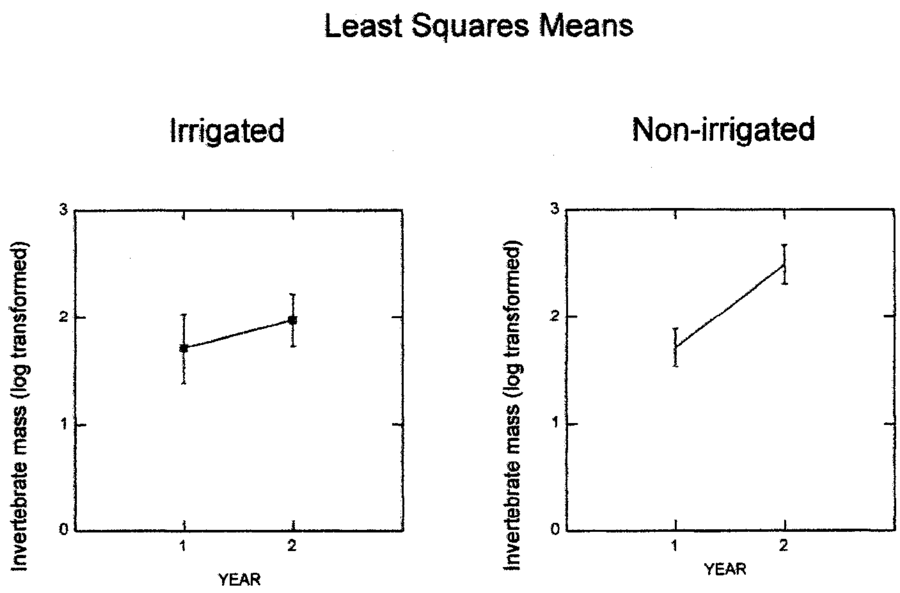

Figure 14: Invertebrate Mass and Year

Irrigated Sites: 1 = 2005 (N = 7), 2 = 2006 (N = 12)

Non-irrigated sites: 1 = 2005 (N = 23), 2 = 2006 (N = 23)

Prey Abundance between Long versus Short Vegetation

Small Mammal Trapping

A total of 1,060 Sherman live traps were placed at the five sites during 2005, and 600 traps during 2006. Two *Mus musculus* were captured at Shoreline Park in 2005, and one European Starling (*Sturnus vulgaris)* was captured at Sunnyvale Park in 2005. No species were caught during trapping in 2006.

Invertebrate Trapping

Dermaptera were poorly represented in the trapping results, whereas Arachnids were the most numerous Order captured (Table 9).

Table 9

Results of Pitfall and Sweep Net Trapping

	Subtotals				% of Total Captures			
	Pitfall Traps		Sweep Nets		Pitfall Traps		Sweep Nets	
	Long Grass	Short Grass		Total	Long Grass	Short Grass		Total (300%)
Dermaptera	3	2	0	5	0.44	0.30	0.00	0.74
Coleoptera	18	40	29	87	2.65	6.07	27.10	35.82
Orthoptera	11	3	24	38	1.62	0.46	22.43	24.51
Stylommatophoro	66	19	12	97	9.69	2.88	11.21	23.78
Larvae unidentified	14	19	18	51	2.05	2.88	16.82	21.75
Isopoda	29	50	1	80	4.26	7.59	0.93	12.78
Arachnid	462	464	5	931	67.84	70.41	4.67	142.92
Opisthoptera	3	3	0	6	0.44	0.46	0.00	0.90
Hymenoptera	46	50	4	100	6.75	7.58	3.74	18.07
Lepidoptera	1	0	0	1	0.15	0.00	0.00	0.15
Decapoda	0	0	0	0	0.00	0.00	0.00	0.00
Diptera	25	4	0	29	3.67	0.61	0.00	4.28
Centipede	1	1	0	2	0.15	0.15	0.00	0.30
Nematocera	1	4	0	5	0.15	0.61	0.00	0.76
Lizard	1	0	0	1	0.15	0.00	0.00	0.15
Hemiptera	0	0	14	14	0.00	0.00	13.08	13.08

There was no significant difference in the number of invertebrates captured via pitfall traps in long vegetation (mean = 77.500, N = 10) (t = 0.171, df = 16.6, p = 0.867) versus short vegetation (mean = 73.400, N = 10).

There was no significant difference in the number of taxa captured via pitfall traps in long vegetation (mean = 7.200, N = 10)(t = 0.381, df = 16.7, p = 0.708) versus short vegetation (mean = 6.800, N = 10).

A one-way analysis of variance showed significantly more invertebrates were caught during trapping in 2005 ($F_{(1, 16)} = 9.454$, p = 0.007) versus 2006 in pitfall traps (Figure 15).

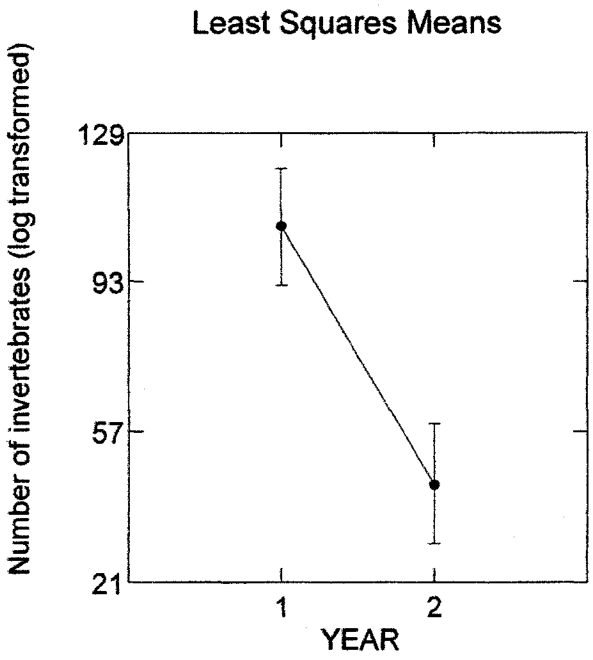

Figure 15: Number of Invertebrates in Pitfall Traps by Year

1 = 2005 (N = 10), 2 = 2006 (N = 10)

Comparison of Present Study Data to Pre-study Data, and Other Locations

Data on the diet of burrowing owls collected during the 2005-2006 breeding seasons were compared to pre-study data from 1999, 2000 and 2001 collected during the Trulio and Chromczak study as analyzed by Rosenberg. For 1999, 2000 and 2001, invertebrate data was only recorded as presence or absence of invertebrate Orders. Three Orders Hemiptera, Chilopoda and scorpion from the order Araneae were recorded in the pre-study data that were not present for the breeding seasons of 2005 and 2006. The present diet study included four Orders not found in the earlier data, although the number of individuals was relatively small except for the last order; these include: Hymenoptera (3 individuals), Opisthopora (3 individuals), Lepidoptera (1 individual), and Stylommatophora (46 individuals).

The difference in vertebrate richness between the earlier and present data was also very small. For 1999-2001, three species were present that were absent from the present study and include the following: *Dipodomys* (4 individuals), *Perognathus* (1 individual) and *Rattus* (6 individuals). The present study had one species *Lepus* (2 individuals) that was not present previously. Figure 16 shows the general trend in biomass/sample of vertebrates for the three breeding seasons of 1999-2001 and 2005-2006. *Microtus* biomass/sample is declining (from a high of 6.88g in 1999 to a low of 2.75g in 2006), while *Thomomys* biomass/sample is increasing (from a low of 1.69g in 1999 to a high of 6.38g in 2006); the three mice species were relatively constant.

The frequency of vertebrates versus invertebrates for this study was comparable to several studies in Washington, Oregon and Idaho, while the results differ from studies in Southern California, Colorado and Montana (Figure 17).

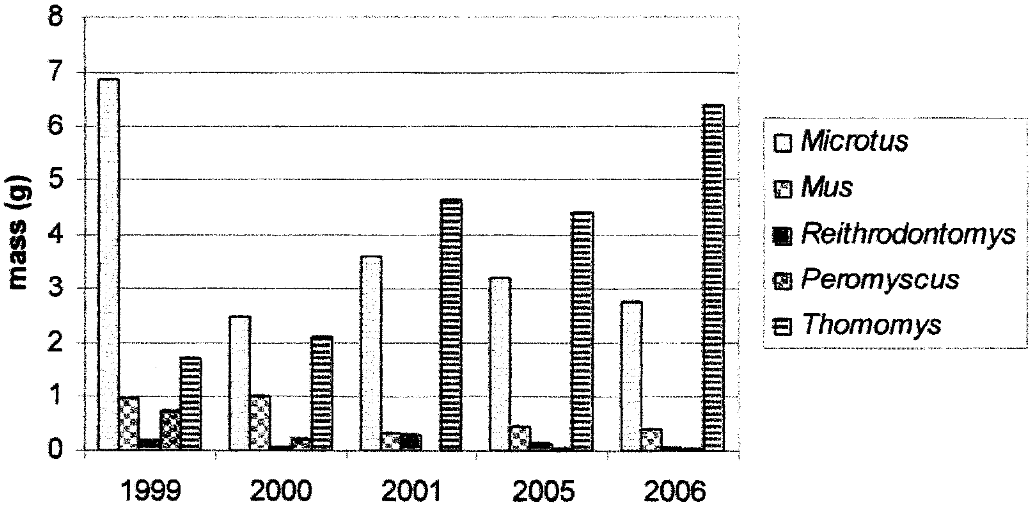

Figure 16: Pre-Study and Present Study Biomass per Sample of Vertebrates

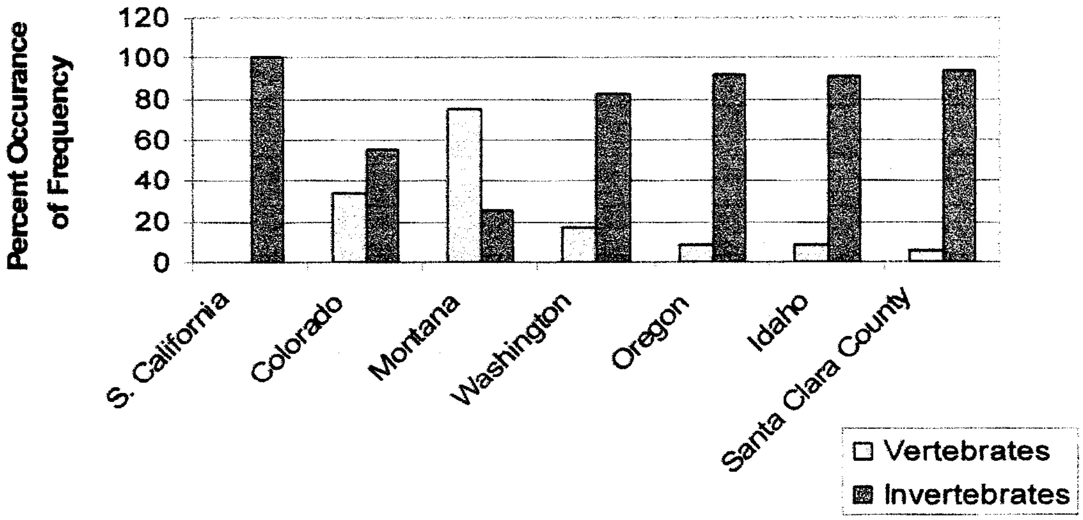

Figure 17: Sample Diet Results of Burrowing Owls Nationwide

Source: S. California – York, Rosenberg and Sturm, 2001
Colorado – Plumpton and Lutz, 1993
Montana – Holt. Norton and Atkinson, 2001
Washington and Oregon – Green et al., 1992
Idaho – Gleason and Craig, 1979

CONCLUSION

Overall Diet of Burrowing Owls

The results of this study were similar to some others conducted on the food habits of burrowing owls. The invertebrate to vertebrate ratio of this study, 94:6%, generally agrees with the 91:8 ratio found by Gleason and Craig (1979) in southeastern Idaho, and the 90:10 ratio found by Green, Fitzner and Anthony (1992) who studied owls in Oregon and Washington. However, it differs from Holt, Norton and Atkinson (2001) who studied owls in south-central Montana, Plumpton and Lutz (1993) who studied owls in Colorado, and York, Rosenberg and Sturm (2001) who studied owls in the Imperial Valley of California. Hence, the prey base ratios of urban Santa Clara County are comparable to some more natural areas and differ from others, confirming that diet is site specific, although species diversity was not always similar at the sites.

Earwigs (*Forficula auricularia*) (Order Dermaptera) were numerically dominant in the diet of Santa Clara County owls, as they were for Coulombe (1971), who studied owls in the Imperial Valley of California, and Morgan, Cannings and Guppy (1993), who studied owls on southern Vancover Island. However, although insects were the most numerous prey, vertebrates especially rodents, dominated the diet by biomass. Although they dominated by weight, rodents may be a factor limiting reproductive success in Santa Clara County. For example, burrowing owls in Canada, supplemented with mice in their diet, laid more eggs and fledged heavier chicks and more young than unsupplemented broods (Wellicome 1994). The growth of last-hatched owlets was greater than owlets not supplemented, and female body condition was positively affected with supplemental food (Haley 2002). In Santa Clara County, nests that produced chicks were associated with pellets that had significantly more biomass of vertebrates than those that did not produce chicks. This suggests more vertebrates may improve overall nest success.

Pellets were a good indicator of vertebrate species consumed by the owls; however, insects were probably underrepresented in this study, due to the difficulty in identifying and quantifying insect remains (Coulombe 1971, Holt, Norton and Atkinson

2001). Several invertebrate Orders were only found as prey remains near burrows such as Opisthoptera, Hymenoptera, Lepidoptera and Decapoda, suggesting that these prey may not be easily identifiable in pellets. In addition, *Lepus californicus* and *Spermophilus beecheyi* (apart from 1 juvenile) occurred only as partial remains suggesting that the owls consumed these prey as carrion.

Owls are known to hunt both day and night (Thomsen 1971, Haug and Oliphant 1989) and nocturnal prey in Santa Clara County included the Order Dermaptera, *Mus musculus*, and *Thomomys bottae*; diurnal prey included birds, lizards and the Order Orthoptera. The large prey base of these owls, 11 invertebrate orders, 7 mammal species, birds, frogs and lizards, suggests that the owls are generalists in their feeding preferences and are opportunistic feeders as they switched their diet upon prey availability (Coulombe 1971, Green, Fitzner and Anthony 1992, Plumpton and Lutz 1993). Coulombe (1971) suggests that earwigs and crickets, which prefer the microclimate of burrows, may possibly provide an abundant food supply. Other prey items observed at burrow entrances occupied by owls or squirrels during this study included lizards, spiders, earwigs, pillbugs, beetles, snails, slugs, mice, and flies, all prey items that were found in pellets, apart from slugs and flies. Thus, the diet of burrowing owls in urban Santa Clara County is quite comparable to owls living in more natural settings such as Idaho, Oregon and Washington.

The sample size of rodents and invertebrates that were present/absent in previous years and in the present study (apart from *Microtus, Thomomys, Mus, Peromyscus, Reithrondonomys,* Dermaptera, Coleoptera and Orthoptera) are so small that few conclusions can be firmly drawn with respect to yearly variations. Biomass per sample did not seem to change much from year to year for the present and the previous studies. However, from the long term data 1999-2001 in Santa Clara County, *Microtus californicus* biomass per sample was at a maximum peak in 1999 and then showed a gradual decline. *Microtus* populations regularly exhibit population irruptions, whereby the population reaches an extremely high density only to collapse in following years (Batzli and Pitelka 1970). These irruptions generally occur every 3-4 years (Garsd and Howard 1981). It is possible that 1999 was an irruption year for *Microtus* followed by two years of a population collapse. No data were collected in 2002-2004, however, it is possible that one of these years was also an irruption year followed by a population collapse in 2005 and 2006. Only a long term study of *Microtus* demographics would confirm this population cycle. Such a study of *Microtus* population change and owl reproductive success would be most valuable.

Thomomys on the other hand showed a gradual increase in biomass per sample over the same time period. *Thomomys* also experience periodic population fluctuations (Aldous 1957) and these fluctuations often occur as a result of an extended abundance of green forage in summer which is directly correlated with precipitation levels (Dixon 1929). Precipitation levels during 1999 (29.32cm) and 2000 (24.35cm) were below mean precipitation (36.37cm) levels for Santa Clara County. While 2001, 2005 and 2006 were above mean precipitations levels 43.67cm, 57.0cm and 42.2cm. Other habitat changes conducive to *Thomomys* might also be driving this trend such as disturbed areas with an abundance of forbs and grasses and moist, friable soils (Jones and Baxter 2004).

Several studies have confirmed the importance of rodents in the diet of burrowing owls, and the increased rates of breeding success (Wellicome 1994, York, Rosenberg and Sturm 2001, Haley 2002, Ronan 2002,York, Rosenberg and Sturm 2001). Since, rodent habitat requirements do vary from species to species (Ostfeld and Klosterman 1985), habitat heterogeneity is important to ensuring a diverse rodent population. Studies have found fragmented habitats in general, support fewer species of rodents (Bolger et al. 1995), while unmowed habitat has the highest density of small mammals (Adams 1984, Jones, Bock and Bock 2003). *Microtus* prefer grasslands with *Bromus*, *Lolium* and *Avena* grass species (Batzli and Pitelka 1970), while *Peromyscus* and *Reithrodontomys* only showed a preference for *Avena* (Batzli 1967). Interestingly, *Reithrodontomys* abundance severely declines with *Microtus* population irruptions, and increases during periods of *Microtus* declines (Heske, Ostfeld and Lidicker 1983). *Thomomys* do best in habitats with moist, friable soils, and disturbed areas where grasses and forbs are abundant (Jones and Baxter 2004).

Factors in Pellet Content Differences

The only major difference between sites was invertebrate richness, which was higher at Moffett Airfield compared to the other four sites, with Shoreline Park second. Moffett Airfield is the largest of the five sites in area and covers 683 ha, with the next largest site Shoreline Park (300 ha), both of which dwarf the other parks in size. Invertebrate richness can be expected to increase with patch size. The three smaller sites (Sunnyvale Park (70 ha), Mission College (65.5 ha), and Tasman Drive (62 ha)) are very fragmented, especially at Mission College and Tasman Drive where development has severely reduced owl habitat. Bolger et al. (1999) found a decline in arthropod diversity and abundance over time in fragmented urban habitats in California. They also found that Dermaptera increased in abundance in smaller and older fragments. The higher species diversity at larger sites and the fact that Dermaptera were the most common prey species numerically in the owl's diet of this study, suggests the owls are foraging within the sites where nests are found (Haug, Millsap and Martell 1993). However, these conditions can be improved as irrigation and a diversity of vegetation in urban areas can increase invertebrate abundance, thus increasing owl numbers that feed on the invertebrates (Wesemann and Rowe 1987, Millsap and Bear 1999).

A limitation of this study that makes comparisons difficult was the number of burrows at the different sites. Moffett (N = 37) and Shoreline (N = 41) have large managed populations, while Mission (N = 4), and Tasman (N = 7) are developed sites where nests have been destroyed over time (Trulio and Chromczak in press). Sunnyvale (N = 3) is managed for owls, but there are few pairs there. Comparing sample sizes for diet analyzes places Mission College, Sunnyvale Park and Tasman Drive at a disadvantage.

Microtus californicus were absent from the diet at Mission College, yet they were the most numerous vertebrate prey species at the other four sites. Mission College is the most isolated and fragmented of all five sites and the entire campus is mowed several times per year with no tall vegetation present at the site. Bolger et al., (1995) found that over half of the urban fragmented habitats they assessed supported fewer populations of native rodents.

Thomomys bottae were absent from the diet at Sunnyvale Park. The burrow locations at this site were not actually in the park itself but were located within the confines of the water treatment plant, which is located adjacent to the park. This site is significantly commercial and consists of several buildings, numerous water treatment tanks, and two large treatment ponds where solid waste is dried naturally by the sun, and is surrounded by dikes frequented by California ground squirrels, and two burrowing owls. The very hard ground may limit *Thomomys* numbers. These owls were observed hunting within the treatment plant directly adjacent to their burrows where no gopher activity were observed (mounds).

It is expected that parkland might have a better prey base than urban sites, but this study did not find that result. There was no overall difference in the prey base in urban versus parkland sites. There was a significant variation in vertebrate biomass at urban sites from 2005 to 2006, mainly due to a difference in *Microtus californicus* numbers. During 2005, the total number of individuals was 78, whereas in 2006 the number was 45. Green (1971) confirmed that *M. californicus* would only breed during periods of green vegetation availability, and vegetation growth in California's Mediterranean climate varies during the growing season with rainfall patterns. Mean rainfall amounts in Santa Clara County are 36.37 cm, the total rainfall for 2006 was 42.2cm which is above average, however, the total rainfall in 2005 was 57 cm, prolonging the growing season of grasses, and extending the breeding season of *M. californicus,* as the availability of high-quality food positively correlates with increased demographic success of *Microtus* (Ostfield 1984).

Breeding Season Factors

During the breeding season, avian species have large energy demands (Strong, Rimme and McFarland 2004) and this was reflected in the results. All variables (number of vertebrates, vertebrate richness, invertebrate richness, vertebrate mass, and invertebrate mass) were significantly higher in the breeding season versus the non-breeding season. York, Rosenberg and Sturm (2001) observed similar results from stomach content analysis of burrowing owls in the Imperial Valley of California. Their study confirmed a broader food niche for the breeding season versus the non-breeding season; they surmised this was caused by the need to feed offspring in the breeding season and fewer prey species availability during the non-breeding season (York, Rosenberg and Sturm 2001). An abundance of vertebrate prey is important because owls may focus on these species and may even deplete them within their territories (Green 1983).

Burrowing owls capture single prey items and carry the prey to their young (Green, Fitzner and Anthony 1992). Invertebrates therefore, may represent a negative energy gain compared to rodents, due to the greater biomass, especially during periods of food-stress such as feeding young (Gleason and Johnson 1985, Green, Fitzner and Anthony 1992). This study found invertebrate richness and mass (in 2006) was significantly greater for pairs of owls without chicks, while vertebrate mass was significantly greater for pairs with chicks. Burrowing owl nests supplemented with rodents in the diet had higher productivity influenced by the higher proportion of rodents (Wellicome 1994, Haley 2002, Ronan 2002). Burrowing owls with chicks appear to be concentrating on rodents as opposed to invertebrates for the higher energy gains associated with the greater biomass. These findings, once again, highlight the importance of rodents to productivity (York, Rosenberg and Sturm 2001).

Irrigated versus Non-irrigated Sites and Year

Number of vertebrates and vertebrate richness was significantly greater on irrigated sites versus non-irrigated sites, whereas, invertebrate richness and biomass was significantly greater on non-irrigated sites versus irrigated sites. These results showed both habitat types are important and contributed to the overall diet of these owls. The burrows on irrigated sites were all located at Moffett Airfield and Shoreline Park. All burrows on irrigated areas at Shoreline Park were located on the golf course or directly adjacent to it (rough grass areas or along road edges across from the golf course), as was the case for Moffett Airfield with the exception of one burrow that was located adjacent to a baseball field. Maintenance practices on the golf courses are quite intensive and include the following during the late spring/summer/early fall period:

- Mowing of fairways and tees twice per week, greens daily and rough areas weekly;

- Application of fertilizer every 3-4 months on fairways and monthly on greens (fertilizer includes gypsum, lime, chicken droppings and general over the counter fertilizer);
- Herbicides applied during late spring early summer on tees and fairways;
- Entire course is irrigated daily for 5-15 minutes.

York, Rosenberg and Sturm (2001) found that burrowing owls in the Imperial Valley of California living in irrigated agricultural areas had a significantly greater amount of invertebrates in their diet compared to other areas. The irrigated fields were conducive to invertebrate, especially Orthoptera species habitat; however the fields contained crops of different layers and structures. Intensive management practices on golf courses maintain the vegetation very short, and this would explain the lower invertebrate richness and biomass on these irrigated areas as invertebrate species are impacted by the structure and microclimatic conditions found in grasslands (where they move vertically among the different layers) as opposed to the diversity of plant species, hence invertebrate species richness is higher on extensively than on intensively managed meadows (Giulio, Edwards and Meister 2000, Kruess and Tscharntke 2001).

Adams (1982) found a very low small mammal density in mowed areas, while Moulton, Brady and Belthoff (2006) found that trapping of rodent prey species around burrowing owls inhabiting areas near irrigated sites was greater compared to non-irrigated agricultural sites. During this study, no small rodent burrows were observed (apart from California ground squirrels) on the golf courses. However, both golf courses are heavily fragmented and dissected by creeks, roads with medium strips of tall vegetation and rough areas (areas of grass patches along the perimeter of the course that is not subjected to regular maintenance practices at some areas). Burrowing owls are possibly hunting both in the irrigated areas of the golf course and in adjacent areas of taller vegetation where rodents reside and possibly feed on the irrigated vegetation of the golf course, especially during the dry summer season.

Prey Abundance between Long versus Short Vegetation

Mammal trapping during both years yielded dismal results, with only two mice (*Mus musculus*) caught during 1,660 trap nights. The Sherman live traps used during the study were the larger version trap (7.5x8.75x30cm). One mouse was caught using the larger Sherman trap, and with little trapping success it was decided to use the smaller size Sherman trap (5x6.25x16.25cm) to determine if the (7.5x8.75x30cm) trap was too large for mice. Using the smaller trap only one mouse was caught. Trap size did not seem to make a difference for mice, a conclusion also reached by Kisiel (1971) who found no significant difference between trap sizes for trapping *Peromyscus* and *Reithrodontomys*. The number of rodents found in pellets and as prey remains during the 17 month study totaled 298 individuals excluding *Thomomys* (which were not targeted with the traps due to their subterranean existence). This is not a substantial number of animals considering the time period involved. Fragmentation, disturbance and mowing are factors that are playing a major role in the low abundance and diversity of rodents at the five Santa Clara County sites (Batzli 1985, Bolger et al. 1995).

Arachnids were the most common Order numerically represented in trapping conducted at the five sites, yet pellet analysis and prey remains found very few Arachnids. Pellets and prey remains showed that the Order Dermaptera was the dominant prey species, yet trapping revealed very few Dermaptera. Arachnids are soft bodied in general and this may result in poor representation in pellets. Apart from Arachnids and Dermaptera the other Orders: Coleoptera, Orthoptera and Stylommatophora were represented numerically as second, third and fourth in both trapping and pellets.

The number of invertebrates caught during trapping in 2005 was significantly higher than in 2006. Rainfall levels were above average in 2005 compared to 2006 (57:42.2cm) the mean area rainfall level is 36.37cm. The Mediterranean climate of California has a wet season in winter/early spring with an abundance of vegetative growth corresponding to precipitation levels. Invertebrate abundance correlates to the wet season (Tanaka and Tanaka 1982) with invertebrate abundance reaching a seasonal peak during the rainy season (Wolda 1980).

RECOMMENDATIONS

The literature on the diet of burrowing owls confirms that they are generalists and opportunistic in their feeding habits. Studies show that owls hunt close to their nest burrows (Haug and Oliphant 1989) and this study confirmed that they hunt within their habitat patch. Hence although generalists, their diet is essentially limited to what is available in their local vicinity. There were dietary differences among the five sites, driven by fragmentation size, isolation of the site, and site management (irrigated or non-irrigated, timing/extent of mowing, hardness of soil, predator abatement etc.). Given the results of this study, the following habitat management practices are recommended to enhance the prey base of burrowing owls in urban environments.

Maintain a Mosaic of Different Habitat Types

Maintaining short vegetation in nesting burrowing owl habitats by mowing or grazing is a standard procedure for successful burrowing owl survival. Several studies conducted at two of the sites where this study was researched confirmed the importance of short vegetation around burrowing owl nests. Trulio (1997) concluded that owls at Shoreline Park and Moffett Airfield choose nest burrows in short vegetation in proportion to its availability, while Fisher et al. (2007) found that the size of areas with clusters of active burrowing owl burrows at Moffett Airfield was related to the scale of mowed areas at the site. However, important as short vegetation is to nesting burrowing owls, it is not always conducive to the ecology of other species, especially insects and small rodents, all major prey species of burrowing owls. Jones et al. (2003) found small rodents in significantly greater abundance in areas with the most and tallest vegetative cover, while Giulio et al. (2001) found that insect diversity was greater in extensively managed meadows (areas mowed once or twice per year) as opposed to intensively managed meadows (areas mowed more than two times per year). A mosaic of different habitats consisting of both tall and short vegetation would enhance the prey base of burrowing owls by providing a diversity of habitats for insect and mammal species. Past or present areas where owls nest should be mowed regularly while other areas should be left unmowed or only mowed once per year, or alternate mowed areas to leave strips of tall vegetation adjacent to short vegetation.

Plant Native Perennial Plants

Native perennial plants would enhance the prey base of burrowing owls (Moulton et al. 2006) by providing an additional year round source of cover, especially for small rodents, who occur in greater abundance in a mixture of high density, and diversity of shrubs and mixed-grass (Windberg 1998). The non-native annual grasses in California have a short but rapid growing period during the wet season, and then dry out shortly afterwards. Seeds disappear and soil becomes hard, inhibiting a number of species. Native perennials could be chosen to provide a year round supply of food based on their supply of seeds, berries, and fruit. Consideration of plant heights will be important when planting native perennials adjacent to active owl burrows with special emphasis on low growing perennials while taller perennials could be planted further away from active owl colonies, or along the peripheral of owl habitat. Some suitable plant species could include the following: *Arctostaphylos* ssp. , *Atriplex* ssp., *Ceanothus* ssp., *Eriogonum* ssp., *Lupinus* ssp., *Mimulus* ssp., *Monardella* ssp., *Ribes* ssp., *Rosa* ssp., and *Salvia* ssp.

Feral Cat Removal

Domestic cats are superb predators, and those that have become feral can have adverse impacts not only to burrowing owls, but also other bird species and rodents, where they can cause severe declines to small fauna populations (Erlinge 1988). Millsap and Bear (1988) found that domestic cats were responsible for 30% of known deaths to burrowing owls at their study site in Florida.

Install Irrigated areas near active burrowing owl habitat

Irrigated areas where the vegetation is permitted to grow tall will provide a stable and abundant supply of invertebrates and small rodents for burrowing owls (Moulton et al. 2006). Tall vegetation that provides a year round supply of green vegetation especially during the dry season in California will provide seeds and cover that will benefit many prey species.

Supplemental Feeding

The number of successful chicks leaving a nest and the quality of those chicks is dependant upon the food supply during the nestling period (Wellicome 1994). Haley (2002) found that burrowing owls that were supplemented with dead mice in their diet experienced greater nest attendance during both the incubation and brood-rearing period.

The results of this study confirmed that the growth rate of last-hatched owl chicks was greater for supplemented nests, and that the body condition of nesting females was positively affected by supplemental feeding. This cannot be a long-term practice, but could be used until diverse, high quality habitat is produced.

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