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Barn Owls (Tyto alba) and Biodiversity Near Hemp Farms and Grasslands in Oregon, USA

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BARN OWLS (TYTO ALBA) AND BIODIVERSITY NEAR HEMP FARMS AND GRASSLANDS IN OREGON, USA

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ABSTRACT

BARN OWLS (TYTO ALBA) AND BIODIVERSITY NEAR HEMP FARMS AND GRASSLANDS IN OREGON, USA

by Lacey Brianne Thun

Extensive agriculture poses a major threat to biodiversity worldwide, although some species, such as the barn owl (*Tyto alba*), can thrive in many agroecosystems. Barn owls, the world's most widely distributed owl, provide rodent management, and their presence may be both an indicator of and support for ecosystem biodiversity. Little previous research documents the relationship between barn owls and adjacent crop attributes, however. In 2018, hemp (*Cannabis sativa*) was taken off the federal Controlled Substance Act list and permitted as an agricultural crop. Hemp is now rapidly increasing in extent in Oregon, USA. This research assessed the reproductive success and diet of barn owls, as well as the biodiversity of prey and nest visitors, near hemp fields as compared to near managed grasslands. I collected barn owl pellets and used camera data to assess nest success and prey diversity and to describe what other species visited nest boxes in five organic/no-spray hemp farms and six managed grasslands during the 2021 and 2022 nesting seasons. Barn owl nest box occupancy and success were similar, and vertebrate biodiversity was greater, in sites near hemp farms versus managed grasslands. Longer-term studies are needed to confirm my findings, but the observations indicate that hemp poses no greater threat and possibly more support to barn owl success and agroecosystem biodiversity than do managed grasslands.

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BANO – Barn Owl

Introduction

Agricultural systems can pose a significant threat to biodiversity. Since 1995, the estimate of biodiversity loss lies between 100 and 10,000 times the background extinction rate (Pimm et al., 1995). According to McLaughlin (2011), an estimated 40% of the earth's land surface and 70% of the world's fresh water are used for agriculture. If agriculture intensification continues at its the rate found in 2018, Egli et al. predict the global biodiversity value of agricultural lands will decrease 11% by 2040. Likewise, more than a decade earlier, Green et al. (2005) found agriculture to be the greatest extinction threat to current and future bird species. By 2100, if early 21st century management practices continue, six to 14% of all bird species will be extinct, seven to 25% will be functionally extinct, and 13 to 52% will be functionally deficient (Şekercioğlu et al., 2004). Additionally, the International Union for Conservation of Nature (IUCN, 2021) Red List cites agriculture as the largest threat vertebrate species, accounting for 5,407 (62%) of vertebrate listings.

In the United States, Lark et al. (2020) observed an increase in grasslands and other natural areas being transformed into row-crops at the start of the mid-to-late 2000s. They identified that croplands in the United States had risen at a rate of over one million acres per year since 2008 with some of this expansion occurring on high-quality wildlife habitat. They argue that further research on this topic is needed to know what kind of consequences this, if any, can have on wildlife.

There is growing interest in planting hemp as a row crop. In 2018, hemp (*Cannabis sativa*) was taken off the US Controlled Substance Act list and permitted as an agricultural crop. With legalization, the production of hemp in Oregon went from zero in 2013 to 15,544 hectares in 2018, and then to 19,918 hectares in 2019 (Oregon State University, 2019). This surge in hemp production is very recent and there is little to no available data regarding the impact hemp may have on local ecosystems. Jackson County, which had the greatest registered outdoor planted area of hemp in the state of Oregon in 2020 at 2,581 hectares (Jones, 2020), is an ideal location to study the effects of hemp production on local ecosystems, including the barn owl.

The barn owl is a top predator and a species that has adapted well to agricultural systems (Colvin & McLean, 1986), making this bird an exemplary indicator species for studying the impacts of hemp. Sergio et al. (2006) found higher biodiversity at locations with top predators, such as birds of prey, or raptors. They claimed raptor population success was an indicator of ecosystem health, as predator populations depend on a diverse prey base (Sergio et al., 2006). Suitable habitat and prey abundance strongly influence raptor nesting success (Gubanyi et al., 1992; Otteni et al., 1972). Studies of nesting success of raptors can help managers to steward landscapes to promote biodiversity (Colvin, 1985; Sergio et al., 2006).

Literature Review

Threats to Biodiversity from Agriculture

Millennium Ecosystem Assessment (MEA, 2005) found that the largest impact to most terrestrial ecosystems is anthropogenic land use and land use change. Other impacts included climate change, invasive alien species, overexploitation of resources, and pollution (MEA, 2005). Since 2000, Anthropogenic land use has been the leading cause of recent extinctions, taking up 95% of all terrestrial environments (IUCN, 2021; Pimentel et al., 1992; Sala et al., 2000). After urbanization, intensive agricultural land use is the biggest contributor to species decline (Czech et al., 2000). Lands that could once support a diverse range of wildlife are unable to maintain that diversity due to the expansion and intensity of agricultural productions (Reid, 2014).

In the United States, 53% of land is used for cropland, pasture land, or rangeland (Hellerstein et al., 2019). Agricultural impacts on bird species habitats include land conversion, change in trophic food webs, and chemical pollutants. To combat these impacts, Organic farming practices and biological pest management have been implemented in some agricultural systems.

Land converted to conventional extensive agricultural production generates habitat loss and degradation. If plants are tall or dense, prey can efficiently hide inside them, leading to unsuccessful hunting, and thus avoidance, by surrounding raptors (Swolgaard et al., 2008). For example, Garcia et al. (2006) found that lesser kestrels (*Falco naumanni*) avoided cereal fields, vineyards, and olive groves, possibly because their prey was less available in these modified habitats. Similarly, Väli et al. (2017) found that lesser spotted eagles (*Clanga pomarine*) avoided arable fields and preferred hunting in grasslands. As early as 1966, MacArthur and Pianka found that raptors are congregating in areas where prey abundance and availability are highest as a result of varied size and density of agricultural crops.

Land conversion degrades and decreases nesting habitat for a range of bird species (Newton, 1994). Gibbons et al. (2008) simulation model using case studies from Spain, United States, Australia, and Costa Rica predicted that mature tree abundance would drop to zero within 90 to 180 years under current agriculture practices. Removing mature trees used by cavity nesters limits bird populations (Gibbons et al., 2008). Limited nesting habitat can result in lowered bird abundance and diversity (Newton, 1994). Additionally, van Vliet et al. (2020) found the daily survival rate of nests to be negatively affected by agriculture and they argued this was most likely due to a reduction of quality habitat where these nests were located.

Trophic Food Webs. Agricultural landscapes can negatively impact trophic food webs and increase vulnerability of local ecosystems (Welbaum et al., 2004). Natural ecosystems have higher diversity than nearly all natural ecosystems converted to agriculture systems (Newbold et al., 2015). According to Loreau et al. (2003) and the insurance hypothesis, increased biodiversity protects against environmental fluctuations that could cause decline in ecosystem functions. They argue maintaining local diversity over time is an essential part to the insurance hypothesis (Loreau et al., 2003). One good indicator of a functional trophic food web is the presence of a top predator in the ecosystem (Estes et al., 2011). Sergio et al. (2006) found that top predator disappearance can be an indicator of biodiversity loss from anthropogenic causes. They saw consistently higher biodiversity levels at sites occupied by a top predator (Sergio et al., 2006). If biodiversity is greater, there is a higher chance of a functioning ecosystem even if some species are lost (Yachi & Loreau, 1999).

Increased biodiversity can lead to higher community stability and higher probability of sustainable ecosystems functions (Hooper et al., 2005). Trophic cascades may occur in both top-down and bottom-up structured systems. A top-down system is consumer-driver, meaning the system is predator-driven (Hunter & Price, 1992). While, bottom-up is resource-driven, meaning the system is inorganic-driven and not predator-driven (Polis et al., 1997). In an example of a top-down system, Rectenwald et al. (2021) found that raptors exerted top-down influences on the vital rates for northern bobwhite (*Colinus viginianus*) a native game bird. Northern bobwhites were affected by raptors in every biological season even in abundant habitat. In comparison, a bottom-up example is shown by Flowerdew et al. (2017) where woodland rodents were strongly influenced by masting and weather influences. They found bottom-up systems to be a strong influence compared to top-down (Flowerdew et al., 2017).

Raptors are often top predators and important in ecosystems surrounding agriculture. Otteni et al. (1972) proclaimed that predators are known to have direct and/or indirect impacts on prey populations. Predators directly influence prey populations by removing individuals when hunting. Conversely, predators indirectly affect prey populations due to their presence on the landscape. Their presence reduces spatial activity and physiological response from perceived predation risk (Otteni et al., 1972). Habitat changes are among the main causes of decline of raptor populations (Newton, 1994). Using a top-down system, raptors can sometimes regulate ecosystem dynamics by managing prey population (Väli et al., 2017). Loss in top predators, such as raptors, can lead to changes in the entire ecosystem, including rodent pest outbreaks and trophic cascades (Estes et al., 2011; Şekercioğlu et al., 2004).

Chemical Pollutants. Chemical pollutants include rodenticides, herbicides, insecticides, fungicides, and synthetic fertilizer. Chemical pollutants are applied and leak into ecosystems nearby (Gibbs et al., 2009). In 2012, The U.S. Environmental Protection Agency (EPA) data showed that U.S. agriculture producers spent over $9 million on rodenticides, herbicides, insecticides, and fungicides which totaled approximately 40 million kilograms (Hellerstein et al., 2019). In 2014, herbicide quantities reached approximately 232 million kilograms an increase of 56% since 2002 (Hellerstein et al., 2019) The heightened use of these pollutants has created groundwater contamination, evolution of herbicide tolerant weeds, and decreased biodiversity (Gibbs et al., 2009; Murphy & Lemerle, 2006).

Slankard et al. (2019) found raptors that were directly killed or had nonlethal effects after predating on rodents that consumed rodenticides. They found that out of the 48 barn owls they tested (*Tyto alba*) 16 (33%) were positive for rodenticides. Similarly, Murray (2011) found out of 161 birds (red-tail, barred owls, eastern screech, great horned) they tested 86% were positive for rodenticides. Mortality due to rodenticides was diagnosed in 6% of them (Murray, 2011).

Organic Farming and Biodiversity

Organic farming has becoming more prevalent and the benefits of it in comparison to conventional farming is a growing topic of research. Certified organic food is produced without synthetic pesticides, petroleum-based, sewage-sludge-based fertilizers, genetic engineering (biotechnology), antibiotics, or growth hormones (U.S. Department of Agriculture, 2017b). The U.S. Department of Agriculture reported certified organic farming has doubled between 2006 and 2016 due to the rise of product demand in the United States (Hellerstein et al., 2019). In 2021, United States ranches and farms produced and sold $11.2 billion in certified organic products, a 13% increase from 2019 (U.S. Department of Agriculture, 2022b). There were 17,445 certified organic farms and approximately 1,982,960 hectares of organic farmland (U.S. Department of Agriculture, 2022b).

Organic farming is associated with soil health, including longer crop rotations, non-chemical pest management, and use of cover crops (Tuck et al., 2013). Tuck et al. (2013) conducted a meta-analysis of studies that compared biodiversity of organic versus conventional farming methods. They found that on average organic farming increased species richness of arthropods, birds, microbes, and plants by 30% in comparison to conventional farming (Tuck et al., 2013). Beecher et al. (2002) found bird abundance to be 2.6 times higher on organic farm sites than on conventional farming sites and organic sites had higher abundance and richness of insectivores, omnivores, granivores, and migratory groups compared to conventional sites. Likewise, a Kirk et al. (2020) study conducted in Canada established that birds can benefit from organic farming. They found that the benefit of organic farming increases as agriculture intensity increases (Kirk et al., 2020). Organic farming is a dependable method for increasing biodiversity on farmlands (Tuck et al., 2013).

Barn Owls (Tyto Alba) Life History

Barn owls belong to their own family called Tytonidae, derived from the Greek word tuto, meaning "night owl." They are distributed worldwide, and are the most widely distributed owl species (Taylor, 1994). Barn owls (*Tyto alba*) are a nocturnal, cosmopolitan raptor species. They are medium sized (32 to 40 cm) and have an average lifespan of two years (Taylor, 1994). Barn owls have a white to light brown heart-shaped face, short tail, no ear tufts, buff feather coloration, and small eyes that distinguish them from other owls. Barn owls do not migrate and prefer open habitats such as grasslands, deserts, marshes, and agricultural fields (Taylor, 1994). Barn owls are cavity nesters, nesting in cliffs, banks, caves, abandoned bird nests, and man-made structures such as towers, barns, and nest boxes (Otteni et al., 1972). This ability to adapt to human-altered environments has allowed barn owls to be widely dispersed. Although this species can adapt to human-altered environments, still, land conversion and urbanization has led to decreased worldwide populations of barn owls due to loss of hunting and nesting habitat (Taylor, 1994).

Barn owls' tolerance for conspecifics is uncommon among raptors (Smith et al., 1974). Where suitable nesting sites are numerous, barn owls gather and exhibit low territory response to conspecifics. They have a monogamous mating strategy and tend to mate for life, although polygyny has been recorded (Marti, 1990). Barn owls lay their eggs directly on hard surfaces or on top of trampled pellets (Otteni et al., 1972). The compressed pellets full of animal bone, feathers, and fur create a mat for the eggs (Otteni et al., 1972). Barn owls' nesting season typically begins in spring and ends in late summer, but pairs have been seen raising young year-round. Barn owls lay one to two clutches, and the average clutch size is 4 to 7 eggs, a relatively large number of eggs compared to other raptor species (Taylor, 1994). While the female incubates eggs, she rarely leaves the nest, replying on the male barn owl to supply the food (Marti, 1990). Barn owl owlets are cared for by both parents, they are provided the same diet as the adults and are fed for more than two months after fledging (Kopji, 2013). For adult barn owls to be reproductively successful, they need food supplies to be adequate for roughly 18 weeks (Kopji, 2013).

Barn owls are opportunistic foragers, but predate primarily on small mammals (Taylor 1994), however, barn owl diet can also include birds, reptiles, amphibians, and insects (Otteni et al., 1972; Taylor, 1994). Pellets collected in a study by Gubanyi et al. (1992) showed 99.3% of all prey were of mammal species and Colvin and McLean (1986) state that barn owl numbers are especially dependent on voles (*Microtus* species) availability. Barn owl population productivity will significantly decrease when small mammal availability as prey reduced (Otteni et al., 1972). Otteni et al. (1972) found 1.5 times as many barn owl young raised per pair in years when rodent prey populations were abundant than in years when prey was limited. Barn owls, as well as many other species of raptors, regurgitate pellets of indigestible material (i.e., hair, bone, exoskeleton, etc.) that they consume. Prey analysis is readily accessible due to this. Pellets can be dissected to distinguish what prey was ingested by the owls (Colvin & McLean, 1986; Kross et al., 2016). Data for barn owl diets from pellets are extensive and from various agricultural systems, however no studies have been done in southern Oregon.

Biological Pest Management

Rodents are prevalent pest species in farms and agricultural areas and can be a limiting factor in conventional farms (Garbach et al., 2014). In the U.S., yearly rodents lead to millions of dollars in damage to conventional agriculture systems (Keirn, 2017). Conventional pest management includes trapping or poisoning. Both of these methods are costly, time-consuming, and have significant adverse effects on non-target species. Rodent eaters, such as barn owls, can benefit agriculture by providing biological pest management due to them predating on local pest species (Meyrom et al., 2009). Placing raptor sized nest boxes in agricultural systems can increase local cavity nesting raptor populations, decreased nestling predation, and increased nesting habitat (Moller, 1994).

Motro (2011) found barn owl presence had a positive effect on alfalfa crop yield, enhancing crop by 3.24% and a net profit of $30/hectare-year. Meyrom et al. (2009) found since establishing the pest control program, farmers use barn owls as an alternative method of rodent control which resulted in greatly reducing the use of rodenticides. Worldwide, nest boxes have been used to attract predatory birds to help provide biological pest control in agricultural systems. Internationally, nest boxes have been used in a variety of agricultural systems including alfalfa and mixed agriculture (Meyrom et al., 2009; Motro, 2011). In the United States, nest box programs have been used in row crops and vineyards (Kross et al., 2016; Wendt & Johnson, 2017). Kross et al. (2016) found 99.5% of all prey of barn owls were agricultural pest species.

Barn owls are an excellent species for nest boxes, since they are only territorial in direct vicinity of their nest during the breeding season (Meyrom et al., 2009). A breeding pair of barn owls will live together at the nesting site and produce large numbers of young that eat the same diet as adults, which means they have a high likelihood of predating on pest species.

Hemp on the Landscape

Hemp is an herbaceous dioecious annual crop with a rigid woody stem ranging in height from one to over five meters (Ehrensing, 1998). Hemp (*Cannabis sativa* L.) was first recorded in central Asia as early as 2800 BCE and was originally used for cloth, fuel, food, and oil (Ehrensing, 1998). In 1645, the Puritans in New England introduced hemp into the U.S. to be used in household spinning and weaving (Ehrensing, 1998). Hemp is highly versatile and grows in diverse environmental conditions within the temperate climatic zone (Ehrensing, 1998). Hemp grows best in warm growing conditions (between 15.55° to 26.67° C), highly productive soils, and ample moisture during the growing season (Ehrensing, 1998). Hemp is cultivated for its stem fibers, seed oil, and medicinal properties and potential commercial uses today are fiber, pharmaceuticals products, grain, and seed (Ehrensing, 1998; U.S. Department of Agriculture, 2019).

In 1937, the U.S. passed the Marijuana Tax Act that restricted production of psychoactive *Cannabis* varieties in the U.S. This tax, in addition to penalties for production and sales, wrecked the U.S. hemp industry (Ehrensing, 1998). The 2014 Farm Bill legalized *Cannabis* production (Cherney & Small, 2016). In 2018, hemp (*Cannabis sativa*) was taken off the federal Controlled Substance Act and deemed an alternative agricultural crop. Hemp produced in the United States increase from zero hectares in 2013 to 21,914 hectares in 2021 (Mark et al., 2020; U.S. Department of Agriculture, 2022a). In 2021, U.S. in the open hemp production totaled $712 million (U.S. Department of Agriculture, 2022a).

Hemp is strongly competitive with weed species. Due to hemp being competitive, herbicides are not usually needed (Ehrensing, 1998). Furthermore, hemp traditionally does not need the use of pesticides, as it is a natural repellant of insect species (Cherney & Small, 2016). This results in less use of pesticides and herbicides in the landscape compared to other crops. However, according to McPartland (1996), mice and a variety of bird species feed on hemp seeds, leaves, and stems resulting in significant crop losses (McPartland, 1996). Barn owls' nest boxes may mitigate these crop losses by predating on potential pest species.

Objectives

Agriculture generates modifications to the natural environment that include habitat loss, negatively impact trophic food webs, and upsurge of chemical pollutants that all adversely affect biodiversity (Estes et al., 2011; Gibbs et al., 2009; Newton, 1994). There is expanding literature investigating how wildlife uses agricultural habitats, but specific geographical and crop-based research would increase successful application of the results in management plans. Raptors are top predators their presence is an indicator of a functional ecosystem (Estes et al., 2011; Şekercioğlu et al., 2004). Loss of raptor populations has been linked to agricultural expansion and loss of grassland habitat (Colvin, 1985; Taylor, 1994). Some species are adapting to these changes; however, additional research is needed to know what habitat characteristics are essential for raptor survival (Swolgaard et al., 2008; Wendt & Johnson, 2017). Additionally, rodenticides are linked to toxicity in wildlife species and lower prey abundance (Gibbs et al., 2009). More research is needed on pest management options to eliminate or reduce the use of these chemicals. The rapid, recent growth of hemp as an agricultural crop necessitates research on the potential impact of this crop on local ecosystems.

The barn owl is a raptor that is highly adaptable to agricultural systems and are significant predators of rodents (Colvin & McLean, 1986). In particular, attracting barn owls to specific agricultural sites using artificial nest boxes has shown positive results (Meyrom et al., 2009; Wendt & Johnson, 2017). Because of their adaptability to agriculture, barn owls are a potential indicator species for studying the impacts of hemp farms on biodiversity and the potential benefits of barn owls for hemp agriculture. While substantial research has been conducted in other agricultural systems, no data connects the growing number of hemp farms in the United States with barn owl behavior, nesting success, and diet. Hemp production in Oregon is growing rapidly and a number of farms use organic or chemical-free methods. Thus, Oregon provides opportunities for research into the interaction between barn owls and organic/no spray hemp farms. The objective of this research was to evaluate barn owl nest boxes and to collect preliminary information on the extent to which barn owls will use nest boxes near hemp farms in relation to managed grasslands.

Research Questions

This thesis research investigated the following research questions:

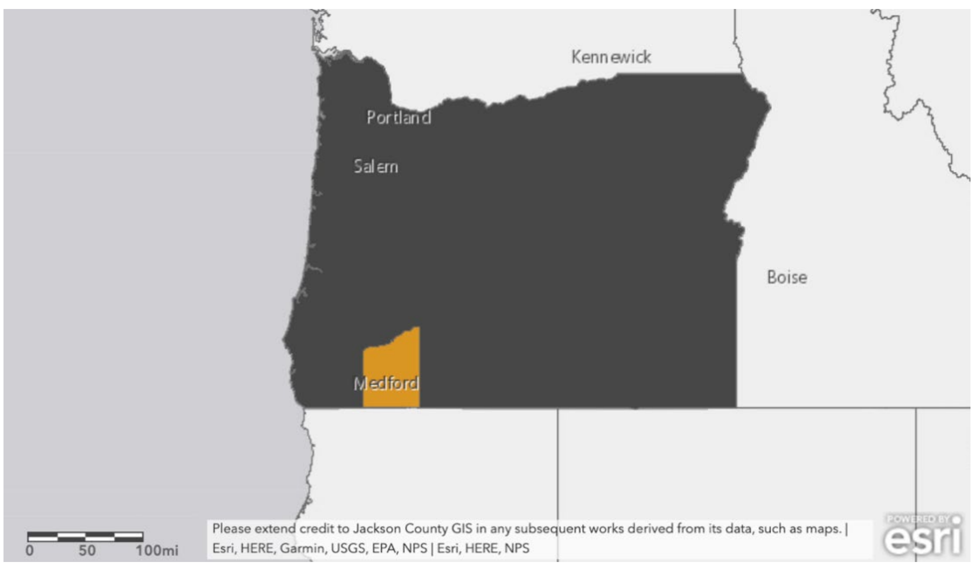
> In Jackson County, Oregon, how do organic/no spray hemp farms differ from managed grassland with respect to:
>
> > **RQ1**: occupancy and nesting success of barn owls in nest boxes and/or at other nest sites?
> >
> > **RQ2**: breeding barn owl prey composition?
> >
> > **RQ3**: other avian species visiting barn owl nest boxes or the immediate vicinity of the nest boxes?

Methods

Study Sites and Target Populations

The study sites were located within 1.2 km of the western border of the Jackson County, in southwestern Oregon (Figure 1). The county covers approximately 7,209 km^2 and has a human population of approximately 219,564 in 2018 (U.S. Census Bureau, 2018). The climate is Mediterranean. Average temperature ranges are 4.4 to 33.78 °C. Jackson County has a variety of vegetation zones including mixed conifer, chaparral, oak savanna, grassland, and riparian zones.

Figure 1
Jackson County, Oregon



Note. Location of study area within Oregon. Adapted from "World topographic map," by Esri, 2022, https://sjsugis.maps.arcgis.com/apps/mapviewer/index.html

In 2017, the County reported 2,136 farms and 690 km^2 out of 7,209 km^2 of land was used by farms (U.S. Department of Agriculture, 2017a). Land used in farms was distributed by cropland (24%), pastureland (39%), woodland (30%), and other (7%) (U.S. Department of Agriculture, 2017a). Jackson County had the highest registered outdoor hemp hectares of

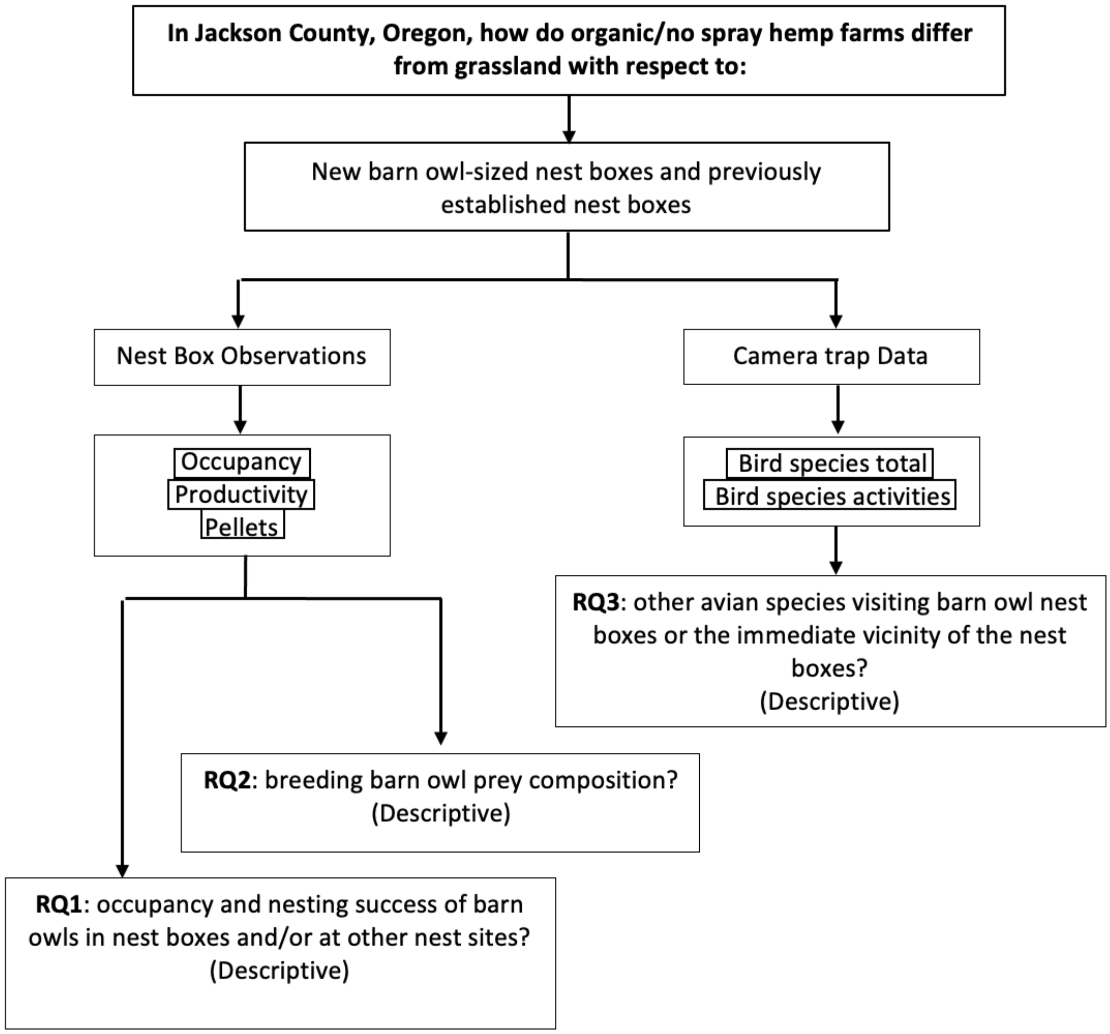
2,582 out of 11,102 in all the Oregon counties in 2020 (Jones, 2020). Study sites included both organic/no spray hemp farms and managed grasslands.

All five hemp farms used in this study were no spray. The term *no spray* is used to describe hemp farms where no pesticides, herbicides, or fungicides are applied at any point during crop production. Two hemp farms were owned by Horn Creek Hemp. The Horn Creek Hemp website includes the following statement: "Horn Creek's hemp flower is grown using biodynamic and organic practices. We adhere to a stringent program that meets or exceeds USDA organic practices. Our USDA certification in 2021 was incomplete due to a non-certified biodegradable mulch" (Horn Creek Hemp, 2022).

Certified organic farms accounted for only 2% of farms in Jackson County (U.S. Department of Agriculture, 2017a), but many producers involved in this study report informally that they do not use synthetic chemicals. Three hemp farms included in this study were certified organic. Managed grasslands are grasslands that choose and manage forages, soil fertility, fencing, water development and distribution, harvesting, and resting of the grasslands (U.S. Department of Agriculture, 2000). The grassland managers reported using no rodenticides, insecticides, herbicides, and fungicides in those lands.

The target sample population was breeding-age pairs of barn owls using nest boxes during the 2021 and 2022 breeding season (Figure 2). Barn owls are year-round residents in Oregon and regularly breed in Jackson County. Barn owls are considered common in agricultural systems in Oregon and have not been listed as a rare or threatened/endangered species within Oregon (Oregon Department of Fish & Wildlife, 2022). Established owl

Figure 2
Study Design Flowchart



Note. Flowchart for 2020 through 2022 Surveys and how they were used to answer the research questions

residents may begin nesting as early as March, with nests being occupied from March to August.

Other species studied included local avian species and barn owl prey species. Because Oregon has diverse habitats and landscapes, a variety of avian species can be observed (Figure 2). Bird species that could use these nest boxes are other cavity nesters such as

American kestrel (*Falco sparverius*), western bluebird (*Sialia mexicana*), acorn woodpecker (*Melanerpes formicivorus*), northern flicker (*Colaptes auratus*), tree swallow (*Tachycienta bicolor*), and house wren (*Troglodytes aedon*) to name a few (Coe, 2014). Barn owls predate upon a variety of species. These prey species include rats, mice, voles, gophers, birds, and insects (Kross et al., 2016). In Oregon, barn owl diet has been shown to be predominately voles (genus Microtus) and pocket gophers (Geomyidae) (Browning, 2015).

Study Design

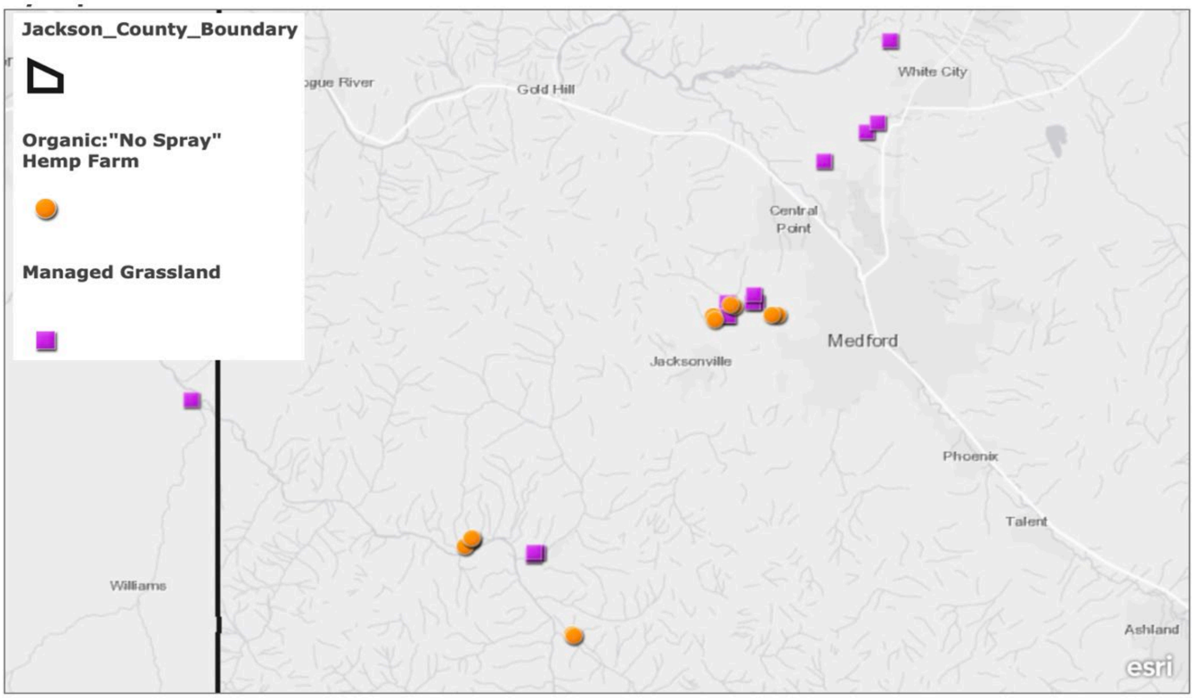
The study period extended from February to early September 2021 and February to July 2022. Hemp farms ranged from 5 hectares up to approximately 142 hectares. Hemp was planted as early as May and harvested in September. Adjacent habitat included oak woodlands, mixed conifer forests, and rangeland. Grasslands were managed through mechanical control. Mechanical control included mowing weeds or harvesting hay.

I distributed a total of 20 nest boxes across five organic/no spray hemp farms and six grasslands (Figure 3). Next boxes were installed starting March 2020 and ending February 2021. Two nest boxes were placed on the perimeter of each individual survey site for the five farm locations and four of the grasslands, and two additional nest boxes were placed at separate grassland locations, resulting in a total of 10 nest boxes in each habitat type (Figure 4).

Nest boxes were used to monitor barn owl occupancy and nesting success. In addition to 10 newly-established nest boxes, six previously-established barn owl nest boxes were observed in 2021 and 2022 (Table 1 and Figure 5). Surveys for occupied nests began in February to determine nest box occupancy, as per Wendt and Johnson (2017).

Figure 3

Barn Owl Nest Boxes within Jackson County, Oregon



County of Jackson, OR, Bureau of Land Management, State of Oregon, State of Oregon DOT, State of Oregon GEO, Esri, HERE, Garmin, USGS, EPA, NPS | Esri, HERE, NPS

Note. Locations of barn owl nest boxes within and adjacent to Jackson County, Oregon. Adapted from "World topographic map," by Esri, 2022, https://sjsugis.maps.arcgis.com/apps/mapviewer/index.html

I installed ten camera traps at Nest ID BANO04, BANO06, BANO07, BANO09, BANO12, BANO13, BANO14, BANO15, BANO17, BANO18. The purpose of these camera traps at barn owl nest boxes was to collect data on occupancy, prey delivery numbers, prey type, reproductive success, numbers of chicks, and nest disturbances. Camera traps also collected data on other avian species present at nest boxes, number of species present, location, activity displayed, time, and duration. Camera trap placement was limited to sites where permission was received by the homeowners/landowners. I checked cameras every two to three weeks for occupancy. Additionally, I checked newly and previously established

Figure 4

Example Placement of Organic/No Spray Hemp Nest Boxes

Note. Location of barn owl nest boxes (Nest ID BANO01 and BANO02) on the perimeter of an organic hemp farm. Adapted from Google Earth; "World topographic map," by Esri, 2022, https://sjsugis.maps.arcgis.com/apps/mapviewer/index.html

nest boxes with and without cameras every two to three weeks, looking for clutch size, number of nestlings, and young that fledge to determine nesting success (Hindmarch et al., 2012; Martin et al., 2010; Wendt & Johnson, 2017).

In addition to the camera data, I conducted pellet analysis on pellets egested inside and outside the barn owl nest box in 2021 (Engeman et al., 2016). Pellet analysis gave data on prey species composition, differential prey selection, and minimal number of prey items (Colvin & McLean, 1986). Pellets also helped to determine if barn owl nesting diet includes pest species (Meek et al., 2009; Moore et al., 1998). After the nesting bird season, I cleared the nest boxes of sticks, pellets, and hornet nests. This procedure occurred during the evening

Table 1
All Barn Owl Nest Boxes Studied during the Project for 2021 and 2022 in Jackson County, Oregon

Nest ID	Field Type	Year Box Established	Mounting Surface	Year(s) Studied
BANO01	Hemp	2020	Metal Pole	2021, 2022
BANO02	Hemp	2020	Metal Pole	2021, 2022
BANO03	Grassland	2020	Tree	2021, 2022
BANO04	Grassland	2020	Metal Pole	2021, 2022
BANO05	Grassland	2020	Metal Pole	2021, 2022
BANO06	Grassland	2020	Metal Pole	2021, 2022
BANO07	Grassland	2020	Metal Pole	2021, 2022
BANO08	Hemp	2020	Metal Pole	2021, 2022
BANO09	Hemp	2020	Metal Pole	2021, 2022
BANO10	Hemp	2020	Metal Pole	2021, 2022
BANO11	Hemp	2020	Metal Pole	2021, 2022
BANO12	Hemp	2020	Metal Pole	2021, 2022
BANO13	Hemp	2020	Metal Pole	2021, 2022
BANO14	Hemp	2020	Metal Pole	2021, 2022
BANO15	Hemp	2020	Metal Pole	2021, 2022
BANO16	Grassland	2020	Metal Pole	2021, 2022
BANO17	Grassland	2020	Metal Pole	2021, 2022
BANO18	Grassland	2020	Metal Pole	2021, 2022
BANO19	Grassland	2021	Metal Pole	2021, 2022
BANO20	Grassland	2021	Metal Pole	2021, 2022
BANO21	Hemp	Prior to 2020	Barn	2021, 2022
BANO22	Hemp	Prior to 2020	Barn	2021, 2022
BANO23	Grassland	Prior to 2020	Barn	2021, 2022
BANO24	Grassland	Prior to 2020	Building	2021, 2022
BANO25	Grassland	Prior to 2020	Building	2022
BANO26	Grassland	Prior to 2020	Barn	2022

Figure 5
Managed Grassland Established Barn Owl Nest Box

Note. Example location of an established barn owl nest box (Nest ID BANO22) placement on managed grassland location.

and involved reaching into the top opening of the nest box with a ladder. Prior to approaching the ladder, I checked all nest boxes for occupancy using the same protocol that I used during the nesting bird season.

Data Collection/Procedures

I studied barn owl nest boxes for a total of 23 months during 2020 through 2022. Barn owl nest boxes were created following the design provided in Wade et al. (2012) (Figure 6 and Figure 7; Appendix A). To access study sites, I asked permission from individual landowners to build, monitor, and survey the areas. I contacted landowners using email or by phone. Once in contact, I obtained written permission to access sites for the duration of the study.

Figure 6

Managed Grassland Newly-Established Barn Owl Nest Box

Note. Barn owl nest box (Nest ID BANO05) at managed grasslands location.

Figure 7

Organic/No Spray Hemp Newly-Established Barn Owl Nest Box

Note. Barn owl nest box (Nest ID BANO09) at hemp field location.

Between the hours of 1000 and 1600, I recorded time of collection, quantity, and location and number of pellets on each nest visit. Barn owl nest box examinations were done using a small camera (DEPSTECH 5.5mm WiFi Borescope Wireless Endoscope Camera) attached to an extendable pole, into the nest box opening (Figure 8) (Wendt & Johnson, 2017). Two nest boxes (Nest ID BANO22 and BANO23) could not be examined using a small camera as they were inaccessible by ladder (Nest ID BANO22) or were blocked by work equipment (Nest ID BANO24). These two boxes were examined by observing nest boxes for four hours on each visit to detect adult or young activity.

Figure 8

Photo of Barn Owl Adult on Top of Nestling in Managed Grassland in 2022

Note. Example photo collected with a small camera attached to an extendable pole, into the nest box opening at a previously-established barn owl nest box (Nest ID BANO26).

Pellet analysis used skulls, mandible, femurs, and dentition to identify prey items (Huysman et al., 2018). Skulls, femurs, and dentition were used to identify prey genus or species (Balčiauskas & Balčiauskienė, 2011; Trejo & Guthmann, 2003). When non-mammalian prey was found, skulls and mandibles were used to identify prey to genus or species (Glue, 1974). Pellets were only collected from three nesting sites (Nest ID: BANO21, BANO22, BANO23) as I knew these were fresh from the 2021 breeding season.

Camera trap data was collected on game cameras Bushnell - Nature View HD Cam and Bushnell - Trophy Cam. Game cameras were installed with reusable batteries and 16GB SD cards. Game cameras were placed approximately five to six meters from nest boxes (Gronnesby & Nygard, 2000); however, distance was limited as I relied on old fence posts and tree trunks for camera placement. Game cameras settings were set to photo mode, burst of three photos, 30-second delay between photos, and high sensitivity. SD cards were checked every two to three weeks and downloaded to a MacBook pro in the field. All data was entered into excel. Photos were viewed individually and categorized into three categories. The three categories were "empty" as in nothing was in the photo, "wildlife" when any type of wildlife or domestic species was included, and lastly "human/human object" when a human or machinery were in the photo. The wildlife category was broken down further to three additional categories in reference to the nest boxes which included if an individual entered the nest box, perched on the nest box, or were flying by. Each nest box was checked a total of 30 times during the study, approximately 445 hours of boxes were observed, and roughly 62,000 photos were processed from the camera traps.

Data Analysis

I manually entered all data into Excel. Nest box occupancy, nest box productivity, barn owl prey composition, and bird species observed by camera traps were all summarized in table form.

Results

Nest Boxes

Occupancy

Over the first 18 months of this study, no birds of any species were observed nesting in the boxes established in 2020 and 2021. During the final five months in 2022, two of the nest boxes one in a hemp farm (Nest ID BANO11) and one in a managed grassland (BANO19) were occupied (Table 2). Both nest boxes that became occupied had attempted nests, but both nests failed. In 2021, all six previously-established barn owl nest boxes were occupied with barn owls and all fledged young (Table 2). In 2022, five (BANO21, BANO22, BANO23, BANO24, and BANO25) out of the six previously-established nest boxes barn owl occupied them and all fledged young.

Six barn owl nesting attempts were observed, two in previously-established boxes near hemp farms and four adjacent to managed grasslands, one of which was in a study nest box and three in previously-established nest boxes (Table 3). One nest was attempted by an American kestrel in one of the newly-established nest boxes adjacent to an organic/no spray hemp farm (Table 3).

Description of Nesting Attempts in Managed Grassland Nest Boxes

In 2021, sticks were present in three managed grasslands nest boxes (Nest ID BANO01, BANO5, and BANO06) during April and May (Table 2). The majority of the nest boxes were cleaned after the breeding season on September 4 and 5 2021. On September 5, 2021, during the nest box clean out, a juvenile barn owl was flushed from one of the nest boxes in managed grasslands (Nest ID BANO19) during walk-up at 17:00. Due to this, I delayed

Table 2

Newly-Established Nest Box Data for 2021 and 2022 in Jackson County, Oregon

Nest ID	Field Type	Occupancy Species	Occupied Year(s)	Notes
BANO01	Hemp	Unoccupied	-	Stick nest present in 2021
BANO02	Hemp	Unoccupied	-	Large bird poop both years. Sticks inside nest box and BANO feather outside box in 2022
BANO03	Grassland	Unoccupied	-	-
BANO04	Grassland	Unoccupied	-	-
BANO05	Grassland	Unoccupied	-	Sticks inside 2021 and 2022
BANO06	Grassland	Unoccupied	-	Sticks, NOFL feathers inside, small bird scat
BANO07	Grassland	Unoccupied	-	NOFL feathers inside, small bird scat. In 2021 CAGO nested on bottom of tree adjacent to nest box (~1 meter)
BANO08	Hemp	Unoccupied	-	Small pellets (AMKE) present in 2021
BANO09	Hemp	Unoccupied	-	Small pellets (AMKE) present in 2021
BANO10	Hemp	Unoccupied	-	Woodpecker damage to outside of box
BANO11	Hemp	AMKE	2022	Woodpecker damage to box in 2021, AMKE eggs present in 2022
BANO12	Hemp	Unoccupied	-	Small pellets (AMKE)
BANO13	Hemp	Unoccupied	-	Small bird scat
BANO14	Hemp	Unoccupied	-	Hornet nest in 2021
BANO15	Hemp	Unoccupied	-	-
BANO16	Grassland	Unoccupied	-	-
BANO17	Grassland	Unoccupied	-	-
BANO18	Grassland	Unoccupied	-	-
BANO19	Grassland	BANO	2022	BANO seen and pellets in 2021, BANO eggs in 2022
BANO20	Grassland	Unoccupied	-	-

Table 3

Previously-Established Nest Box Data for 2021 and 2022 in Jackson County, Oregon

Nest ID	Field Type	Occupancy Species	Occupied Year(s)	Notes
BANO21	Hemp	BANO	2021, 2022	BANO successfully nested in 2021 and 2022
BANO22	Hemp	BANO	2021, 2022	BANO successfully nested in 2021 and 2022
BANO23	Grassland	BANO	2021, 2022	BANO successfully nested in 2021 and 2022
BANO24	Grassland	BANO	2021, 2022	BANO successfully nested in 2021 and 2022
BANO25	Grassland	BANO	2021, 2022	Not studied in 2021. BANO successfully nested in 2022
BANO26	Grassland	Unoccupied	-	-

cleaning this nest box until the barn owl was not present. The barn owl was not seen again during two following visits (September 18 and October 2) in 2021. On October 2, pellets were collected from Nest ID BANO19 nest box.

During the final five months in 2022, one of the nests was occupied by a barn owl (Nest ID BANO19). On March 14, 2022 numerous pellets were on the ground and inside the nest box. On April 26, I observed four eggs within the nest box and more pellets on the ground. During this observation no adult was seen incubating the eggs nor nearby. During subsequent visits (bi-weekly visits from May 8 to September 2, 2022) no adult barn owl was seen at this location, and the eggs did not hatch. This nest was deemed to have failed (Figure 9).

Figure 9

Photo of Four Barn Owl Eggs in Managed Grassland on April 26, 2022

Note. Photo collected with a small camera attached to an extendable pole, into the nest box opening at barn owl nest box (Nest ID BANO19).

Descriptions of Nesting Attempts in Hemp Farm Nest Boxes

In 2021, there were no nests present in the organic/no spray hemp farms nest boxes. I directly observed raptors in five (Nest ID BANO01, BANO02, Nest ID BANO08, BANO09, and BANO12) indirectly observed pellets or feathers in or around two of those nest boxes (Nest ID BANO01 and BANO02). Additionally, on May 8, 2021, I observed a stick nest inside of Nest ID BANO01. On April 26, 2022, sticks and unknown avian down feathers were located inside Nest ID BANO02. This same day, a barn owl wing feather was located on the ground below the nest box. Lastly, American kestrel pellets appeared in three nest boxes (Nest ID BANO08, BANO09, and BANO12) between March and May 2021. No pellets were observed in 2022.

In 2022, one newly-established nest box became occupied by an American kestrel (Nest ID BANO11). On March 15, while I was checking the nest box I observed an American Kestrel adult leaving the opening of the box. The American kestrel was observed flying away and flew into a group of trees where location of the bird was lost. No eggs were seen at this time. On April 26, two American kestrel eggs were observed in the box and no adult was present (Figure 10). On May 13, five eggs were observed in the box and again no adult was present. Following bi-weekly visits (June 1 to September 2, 2022) to this nest, the eggs never hatched and the nest box was also deemed to have failed.

Previously-Established/Occupied Boxes

During the 2021 breeding season, all four previously-established/occupied barn owl nest boxes that were surveyed became occupied with barn owls. Two barn owl boxes were in managed grasslands and two nest boxes were in organic/no spray hemp farms. Each of the

Figure 10

Photo of Five American Kestrel Eggs in Organic/No Spray Hemp Farm on June 1, 2022

Note. Photo collected with small camera attached to an extendable pole, into the nest box opening at barn owl nest box (Nest ID BANO11).

barn owl pairs at the four nest boxes attempted one clutch and successfully fledged chicks (Table 4). Throughout the 2022 breeding season, five out of six established barn owl nest boxes that were surveyed became occupied with barn owls. For the one unoccupied nest box (Nest ID BANO26), no bird activity was observed throughout the whole season. All five (100%) of the active nests successfully fledged chicks and attempted one clutch each (Table 4). Incubating barn owls were observed beginning on March 14 and March 16 (Nest ID BANO21, BANO23, BANO24, and BANO25).

Description of Nesting Attempts in Managed Grassland Nest Boxes

In 2021, I did not observe egg laying and nestlings at two of the barn owls' nests in managed grasslands (Nest ID BANO23 and BANO24) (Table 3). In 2021, Nest ID BANO23 nest had adults occupying the nest box starting April 28. On June 13, I heard a minimum of two young inside the nest box. On July 2, fledgling was observed outside of nest the box. On

Table 4

Reproductive Data for Newly and Previously-Established (Barn or Open) Barn Owl Nest Boxes for 2022 in Jackson County, Oregon

Nest ID	Field Type	Newly or Previously-Established	Building Type	Occupancy Species	Eggs	Nestlings	Fledglings
BANO11	Hemp	Newly	On pole	American Kestrel	5	0	0
BANO19	Grassland	Newly	On pole	Barn owl	4	0	0
BANO21	Hemp	Previously	Barn	Barn owl	-	3	3
BANO22	Hemp	Previously	Barn	Barn owl	-	-	3
BANO23	Grassland	Previously	Barn	Barn owl	-	-	2
BANO24	Grassland	Previously	Open	Barn owl	6	5	5
BANO25	Grassland	Previously	Open	Barn owl	-	3	3

July 18, landowner confirmed a total of two fledging left the nest box. During follow up visits (bi-weekly from August 1 through September 4) no more fledglings were observed. Lastly, on April 28, Nest ID BANO24 nest had one owlet fledge from the nest.

In 2022, three previously established/occupied nests were surveyed (Nest ID BANO23, BANO24, and BANO25). Due to similar lack of access to view inside the nest box, Nest ID BANO23 egg laying and nestling total was not observed. On April 26, I heard two young inside the nest box. On following visits (bi-weekly May 4 through September 2) no young were seen or heard, however none were found to be deceased nearby. I observed six eggs in Nest ID BANO24 on March 16. On April 27, an adult was observed on nestlings and two nestlings were observed. Adult obstructed visuals, but on May 20 six nestlings were observed (Figure 11). On June 1, Clayton Barber with Oregon Department of Fish & Wildlife informed me that one nestling had died. Nestling had previously fallen out of the nest and was placed back in. However, on June 1, that nestling died. Three out of the five had fledged by June 15. During subsequent visits, I observed the other two had fledged and were roosting in the nest box.

Lastly, established nest box (Nest ID BANO25) eggs were not observed due to incubating adult obstructing view (Figure 7). On April 27, an adult was observed on nestlings and two nestlings were observed. May 20 three nestlings were observed. On June 15, three fledging were seen. Two were seen inside open building near box and the third was roosting in nearby tree (Figure 12).

Figure 11

Barn Owl Nestling Observed in Nest Box in Managed Grasslands

Note. Previously-established barn owl nest box in building (Nest ID BANO24). Four nestling out of five barn owl fledge in 2022.

Figure 12

Barn Owl Fledge Near Nest Box in Managed Grassland

Note. Previously-established barn owl nest box (Nest ID BANO25). One fledgling out of three in 2022.

Descriptions of Nesting Attempts in Hemp Farm Nest Boxes

In 2021, egg laying was only observed in one nesting pair in organic/no spray hemp farms. Of the one nesting pair where eggs were observed, Nest ID BANO21 eight eggs were observed on April 17, 2022. On April 30, a total of seven nestlings were observed. Six nestlings were alive in the nest and one was found dead below the nest (Figure 13). By August 15th, all six owlets had fledged and left the nest. The second nest (Nest ID BANO22) eggs and nestling were not observed due to inaccessibility. On April 3, May 22, and June 13, an adult barn owl was seen on barn beam near roof of barn within 15 meters of nest box. On July 27, two nestling almost fledgling were seen in opening on nest box. On September 4, a single wing and down feathers were found on ground of barn. During this visit no other barn owl were seen or heard.

Figure 13

Adult Barn Owl with Nestlings in Organic/No Spray Hemp Farm

Note. Established barn owl nest in barn (Nest ID BANO21). One adult female and three nestlings out of six in 2021.

In 2022, the first established nest box surveyed (Nest ID BANO21) was on April 3 and eggs were unable to be observed in 2022 due to an aggressive adult. On April 26, three nestlings were observed at the nest. On May 19, one fledgling was observed and none were seen deceased. For Nest ID BANO22, eggs and nestling once again could not be observed due to inaccessibility to nest box. On June 1, I observed two fledglings roosting in the barn and deemed the nest successful. In conclusion, for previously-established boxes, organic/no spray hemp farms are not a limiting factor for breeding barn owls. Previously-established boxes in organic/no spray hemp farms had equal, if not more, chicks fledged in comparison to previously-established nest boxes in managed grasslands.

Pellets Analysis

I collected a total of 60 pellets from three barn owl nests (Table 4). Organic/no spray hemp farms had 57 out of the 60 pellets that were collected. In total, Norway rat (*Rattus norvegicus*), house mouse (*Mus musculus*), California vole (*Microtus californicus*), northern broad-footed mole (*Scapanus latimanus*), and house finch (*Hoemorhous mexicanus*) could be identified from regurgitated pellets collected from September 5, 2021 to September 15, 2021 (Table 4). Prey species were counted as a percentage of total prey found in pellets at each species nest site (Table 5). The highest percentage of prey found in the barn owl pellets for both field types were California vole at 91% (Table 5).

Nest Box Use by Other Species

I captured a total of 25 different bird species on camera from March to September 2021 in a total of roughly 62,000 pictures at 10 nest boxes. 417 photos had captured birds (Figure 14). 7 bird species were captured flying over or by the nest box, 20 were perching on the box,

Table 5

Number of Each Type of Prey in Pellets Collected at Three Barn Owl Nests

Nest ID	# Of Pellets	Field Type	Unknown Rodent Spp.	Norway rat (*Rattus norvegicus)*	House Mouse (*Mus musculus)*	California Vole (*Microtus californicus)*	Northern broad-footed mole (*Scapanus latimanus)*	House Finch (*Hoemorhous mexicanus)*
BANO21	41	Hemp	2	0	4	58	0	1
BANO22	16	Hemp	1	2	0	15	1	0
BANO23	3	Grassland	0	0	0	5	0	0

Figure 14

The Three Main Activities Seen at the Nest Boxes: Flying by, Perching, and Entering

Note. From left to right a house sparrow flying by the nest box (Nest ID BANO09), a Red-tailed Hawk perched on the box (Nest ID BANO15), and a Barn Owl entering into a nest box (Nest ID BANO15).

and 6 entering into the box (Table 6). The most common activity seen was perching on top of the nest boxes with 334 photos (80%).

Among the bird species I captured by camera entering the nest boxes were the following: American Kestrel, Barn Owl, Black Phoebe, European Starling, Northern Flicker, and Western Scrub-Jay. Overall, I recorded a larger number of species at organic/no spray hemp farm boxes (average = 1.6 per box) compared to boxes at managed grasslands (average = 11.8 per box) (Table 5).

Table 6
Species Found in the Vicinity of Nest Boxes by Behavior

Land Use	Nest ID	SPP	Flying Over or By	Perching	Entering the Box
Managed Grassland	BANO04	1		Lesser Goldfinch	
	BANO06	1		European Starling	
	BANO07	2		European Starling, Northern Flicker	
	BANO17	3	Unknown Passerine, Tree Swallow	Barn Owl	
	BANO18	1		Turkey Vulture	
Hemp	BANO09	8	House Sparrow, Unknown Swallow	Barn Swallow, Great-horned Owl, Northern Flicker, Unknown Passerine, Tree Swallow, Western Bluebird	
	BANO12	12	Unknown Corvid spp., Unknown Owl	Brewer's Blackbird, European Starling, House Sparrow, Red-tailed Hawk, Turkey Vulture, Western Kingbird, Western Meadowlark	American Kestrel, Barn Owl, Black Phoebe
	BANO13	7		House Finch, House Sparrow, Northern Flicker, Red-winged Blackbird, Western Bluebird,	European Starling, Western Scrub-jay
	BANO14	12	Unknown Raptor,	Barn owl, Brewer's Blackbird, California Quail, Common Raven, Great-horned Owl, Red-tailed hawk, Sharp-shinned hawk,	American Kestrel, European Starling, Northern Flicker, Western Scrub-jay
	BANO15	20	Canada Goose, Unknown Corvid, House Finch, Unknown Passerine, Unknown Raptor	Acorn woodpecker, Brewer's Blackbird, California Quail, Great-horned Owl, House Sparrow, Red-tailed Hawk, Red-winged Blackbird, Western Bluebird, Western Kingbird, Western Scrub-jay, White-crowned Sparrow	American Kestrel, Barn Owl, European Starling, Northern Flicker

Discussion

Barn owls were used as an indicator species for a preliminary study of a comparison of organic/no spray hemp farms compared to local managed grasslands. Barn owls are a good indicator species of the health of local ecosystems as their numbers have been seen to be contingent with a suitable nesting habitat and a diverse prey base with adequate foraging habitat (Colvin, 1985; Sergio et al., 2006; Taylor, 1994). The loss of either of these can lead to barn owl populations becoming vulnerable (Colvin, 1985; Taylor, 1994). This study found evidence that barn owls nesting near hemp fields can be as productive as those nesting near grasslands that are managed. I found that nest boxes in hemp farms had the same or more barn owls fledged in some boxes in comparison to managed grasslands. The two nests adjacent to hemp farms fledged three chicks, while the average of the four nests near the grasslands was 2.5 chicks. Studies show that barn owls nesting near agricultural sites can be reproductively successful (Kross et al., 2016; Marti, 1994; Wendt & Johnson, 2017). Wendt and Johnson (2017) found in vineyards approximately 75% of occupied nest boxes fledged young each year. Similar to their study, I found 100% of previously-established nest boxes that were occupied fledged young. The fact that the hemp farms included in this study were organic or did not spray with chemicals could be a factor in the success of the barn owl nests near the hemp farms (Beecher et al., 2002; Kirk et al., 2020).

None of the barn owl nest boxes that were established in 2020 and 2021 adjacent to hemp farms and managed grasslands showed any evidence of nesting. Other studies have found artificial nest boxes may take several years to attract breeding barn owl pairs that produce successful nests (Gervais & Young, 2009; Wendt & Johnson, 2017). Gervais and Young

(2009) found that no barn owls nested in their nest boxes within the first year they were installed. The following two years of the study, they continued to have low occupancy; out of the 40 boxes, there were only three barn owl nesting one year and two the second year. Wendt and Johnson (2017) had zero occupancy in the nest boxes they installed within the first year.

In 2022, two nest boxes that were installed in 2020 and 2021 were occupied. One in organic/no spray hemp and one in managed grasslands. One was occupied by a American kestrel and the other by a barn owl. These two nest boxes took one to two years after the boxes were installed to become occupied. Both boxes had eggs laid in them, however, on concurrent visits no female was seen incubating on them and neither hatched nestling. Of the six nests that were occupied by barn owls, five were previously-established nests that had been in existence for a number of years. Only the five of the previously-established nest boxes—two near hemp farms and three near grasslands—produced chicks. Wendt and Johnson (2017) in their previously installed nest boxes one third were occupied and fifty seven percent of those boxes fledged chicks both years. This supports that, over time, established nest boxes are attractive to barn owls, and occupancy could increase.

Even though no barn owls were seen using nest boxes for the 2021 breeding season, barn owls were active, and multiple bird species used the barn owl nest boxes for perching or temporary shelter (Appendix B). Barn owls investigated or stayed inside four of the nest boxes, suggesting that the boxes could be utilized for breeding at a future date as other studies document (Kross et al., 2016; Wendt & Johnson, 2017).

One potential reason the newly-established barn owl nest boxes were unoccupied was their close proximately to agricultural fields. These agricultural fields have an abundance of barns and outbuildings. Presumably there is already a healthy population of barn owls who continue to use barns like they have for previous years, similar to the established barn owl nest boxes that were utilized over the course of this study. Landowners reported these sites have been used continuously by barn owls for many years. Providing nest boxes can increase barn owl population when loss of nesting habitat has constrained barn owl populations (Marti et al., 1979; Taylor, 1994). Because the nest boxes were not quickly occupied, and all established nesting barn owls were successful, this suggests the study sites had suitable nesting habitat for barn owls (Marti et al., 1979). All of the farmers and landowners reported that they want to continue to support barn owl's presence and see their value on their farms/land.

The pellet analysis data from two nests near hemp farms showed owls were finding a range of rodent and small mammal prey. Importantly, I found over 90% of the diet (by frequency) was composed of voles, which are especially important prey for barn owls (Colvin & McLean, 1986). While the hemp farms and the local environment provided adequate prey for barn owls to fledge young, the barn owls were removing rodents that could reduce the productivity of hemp. This study, similar to others, showed that barn owl nest boxes and preserving established nests can be used as a natural strategy to combat pest species in agricultural systems, including hemp (Kross et al., 2016; Meyrom et al., 2009; Motro, 2011).

The diversity of species photographed at boxes near hemp farms exceeded the number photographed at managed grassland boxes. This difference could indicate that the organic/no spray hemp farms were relatively good habitats for a range of species, but many other factors could have contributed to this difference. Other studies have has shown positive effects of organic farming and those that do not use synthetic pesticides or fertilizers on bird abundance (Beecher et al., 2002; Kirk et al., 2020). Still, this was a potentially positive indicator of hemp farms as habitat that deserves further investigation.

The results of this study are a preliminary indication that the change from managed grasslands to hemp still supported barn owls and the presence of other species. However, this study was very small and should be expanded. In particular, the nest boxes installed for this study should continue to be monitored for use by barn owls and other species.

Recommendations for Management and Future Research

Given that hemp only recently become a legalized crop and is now being grown on an industrial level, this project was an important first step in assessing what, if any, impact hemp will have on biodiversity. Future studies are needed to see what effects, if any, hemp agriculture has at all trophic levels. Future research can provide managers with valuable findings they may use to increase the health of their local ecosystems.

Prior nest box research has shown that they can take a few years to be utilized by raptors (Wendt & Johnson, 2017). Due to the current pandemic, there was a significant delay in getting all nest boxes established and landowner permission, which resulted in a missed 2020 breeding season window. Future studies need to be done with longer nest box established times to see if these findings are similar. Additionally, due to the small sample size of pellets collected and limited to the breeding season, more research should be done to examine seasonal and multi-year trends to determine if there is variation of prey selected throughout year.

This study found that barn owls are present in both field types. As a top predator is present in these ecosystems, higher biodiversity is presumed in these areas using the “insurance” hypothesis; increased biodiversity is shown to protect against environmental fluctuations that may cause a decline in ecosystem functions (Yachi & Loreau, 1999). Even if some species are lost, this increased biodiversity will continue to provide a functioning ecosystem (Yachi & Loreau, 1999). As this is only a hypothesis and the sample size that was studied was small, more intensive research needs to be done on biodiversity and species richness in these areas to conclude if this hypothesis holds true.

This project has created a foundation for others to build on and improve. As the popularity of hemp continues to grow and consumers becoming increasingly conscious of the environmental impact the products they buy have, it will be important to answer similar questions to the ones I studied. This study only looked at no spray agroecosystems, to decrease confounding factors caused by synthetic chemicals. Subsequent studies should be done in conventionally-managed hemp farms to determine if results are similar. Having a greater understanding of the level of impact a crop has will help create best practices for protecting wildlife.

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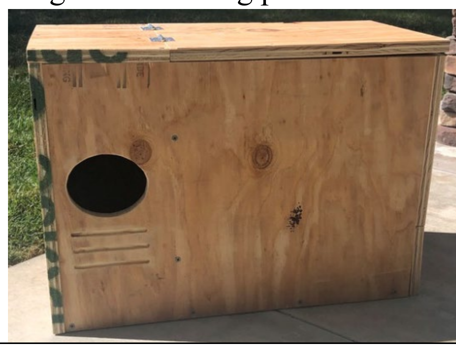
Appendix A

Step by Step Instruction on How This Study Erected the Barn Owl Nest Boxes

Step 1.	Pre-assemble each box at home as shown below. Following steps laid out by Wade et al. (2012). Take care to ensure that everything is level throughout mounting process.  
Step 2.	AUGER: Using the auger drill a hole 2 feet in depth. When drilling STOP frequently to measure hole depth in order to not over drill. 
Step 3.	Once at desired depth remove auger and place pole in hole using a flagpole raise motion for pole raising technique. Note one person is guiding the pole while the other starts at the end and slowly raises it up.
Step 4.	QUICKRETE: Have one person hold the pipe in the center of the hole while the other person pours dry Quikrete per manufactures recommendations. Allow room to place approximately 3 inches of topsoil. IMPORTANT: Check post is vertical with a level and make note where the sheet metal screw pilot hole is to ensure the box will face the desired direction once mounted.

Step 5.	POST SUPPORT: Lay down protective plastic sheet on top of wet concrete. Mount owl box to the bottom of the pole and tighten down all bolts. This will form a supportive base preventing the pole from leaning until dry. Re-check with a level.
Step 6.	BOX INSTALL**:** Once concrete is cured loosen bolts enough to allow box to slide up to the top. Use two ladders and have one person hold the box in place while the other tightens the bolts into position. Finish with self-tapping sheet metal screw where pilot hole was drilled.
Step 7.	Place fence post cap (2-3/8 inch) on top of pole and hammer into place.
Step 8.	Remove plastic sheeting and apply top soil.

Appendix B

Camera Trap Data for 2021 for Camera's Placed Adjacent to Barn Owl Nest Boxes

BANO Box ID	Species	Activities Observed	Location
BANO04	Lesser Goldfinch	Perched	On nearby Vegetation
BANO06	European Starling	Perched	On top of box
BANO07	European Starling	Perched, Flying	On top of box
BANO07	Northern Flicker	Perched, At Opening Flying	On top and at opening of box
BANO09	Barn Swallow	Perched, Flying	On top of box
BANO09	Great-horned Owl	Perched, Flying	On top of box
BANO09	House Sparrow	Flying	
BANO09	Northern Flicker	Perched, At Opening	On top and at opening of box
BANO09	Unknown Passerine	Perched Flying	On camera
BANO09	Swallow spp.	Flying	
BANO09	Tree Swallow	Perched, At Opening Flying	On top and at opening of box
BANO09	Western Bluebird	Perched, At Opening	On top and at opening of box
BANO12	American Kestrel	Entered Box Perched, At Opening	Inside box, on top, and at opening of box
BANO12	Barn Owl	Entered Box Perched, At Opening	Inside box, on top, and at opening of box
BANO12	Black Phoebe	Perched	On top of box
BANO12	Brewer's Blackbird	Entered Box Perched Flying	Inside box, on top, and at opening of box
BANO12	Unknown Corvid	Flying	
BANO12	European Starling	Entered Box Perched, At Opening	Inside box, on top, and at opening of box
BANO12	House Sparrow	Perched	On top of box
BANO12	Unknown Owl	Flying	
BANO12	Red-tailed Hawk	Perched	On top of box
BANO12	Turkey Vulture	Perched	On top of box
BANO12	Western Kingbird	Perched Flying	On top of box
BANO12	Western Meadowlark	Perched	On top of box

BANO Box ID	Species	Activities Observed	Location
BANO13	European Starling	Perched	On top and at opening of box
BANO13	House Finch	Perched	On top of box
BANO13	House Sparrow	Perched Flying	On top of box
BANO13	Northern Flicker	Perched	On top of box
BANO13	Red-winged Blackbird	Perched	On top of box
BANO13	Western Bluebird	Perched Flying	On top of box
BANO13	Western Scrub-Jay	Perched, At Opening	On top and at opening of box
BANO14	American Kestrel	Entered Box Perched, At opening Flying	Inside box, on top, and at opening of box
BANO14	Barn Owl	Perched Flying	To perch on top of box
BANO14	Brewer's Blackbird	Perched Flying	On top of box
BANO14	California Quail	Perched Flying	To perch on top of box
BANO14	Common Raven	Perched Flying	On top of box
BANO14	European Starling	Entered Box Perched, At Opening Flying	Inside box, on top, and at opening of box
BANO14	Great-horned Owl	Perched Flying	On top of box
BANO14	Northern Flicker	Entered Box Perched, At Opening Flying	Inside box, on top, and at opening of box
BANO14	Unknown Raptor	Flying	
BANO14	Red-tailed Hawk	Perched Flying	On top of box
BANO14	Sharp-shinned hawk	Perched	On top of box
BANO14	Western Scrub-Jay	Entered Box Perched, At Opening Flying	Inside box and at opening of box

BANO Box ID	Species	Activities Observed	Location
BANO15	Acorn Woodpecker	Perched	On top of box
BANO15	American Kestrel	Entered Box Perched, At Opening Flying	Inside box, on top, and at opening of box
BANO15	Barn Owl	Entered Box Perched, At Opening Flying	Inside box, on top, and at opening of box
BANO15	Brewer's Blackbird	Perched	On top of box
BANO15	California Quail	Perched Flying	On top of box
BANO15	Canada Goose	Flying	
BANO15	Unknown Corvid	Flying	
BANO15	Great-horned Owl	Perched Flying	To perch on top of box
BANO15	European Starling	Entered Box Perched, At Opening Flying	Inside box, on top, and at opening of box
BANO15	House Finch	Flying	
BANO15	House Sparrow	Perched Flying	On top of box
BANO15	Northern Flicker	Entered Box Perched, At Opening Flying	Inside box, on top, and at opening of box
BANO15	Unknown Passerine	Flying	
BANO15	Unknown Raptor	Flying	
BANO15	Red-tailed Hawk	Perched Flying	On top of box
BANO15	Red-winged Blackbird	Perched Flying	On top of box
BANO15	Western Bluebird	Perched Flying	On top of box
BANO15	Western Kingbird	Perched Flying	On top of box
BANO15	Western Scrub-Jay	Perched Flying	On top of box
BANO15	White crowned Sparrow	Perched Flying	To perch on top of box
BANO17	Barn Owl	Perched	On top of box
BANO17	Unknown Passerine	Flying	Infront of box
BANO17	Tree Swallow	Flying	Infront of box
BANO18	Turkey Vulture	Perched, Flying	On top of box