Investigating Biotic Interactions as Limiting Factors of Burrowing Owl (*Athene cunicularia*) Population Recovery in British Columbia

by

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Degree:	**Master of Science**
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Abstract

Burrowing owls (*Athene cunicularia*) were considered extirpated from British Columbia by 1980 and still require active management to sustain a breeding population. My research objective was to investigate if predator-prey interactions limit the survival and reproductive output of burrowing owls in British Columbia. Wildlife camera photographs and direct observations were used to assess survival, prey return rate and availability, and predator occurrence rate at six different conservation-breeding release sites across two regions and three reproductive-output levels. Ten out of the twelve nests studied successfully produced at least one juvenile owl that is presumed to have survived to the end of the 2023 breeding season. Results indicate that there may be regional differences in reproductive output and prey availability but not predator occurrence. Neither prey availability nor predator occurrence were significantly correlated with burrowing owl reproductive output, although some prey metrics were trending towards significance. However, competition over food resources with other species may be more detrimental to burrowing owls than previously thought, particularly over vertebrate prey items. Relationships between burrowing owls and the other species they interact with in British Columbia are complex; predator-prey dynamics alone do not account for the variability of burrowing owl success rates across the region. Active management such as supplemental feeding and anti-competitor deterrents at the entrances to burrows may be necessary to support this endangered species until it has reached more sustainable population numbers.

Keywords: burrowing owl, endangered species, wildlife management, predator-prey, trail cameras

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Glossary

Artificial Burrow: An underground chamber used for shelter that has been man-made to substitute for the loss of naturally available burrows. Typical structure for artificial burrows made for burrowing owls includes stacked buckets for top access for researchers attached to a corrugated pipe that provides surface access for the owls (Johnson et al. 2010).

Burrow: An underground tunnel, usually excavated by an animal for the purposes of shelter.

Brood: The number of hatched juveniles from one nesting attempt being cared for by their parents (Griebel et al. 2007).

Clutch: The number of eggs in a single nesting attempt.

Corvid: A member of the Corvidae family; including crows, ravens, magpies, and jays.

Fledgling: A juvenile bird that can fly and begins to start practicing hunting on its own.

Fossorial: An animal adapted to burrowing.

Hatchling: A juvenile bird that has just hatched and still entirely reliant on its parents for food and protection, is unable to leave the nest.

Juvenile: A young bird that has not yet reached the mature adult stage.

Nestling: A juvenile bird that is able to move and may spend time outside the burrow but is unable to fly more than short distances and relies on parents for food.

Satellite Burrow: A burrow that is not used to nest but is located close to the nest burrow. It is used by burrowing owls for cover and to cache surplus prey items.

1. Introduction

1.1 Declines of burrowing owl populations:

Migratory bird species have declined at unprecedented rates in North America in the last half century and birds that breed in grassland ecosystems have declined more than any other ecosystem type (Rosenberg et al. 2019). Grassland ecosystems only cover approximately 0.74 million hectares (<1%) of British Columbia; however, they contain more than 30% of the threatened or endangered species of the province (Wikeem & Wikeem 2004). One such endangered species historically found in the grasslands of British Columbia is the burrowing owl (*Athene cunicularia*). Only one subspecies of burrowing owl is present in Canada: the western burrowing owl (*A. c. hypugaea*; COSEWIC 2017). Burrowing owls were considered to have been extirpated from British Columbia by 1980 (Leupin & Low 2001). Ongoing recovery efforts from the 1990s to the present have led to a small population of burrowing owls. However, this population is not self-sustaining and burrowing owls are still red listed in British Columbia (COSEWIC 2017). Additional research on what limits the growth of burrowing owl populations will be critical to guiding management actions to save this endangered species from further extirpation in British Columbia and other Canadian provinces.

Burrowing owls are native to grasslands and shrub-steppe regions of North and South America (Poulin et al. 2020). In Canada, burrowing owls are found in southern British Columbia, Alberta, Saskatchewan, and Manitoba. The historical range of burrowing owls within British Columbia is generally believed to have been mostly restricted to the grasslands of the Okanagan-Similkameen and Thompson-Nicola regions (Figure 1; Ministry of Environment, Lands and Parks 1998). There were also reports of burrowing owls in the Fraser Delta until 1976, but only ever one or two pairs (Ministry of Environment, Lands, and Parks 1980). Recovery efforts in British Columbia through the relocation of owls from Washington began as early as 1983 (Leupin & Low 2001). By 1990, a breeding program was established within British Columbia, at the Kamloops Wildlife Park. Today, the Burrowing Owl Conservation Society of BC (BOCSBC) breeds owls at three specialized breeding facilities. The conservation-breeding and release program has successfully bred and released owls into artificial burrows that survive to migration and return to British Columbia for a subsequent breeding season (Pyott et al. 2023). As of 2018, over 1700 owls had been released and 359 owls had been confirmed to have returned in a subsequent breeding season (Pyott et al. 2023). However, reproductive success and return rates vary across nesting sites and a self-sustaining population has not yet been achieved in British Columbia.

a) b)

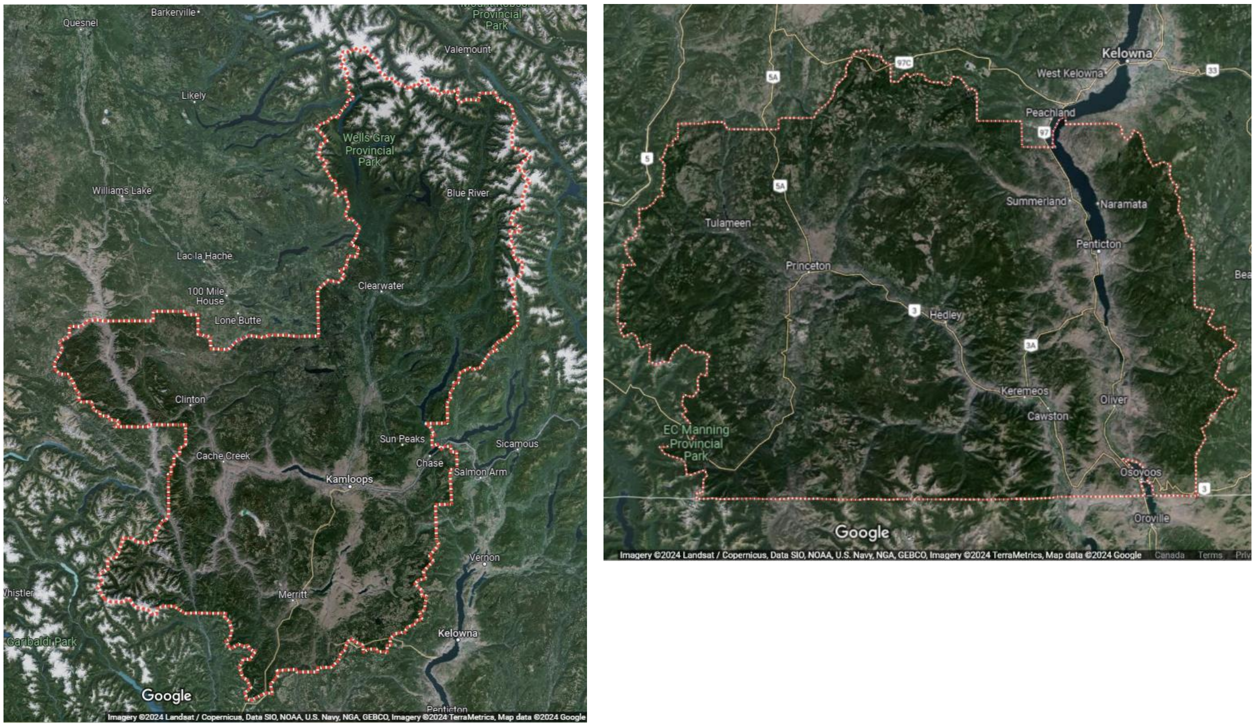


Figure 1: The a) Thompson-Nicola and b) Okanagan-Similkameen Regional Districts of British Columbia where burrowing owls were historically present (Google 2024; Map data: Google, Copernicus, Data SIO, NOAA, U.S. Navy, NGA, GEBCO).

British Columbia is not the only region where burrowing owl populations have drastically declined in recent decades. In Canada, severe declines have occurred in Alberta and Saskatchewan, and burrowing owls have almost been extirpated from Manitoba (Pyott et al. 2023). Surveys completed by Operation Burrowing Owl in Saskatchewan estimated that by 2000, there were fewer than 10% of the breeding pairs that were present in the 1980s (COSEWIC 2017). Observations in Alberta by Operation Grassland Community estimated a 40% decline in the number of breeding owl pairs from 57 pairs in 2006 to 34 pairs in 2014 (COSEWIC 2017). Similar declines have been observed in the northern United States (Conway & Pardieck 2006; U.S Fish & Wildlife Service n.d.). Estimates of the population decline in Washington ranged from a 1.5% to 3.1% decline annually by the early 2000s (Conway & Pardieck 2006). The burrowing owl has been listed as endangered or threatened in several states including Washington, Oregon, and California. Unfortunately, these western states also fall along the migratory path of owls that breed in BC and may be indicative of stressors in the wintering range of owls that breed in British Columbia. Burrowing owls were recently declared extirpated in Orange County, California in 2014, after eight decades of observed decline (Bloom 2023). In Mexico, burrowing owls are a species with special protection (Lincer et al. 2018). Although specific factors influencing population dynamics may differ locally, the population decline of burrowing owls is widespread in the northern and western regions of their range.

1.2 Burrowing owl biology:

Throughout their range, burrowing owls are easily identifiable and have many adaptations that make them unique among owls. They are a relatively small owl, weighing only 150 to 170 g on average and are about 19 to 25 cm in length (Poulin et al. 2020). Burrowing owls arrive in British Columbia from April to May to breed throughout the summer and migrate south along the Pacific coast in the fall (Holroyd et al. 2010). Burrowing owls are generally most active at dawn and dusk, and unlike most owls are active during the day. Burrowing owls lay an average of five to eight eggs per clutch in British Columbia (Leupin & Low 2001; Mitchell et al. 2011; Pyott et al. 2023). More than one clutch per breeding season is rare, though exceptions have been noted to occur in the wild, particularly following predation events (Catlin & Rosenberg 2008; Poulin et al. 2020). Burrowing owls are indeterminate layers, meaning that the number of eggs is not predetermined prior to laying, and they can adjust by laying more eggs in response to a loss of eggs (Wade & Belthoff 2016). Eggs are incubated for approximately 4 weeks and hatch asynchronously (Poulin et al. 2020). Hatchlings remain in the nest burrow and are cared for by their parents for the first two weeks before beginning to explore outside their natal burrow. Juveniles begin to leave their natal nests and primary parental care approximately 7 to 8 weeks after hatching and migrate south in the fall (Todd et al. 2007; Poulin et al. 2020).

Burrowing owls live in abandoned burrows made by fossorial mammals and have adapted a higher tolerance for carbon dioxide than other owls that nest above ground (Poulin et al. 2020). In undisturbed habitats, burrows would likely have been created by Columbian ground squirrels (*Urocitellus columbianus*) and American badgers (*Taxidea taxus*) in British Columbia (Conway 2018). Other fossorial species such as prairie dogs (*Cynomys* spp.), Richardson’s ground squirrels (*Urocitellus richardsonii*), and kangaroo rats (*Dipodomys* spp.) are important burrow excavators for western burrowing owls outside of British Columbia (Conway 2018).

Typical vegetation communities surrounding nesting sites include grassland and shrub-steppe (Poulin et al. 2020). Burrowing owls generally choose nests in areas with short sparse vegetation and tend to prefer native grassland and pasture over cropland (Gervais et al. 2003; Machicote et al. 2004; Poulin et al. 2005). Patches of short grass and bare ground are generally believed to provide enhanced accessibility of prey items for owls and increase visibility for predator detection; although denser, tall grass usually provides good habitat for prey populations (Machicote et al. 2004; Lantz et al. 2007; Marsh et al. 2014; COSEWIC 2017). Therefore, having short vegetation immediately surrounding the burrow but a patchier matrix of vegetation in the surrounding area is preferred. Burrowing owls also prefer nesting in areas with high available burrow density (Lantz 2007; Ray et al. 2016). Short vegetative cover was likely historically maintained by fossorial herbivores such as ground squirrels and prairie dogs as well as natural disturbance such as wildfire (Machicote et al. 2004; Wikeem & Wikeem 2004). Today, the same process is often also performed by cattle grazing which has become a predominant use of the grasslands of North America (Machicote et al. 2004; Wikeem & Wikeem 2004; Rebolo-Ifrán et al. 2017). In addition to short vegetative cover for visibility, low perches are also important in creating enough visibility for predator vigilance and foraging (Scobie et al. 2014). This includes burrows being on a slight mound of soil, nearby rocks, and short posts. Higher perches, such as telephone poles, would likely attract larger avian predators, which increases predation risk for burrowing owls (Scobie et al. 2014).

Burrowing owls are generalist feeders, but most of their diet consists of small mammals (mostly voles and mice) and invertebrates (mostly grasshoppers, crickets, and beetles; Moulton et al. 2005; Ruiz Ayma et al. 2019). Observed prey items previously found in pellets of owls in British Columbia include: meadow vole (*Microtus pennsylvanicus*), deer mouse (*Peromyscus maniculatus*), northern pocket gopher (*Thomomys talpoides*), carrion beetle (*Silphidae* spp.), ground beetles (*Carabidae* spp.), spur-throated grasshoppers (A*cridae* spp.), Great Basin spadefoot (*Spea intermontane*), western toad (*Anaxyrus boreas*), western meadowlark (*Sturnella neglecta*), vesper sparrow (*Pooecetes gramineus*), mountain bluebird (*Sialia currucoides*), and western terrestrial garter snake (*Thamnophis* elegans; Leupin & Low 2001). Invertebrate prey generally composes the majority of prey items but not prey biomass, as vertebrate prey items, although caught less, are larger. Invertebrate items can make up to 75% to 95% of the prey items returned to the nest (Moulton et al. 2006; Balin et al. 2022). During the breeding season, burrowing owls typically forage close to burrow entrances for invertebrates and forage farther away at night for small mammals (Marsh et al. 2014). The hunting range for burrowing owls is highly variable depending on individual and habitat characteristics but averages of 400 m to 900 m have been reported with maximum distances upwards of 1600 m (Gervais et al. 2003; Marsh et al. 2014)

Recorded predators of burrowing owls in the Thompson-Nicola region include coyotes (*Canis latrans*), northern harriers (*Circus hudsonius*), red-tailed hawks (*Buteo jamaicensis*) and great horned owls (*Bubo virginianus*; Leupin & Low 2001). It is likely that other predatory mammals and birds would also prey upon burrowing owls if the opportunity arose. For example, weasels (*Mustela* spp.), Swainson's hawks (*Buteo swainsoni*), American badgers (*Taxus taxidae*) and common ravens (*Corvus corvax*) have been identified as predators of burrowing owls in other regions and are present in British Columbia (Moulton et al. 2006; Henderson & Trulio 2019; Poulin et al. 2020). There is not a lot of published literature on the rate of nest predation in burrowing owls, but predation rates of 21 to 28% of burrows have been reported in natural burrows (Moulton et al. 2006; Henderson & Trulio 2019). If predation of a nest or adult occurs, the remaining adult(s) most often abandon the nest within a week (Catlin & Rosenberg 2008; Henderson & Trulio 2019). Nest abandonment has also been observed after a predator approach with unsuccessful predation.

1.3 Reintroduction Program:

The current conservation and reintroduction program of burrowing owls run by the Burrowing Owl Conservation Society of BC consists of a mixture of active habitat management and conservation breeding and release. Habitat management strategies employed include the construction and maintenance of artificial burrows and mowing around burrow entrances. Artificial burrows are constructed out of a 2 to 3 m flexible plastic tube entrance connected a nest chamber made of an inverted plastic bucket (Appendix A; Leupin & Low 2001; Mitchell et al. 2011). A secondary weighted bucket placed on top of the nest chamber provides access for monitoring while preventing predators from digging up the nest chamber. Owls specifically chosen for breeding are cared for in three separate facilities, to prevent a catastrophic event (e.g. natural disaster, disease) from wiping out the entire breeding stock. Each year, these owls produce offspring that are held over winter and then paired and released in April when they are approximately 10 months old (Pyott et al. 2023). Owls are generally released using soft-release pens (nylon mesh enclosures of approximately 2 to 3 m^3) around the artificial burrow entrances for a few weeks as this increases nesting success and the number of offspring produced (Mitchell et al. 2011). Released and return owls are supplement fed throughout the breeding season with mice and chicken chicks. The amount of supplement feeding changes throughout the breeding season depending on the age of the young (highest after hatching), and all sites are provided food at the same rate. The amount of food given is not solely enough to sustain the owl family units.

1.4 Current stressors:

A factor that has long been believed to be largely responsible for the decline of burrowing owls is the loss of available burrows due to declines and extirpation of many burrowing mammals considered to be pests to agriculture and other human activities (COSEWIC 2017; Poulin et al. 2020). Although some subspecies of burrowing owls can dig their own burrows, *A. c. hypugaea*, the subspecies that breeds in Canada and the northwest United States, is not able to dig their own burrows. Therefore, *A. c. hypugaea* are reliant on abandoned burrows from species such as prairie dogs, ground squirrels, badgers, and marmots (Poulin et al. 2005; Conway 2018). Burrowing owls have been found to be relatively tolerant of human activity and readily nest in man-made structures such as culverts and PVC pipes near human development (Poulin et al. 2020). This tolerance of human activity means that organizations, such as the Burrowing Owl Conservation Society of BC, can use artificial burrows to provide a substitute for naturally occurring burrows. As this strategy has been implemented in British Columbia for decades, a lack of available burrows is likely not the main limiting factor for the population recovery of burrowing owls in this region.

Therefore, a yet unidentified stressor(s) is likely limiting the burrowing owls' ability to survive and reproduce post-release, at rates required to sufficiently grow the population to a self-sustaining level. Limiting factors that have been proposed as contributing to current declines and prevention of population growth of burrowing owls in the Pacific Northwest include decreased prey availability, increased predation rate, increasing extreme weather events, and disease (Haley & Rosenberg 2013; Fisher et al. 2015; COSEWIC 2017; Henderson & Trulio, 2019). However, very few studies have been conducted specifically in British Columbia on burrowing owls, and these studies have been focused on release methods (Leupin & Low 2001; Mitchell et al. 2011; Pyott et al. 2023). No formal studies have been conducted on potential factors currently limiting burrowing-owl reproduction and survival in British Columbia. This study focused on food availability and predation rate, as these are the most often cited reasons for mortality through the breeding season in burrowing owls (Leupin & Low 2001; Davies & Restani 2006; Wellicome et al. 2013; Marsh et al. 2014; Henderson & Trulio 2019).

2. Objectives

The goal of the study was to better understand whether prey availability and/or predation rate are related to burrowing owl survival and reproduction, to help inform future decision making and habitat management for burrowing owl recovery. My hypothesis was that the burrowing owl population in British Columbia is limited by prey availability and predation. Therefore, I predicted that release sites with high reproductive success and survival have higher prey availability and/or lower predation rates than sites with low reproductive success.

The specific hypotheses of this study are:

1. Prey Limitation Hypothesis: To determine if release sites with higher reproductive output and survival rates have higher prey availability than sites with lower reproductive output and survival; and

2. Predator Limitation Hypothesis: To determine if release sites with higher reproductive output and survival rates have a lower predator occurrence than sites with lower reproductive output and survival.

3. Methods

<u>3.1 Site Selection:</u>

I selected six pre-existing release sites for burrowing owls across the Thompson-Nicola region of British Columbia for this study. This included three sites in the south Kamloops area and three sites north of Merritt. Exact locations of the release sites are not disclosed within this paper to protect the owls from disturbance and landowner privacy, as there are very few locations of burrowing owls left in British Columbia and they are a popular subject of photography. Elevations of the study sites ranged from approximately 930 m to 1020 m in the Kamloops region and 650 m to 700 m in the Merritt region. All sites fall within the Bunchgrass

Very Dry Warm (BGxw1) biogeoclimatic zone (Wikeem & Wikeem 2004). This region is characterized by dry, open, sloping grasslands with sparse shrub cover. Common native vegetative species in the region include bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg's bluegrass (*Poa secunda*), needle-and-thread grass (*Hesperostipa comata*), junegrass (*Koeleria macrantha*), big sagebrush (*Artemisia tridentata*), thread-leaved daisy (*Erigeron filifolius*), large-fruited desert-parsley (*Lomatium macrocarpum*), sagebrush mariposa lily (*Calochortus macrocarpus*), yarrow (*Achillea millefolium*), and arrowleaf balsamroot (*Balsamorhiza sagittate*; Wikeem & Wikeem 2004). Introduced and invasive species are also present, due to the long history of agriculture and ranching in the region. All the sites were located on private property and the predominant land use across all sites was cattle grazing.

I selected sites for the study that had at least two pairs of nesting owls (including return owls) after the Burrowing Owl Conservation Society of BC's release of owls in April of 2023. The experimental design was a randomized complete block design. Sites were blocked according to location: Kamloops region and Merritt region. Each block included three sites: one with a relative historically low reproductive output, one with a relative historically mid-range reproductive output and one with a relative historically high reproductive output (treatments). I defined reproductive output as the number of owls born and fledged (fledglings) in the wild per released owl pairs based on data from 2015 to 2022. I used fledglings per released owl pair instead of total fledglings as a way to standardize the reproductive output with release effort since the number of owls released at each site varied among sites and years. As environmental conditions, especially prey and predator populations are dynamic; survival and reproductive output from historical breeding seasons were not compared to the 2023 prey availability and predation measurements. However, by including sites that have had historically different average reproductive outputs as treatments, I expected to capture a representative sample of the natural range of reproduction and survival to be able to compare prey abundance and predation among these sites. Additionally, I could assess whether recent historical reproductive output was a good indicator of the current year's reproductive output. However, prior to analyzing whether the 2023 reproductive outputs were correlated with prey availability and predator occurrence, the sites were re-grouped based on the 2023 reproductive output into high, medium, and low treatments within each block to accurately represent the 2023 conditions. Each block still maintained one low, one medium, and one high reproductive site.

3.2 Field Observations & Camera Set-up:

At each of the six sites, I measured owl survival rates and reproductive output through the 2023 breeding season from two nesting pairs (total 12 pairs, 24 owls). Owls were considered to have survived the breeding season if they were encountered during banding (approximately 4 weeks after hatching). After this point, fledglings generally start exploring the surrounding area and survival would be difficult to differentiate between mortality and movement without finding evidence of fatality. Mortality date and cause was recorded if fatalities were observed or reasonably suspected prior to the end of breeding season.

I used Camera traps using Reconyx Hyperfire (Reconyx Hyperfire 2 Covert IR Camera; Reconyx Inc., Holmen, Wisconsin) trail cameras to identify prey items returned to the burrow and predator occurrence. Each nest had two cameras set at two distances to get a near view and wide-angle view (Appendix A). A near camera (approximately 0.5 m from the mouth of the burrow) was set to photograph when motion activated for 90 mins before and after dawn and dusk (total 6 hours per day), when burrowing owls are most active. A second camera, approximately 4 m away, was set to face the burrow entrance to get a wide view of the burrow complex. This camera was also set to record when motion activated and ran 24 hr/day. Flash was not used to avoid nest abandonment from repeated flash exposure. Therefore, most photos were only clear enough for identification of species from dawn to dusk. Therefore, the period of 90 mins before dawn to 90 mins after dusk (approximately 19 hours) was used to calculate per hour occurrences. Each motion activation triggered three successive photos.

3.3 Objective 1 – Prey Limitation:

I assessed prey availability using both photographs taken by cameras and ground truthing surveys of arthropods (British Columbia Ministry of Environment, Lands and Parks 1998; Moulton et al. 2006; Mrykalo et al. 2009; Montgomery et al. 2021). Beetles, crickets, grasshoppers, meadow voles, and deer mice are the most commonly reported prey items of burrowing owls in the Pacific Northwest (Leupin & Low 2001; Moulton et al. 2005; COSEWIC 2017; Poulin et al. 2020). I identified prey returns to the nest from the photographs taken by the trail cameras using field guides. Prey items were identified to species if possible. If species identification was not possible, the items were assigned to a broader category such as “vole”, “grasshopper”, or “rodent”. The number of prey items at each nest was then divided by the total number of hours the cameras were active to achieve a standardized return rate.

Pitfall trapping of arthropods was completed to supplement the photo data and compare whether trends from the photographs matched true site conditions. Each pitfall trapping station consisted of a 16-ounce (~473 ml) clear plastic cups set flush with the ground following established RISC protocol and what was recommended based on literature review (British Columbia Ministry of Environment, Lands and Parks 1998; Hohbein et al. 2018). Covers were placed approximately 2 cm above half the pitfall stations to exclude rainfall and discourage vertebrates from entering traps. The other half were left open to lessen bias against flying insects. A non-toxic solution of water and dish soap was used within traps and preservation (isopropyl alcohol and freezing) occurred after traps were checked. Invertebrate trapping occurred once in June and once in July.

Due to unforeseen cattle interference (cows pulling up the pitfall traps), a second planned pitfall trapping session in July was not completed. Instead, grasshoppers were counted along an encounter transect at each site to estimate the abundance of the most common arthropod food source. For all arthropod sampling sessions, samples were taken along transects relatively close to burrows (15 m, 30 m, and 45 m from burrows for pitfall traps and along a 45-m transect for encounter transects) to be consistent with the foraging behaviour of burrowing owls (Moulton et al. 2006; COSEWIC 2017; Poulin et al. 2020). Two transects were sampled for each nest burrow (four per site). The direction of the transects was a randomly assigned cardinal direction from the approximate centre of the burrow complex.

At trapping stations (3 per transect, 4 transects per site), I conducted a vegetation survey consisting of vegetation height using an obstruction (Robel) pole and percent cover of a 1 m by 1 m quadrat. The purpose of the vegetation survey was to characterise whether arthropods caught at that location would likely be accessible to owls (Marsh et al. 2014). The Robel pole obstruction was conducted by viewing a pole marked with alternating colour every 10 cm at a 1 m height, 4 m from the pole (Robel et al., 1970). Observations of how many 10 cm sections were not visible (obstructed) were taken from the four cardinal directions and averaged. Percent cover was visually estimated by categorizing within five groups using a modified Daubenmire method: 0-20% vegetative cover, 20-40% vegetative cover, 40-60% vegetative cover, 60-80% vegetative cover, and 80-100% vegetative cover (Coulloudon et al. 1999). Observations were recorded as the mid-point in the category, for example 20-40% cover would be recorded as 0.30. Average cover per site was then compared.

3.4 Objective 2 – Predator Occurrence:

I used trail cameras to assess predation risk at each site as well as prey availability. The number of predator approaches to the burrow was recorded, as well as any predation events. It was also recorded whether owls abandoned the nest following a predator approach. I also recorded approaches of species that may act as predators of eggs or hatchlings but were more likely competitors for invertebrates and small mammals. Corvids are an example of this, as they were observed several times to steal prey items from the burrows. The occurrence of predators was then divided by the total number of hours the cameras were active to provide a standardized predation or disturbance rate.

3.5 Data Analysis and Management:

The rate of prey return per hour and predator occurrence per hour were calculated for each site. I included four weeks of data for each nest, corresponding with the period from hatching to assumed fledging of juveniles. This period is the most important for both food availability and predation (Davies & Restani 2006; Mitchell et al. 2011; Wellicome et al. 2013; Henderson & Trulio 2019). The only exception to this was one nest in the Kamloops region which hatched earlier than expected. Eleven days during the early hatchling and nestling period were not captured, so the camera hours for that nest were adjusted accordingly. Camera hours were also adjusted for a couple of sites if a camera was knocked over and the intended field of view was not captured. Days with over 10 mm of precipitation in a twenty-four-hour period were also excluded from the analysis, as owls were expected to be less active in rainy conditions (Fisher et al. 2015). Daily precipitation amount was determined via Environment Canada using the nearest available weather station.

For each site, the average of two nests was used for site statistics unless a nesting attempt completely failed prior to hatching. After nest failure (burying of the eggs), surviving adults tended to remain in the area for a few days before disappearing. Therefore, data collected from these nests were not considered representative of the true prey availability and predation rate for those sites. Two nest failures occurred in the Merritt region. For these sites, data for the remaining successful nest was used instead of an average, as it was considered more representative of the site conditions relevant to the study. Count data was transformed by taking the square root to approximate a normal distribution more closely prior to running statistical tests.

An ANOVA was used to compare differences in egg survival, prey availability, predator occurrence, and vegetation metrics between sites with a low, medium, and high reproductive output treatments (two sites per treatment). A significant difference indicated that the treatments differed in terms of biotic environmental conditions that would be expected to affect reproductive output. A student's t-test was used to compare differences between the two regional blocks (Merritt and Kamloops, BC). A significant difference indicated that the region where the owls were released affects outcomes and was expected to represent differences in climate, vegetative communities and regional prey and predator densities. Pearson's correlation was used to determine if prey availability, predator occurrence, and egg survival were correlated with the number of fledglings (Wickham et al. 2023). Significant differences for all tests were assessed at $p \leq 0.10$. All statistics were calculated using R in RStudio (R Core Team 2023; RStudio Team 2023, version 2023.09+463).

4. Results

The 24 adult owls included in this study produced a total of 50 offspring. Ten out of the twelve nests successfully produced at least one offspring, a nesting success rate of 83%. One nest failed following female mortality caused by weasel predation. The reason for the second nest failure is unknown. There was not a specific predation event captured on camera, but several corvids and one coyote were seen in the area of the nest in the days preceding the eggs being buried.

The mean (± standard deviation) number of offspring that survived to fledgling per successful nesting attempt for all study sites was 5 (± 2.1) (range = 2 – 10). The mean number of eggs laid per successful nest was 7.7 (± 1.6). The mean percent of eggs laid that survived to fledge in successful nests was 74.3% (± 16.5%). Including unsuccessful nests, the mean number of fledglings was 4.2 (± 2.8) and the number of eggs per clutch was 7.8 (± 1.5).

The twelve nests were observed using camera traps for a total of 5799 hours during the 2023 breeding season. The expected variability was observed, with one site reporting at least double the reproductive output, invertebrate prey, vertebrate prey, total prey, or predator occurrence than another site (Table 1). Unexpectedly, the sites with the highest prey return rates were not the sites with the highest reproductive output, nor did the sites with the lowest prey return rates necessarily have a low reproductive output. Predator occurrence was generally less variable than prey return rate.

Table 1: Mean (±SD) fledglings per successful nesting attempt, vertebrate prey per hour, invertebrate prey per hour, total prey per hour, and predators per hour. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023. *indicates that data was based on one nest instead of an average between two as only one nesting attempt was successful.

Site (Reproductive Treatment)	Fledglings per Successful Nest	Vertebrate Prey Per Hour	Invertebrate Prey Per Hour	Total Prey Per Hour	Predators Per Hour
Kamloops L (Low)	4.5 (2.12)	0.02 (0.01)	0.08 (0.10)	0.10 (0.09)	0.02 (0.00)
Kamloops M (Medium)	5.5 (0.71)	0.06 (0.04)	0.14 (0.11)	0.20 (0.06)	0.02 (0.01)
Kamloops H (High)	8 (2.83)	0.14 (0.10)	0.03 (0.03)	0.17 (0.07)	0.02 (0.02)
Merrit L* (Low)	2 (NA)	0.11 (NA)	0.03 (NA)	0.14 (NA)	0.04 (NA)
Merrit M (Medium)	3.5 (0.71)	0.04 (0.01)	0.03 (0.03)	0.07 (0.07)	0.01 (0.00)
Merrit H* (High)	5 (NA)	0.05 (NA)	0.01 (NA)	0.06 (NA)	0.01 (NA)

4.1 Return Owls:

Return owls have been found in previous studies to produce more offspring then release owls, likely due to increased hunting ability and predator avoidance behavior with age (Pyott et al. 2023). Return owls produced more fledglings than newly released owls in both cases where both types were present, but the difference was not significant (t_2 = -1.21, p = 0.35). No significant differences were detected between return owls versus release owls for vertebrate prey per hour returned (t_2 = -1.54, p = 0.26), invertebrate prey per hour returned (t_2 = 1.09, p = 0.39), or total prey per hour returned (t_2 = -0.05, p = 0.97). Therefore, nests with return parents were not considered to have significantly skewed the results and were included in the site comparisons. Additionally, the nest that produced the fewest fledglings (2 fledglings) had a return male and there were return nests not included in the study that failed. It should be noted that the Merrit L return nested much later in the season than would be expected for a return owl, as return owls usually arrive at sites prior to the released owls. Therefore, including return owl nests for this study was deemed valid, as no significant differences between the return owls and released owls for the parameters included was detected and site characteristics (such as prey availability and predator occurrence) affect both return owl and release owl success.

4.2 Prey Items & Predator Occurrence:

A total of 666 prey items were identified during the hatching to fledgling period across all sites. Voles (*Microtus* spp.) were the most common vertebrate prey, followed by mice (*Peromyscus* and *Zapus* spp.). Pockets gophers, amphibians, sparrows, and shrews were also identified in smaller numbers. The majority of invertebrates could not be identified to family from the photographs but were likely mostly a mixture of ground (Carabidae spp.) and darkling (Tenebrionidae spp.) beetles, based on field observations. The more distinctive grasshoppers, carrion beetles, and Lepidoptera species could be identified to family or higher in photographs when owls were consuming them. Of these, grasshoppers were consumed the most often. The proportion of prey items by type identified at each site is shown in Figure 2.

A total of 185 predators (and competitors) were identified during the hatching to fledgling period across all sites. Corvids (crows, ravens, and magpies) were the most commonly identified species in the trail camera photographs. The proportion of predators by type identified at each site is shown in Figure 3.

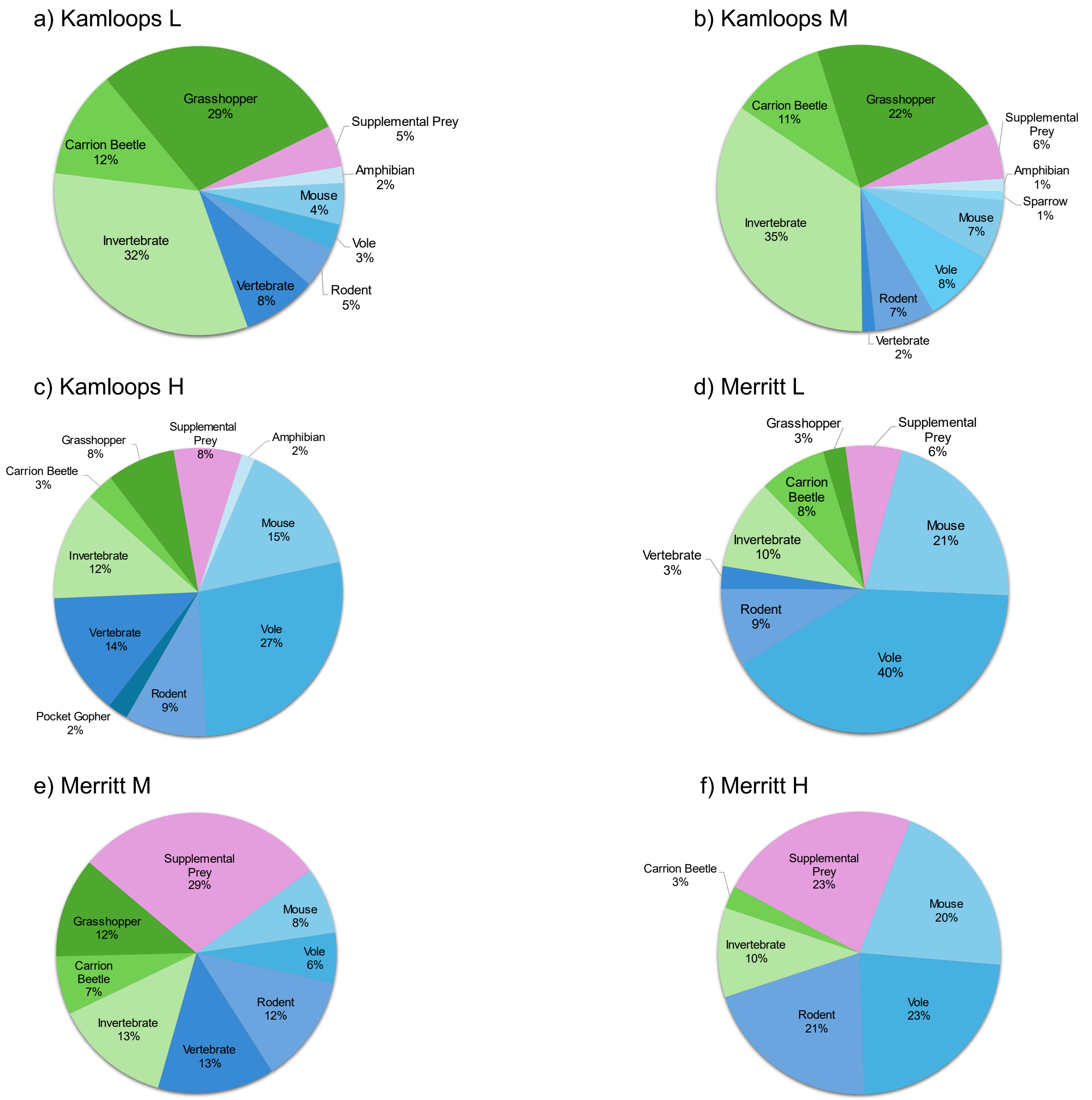


Figure 2: The proportion of prey items observed at each site. Shades of blue indicate vertebrate prey, shades of green indicate invertebrate prey, and pink indicates supplemental prey items given to the owls by the Burrowing Owl Conservation Society during their monitoring activities. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

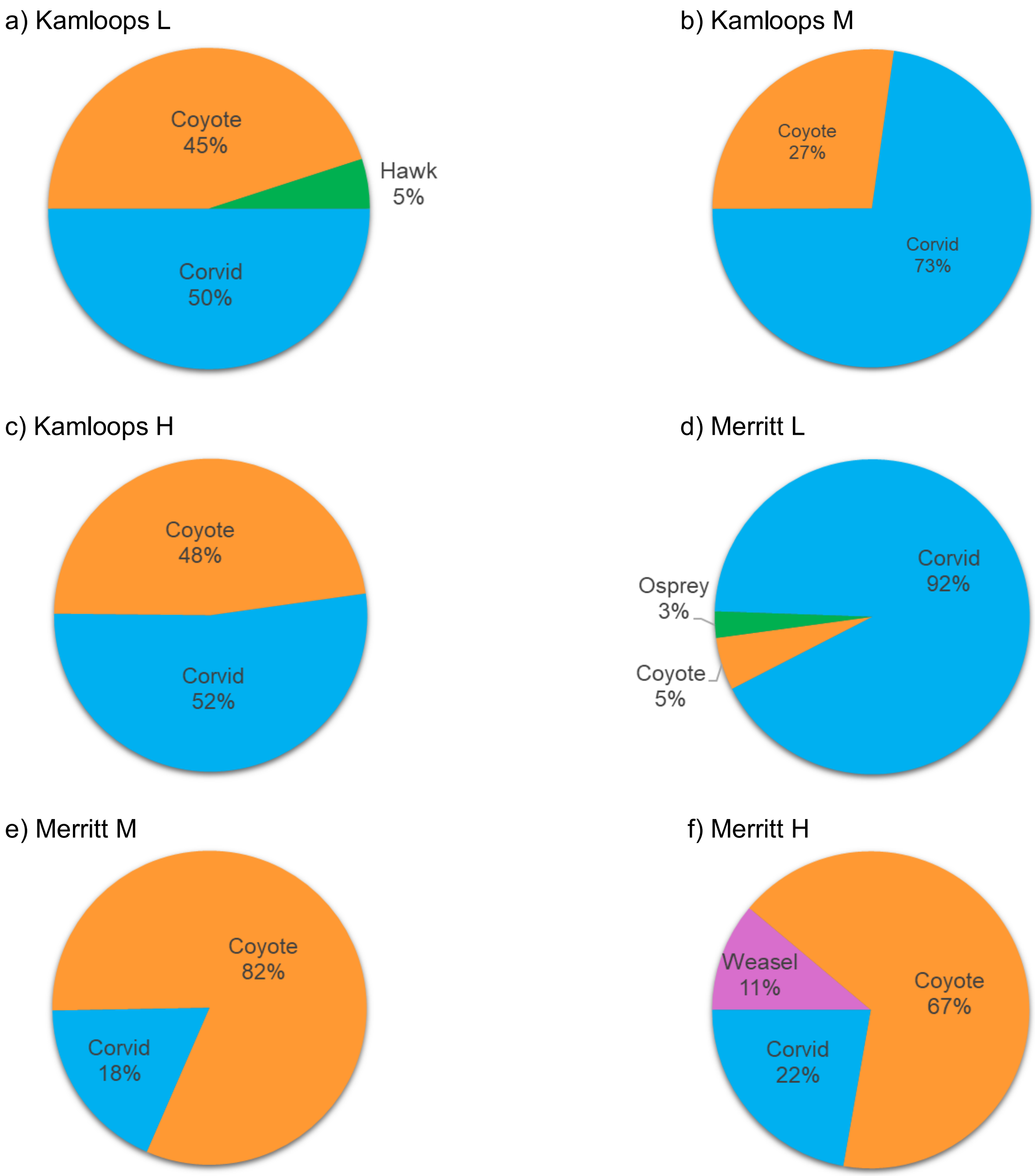


Figure 3: The proportion of each type of predator and competitor observed at each site. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

4.3 Reproductive Treatments & Region Blocks:

There was a significant difference between the three reproductive treatments (high, medium, and low) for 2023 reproductive output ($F_{2,2} = 59.36$, $p = 0.02$). A Tukey Honest Significant Differences test for the reproductive output indicated that all treatments were significantly different from each other ($p = 0.02 – 0.07$). There was not a significant difference between the three reproductive treatments for egg survival ($F_{2,2} = 2.84$, $p = 0.26$), total prey per hour ($F_{2,2} = 0.05$, $p = 0.95$), invertebrate prey per hour ($F_{2,2} = 5.06$, $p = 0.17$), vertebrate prey per hour ($F_{2,2} = 0.22$, $p = 0.82$), or predator occurrence ($F_{2,2} = 0.94$, $p = 0.52$). Although not significant, the difference between invertebrate prey per hour between treatments was approaching significance ($p \leq 0.20$). In both blocks, the site with historically mid-range reproductive output outperformed the historically high reproductive output site in terms of 2023 reproductive output. Two out of the three Kamloops sites had a higher 2023 average number of fledglings per successful nesting attempt than their historical average. All three Merritt sites had a lower 2023 number of fledglings per successful nesting attempt than their historical average.

There were no significant differences between the Kamloops and Merritt blocks for reproductive output ($t_4 = 1.81$, $p = 0.15$), egg survival percent ($t_4 = 2.07$, $p= 0.11$), total prey per hour ($t_4 = 1.54$, $p = 0.20$), invertebrate prey per hour ($t_4 = 1.88$, $p = 0.13$), vertebrate prey per hour ($t_4 = -0.09$, $p = 0.93$), or predator occurrence ($t_4 = 0.87$, $p = 0.47$). Although no significant difference was detected, the number of fledglings, percent of eggs laid that survived to fledgling, total prey per hour, and invertebrate prey per hour were trending towards significance ($p \leq 0.20$).

4.4 Correlation:

There was a significant correlation between the percent of eggs laid that survived to fledgling and the average number of juveniles fledged (Figure 4; $p = 0.02$). There were no significant correlations between prey availability (invertebrate, vertebrate, or total return rate) and reproductive success (Figure 5; $p = 0.48 – 0.77$). There was also no significant difference between predator occurrence and reproductive output (Figure 5, $p = 0.63$).

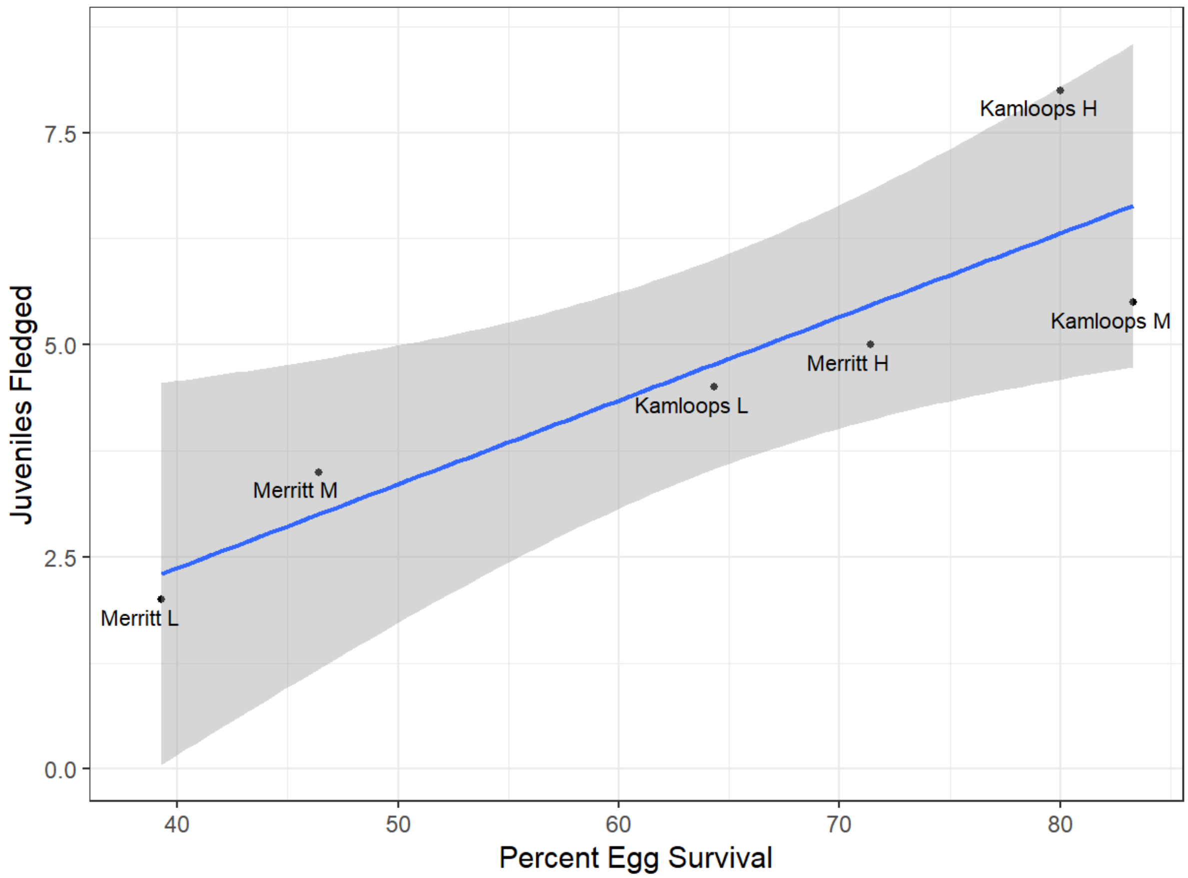


Figure 4: The percent of eggs laid that survived to the fledgling stage, approximately 4 weeks post-hatching versus the number of fledglings ($t_4 = 3.62$, $p = 0.02$, $r^2 = 0.77$). Shaded area represents the 95% Confidence Interval. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

Merritt L was not statistically an outlier as all site reproductive outputs were within two standard deviations of the overall mean (5 ± 2.1). As such it was included in all statistical analysis of differences between treatments and blocks and correlations described previously. However, Merritt L had at least double the corvid (crows, ravens, and magpies) occurrence rate of any other site, and multiple instances recorded of corvids stealing vertebrate prey items which may have effectively lowered the available vertebrate prey to consume than what was recorded in Table 1. As such, an additional correlation analysis excluding Merritt L was also conducted (Figure 6).

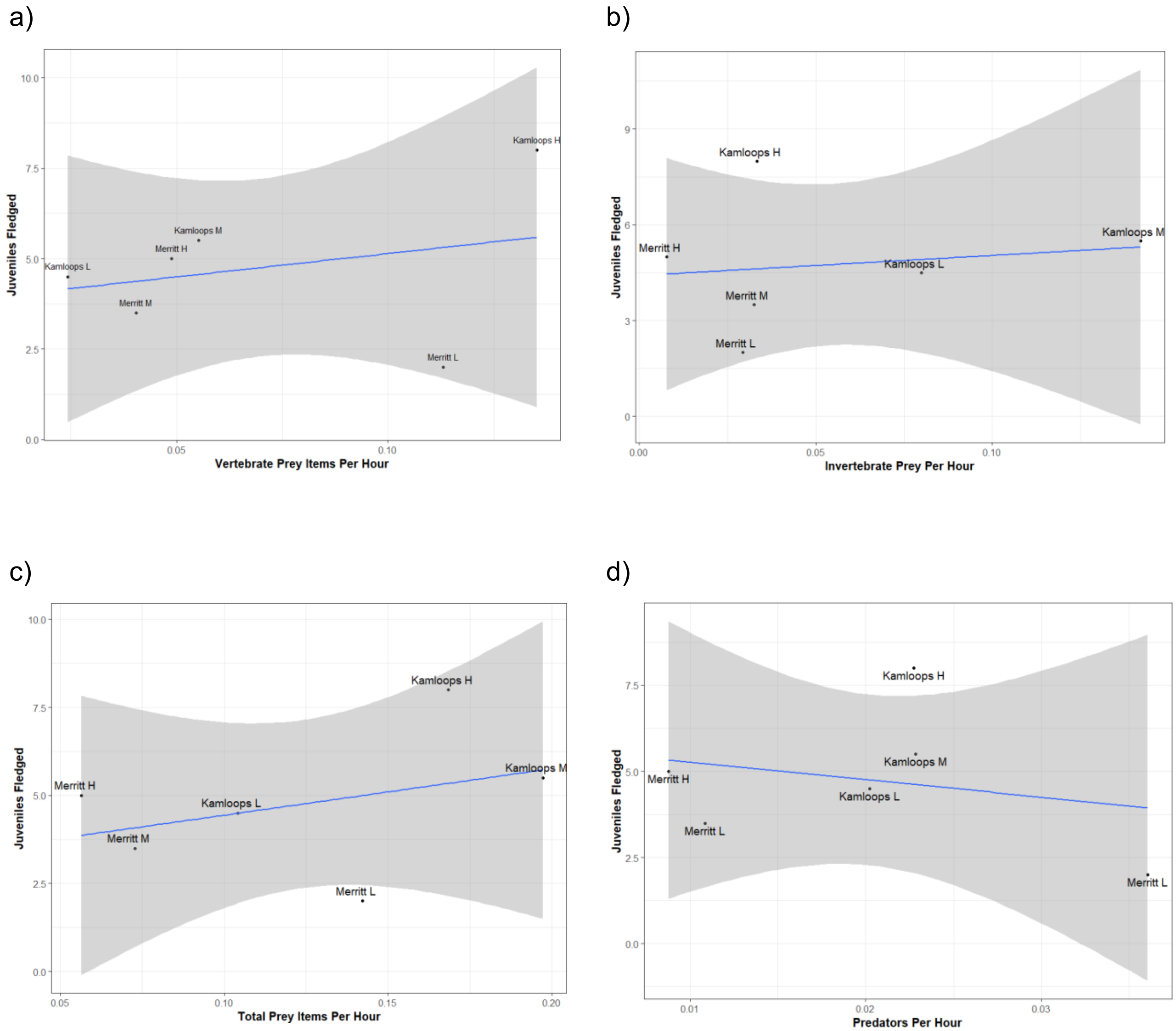
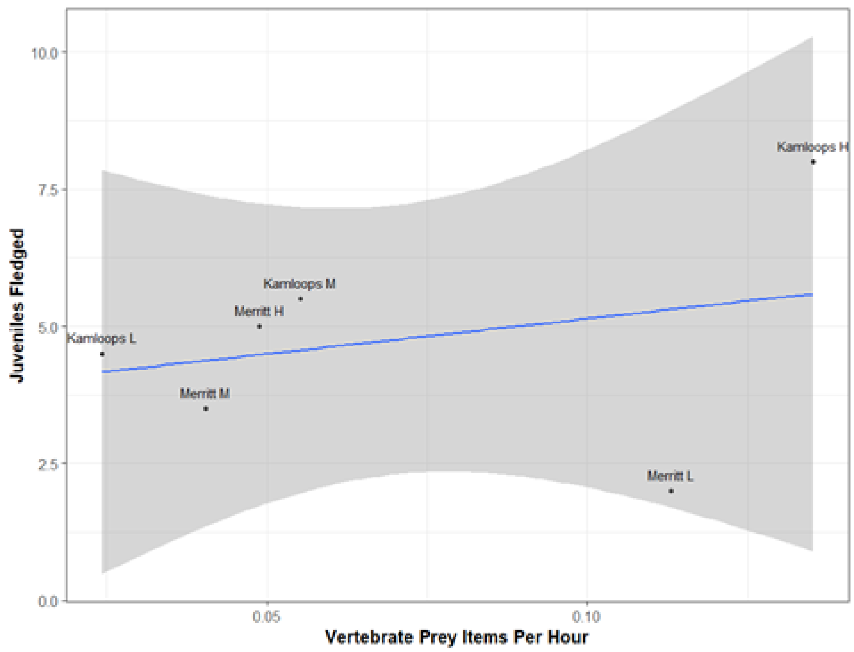


Figure 5: The a) vertebrate prey per hour ($t_4 = 0.59$, $p = 0.59$, $r^2 = 0.08$), b) invertebrate prey per hour ($t_4 = 0.31$, $p = 0.77$, $r^2 = 0.02$), c) total prey per hour ($t_4 = 0.77$, $p = 0.48$, $r^2 = 0.13$), and d) predators per hour ($t_4 = -0.51$, $p = 0.63$, $r^2 = 0.06$) at each site vs. juveniles fledged per successful nesting attempt. Shaded areas represent the 95% Confidence Intervals. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

a)



b)

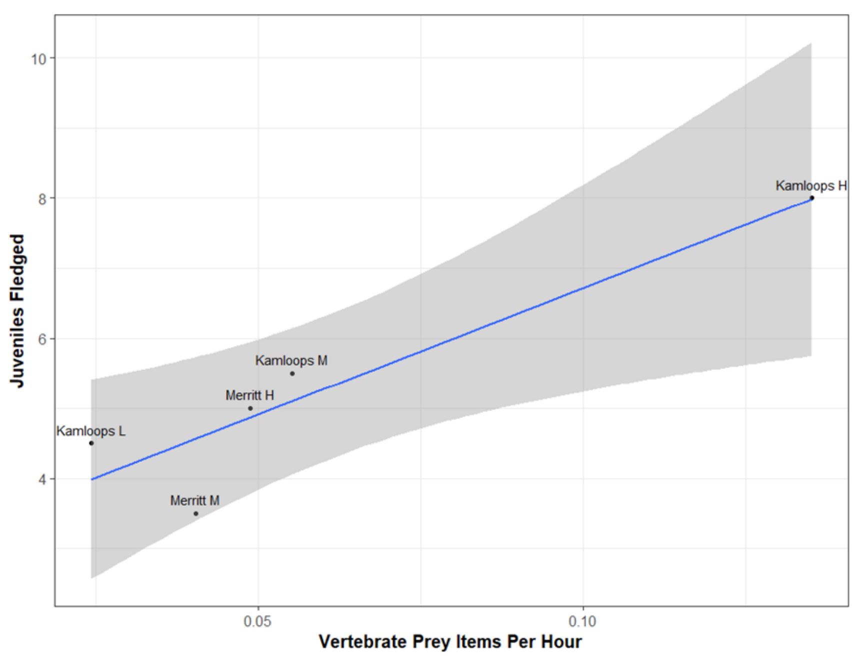


Figure 6: The vertebrate prey per hour versus juvenile fledged a) with Merritt L (t_4 = 0.59, p = 0.59, r^2 = 0.08) and b) without Merrit L (t_3 = 4.30, p = 0.02, r^2 = 0.86). Shaded areas represent the 95% Confidence Intervals. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

4.5 Total Fledglings:

Considering the total number of fledglings at the sites (including nests not included in the two per site used for calculations of average fledglings and prey availability) generally strengthened the regional (block) patterns observed previously for reproductive output (Table 2). There was, however, no significant difference between reproductive treatments ($F_{2,2}$ = 0.53, p = 0.23) when considering all nests per site. There was a significant regional difference in total fledglings per site (t_4 = 2.81, p = 0.05). Total number of fledglings was correlated with average fledglings per successful nesting attempt (t_4 = 2.79, p = 0.05, r^2 = 0.66) and total prey returns per hour (t_4 = 2.26, p = 0.09, r^2 = 0.56).

Table 2: The mean number of fledglings per successful study nest, successful nesting attempts per site, percent eggs laid that survived to fledgling, average fledgling weight, and total number of fledglings (including all nesting attempts) per site. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

Site	Fledglings per Successful Study Nest	Successful Nesting Attempts	Percent Survival of Eggs Laid	Average Fledgling Weight	Total Fledglings at Site
Kamloops L	4.5	2	0.64	148.22	9
Kamloops M	5.5	4	0.83	149.91	23
Kamloops H	8	3	0.80	148.25	22
Merrit L	2	1	0.39	160.50	2
Merrit M	3.5	2	0.46	158.00	7
Merrit H	5	1	0.71	144.60	5

4.6 Grasshopper Count & Pitfall Trapping:

There was a significant difference between the treatments for the July grasshopper count ($F_{2,2}$ = 10.03, p = 0.09). The high reproductive output treatment had significantly more observed grasshoppers than the low reproductive output treatment (p = 0.10). Kamloops had more grasshoppers observed than Merritt, which was approaching a significant difference (t_4 = 1.88, p = 0.13). There was not a significant correlation between the grasshopper count data and the number of invertebrates returned per hour from the camera counts (Figure 7a; p = 0.51). There was, however, a correlation between the average grasshopper count and juveniles fledged (Figure 7b; p = 0.01).

Due to cattle disturbance of pitfall traps in the Kamloops region, only the Merritt region had enough pitfall count data samples to be analyzed. A total of 519 prey items were recovered from the traps. Merrit L had the most arthropods (232), followed by Merrit M (186), and finally Merrit H (101). Of these arthropods, 88% were grasshoppers in Merrit L, 77% were grasshoppers in Merrit M, and 48% were grasshoppers in Merrit H. At all three sites, grasshoppers were the most common item found in the pitfall traps. Beetles and spiders were also present at all three sites. The arthropods were relatively evenly spread across traps set 15 m (171), 30 m (186), and 45 m (162) from the burrow complexes.

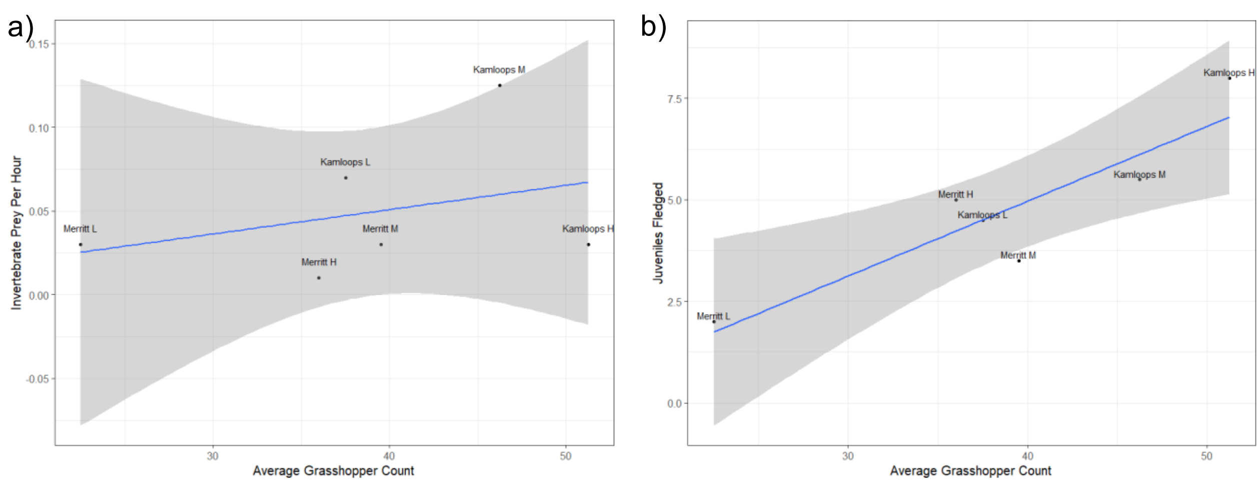


Figure 7: The average grasshopper count (taken July 19-20) versus a) the rate of invertebrate prey returns (t_4 = 0.73, p = 0.51, r^2 = 0.12) and b) the number of juveniles fledged (t_4 = 4.14, p = 0.01, r^2 = 0.81). Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

4.7 Vegetation Survey:

Robel scores were variable across sites and treatments (Table 3). However, there was no significant difference between the treatments ($F_{2,2}$ = 0.05, p = 0.96). The mean Robel score of the Merritt region (0.87) was more than double the mean Robel score of the Kamloops region (0.37) and significantly different (t_4 = -2.65, p = 0.06). There was not a significant correlation between the Robel scores and the number of juveniles fledged (t_4 = -1.47, p = 0.22, r^2 = 0.35).

Table 3: Mean (±SD) Robel (obstruction score; scale of 1 = 10 cm) and percent vegetative cover of six release sites. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

Site	**Kamloops L**	**Kamloops M**	**Kamloops H**	**Merritt L**	**Merritt M**	**Merritt H**
Robel Score	0.15 (0.20)	0.44 (0.34)	0.52 (0.48)	1.13 (0.57)	0.88 (0.77)	0.60 (0.63)
Percent Cover	0.57 (0.13)	0.65 (0.26)	0.33 (0.22)	0.50 (0.27)	0.37 (0.13)	0.38 (0.20)

Percent cover was also variable within sites and between sites (Figure 8). There was no significant difference between the treatments ($F_{2,2}$ = 1.25, p = 0.44) or blocks (t_4 = 0.96, p = 0.39). The mean percent cover was not correlated with the number of juveniles fledged (t_4 = -0.50, p = 0.64, r^2 = 0.06).

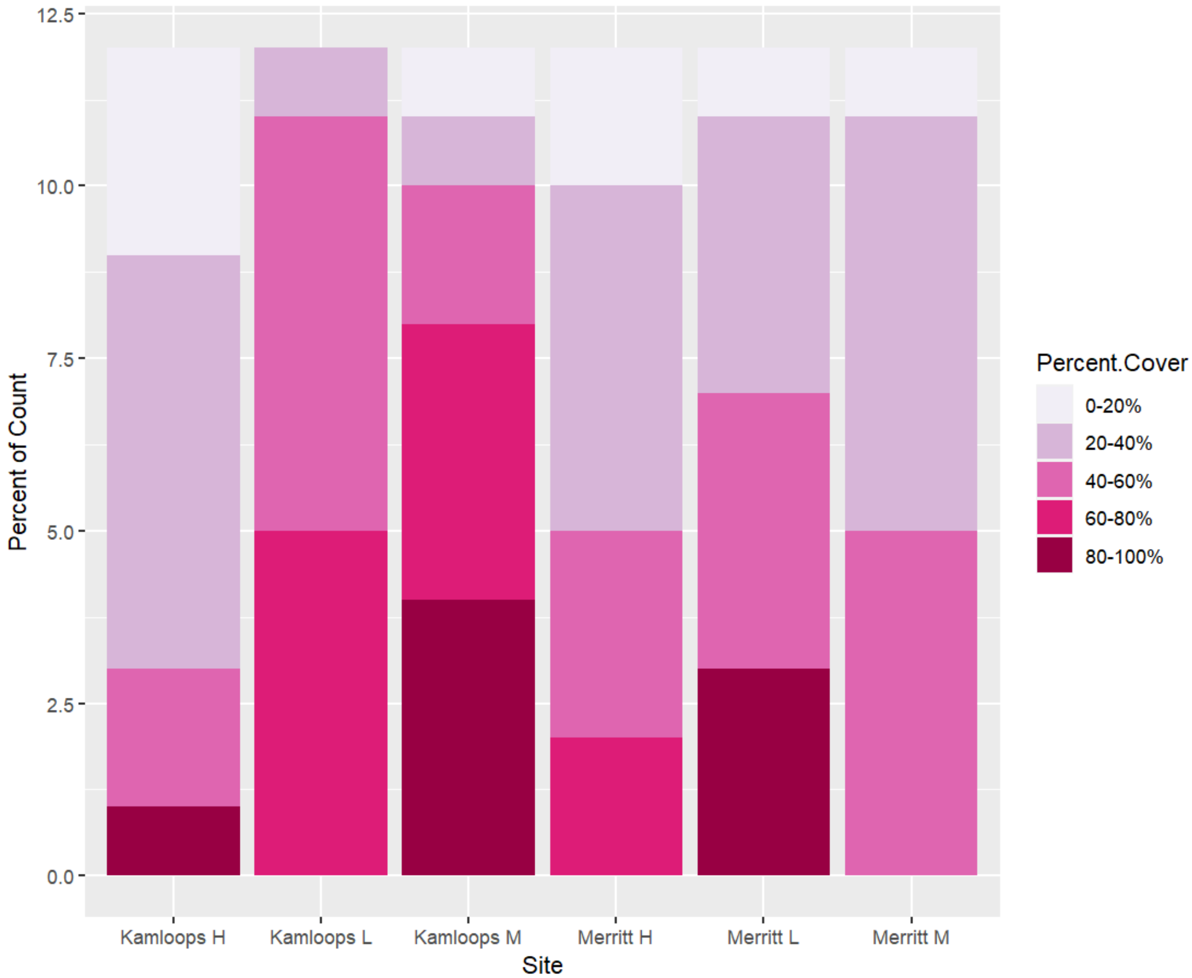


Figure 8: The proportion of percent cover category found at each of the six sites. Percents were based on twelve observations of a square meter pot per site in the areas surrounding burrow complexes. Data represented two research blocks (Merritt and Kamloops, BC, Canada) and three treatments (low, medium, and high reproductive output for burrowing owls). Data were collected for the summer 2023.

5. Discussion

5.1 Objective 1 – Prey Availability:

Although there were differences in prey availability across treatments and the two blocks (Kamloops and Merritt), prey availability was not correlated with the number of fledglings produced per successful nesting attempt. The results, therefore, did not support my hypothesis that prey availability is limiting burrowing owl success. Possible explanations for this include that prey is not a limiting factor of burrowing owls in British Columbia, supplemental food ensures owls have enough food to reproduce near maximum levels, and competition for food after it has been returned to the nest depletes the actual available food supply. It should be noted that several metrics of prey availability were trending toward significant differences between the blocks, indicating that repeating the study with a larger sample size may show significant regional differences for prey availability.

Supplemental food during the nestling stage is well known to increase the number of offspring that survive to fledge (Haley & Rosenberg 2013; Wellicome et al. 2013). The fact that supplemental food was provided from release (pre-egg laying) to fledgling may have allowed sites with lower available food to still produce offspring where there may not have been enough naturally available food. Sites with higher available natural food sources would still have benefitted from supplemental food but it likely had a lesser effect on the offspring produced. Removing supplemental feeding would likely have resulted in a stronger correlation between food availability and offspring produced.

Merrit L was not considered an outlier as it was within two standard deviations for reproductive output and prey availability metrics; however, it did have some interesting aspects that may be indicative of differing biological conditions. Further investigation with additional replicates would be required to show whether excluding it may be more representative of the biological conditions. Merrit L had by far the largest corvid presence (twice that of the next highest site) and the most instances of corvids stealing food from a burrow. Potentially, for that site, the prey availability metrics based on food seen returned to the nest may not truly represent the amount of food that was available to the owls as a portion was stolen. I reran the correlation between vertebrate prey and reproductive success excluding Merrit L, and it was significant. This supports the hypothesis that prey availability is important for owl success, but availability can be affected post-catch by theft from other species. The potential influence of interspecific competition as an unexpected biological interaction that limits burrowing owl reproductive success is discussed further in section 5.3.

The grasshopper count was only weakly correlated with the amount of invertebrate prey returned to the nest seen on camera, but it was correlated with the number of juveniles fledged. The grasshopper count occurred from 15 to 45 m from the center of a burrow complex. At the same time, invertebrates were only captured on camera if an adult consumed it in front of the burrow or brought it back to the burrow for a juvenile to consume. Therefore, the grasshopper count may be more representative of the actual food availability, since it is likely owls consume invertebrates more regularly where they are caught. This is likely not an issue for vertebrate prey which require more handling and are often cached, and therefore are likely more often consumed near the burrow. Additionally, the rate of invertebrate consumption identified during this study was lower than expected, based on other studies of burrowing owl diet (Moulton et al. 2005; Poulin et al. 2020; Balin et al. 2022; Romero-Vidal et al. 2023). Therefore, camera traps are likely more accurate for vertebrate prey than for invertebrate prey.

5.2 Objective 2 - Predator Occurrence:

Predation from terrestrial species was not found to be a major stressor for burrowing owls on their breeding grounds in British Columbia, contrary to my hypothesis that predator occurrence would be limiting burrowing owl success. A few nests did fail due to recorded or suspected predation activity; however, that is to be expected. Overall, the adult survival and nesting success rate was high. Only one post-fledgling mortality in a juvenile owl was suspected (bands seen removed from owl). It should be noted that due to extreme fire risk, making observations post-fledgling was limited to camera trap observations. Given the increased mobility of juveniles at that stage additional mortality events away from the natal burrow complex were possible.

The low number of nest predation (no nests across all sites were completely depredated) indicated that the artificial burrows used are successful in deterring predation of nests. Nests that did fail, the eggs were buried not predated, indicating either a lack of available resources (prey) or adult mortality causing the remaining parent to abandon the nest. Coyotes were seen investigating the burrow at least once at all twelve nests included in this study. No mortality events occurred due to coyotes and there was never any evidence of coyotes attempting to dig up the artificial burrows.

5.3 Competition:

Competition for food resources from other species particularly from the Corvidae family may play a larger role in limiting the burrowing owl of British Columbia than previously suspected. American crows (*Corvus brachyrhynchos*), common ravens (*Corvus corax*) and black-billed magpies (*Pica hudsonia*) were all identified at the entrance to a burrow. These species are known to (like burrowing owls) consume Orthoptera, Coleoptera and small mammals (Omrod et al. 2021). Crows and ravens were more common than magpies, which were only spotted a couple times overall. Common ravens have been observed approaching burrowing-owl nests at previous studies that monitored nests with cameras in Nevada and California (Hall & Greger 2014; Henderson & Trulio 2019). However, these studies identified ravens as potential predators of burrowing owls and did not discuss interspecific competition. Crows are known to steal food from other avian species; however, I could not identify any sources for this behaviour specific to burrowing owls (Verbeek & Caffrey 2021). The potential effect of corvid competition (or interspecific competition in general) on burrowing owl reproductive success to my knowledge has not been explicitly studied previously. Several studies have investigated burrowing owl density and success in rural versus urban areas, which may in part be indirectly related to both predation and competition differences between urban and rural areas (Moulton et al 2005; Conway et al 2006; Rebolo-Ifrán et al 2017; Luna et al 2019). Specific information on how interspecific competition affects burrowing owls is a knowledge gap that warrants further investigation.

5.4 British Columbia Compared to Other Areas:

The average number of fledglings per successful nesting attempt in 2023 was higher than results from British Columbia reported from 1994 to 1997 (4.1) and 2005 to 2007 (2.4) (Leupin & Low 2001; Mitchell et al. 2011). A more recent study in British Columbia found a mean (± SD) number of eggs per pair was 5.88 ± 0.40, with 2.02 ± 0.40 fledged per captive-released pair from 2015 to 2019 (Pyott et al. 2023). For returning owls, the numbers were higher: 7.70 ± 0.31 eggs per pair and 4.22 ± 0.40 fledglings per pair (Pyott et al. 2023). The results from this study (7.8 ± 1.5 eggs per pair and 4.17 ± 2.8 fledglings) in 2023 were generally higher than the long-term average and previous studies in British Columbia. The reproductive output was comparable to the returning pair results from Pyott et al. (2023).

Other areas with managed burrowing owl populations include Manitoba and the San Jose International Airport in California. In Manitoba, from 2010 to 2020, there was an average of 6.07 ± 0.43 eggs per pair and 2.67 ± 0.37 fledglings per pair (Pyott et al. 2023). However, it should be noted that the Manitoba management program is able to invest more resources (such as repairing and relocating owls from failed nests) in individual pairs due to the lower number of pairs released per year (~10 versus ~50 in British Columbia). British Columbia was noted to have a higher percent of total nest failures, which likely is at least part of the reason for this difference (Pyott et al. 2023). In San Jose, from 1991 to 2007 there was an average of 3.36 ±

0.98 juveniles per pair and a nesting success rate of 79% ± 15.6% (Barclay et al. 2011). The San Jose Airport population does not include conservation breeding but does have management measures such as building artificial burrows and mowing surrounding vegetation (Barclay et al. 2011; Menzel 2018). Reproductive output from this study were comparable to the reproductive output of this area. Overall, I found in this study that the current reproductive output in British Columbia is comparable to other managed owl populations; however, improving habitat quality could likely improve the reproductive output by owl pairs. Although this study only included one field season and a subset of nests from the overall population, I did not find evidence to indicate that the number of juveniles fledged is significantly different than what would be expected given the management actions taken.

5.5 Regional Differences:

The strongest pattern found was a difference between the Kamloops and Merritt regions. There was weak evidence that Kamloops produced more fledglings and had more prey availability than Merritt. There are several physical characteristics that may have led to these results. Nests in the Merritt block tended to be on steeper slopes at lower elevations than the Kamloops block. Kamloops sites tended to be located on higher elevation plateaus and rolling hills than those in the Merritt block. In Kamloops during June (when hatching to fledging occurs), the monthly average temperature was 17.7 degrees Celsius, and the total rainfall was 45.2 mm (Environment Canada 2023). The extreme was June 10th which had 23.6 mm of rainfall. In Merritt during June the monthly average temperature was 16.9 degrees Celsius, and the total rainfall was 35.4 mm. The extreme was June 20th with 11 mm of rainfall. The nest at Merrit L hatched approximately on this day, cool and damp conditions may have led to less food availability in the critical first few days after hatching. Extreme precipitation has been noted to reduce reproductive success and juvenile survival rates, particularly in non-supplemented nests (Fisher et al. 2015). Hatchlings are also more susceptible to exposure-related mortality than older birds (Fisher at al. 2015; Poulin et al. 2020). There was also significant rainfall on approximately the day of hatching at both nests at Kamloops L and one nest at Kamloops H. Although these nests did relatively better than the nest at Merrit L, at both these sites the nest that hatched during the higher precipitation event did worse than the other on-site nest.

Another regional difference that may be related to the difference in burrowing owl success was the vegetation cover. The average vegetation Robel score was twice as high for the Merritt region, indicating taller, denser vegetative cover. A potential source of this difference is different cattle grazing rotation. All three Kamloops sites had a cattle herd grazing in the field where the owl nests were during the post-hatching period in June. None of the Merritt area sites had cattle in the fields where the owls were located. Its possible cattle grazing improved the habitat quality by keeping the vegetation shorter and patchier, which is generally preferable to burrowing owls (Azpiroz & Blake 2016; Lagendijk et al. 2019). Working with landowners and land managers towards annual low intensity grazing patterns may be a suitable management strategy warranting further investigation.

5.6 Assessment of Study methods:

Camera traps were successful in identifying prey returns to the nest and predator occurrence in the vicinity of the burrow entrance. Photographs were better suited to counting vertebrate prey as opposed to invertebrate prey. As such, cameras should still be used along with conventional methods of invertebrate counts such as transect-counts, etc. Pitfall traps were proven to be an unsuitable method of counting invertebrates in this region. Cameras may be a useful tool in conducting vertebrate counts, but species-specific identification was rare. It was a suitable method for doing this comparative study, but caution should be taken if using cameras for determining exact population numbers. Additionally, a pilot study using the cameras at night may improve accuracy. This study captured the period when burrowing owls are known to be most active during the breeding season (dawn and dusk); however, overnight prey return rates were not collected which would likely improve the reliability of the vertebrate return rate results. This was done as there was not sufficient previous evidence to determine whether the flash emitted when taking pictures in low light would disturb the owls to the point of nest abandonment. Other observational studies have used cameras at night; however, they were either set-up prior to nesting for the owls to inspect, only present for a few days or located further from the burrow entrance (Hall & Greger 2014; Marsh et al. 2014; Henderson 2019; Scobie et al 2020; Balin et al. 2021).

5.7 Recommendations for BOCSBC:

The historic success of a site did not necessarily predict the current year’s success. Historic reproductive output was a poor indicator of this season’s juveniles fledged, prey availability, and predator occurrence. Both sites expected to perform mediumly well based on historical output outperformed the expected high reproductive sites. Therefore, site characteristics are likely quite variable from year to year and should be evaluated annually prior to determining release sites if possible. Due to the small sample size of this pilot study, more research into the specific thresholds required for owl success is needed. However, based on this study, some characteristics that warrant further investigation include prey abundance and competition.

Based on the findings of this study, I would recommend the following specific actions to the Burrowing Owl Conservation Society of BC:

1. Further research into prey availability at the release sites.

This study showed that prey availability at the release sites is potentially related to how many offspring are produced. Although not strongly correlated with reproductive output in this study, the number of prey items returned to nests was quite variable between sites. Given the small scale of this study, it is not particularly surprising that there were not significant results. As some direct prey availability metrics (camera return rates) were approaching significant differences between regions and indirect measures (grasshopper transect count and exclusion of site with high observed competition) were correlated with juvenile success, there is not enough evidence to reject the hypothesis that prey availability is limiting burrowing owl populations. A larger scale than used here would be useful to confirm or refute the patterns and weak correlations seen in this study. Ideally, we would be able to improve predictions for which areas will have high prey abundance prior to release of owls in April. Potential aspects that may be predictors to research further could be vegetation cover and height, as well as grazing rotation.

2. Experiment with measures to discourage corvids from entering nesting burrows (and satellite burrow caches) and stealing food.

As discussed above, interspecific competition for prey resources may limit burrowing owl success and yet has not been studied in burrowing owls. Populations of avian competitors such American crows and common ravens are reported to have increased in recent years, potentially exacerbating the problem (Rosenberg et al. 2019). Interestingly, Merrit H and Merrit M had much lower rates of corvid activity than elsewhere (less than half that of the next lowest sites), potentially due to a lower amount of prey availability. Crows in British Columbia are known to be attracted to short grass areas with higher availability of grasshopper prey (Kennedy & Otter 2015). Therefore, habitat management to increase prey availability for burrowing owls would likely also attract larger corvid competitors. Given this shared prey niche and widespread abundance of corvids across the study area, it is unlikely that identifying future release sites with low density of corvids would be feasible. Therefore, management actions that discourage corvids from stealing prey items already caught by burrowing owls may be more effective at managing competitive pressure. Potential solutions may include physical deterrents such as spikes in the burrow entrances reducing maneuverability or leaving sites with increased corvid activity without releases for a few years until the corvids un-learn vertebrate cache theft behaviours.

3. Continue collaborations with other organisations and satellite transmitters to determine where owls migrate to and over-winter.

Pressures during the non-breeding season are potentially contributing to the low number of returns (Bloom 2023). Adjustments may be possible to slightly increase the number and quality of juveniles fledged each year, but the conservation program is already successful in producing fledglings each year and reproductive output is comparable to other conservation programs. Burrowing owls originating from B.C. are either supplementing other populations in the Pacific Northwest otherwise experiencing population declines or are outcompeted for limited resources during the non-breeding season. A recent stable isotope study by Macías-Duarte and Conway (2021) found that burrowing owl populations in northern regions such as Alberta, Saskatchewan, and Washington (British Columbia was not included) had immigrants that had dispersed from the previous breeding season larger distances than most southern populations. However, there was no evidence that burrowing owls with Canadian isotopic signatures were dispersing to breed in northwestern Mexico or the southwestern United States. This leads to the question of what the fate of dispersing Canadian owls is if they are not returning or dispersing to southern locations, which is yet to be answered. Conditions, particularly weather during the winter season is known to affect the survival and migration patterns of burrowing owls (Wellicome et al. 2014; Porro et al. 2020). Therefore, a better understanding of the movements of burrowing owls during the non-breeding season will help inform management decisions for the breeding season.

5.8 Conclusion:

Burrowing owls are declining across much of their range and require active management to save them from extirpation in Canada. It is imperative that we better understand burrowing owl habitat needs and limitations in order to restore a self-sustaining population to British Columbia, in line with the goals of the Burrowing Owl Conservation Society of BC. This study filled a knowledge gap by being the first in British Columbia to investigate whether biotic interactions are limiting the reproductive success of burrowing owls. Although I did not find a significant correlation between prey availability or predator occurrence and burrowing owl success, several important areas for future research and management were identified. Evidence of corvid theft of vertebrate prey items from underground burrowing owl caches was recorded for what may be the first time. The biotic interactions of burrowing owls may be more complex than assumed linear predator-prey interactions. My recommendations to the Burrowing Owl Conservation Society of BC based on the findings of this study should be useful for future management decisions and deciding what future research priorities should be.

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Appendix A

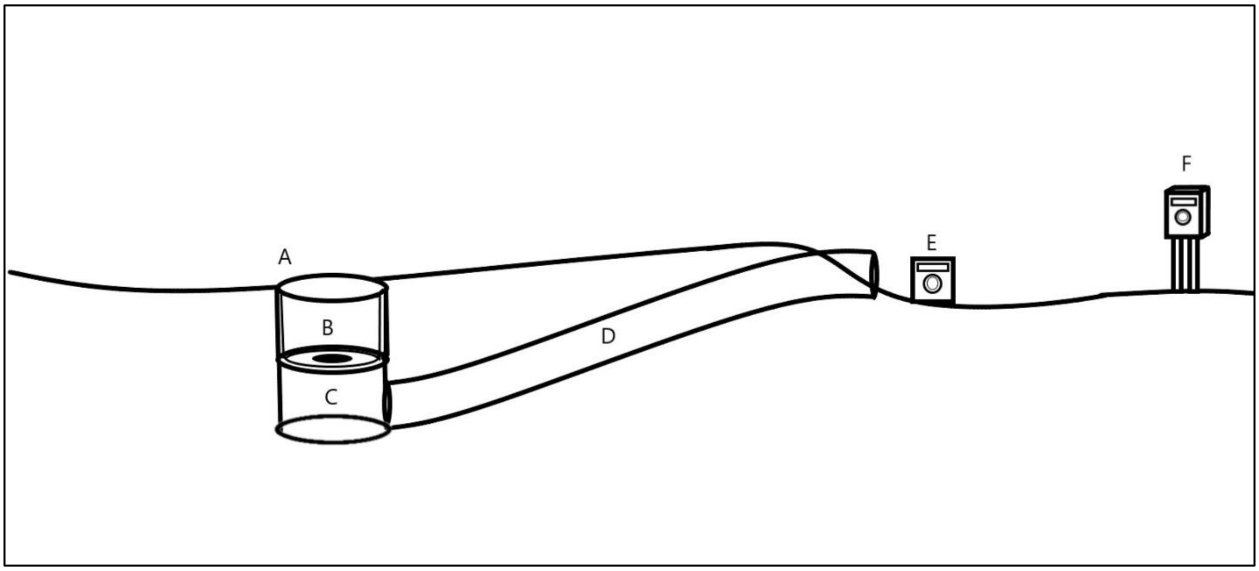

Figure A1: A diagram of the artificial burrows used at the study sites and the camera set-up (diagram not to scale).

A: The top access hatch for the Burrowing Owl Conservation Society of BC to monitor nests.

B: A removable weighted bucket within a fixed empty bucket with a hole cut in the bottom to access the nest chamber.

C: The nesting chamber, composed of an inverted plastic bucket.

D: A corrugated tube providing access for the burrowing owls from the surface to the nest chamber.

E: A wildlife trail camera set up approximately 0.5 m perpendicular to the burrow entrance. This camera provided a close-up view of activity directly in front of the burrow.

F: A wildlife trail camera set up approximately 4 m away from the burrow entrance, directed at the entrance. This camera provided a wider-angle view of activity around the burrow entrance.

Appendix B

P1: An example photograph of the close up view, showing two juvenile owls.

P2: An example photograph of the wider view, showing a perching male adult and flying female adult.

P3: Example of photo showing an adult owl with a jumping mouse (*Zapus* sp.).

P4: Example of a photo showing an adult owl chasing a black-billed magpie.