JOINT BASE LEWIS-MCCHORD AS A CASE STUDY

FOR POTENTIAL WEATHER METRICS FOR

MICROBAT POPULATION MONITORING

by

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ABSTRACT

Joint base Lewis-McChord as a case study for potential weather metrics for bat population decline.

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Bats provide important ecosystem services. However, their populations have been declining globally due to habitat loss, disease, and climate change. Previous studies have failed to explicitly assess the impact of weather metrics on the number of bat sightings observed during bat surveys. The objective of this study was to fill this knowledge gap. The ideal survey location is a place in which habitat loss and disease are minimal. Joint Base Lewis-McChord (JBLM) meets these criteria. It has a comprehensive forest management plan and no cases of White Nose Syndrome have been observed. Data collected between 2018 and 2021 were provided by the Washington Department of Fish and Wildlife (WDFW). Using these data, correlation analyses were conducted. A negative correlation was identified between the number of bat sightings and annual precipitation. This is consistent with previous reports that bats use more energy to fly when they are wet. No correlations were identified between the number of bat sightings and temperature or wind speed. This is inconsistent with previous reports about the impact of temperature and wind speed on bat activity. These findings may have been impacted by limitations in the data due to sample size, inconsistent record keeping, and lack of standardization. Based on this study's findings, future studies should utilize a combination of bat monitoring methodologies, standardize data collection and documentation, and collaborate with other regional bat monitoring organizations. The implementation of these recommendations would enable researchers to answer the impacts of weather metrics on bat populations. This will be valuable in predicting the impacts of climate change.

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I. INTRODUCTION

Joint-base Lewis McChord (JBLM) is a U.S. Army and Air Force Installation. It is in the South Puget Sound region of Western Washington which has a temperate maritime climate with long wet winters, short dry summers, and a mean annual temperature of 51°F. According to the University of Washington, the Pacific Northwest experienced an increase in the average daily high temperature of 1.3°F between 1895 and 2011. This change in temperature has increased the frequency of warmer extremes , with night time temperature increases being the most noticeable (University of Washington, 2013*)*. The trend is expected to continue. Temperatures are expected to rise approximately 5.8°F between 2021 and 2070 (University of Washington, 2013, 2020). Changing temperatures could cause an increase in the severity of heavy rainfall events, increased temperature during all seasons, and both more frequent heat extremes and fewer extreme cold events (University of Washington, 2020). Counterintuitively, it has also been predicted that winters and summers will have increased rainfall (ED DPW, 2017; University of Washington, 2020). These changes could cause an increase in flooding, landslides, and fires in the area.

JBLM encompasses 91,126 acres of land. It consists of 61,000 acres of forested, woodland, and savanna areas; ideal habitats for most many species including bats (ED DPW, 2017; Falxa, 2008a). JBLM is also home to 20,000 acres of prairie and oak woodlands created by glacial outwash over 15,000 years ago. This habitat is home to multiple federally endangered species, and is one of the rarest and most endangered ecosystems in Washington with only 3% of the original prairie land remaining (Delvin, 2013; WDFW, 2021b). There are 3,850 acres of wetlands, including 1,200 acres of forested wetland and riparian areas which attract insects (ED DPW, 2017). All these geographical features and habitat types are predicted to be impacted by climate change (ED DPW, 2017; University of Washington, 2013*)*.

Globally, bats play important but often unappreciated roles. For example, bats provide many ecosystem services to natural biomes and increase human well-being (Kunz et al., 2011). These services include insect suppression, pollination, seed dispersal, and maintaining ecosystems (Kunz et al., 2011; Law et al., 2019). Anthropogenic factors have caused the decline of bat populations, risking the loss of the services they provide (Kunz et al., 2011; Law et al., 2019). To understand how these factors impact bats and to mitigate their impact, multiple studies have been conducted that focus on habitat loss, disease, and climate change (Bat Conservation Trust, 2021; Kunz et al., 2011; Law et al., 2019). There is no single cause for decline of bat populations, rather the cause of their decline is multifactorial. Habitat loss, disease, and climate change are widely regarded as having the most impact. Habitat loss typically occurs where there is an influx in anthropogenic disturbances such as development or urbanization. The devastating bat disease called White Nose Syndrome has spread amongst bat populations worldwide. Finally, increased temperatures due to climate change alter food availability and hibernation patterns. While the impact of climate change on bat populations has been a major focus for years, comparatively little is known about the impact of weather on the number of bat sightings during surveys. The combination of habitat loss, disease, and climate change in most locations, makes it difficult to determine the impact of weather. In order to isolate this impact, large sample sizes and sophisticated statistical methods could be used. However, that approach requires significant funding. An alternative approach is simply to make observations in a location where confounding factors are relatively constant. Joint Base Lewis McChord meets this criterion and was therefore selected as the site for this retrospective study.

JBLM is an ideal location because it has a comprehensive forest management program that closely monitors forest health by preparing harvested timber sites for replanting, monitoring, and removing invasive species such as Scot's Broom, and maintaining density harvesting to provide heterogeneity of the forests. By upholding these practices JBLM's forest management program has been a certified as a sustainable forestry operation since 2002 by the Forest Stewardship Council (ED DPW, 2017). This means that habitat loss and deforestation are not currently problems being experienced by the installation. In addition, while White Nose Syndrome has been identified in Washington State, it has not been observed on JBLM, despite JBLM's diverse bat population: 9 of the 15 species of Washington bats can be found on JBLM (Falxa, 2008a; G. Hayes & Wiles, 2013). Consequently, habitat loss and disease are unlikely to have major impacts on JBLM's bat populations.

Study Objectives

Using JBLM as a case study, several research questions were asked to determine whether the frequency of bat sightings is negatively impacted by the following weather metrics: temperature, precipitation, and wind speed.

Question 1: Are bat sightings affected by how early in the year the temperature regularly exceeds 40°F?

Briefly, the bat species on JBLM hibernate when the average low temperature is about 40°F. Thus, it was predicted that the number of bat sightings during a given observation period would be lower if the average low temperature exceeded 40°F later in the year.

Question 2: Are bat sightings affected by total annual rainfall?

Wet bats expend more energy to fly. It was therefore predicted that fewer bat sightings would be observed when total annual rainfall was high.

Question 3: Since day-to-day weather conditions can affect survey results, which conditions are important to consider when conducting surveys?

Research suggests that bats are likely to be most active when temperatures are warm and wind speeds are low. These specific predictions were evaluated in this question.

II. LITERATURE REVIEW

Bats are mammals that belong to the order *Chiroptera* (Bat Conservation International, 2021; de Oliveira, 2020; Marshall, 2022). This group is the second largest in the class Mammalia. To put this in perspective, one out of every five animals on Earth is a member of this class. *Chiroptera* includes two suborders: *Yinpterochiroptera* and *Yangochiroptera*.

Yinpterochiroptera contains bat species that are commonly referred to as megabats. Though, megabats are not the focus of this study it is important to briefly describe this suborder because it too provides important ecological services and has seen declining populations. Megabats are characterized by their large size with some species weighing up to 3.2 pounds. They do not develop echolocation because they lack a specialized feature in their ears that is present in other bat species(de Oliveira, 2020; Marshall, 2022). Their diets consist of mostly fruit and nectar. Pollen from these food sources will frequently stick to the hairs on the bats' bodies. The pollen from their body hairs are transferred to other plants while feeding, resulting in pollination. Without this form of bat pollination, known as chiropterophily, it is likely that we would not have fruits such as bananas, avocados, or mangoes. Even alcohols, such as tequila, rely on bat pollination, specifically of the agave plant (US Department of the Interior, 2017). Over 80 medicines are that are made from plants rely on bats for pollination and seed dispersal (Gettler, 2013; US Department of the Interior, 2017). Some medicines are even developed using a protein in bat saliva derived from some species of megabat which are used to help mitigate blood clots in stroke victims (Thompson, 2021).

The second suborder of bat, and the focus of this study, is *Yangochiroptera* also known as microbats. Of the 1,400 bat species, 70% of them are microbats (Bat Conservation International, 2021). These bats are characterized by echolocation, and the ability to hibernate (Burnett Mary Regional Group, 2021). Bats of this suborder are smaller in size, and have large ears and a tragus used for echolocation (de Oliveira, 2020). In contrast to the foraging practices of megabats which include consumption of fruits and nectar, microbats are predominantly insectivores (Falxa, 2008a; Frick et al., 2012; National Science Foundation, 2012). All bats found in Washington state are microbats, and more specifically are in the family *Vespertilionidae,* the most widespread bat family. This family consists mainly of insectivores and is especially abundant in temperate climates (Kunz et al., 2011).

Seventy percent of microbats consume insects and other small arthropods for food. They can eat their body weight in insects each night, which could potentially consist of thousands of insects (US Department of the Interior, 2017). According to the United States Geological Survey (USGS), a single little brown bat, a species that can be found on JBLM, can eat 4 to 8 grams of insects nightly. To put this into context, the average mosquito weighs 2 milligrams. So in one night, the little brown bat could eat roughly 2,000 to 4,000 mosquitoes (USGS, n.d.). The USGS goes on to report that the Northeastern U.S. has lost over one million bats, which results in between 660 and 1320 metric tons of insects no longer being eaten by bats (USGS, n.d.). Without a healthy bat population consistently consuming these insects, the insect populations in the U.S. could grow, impacting the environment and the economy.

Bats are a major contributor to important ecosystem services and may be sensitive indicators of ecosystem function and environmental threats (G. Hayes & Wiles, 2013). First, they act as a system for maintaining the health of ecosystems by providing pollination and seed dispersal, and secondly, they act as an effective biological pest controller (Aubry et al., 2003; G. Hayes & Wiles, 2013; National Science Foundation, 2012).

Pollination and seed dispersal are two crucial phases in the plant reproductive cycle. Bat pollination is performed by most species of bat worldwide and is a major contributor to the survival of these various plant species (Mahandran et al., 2018). Bats are effective in aiding these processes due to their increased mobility granted through flight, their fur is able to carry and transfer large pollen loads (Fleming et al., 2009), and their capability of defecating while midflight, allows for the movement of different species of plants across the span of a landscape (Fleming et al., 2009). This defecation process allows them to be a key source of nutrient transport from riparian areas to upland areas (G. Hayes & Wiles, 2013). With the increase in habitat fragmentation, the ability to pollinate over long distances has important implications for plant and ecosystem conservation efforts (Fleming et al., 2009; Mahandran et al., 2018).

Agricultural insects and pests cost the U.S agricultural industry over $33 billion dollars a year in crop losses. These pests also destroy 25-50% of crops across the globe (Maslo & Kerwin, 2020). Most microbat diets consist of arthropods, with the type depending on the species of bat and geographical location. However, they are the most important natural predator of nocturnal insects such as mosquitoes, moths, beetles, crickets, leafhoppers, and chinch bugs (Bat Conservation International, 2016). These insects are some of the most serious agricultural pests. It is predicted that bat consumption of these pests specifically saves the U.S. Agricultural Industry over $22.9 billion annually, and helps reduce the use of pesticides which can harm the environment (Bat Conservation International, 2016; Griggs, 2015; Maslo & Kerwin, 2020).

Contributors to Bat Population Decline

The bat population is in a state of rapid decline (USGS, 2016). There are many contributors to bat population decline which include habitat loss, disease, and climate change. There are 15 species of bat found in the state of Washington (Table 1) (G. Hayes & Wiles, 2013).

Microbats Found in Washington State	
Common Name	Scientific Name
1. Big Brown Bat*	*Eptesicus fuscus*
2. California Myotis*	*Myotis californicus*
3. Canyon Bat	*Parastrellus hesperus*
4. Fringed Myotis	*Myotis thysanodes*
5. Hoary Bat*	*Lasiurus cinereus*
6. Keen’s Myotis*	*Myotis keenii*
7. Little Brown Myotis*	*Myotis lucifugus*
8. Long-legged Myotis*	*Myotis volans*
9. Pallid Bat	*Antrozous pallidus*
10. Silver-haired Bat*	*Lasionycteris noctivagans*
11. Spotted Bat	*Euderma maculatum*
12. Townsend’s Big-eared Bat*	*Corynorhinus townsendii*
13. Western Long-eared Myotis	*Myotis evotis*
14. Western Small-footed Myotis	*Myotis ciliolabrum*
15. Yuma Myotis*	*Myotis yumanensis*

Table 1. The species of bat identified in the Washington State Bat Conservation Plan (G. Hayes & Wiles, 2013).
* Bat species confirmed on JBLM in the 1992 and 2008 bat surveys (Falxa, 2008a).

Habitat Loss

The most important habitat types for bats in Washington are those used in roosting and foraging such as trees, snags, caves, mines, cliffs, buildings, and bridges. Urbanization and human expansion have resulted in the destruction of the bats’ natural roosting and foraging sites (Falxa, 2008a; J. P. Hayes, 2003; Loeb & O’Keefe, 2011). While some bats have adapted to using man-made structures such as buildings, the loss of historic roosting habitats such as old growth snags and forests, has forced many bat species to prioritize areas suitable for foraging or for habitat, rarely both (Falxa, 2008b; Freed & Falxa, 2010). Washington’s natural landscape used to provide habitats that were in key foraging locations such as large trees or snags. However with urban development, bats have been forced to adapt and relocate to man-made and artificial roosts such as roofing, siding, attics, bridges, and bat boxes (Freed & Falxa, 2010). In addition to having to relocate, many of these locations are not near ideal foraging locations such as meadows, riparian areas, small gaps in forests, or even shrub-steppe and grassland habitats. Although with the addition of artificial roosts to forested areas, conservationists have been able to situate roosts near foraging resources (Baker & Lacki, 2004).

Because of deforestation and logging practices the physical distance between roosts and foraging grounds have increased. Since a variety of bat species prefer large trees and the loss of old growth forests has been substantial, habitat availability has been negatively impacted (G. Hayes & Wiles, 2013; J. P. Hayes, 2003). While regulations that require the retention of snags and buffers around riparian zones have reduced the impact of habitat loss, their implementation is inconsistent.

Disease

There are also rapidly spreading diseases that impact bat populations, White Nose Syndrome (WNS) for example. WNS is caused by the fungus *Pseudogymnoascus destructans*. In early stages of the infection, hibernating bats infected with this fungus use twice as much energy as uninfected bats. Eventually this prevents the bat from reentering full hibernation. The fungus also causes the bats to awaken more readily because of warm temperatures. In both cases, the result is that the bats deplete their fat stores, which often leads to death (Duvergé et al., 2000; Frick et al., 2012).

Climate Change

Climate change affects bats in at least three different ways: 1) altering the temperature of their roosting sites, 2) exposing them to severe weather events, and 3) altering their foraging behavior and inadvertently exposing them to predators (Loeb & O'Keefe, 2011). Bats increasingly live in artificial roosts such as bat boxes. Since artificial roosts are small, rising temperatures due to climate change are a concern because the internal temperature of an artificial roost can become very hot. According to the University of Washington, the annual and seasonal temperatures of Washington state are expected to increase with more frequent extreme heat events (University of Washington, 2020). The temperatures inside artificial bat boxes can reach up to 52°C (125.6°F) (Groc, 2021). Changes in ambient temperature also affect the availability of prey, which in turn affects bat foraging behavior, generally leading them to forage earlier in the day when insect activity is high. Consequently, this exposes them to increased predation and competition with species that are active during the day (Frick et al., 2012). Finally, as changes in the climate are expected to result in more frequent and severe weather events, bat habitats are at a higher risk of disturbances from events such as extreme heat which can severely impact artificial roosts or even cause the complete destruction of roosts, e.g. by causing wild fires or severe flooding (Frick et al., 2012).

Bats in western Washington use a variety of methods to regulate their body temperatures. For example, many species in western Washington reside in tight, warm spaces. They can minimize thermoregulatory costs by selecting habitats with the optimal temperatures or by colonial clustering (de Oliveira, 2020). In addition, all species of bat rely on the large surface area of their wings as a form of passive thermal conductance during flying and roosting (de Oliveira, 2020).

In the Pacific Northwest there is increasing interest in understanding how habitat loss and climate change impact bat populations. However, to date few bat surveys have been conducted in Washington state. Three studies were conducted on Joint Base Lewis-McChord (JBLM) since the 1990s. This includes the present study. While none of the 15 species of bats that live in Washington are currently listed as endangered or threatened at the federal or state level, two of them have been declared species of concern, specifically Townsend's Big-eared bat and Keen's myotis (Table 1) (WDFW, 2021a).

Behavioral Adaptations to Environmental Change

In order to adapt to the changing climate in North America, bats have adopted multiple behavioral strategies. These strategies include migration, hibernation, relocation, and using artificial roosts or habitats. According to the US Geological Survey (USGS), many species of bats are known or believed to be declining based on bat population data collected between 1955 and 2001 (USGS, 2016). While bats adapted to selective pressure by developing a notable array of capabilities (i.e. true flight, echolocation, and hibernation), this process took millions of years. In the last 150 years, anthropogenic pressures have significantly grown, resulting in drastically altered or lost habitats. The true impact of these pressures is poorly understood because the current methods for bat monitoring are difficult and inconsistent across organizations such as the USGS, Department of Fish and Wildlife, Bat Conservation International, the Bat Conservation Trust, and the Nature Conservancy.

According to fossil records, bats have existed for millions of years. In 2003, the earliest well-formed bat fossil was discovered in the state of Wyoming, dating back more than 52 million years to the Eocene period (Gunnell et al., 2008). Bat fossils are rare, due to the bones being light weight and small (Ramel, 2020). Therefore, this discovery was particularly exciting for researchers because it represented an evolutionary intermediate linking modern bats to their non-flying ancestors (Gunnell et al., 2008; Gunnell & Simmons, 2005). This new species was named *Onychonyteris finneyi*, and with it researchers were able to answer many questions posed concerning how bats evolved echolocation and flight (American Museum of Natural History, 2008). According to Gregg Gunnell, a research scientist at the University of Michigan, the three leading theories developed were: 1) bats developed flight before echolocation, 2) bats developed echolocation first, and 3) bats developed both simultaneously (Gunnell et al., 2008). The physical appearance of the fossil suggests that bats evolved flight before echolocation. This was hypothesized because *Onychonyteris* lacked specific features in the skull near the ear that are needed for echolocation in modern bats (American Museum of Natural History, 2008; Gunnell et al., 2008). Without the use of echolocation *Onychonyteris* had to rely on "visual, olfactory, or passive cues to hunt" (Gunnell et al., 2008). Since the skull, including the orbits, was incomplete, the size of the bat's eyes could not be determined. Had the fossil been complete, it could have provided insight into the evolution of bat vision. In particular, it could have helped identify similarities with modern day bats that do not echolocate, e.g. the family *Pteropodidae* (Fig. 1) also known as megabats or Old World fruit bats (Luzynski et al., 2009).

While seasonal survival has been extensively studied in many animal species, this is a relatively unstudied aspect of chiroptology. The four main mechanisms that bats have developed in order to mitigate seasonal mortalities are migration, torpor, hibernation, and artificial structure habitation (Reusch et al., 2019). Studying these factors is challenging because data collection methods and validated analytic tools (i.e. reference databases) are lacking in the bat field. In contrast, bird research has benefited from long-term high quality data and an array of validated analytic tools (Reusch et al., 2019).

To survive periods of cold weather and food and/or water shortages, bats have developed multiple mechanisms to help them improve their chances of survivability such as migration, torpor, and hibernation (Reusch et al., 2019).Since western Washington has a mild maritime climate, bats in western Washington may be able to employ different wintering strategies than bats at colder climates (Falxa, 2007). Interestingly, however, there are still species of bats that have been identified as seasonal migrators (U.S. Fish and Wildlife, 2020). The hoary bat *(Lasiurus cinereus)* is one of these species. It migrates more than 1,000 km during its migratory season, although not much is known about where this species of bat spends its winter months (U.S. Fish and Wildlife, 2020).

It is suggested that some bats that live in western Washington remain active regardless of the season (U.S. Fish and Wildlife, 2020). The California myotis (*Myotis californicus*) and silver-haired bat (*Lasionycteris noctivagans*) are two species in the Pacific Northwest that have been observed outside of roosts throughout the winter months (U.S. Fish and Wildlife, 2020). It is believed that they can avoid going into hibernation by going into a state known as torpor which is a shortened state of hibernation that is triggered during inclement weather in order to conserve and slow the expenditure of energy. This enables them to awaken from torpor multiple times throughout the winter when the weather is warm enough.

Hibernation is one of the most crucial mechanisms bats have evolved to survive cold winters. Hibernation is a state in which body temperature, metabolic rate, heart rate, and respiration are reduced to prevent the depletion of fat reserves (Briggs, 2021; Link, 2004; U.S. National Park Service, 2020). When ambient temperatures, drop below 40° F many bats will hibernate. Microbats' hibernation sites (also called roosting sites or their hibernaculum) include large trees, caves, mine shafts, tunnels, old wells, artificial roosts, and other man-made structures (Link, 2004). To survive winter, the hibernaculum needs to be quiet and cool, with a consistent temperature and humidity. A hibernaculum protects bats from predation, light, noise, and other types of disturbances (Link, 2004; WDFW, 2020). These roosts allow them to safely hibernate when food sources become scarce (Briggs, 2021). Unfortunately, because of the lack of standardization in chiroptology, it has been suggested that the term torpor and hibernation are used interchangeably in some of the literature (Lactis, 2020; U.S. National Park Service, 2020; Weller et al., 2016; Wildlife Online, n.d.).

Utilization of Artificial Roosts

All species of female bats birth one large pup during each pregnancy. While bats only have one breeding season, they can have multiple litters during that one season (Bat World Sanctuary, 2013). These pups are born hairless and have limited thermoregulatory abilities (de Oliveira, 2020). Similar to large mammals, bats rely on their mother's milk for nutrition until weaning, which can take anywhere from six weeks to four months depending on when their wings become fully developed (Bat World Sanctuary, 2013; de Oliveira, 2020). Non-nutritional care provided by the mother consists of protection, sensory stimulation, thermal influence, and transport. Females must frequently leave their offspring while foraging which is why habitat loss is impacting the bat population so heavily. Instead of leaving the pup in the colony, some females take their young to their day roosts. This is not only to keep their pup close to them for safety, but their colony is more vulnerable to disturbance and can be destroyed by a single destructive act such as a flood, severe rain event, or fire (Ammerman et al., 2012).

Once weaned, juvenile bats venture out of the colony to begin foraging for themselves (Ammerman et al., 2012). When a bat reaches adulthood, it can be challenging to determine its age. The primary method of identifying adults is by morphological traits, including their long bones, body mass, pelage coloring (facial and body markings), tooth wear, and the size of the pulp cavity. The pulp cavity is an internal opening of a vertebrate tooth that contains connective tissues, blood vessels, and nerves (Brunet-Rossini & Wilkinson, 2009).

Bat Population Monitoring

Microbats are difficult to study. They tend to be well hidden in trees or caves and exit their roosts at night to hunt for insects (Loeb et al., 2015). Consequently, various survey methods have been developed which include: visual or direct counts, nets, and acoustic surveys. These methods are commonly used for observing and documenting bat population data (National Park Service, 2018). According to the United States Department of Agriculture, there is no public or private program that is conducting a standardized monitoring of bat species in North America (Loeb et al., 2015).

In 1994, the USGS, began the Bat Population Data Project. The project identified significant knowledge gaps concerning bat populations in the United States (USGS, 2016). This led to a multi-phase and comprehensive effort to compile bat population data across organizations in the U.S. and its territories. The results were published in 2003. An article published in 2016 suggested that the database was being updated, however, further information regarding this specific project was not found (USGS, 2016). USGS has been leading, managing, and coordinating the North American Bat Monitoring Program (NABat). According to the NABat management Plan, the Bat Population Data Project has become a repository of bat population data called the Bat Population Database. The plan for this database is for NAbat partners to upload their data with site-specific information such location, grid cell number, date, times, environmental conditions, variables related to bat detectors, species identification information, years of experience identifying species or counting bats, and the metadata associated with acoustic surveys (Loeb et al., 2015).

Currently, this program is monitoring 47 species of North American bats, which is a huge step toward data standardization. However, NAbat does not provide any monitoring equipment or software to any agencies or organizations, which likely limits the rate of data deposition (Loeb et al., 2015).

Bat Surveying

Without acoustic sampling or bat detection equipment, visual bat sightings are one of the main indicators of whether bats are present in an area (Predator Free New Zealand Trust, n.d.). There are other indicators of bat activity such as the presence of guano or changes to bat roosts or hibernacula. However, the latter indicators do not reveal how recently bat activity occurred. While bat sightings tend to underestimate true bat counts by roughly 4%, visual counts are still the most cost effective, easiest method for data collection, and does not require time for set up, unless infrared monitors or cameras are being utilized (Sedgeley, 2012).

There are a range of reasons why bats are difficult to monitor and survey. These range from their small size (as small as 2-2.6 grams), their nocturnal and elusive habits, and the lack of standardized monitoring programs and procedures (Loeb et al., 2015; United States Geologic Survey, 2016). While bats consist of one fifth of the world's mammalian biodiversity with over 1400 species (Frick et al., 2019), there is a lot about bats that is unknown, which makes attempts to prioritize and plan conservation efforts difficult and demanding (Frick et al., 2019; Loeb et al., 2015). In a report published by the U.S, Geological Survey in 2003, it was stated that "scientific validity of the past and current efforts have not been critically examined and there have been no efforts to synthesize and summarize these efforts (O'Shea & Brogan, 2003)". However there are multiple state and government agencies that are collaborating on bat conservation, including the National Fish and Wildlife Foundation, Bat Conservation International, the U.S. Forest Service, the U.S. Bureau of Land Management, and the U.S. Geological Survey (O'Shea & Brogan, 2003).

Each organization uses their own criteria or key words to categorize survey types. After reviewing multiple organizations' methods, a pattern was identified, allowing for the most frequently referred to surveys to be classified based on general categories. The methods used by the following organizations and others not listed were reviewed: NABat, Bat Conservation International, USGS, the National Park Service, Bat Survey

Ireland. Many terms were used to describe visual surveys, including‘dusk’, ‘dawn’, ‘emergence’, ‘reentry’, ‘activity’, ‘return to roost’, ‘sunset’, ‘roost’, and ‘hibernation’. Because so many terms were used to describe the same approach, a classification scheme was devised to differentiate the main approaches. Three categories were identified:: 1) visual or count, 2) capture and release, and 3) acoustic. There were only two organizational surveying guides identified during the research process. This included the “Bat Survey Guidelines for Professional Ecologists” from Bat Conservation International (Collins et al., 2016) and “A plan for North American Bat Monitoring Program” from the Department of Agriculture (Loeb et al., 2015). These are the only two publications that described the specific criteria that determine when particular survey types are required.

Visual or Count

The most widely used survey is the visual or count survey. This type of survey serves two purposes: 1) to identify the presence of bat and 2) to quantify the level of activity (units being the number of bats). This method is the most widely used because it is cost effective, and no equipment is needed. However, compared to the other three method types, it is not the most efficient. Types of field surveys include visual, colony emergence or re-entry counts, roost searches, and identification of activity.

Capture and Release Methods

Capture and release methods are conducted using traps or nets set up by researchers. This approach uses mist nets or harp-traps. Nets are the most common form of capture and release method conducted on bat populations and provide life history information. For example, a captured bat can be used to measure morphology, acquire samples (blood, tissue, parasites), and assess physiological status such as species, gender, or breeding status (Collins et al., 2016; Darras et al., 2021). Mist nets are ultrafine monofilament nylon nets that are 12m in length and 3m in height. Setting up mist nets takes place 3 hours prior to dusk and require personnel to monitor them consistently until the end of the netting session (Brunet-Rossini & Wilkinson, 2009). Harp-traps help to capture bats without exposing them to the entanglement that occurs in the netting of mist nets. It uses vertical nylon strings, similar to those in the harp instrument, and funnels the bats during flight into a canvas collecting bag at the bottom (NHBS, 2019). Both methods can cause injury or death to bats. For the netting mechanisms to function, bats are required to fly directly into them. This can cause a bias in the species that are captured. For example, species of bat that fly at higher altitudes will be underrepresented when using these methods. On the other hand, capture and release methods provide life history information that neither visual count or acoustic methods can provide.

Acoustic Methods

All bats in the United States use echolocation (Falxa, 2008b). Thus, acoustic sampling is one of the best methods for bat monitoring since it is the least obtrusive and most efficient way to speciate and record bat calls (United States Geologic Survey, 2016). Most bat species can be distinguished based on the varying frequencies of their calls. This allows for the detection of a larger number of species of bats in a short amount of time. However, this approach entails a reliance on sensitive, battery-powered devices.

III. STUDY AREA: JOINT BASE LEWIS-MCCHORD

Joint Base Lewis-McChord (JBLM) is an ideal location for identifying how weather metrics impact bats survey results. Specifically, many of the factors that might confound analyses in other location are controlled for on JBLM. Two key variables are factors that have been implicated in the decline of bat population sizes elsewhere: habitat loss and disease, namely White Nose Syndrome. Since 1) White Nose Syndrome has not been observed on JBLM and 2) JBLM has an intensive forest management plan that puts strict limitations and controls over the habitats on JBLM, these factors cannot confound the analysis. This allows for the unconfounded determination of the relation between weather metrics such as temperature, precipitation, and wind on the number of bat sightings.

JBLM has eight different habitat types which helps to provide a variety of locations for bats to colonize and forage. These eight habitat types include: 1) marsh (wetland without significant open water), 2) forest edge (clearing, non-native vegetation), 3) riparian forest (stream in the forest), 4) dry forest corridor (road, pipeline), 5) savanna with sparse trees (near a marsh, pond, or stream), 6) savanna (grass or shrub land with sparse oak or pine stands), 7) large open water (lake, pond, or river), 8) open field (non-native or no vegetation). According to the Washington State Bat Conservation Plan, all these habitat types are ideal for bat foraging and habitation (ED DPW, 2017).

Not only does JBLM have a variety of habitat types ideal for bat habitation, but it also consists of huge swaths of land reserved for restoration and the conservation of threatened and endangered species. JBLM has a comprehensive forest management program and has been certified since 2002 by the Forest Stewardship Counsel as a sustainable forestry operation. With JBLM's forest management plan and conservation practices (ED DPW, 2017), one of the major contributors to bat population decline, habitat loss, is not a current threat. Because literature on bat research is limited, the inclusion of rare habitats such as lowland forests and prairies make JBLM one of relatively few contributors of data for these types of habitats (Falxa, 2008a).

JBLM consists of 91,126 acres of land, and is home to nine of the 15 species of bat found in Washington state make JBLM their home which includes the two Washington State Candidate species, Keen's Myotis (*Myotis keenii*) and Townsend's Big Eared Bat (*Corynorhinus townsendii)* (G. Hayes & Wiles, 2013). These bats have been observed in two of the three major bat surveys that have been previously conducted on JBLM. The first survey was conducted in 1992 by the USDA Forest Service, and the second survey was conducted in 2008 by Cascadia Research (Falxa, 2008a). JBLM is important for the monitoring of these species of bats. Keen's myotis has one of the smallest ranges in North America and is assumed to be rare. Townsend's Big-eared bat is a species at risk especially in areas with pesticide spraying activities that can be seen in many forests and agricultural areas. Since JBLM has a comprehensive forest management plan, it is likely that the base would be an ideal location to monitor this population. While these bats do prefer caves and mines, they do use large snags as habitats (J. P. Hayes, 2003). Part of JBLM's forest management practice is to try to create and maintain snags for habitat and species conservation (ED DPW, 2017).

Site Selection Previous Studies on JBLM

According to the 2008 bat study conducted on Fort Lewis, the observation locations were chosen in order to represent the eight habitat types that could be found on present day JBLM. By including these eight habitat types, it allowed for the inclusion of non-developed, accessible land within the constraints of troop training schedules, since JBLM is a military installation, and ensuring the safety of survey personnel is critical. While some high security areas (such as artillery impact zones) were off limits to the 2008 study, the ability to sample the perimeters of these areas or sampling areas with a similar habitat type would allow for the prediction of species variation based on the activity levels among different bat species in the various habitat types (Falxa, 2008a).

The survey conducted on Fort Lewis in 2008, monitored a total of 82 sites which included 67 acoustic sites and 15 net capture sampling sites which are depicted in Figure 1. The sites selected for net capture were identified as productive sites for bat sightings in the 1992 study, conducted by the USDA Forest Service. The 1992 report was unpublished and thus unavailable at the time of this study's research. However, the 2008 study did have access to the 1992 report and were able to summarize the data and the study's findings. Thus allowing, the 2008 study to use the population data acquired during the 1992 survey to determine where to set up sampling equipment, and eventually allowing them to resample the sites in order to run a comparative analysis.

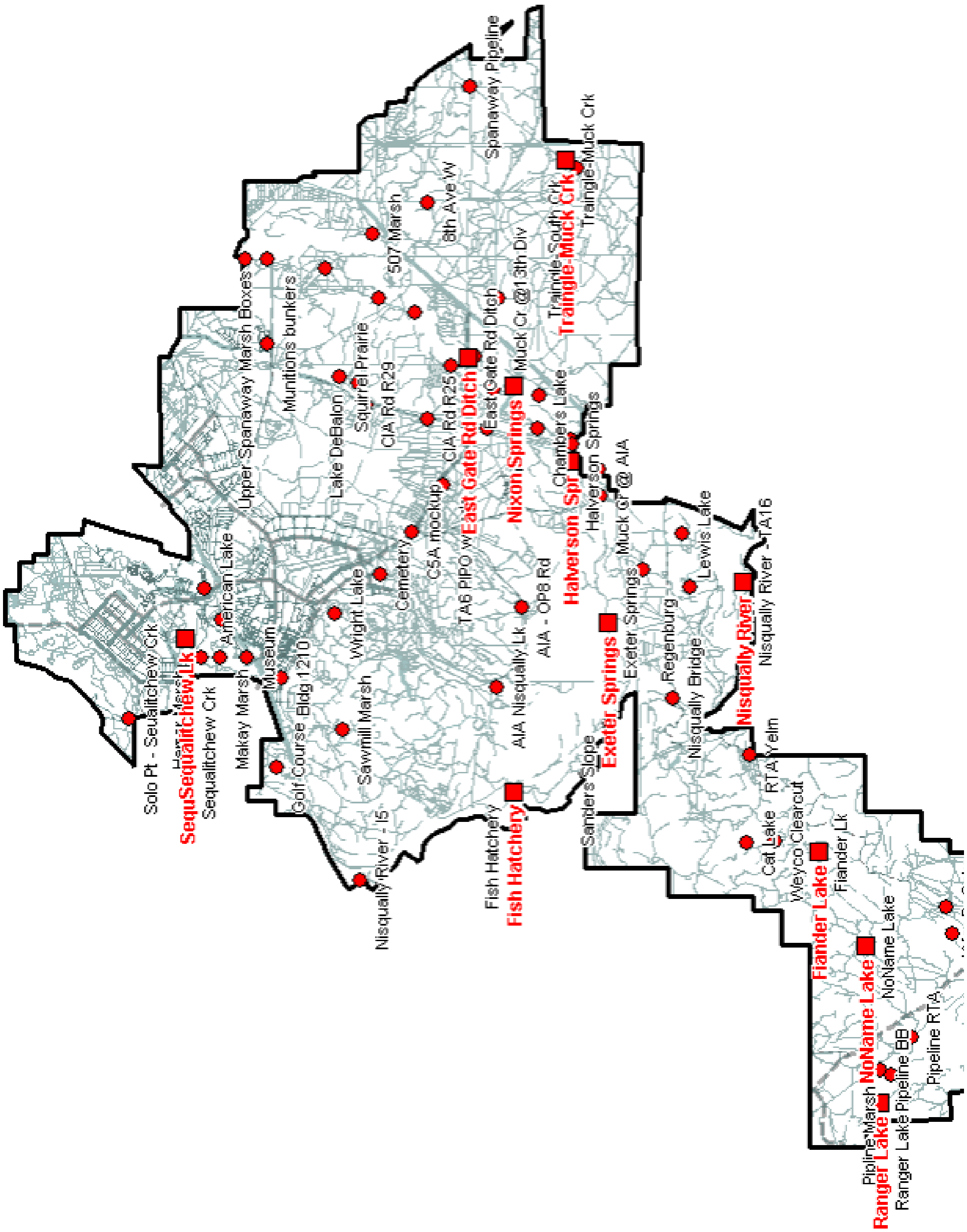


Figure 1. A map of the sampling locations used in the 2008 survey on Fort Lewis. Both acoustic (red circles) and mist net sites (red squares) are included (Falxa, 2008a).

IV. METHODS

Methods Used in Previous Studies on JBLM

There have been three bat survey studies conducted on JBLM over the past three decades, the first was conducted in 1992, the second in 2008, and the third spanning 2018 to 2021. While these surveys all had similar objectives, the ability to compare their research is limited due to the inconsistency in survey monitoring methods between the three studies. The 1992 and 2018-2021 studies were focused on gauging the abundance of bat populations on JBLM. In contrast, the 2008 study was more of a species inventory. The methodologies of each study differed in important ways – as detailed below.

The 1992 survey conducted by the USDA Forest Service, incorporated both netting and acoustic recording. However, the report was unpublished, and after significant effort, a copy of the report could not be found. Nevertheless, some of the information from that survey are included in the 2008 Fort Lewis Bat Survey conducted by Cascadia Research and the Nature Conservancy (Falxa, 2008b). The acoustic sampling technology used in the 1992 study did not have the capability of determining the species of bat based on the echo or frequency emitted by the bat. This technology was used merely to identify whether bats were present. Notably, however, it could determine differences in frequencies, allowing for some very limited degree of speciation. There was little information provided about the mist netting practices used in the 1992 survey other than they preferred to use harp traps instead of mist-nets. It was also reported that Big brown bats evade harp traps more than mist net traps which may indicate that there could be some species-specific bias in their findings (Falxa, 2008a).

Similar to the 1992 survey, a mixture of both netting and acoustic sampling were used in 2008. While both used acoustic identification methods, the technology used in 1992 was more simplistic, using heterodyne style tunable units which fail to collect species level information. In contrast, the 2008 survey used time expansion ultrasonic detectors which can be left unattended and when combined with the Sonobat software and a database of reference calls can obtain detailed species identifications (Falxa, 2008a). Acoustic monitoring could potentially identify specific species of bat; however, some species have similar echolocating frequencies which may not provide an accurate identification of the species (Falxa, 2008a).

However, even with this improved technology, there are still some bat species that are difficult to differentiate, e.g. Little Brown Myotis and Long-legged Myotis. Positive identification can be determined using the catch and release method which is the only method that allows for speciation based on physical characteristics. Net capture methods enable surveyors to get a positive identification on most of the species being surveyed. In addition, they can provide useful life history data, which cannot be obtained by visual emergence counts or acoustic recordings. While nets were used in the 1992 survey, the one conducted in 2008 used mist-nets. These are different than harp traps because they are situated lower to the ground. Similar to harp traps, mist-nets can induce some species-specific biases (Falxa, 2008a). More specifically, mist-nets underrepresent the abundance of bats that tend to fly at higher altitudes.

Acoustic sampling methods are the most technologically sophisticated surveying method. Though these methods deliver significant value, their implementation is more complicated. Specifically, acoustic sampling requires a battery to be charged, potentially limiting the survey duration. On the other hand, the surveyor does not need to be present reducing the risk that the surveyor will influence bat behavior. In addition, acoustic methods enable speciation. However, they can have difficulties in differentiating bats that are part of the same genus. In addition, acoustic methods do not reveal bat life history data in the way that live capture or netting can provide. However, the latter methods can introduce species-specific biases and could potentially injure the bats that are captured using these methods (Falxa, 2008a).

Current Study Method

In this retrospective study, data collected and provided by the Washington State Department of Fish and Wildlife (WDFW) were analyzed. The data includes four years of bat emergence survey data collected in the summers of 2018 through 2021 across multiple roosting sites on JBLM by volunteers chosen from the Department of Fish and Wildlife Internship located on JBLM. The data were collected using the guidelines provided in the Colony Assessment Protocol (CAP) generated and provided by the Washington Department of Fish and Wildlife. The data was documented using field data sheets that the survey volunteers were provided during the time of the survey. These forms were later transcribed to an excel spreadsheet for this study. In contrast to the 1992 and 2008 surveys, the current survey conducted from 2018 to 2021 used only visual emergence to survey the bat populations instead of acoustic or catch and release methods.

The Colony Assessment Protocol states that a survey team must be limited to three personnel. This is intended to limit the amount of noise disturbance added to the environment while conducting the survey (Washington Department of Fish and Wildlife, 2018). Communication between surveyors should be made using low soft tones when speaking. In addition, the surveyors must avoid wearing clothing that could make noise (e.g., synthetic material like nylon jackets or pants can make ‘swishing’ noises when moved). Headlamps and flashlights are prohibited from being shone directly onto the bats for more than a few seconds since bats are sensitive to changing light levels (Washington Department of Fish and Wildlife, 2018). McMaster University’s Bat Lab states that light is the primary cue that bats use to sense nighttime, indicating it is time to become active (Conger, 2020). This is important because bats are nocturnal and use the cue of the sun setting as an indication that it is safe to emerge from their roosts (Rehm, 2018). Nighttime helps bats to elude daytime predators such as weasels, snakes, skunks, foxes, and humans. Dusk also increases food availability for bats because birds become scarce at night, thus, reducing the competition for the same food resources (Rehm, 2018).

In order to avoid influencing the emergence data, the surveyors must be in their positions by the roosts’ exits at least 30 minutes prior to sunset. It is important to conduct a pre-survey site analysis to identify where the primary exits are located (Washington Department of Fish and Wildlife, 2018). It is a best practice to space the surveyors so that all sides and angles of the structure can be observed at the same time. The detailed flow chart, Figure 2 outlines the decision-making process for overcoming challenges unique to the roost site (Fig. 2). The CAP, requires that the surveyors use a double-surveyor effort which means that two surveyors will be counting from the same exit (Washington Department of Fish and Wildlife, 2018). The surveyors will sit or stand at the colony site and collect the data for 1-2 hours. The Flow Diagram in Figure 2 was designed to be a resource for helping surveyors trouble shoot issues that could arise while conducting the survey. For example, if a roost had three exists being used by the bats at a specific roost, and only two surveyors were available, the flow diagram can be referenced for guidance on how to proceed. According to Figure 3, the surveyors would determine which exits the majority of the bats were using. The surveyors would then monitor only those two exists instead of trying to monitor all three. If this was not possible, there is also an option to temporarily block one of the entrances forcing the bats to exit through an easier exit to monitor. There was no indication of this occurring in any of the emergence count surveys conducted. The flow diagram also accounts for special circumstances when an internal count of the roost may be necessary such as the inability to clearly see bats emerging from exits. The blocking of one or more exits is preferred since an internal count is very invasive. It consists of either opening up a bat roost or attempting to look inside to see if there are any indications of active bats such as droppings (guano), feeding remains, the absence of cobwebs, an identifiable odor, and scratching or markings around the roost exits (Orme, 2020). This method is very intrusive and can severely disrupt the bats. However, this type of survey was not reported in the 2018 to 2021 data set.

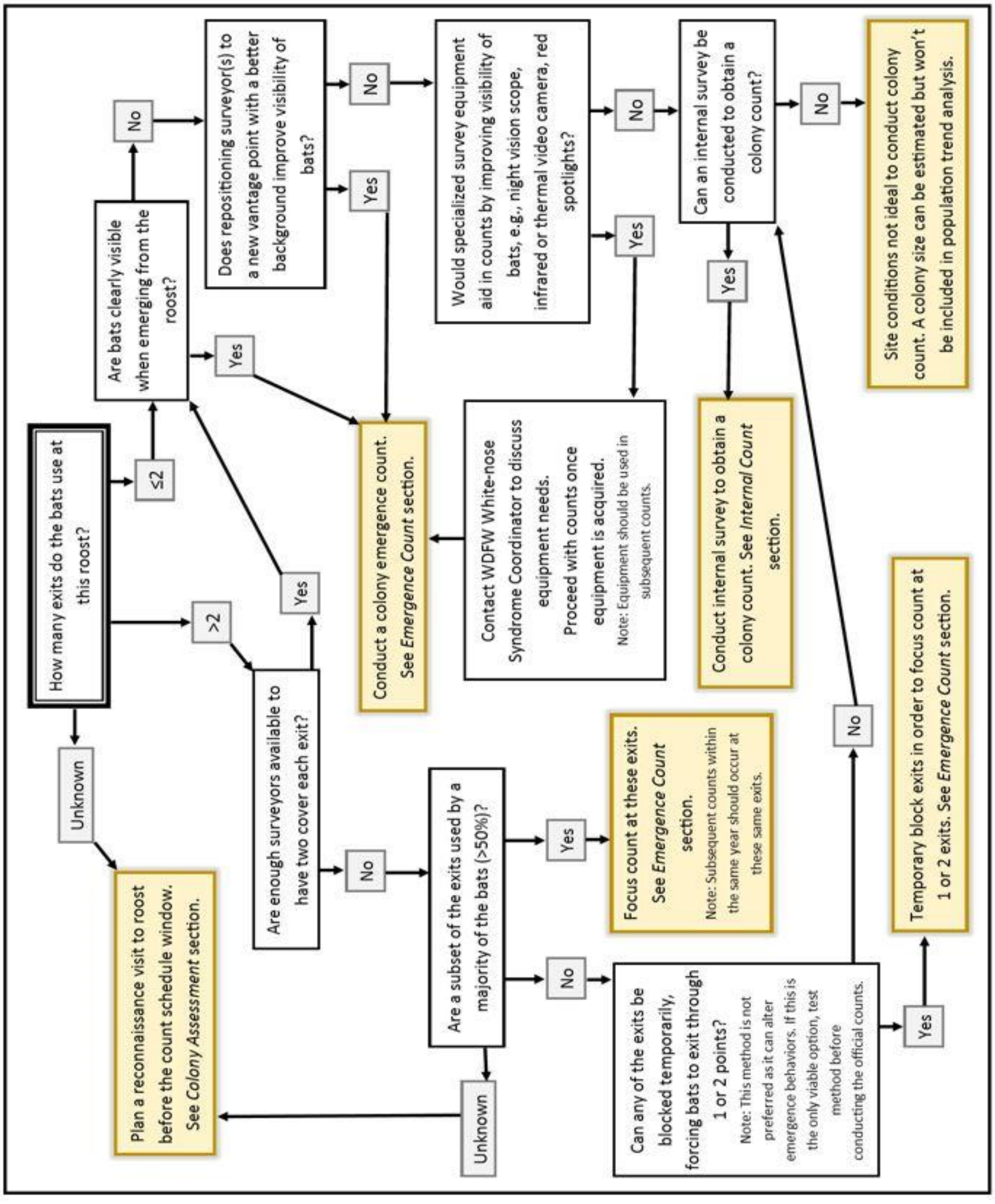


Figure 2. Decision Flow Diagram. The decision flow diagram to determine the best form of count survey to obtain a bat population sample. This figure is from the Bat Colony Protocol used by researchers on JBLM to conduct emergence bat surveys (Washington Department of Fish and Wildlife, 2018).

Bat Colony Site Selection

The bat roost sampling locations for 2018 to 2021 were chosen by using the sites selected during the survey conducted in 2008. Due to limited number of staff available to conduct the emergence surveys, only a portion of the previous survey's roost locations could be studied. Moreover, only the roosts with the most activity were chosen for preliminary inspections to evaluate the roost's activity level. An active roost was identified by having either 1) visible evidence of bats emerging and/or returning to the roost or 2) guano near the roost entrances. While these inspections took place, no documentation or results for these evaluations were available. Thus, it was largely unknown why specific roosts were chosen for a given survey year.

Table 2 shows that the number of roosts being surveyed varied by year. In addition, there was no information to identify why roosts were selected for observation each year. There were only three roosts that were observed in all four years. These roosts are illustrated in Figure 3. The 2018 survey monitored 7 roost sites. However, four of these sites (OP2, OP3, Spanaway, and TA15 Triangle) did not have associated information: the type of habitat (i.e., bridge, wetland, snag) or colony type (i.e., natural or artificial roost). The 2019 survey monitored only three sites, which severely restricted the options for comparing the roosts across the four years. There was no information to indicated why only three sites were monitored. Finally, 7 sites were monitored in 2020, and 8 in 2021.

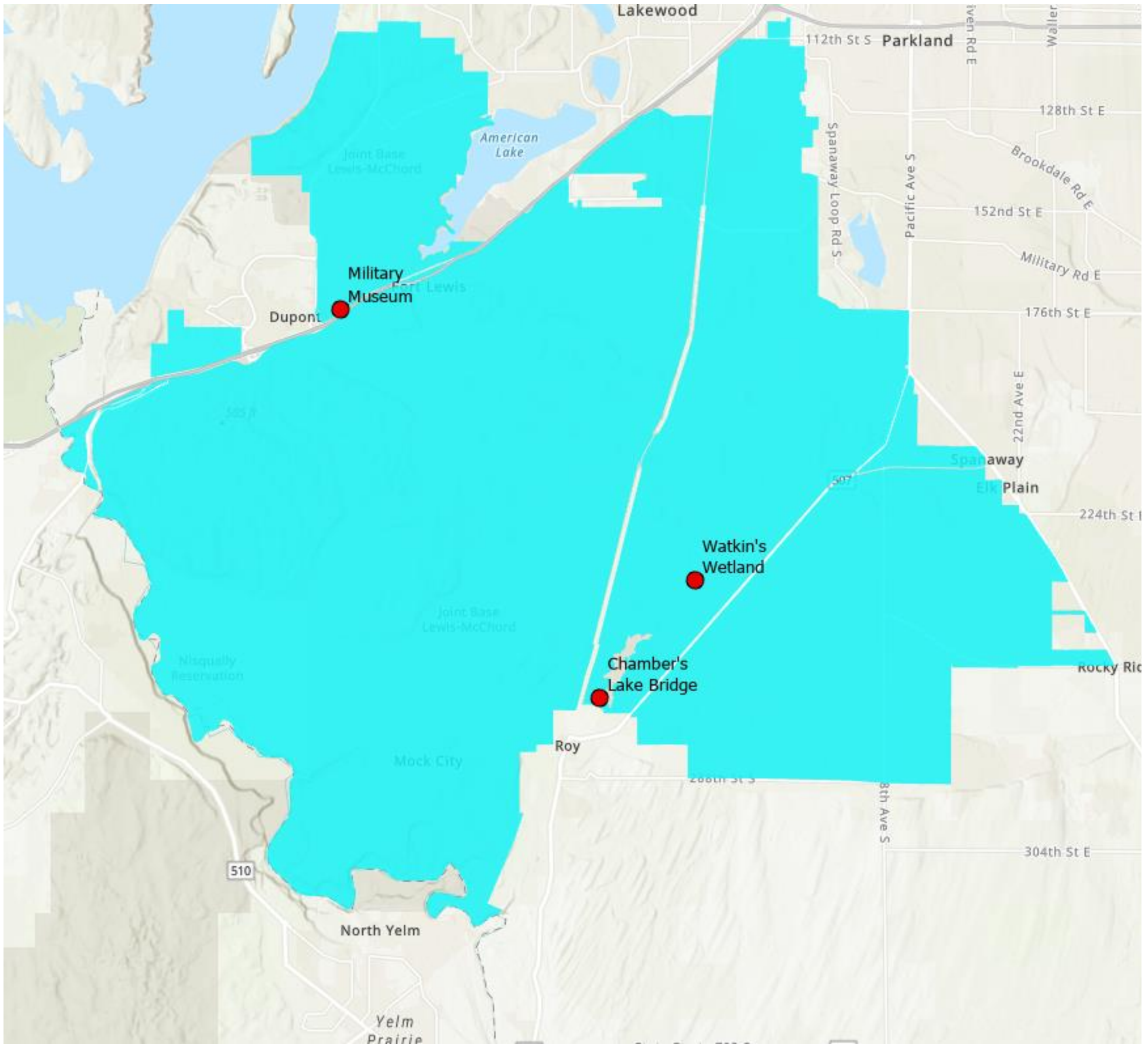


Figure 3. JBLM Map of Main Colonies Surveyed 2018-2021. The three bat roosts that were observed during all four years of bat emergence surveys. The red circles identify the roost or colony site. Image Credit: Erika Larson, 2021.

Survey Year	Site/Roost Name	Frequency
2018	1. Chamber's Bridge 2. Military Museum 3. OP2* 4. OP3* 5. Spanaway* 6. TA15 Triangle* 7. Watkin's Boxes	2 2 1 1 2 2 2
2019	1. Chamber's Bridge 2. Military Museum 3. Watkin's Boxes	2 2 2
2020	1. Batman House 2. Chamber's Boxes 3. Chamber's Bridge 4. Holden Woods RB 5. Military Museum 6. Tank Bridge 7. Watkin's Boxes	2 2 2 1 2 2 2
2021	1. 8^{th} Ave RR Bridge 2. Batman House 3. Chamber's Boxes 4. Chamber's Bridge 5. Fish Hatchery 6. Military Museum 7. Tank Bridge 8. Watkin's Boxes	2 2 2 2 1 2 2 2

Table 2. Roost Sites. The roost names that were observed during each survey year and how many times the surveys were conducted on the specific sites.
* - no description or other information was provided about the site other than the site/roost name

The Colony Assessment Protocol requires that selected roosts be observed one or more times per season. Table 2 demonstrates what roosts sites were being monitored each year. Most of the roosts were surveyed twice during the season. The ideal timeframe for observing a bat population is over the summer months. This is the time when bat populations emerge from their winter roosts and begin to forage and start the mating process. Each species has their own time windows for peak activity. For example, myotis and big brown bats (both observed on JBLM) tend to emerge and become active between the dates of June 15 to July 15, while the Townsend's Big-eared bat (also observed on JBLM) is primarily active between July 1 to July 22 (Washington Department of Fish and Wildlife, 2018). Given these time frames, for all nine species of bat on JBLM, the best time frame to conduct bat surveys is between the beginning of June and the middle of August (Washington Department of Fish and Wildlife, 2018).

V. ANALYSIS OF DATA

Colony site, observation date, and emergence counts were documented by the Department of Fish and Wildlife volunteers conducting the survey. These data were digitally transcribed in a Microsoft Excel workbook. A series of correlation analyses were conducted to identify associations between variables of interest. The following subsections describe the analyses and results for each research question. For all analyses, the same analytic strategy was used: the data were plotted to visualize trends and then Spearman's correlation was calculated.

Roost sites were treated as independent observations. Treating the observations as independent makes sense because temperate bats species are expected to return to the same roosts over the 4-year timescale during which they were observed (Pettit & O'Keefe, 2017). The data for each research question were plotted to observe trends. No linear relationships were observed. Moreover, there is no reason to suspect that the variables of interest should be linearly correlated. Thus, it would be inappropriate to use a statistical measure of correlation that assumes linearity, i.e. Pearson's correlation. Rather, a non-parametric method, i.e. Spearman's correlation, would be more appropriate.

Spearman's correlation ranges from -1 to +1. Numbers close to +1 indicate a positive association between the two variables, while numbers close to -1 indicate a negative association (Andri et al., 2021).

All data analyses were performed using R Version 4.1.2 (R Core Team, 2019). Spearman's correlation and associated P values and confidence intervals were calculated using the *SpearmanRho* function in the *DescTools* R package (version 0.99.44)(Andri et al., 2021).

Scatterplots were generated using the package ggplot2 (Wickham, 2016). Finally, power analysis was performed using the package Webpower (Zhang & Mai, Yujiao, 2021).

Variables Used in Data Analysis

Research Question One: Are bat sightings affected by how early in the year the temperature regularly exceeds 40°F?

Microbats, especially the bats found on JBLM, hibernate when the low temperature is around 40°F (Wildlife Online, n.d.). There are contrasting reports in the literature as to the exact temperature at which bats begin to awaken from torpor or hibernation. Reported values ranged from approximately 35°F to 66°F and could be attributed to variations in the bat species (Anufriev et al., 2003; Frick et al., 2012; Wildlife Online, n.d.). Since microbats prefer to hibernate at 40°F, a temperature ≥ 40°F was chosen to identify when bats are likely begin to emerge from their hibernaculum or winter colonies (Frick et al., 2012). In this study, this variable is referred to as The First Day Above 40°F (FDA40). The FDA40 specifically identifies the first day in the calendar year on which the seven-day average low temperature exceeded 40 degrees Fahrenheit. The FDA40 was calculated using Microsoft Excel by taking daily temperatures pulled from the Weather Underground website for the months January through May of the respective years (The Weather Company, 2021). This time frame was selected because January marked the beginning of the calendar year and the average low temperature in the Pacific Northwest was above 40 degrees in the Month of May for all observation years. Thus, any data beyond May was not required.

Research Question Two: Are bat sightings affected by total annual rainfall?

Addressing the relationship between the number of bat sightings and total annual rainfall required calculating the total annual rainfall for each of the observation years. Total annual rainfall was chosen because it is a metric, albeit not a perfect one, that relates to both direct effects on bats and indirect effects via the impact of rainfall on the availability of food sources. Moreover, precipitation data were inconsistently collected at the time of the surveys. Thus, daily precipitation data for individual sites were unreliable. Consequently, annual precipitation data were downloaded from Weather Underground (The Weather Company, 2021) and imported into Excel for analysis. The total precipitation between January 1 and December 31 of each year were calculated by summing the monthly precipitation in each respective survey year. These values are reproduced in Table 3 below.

Year	Precipitation	Roost/Site	Sightings
2018	29.68	Chamber’s Bridge	31
2018	29.68	Military Museum	26.5
2018	29.68	Watkin’s Boxes	14
2019	25.7	Chamber’s Bridge	28.5
2019	25.7	Military Museum	31.5
2019	25.7	Watkin’s Boxes	24.5
2020	34.61	Chamber’s Bridge	30

2020	34.61	Military Museum	27
2020	34.61	Watkin's Boxes	22
2021	37.71	Chamber's Bridge	16
2021	37.71	Military Museum	0
2021	37.71	Watkin's Boxes	7.5

Table 3. Total Precipitation at Roost Sites. It shows the annual precipitation for each roost location and the corresponding bat sightings for each roost in each survey year.

Research Question Three: Since day-to-day weather conditions can affect survey results, which conditions are important to consider when conducting surveys?

Weather metrics such as temperature and windspeed were collected by the surveyors at the time of observation. These data were documented at the beginning of the observation period in the survey field observation form which was later digitally transcribed. While the other research questions used data that spanned over all four survey years, temperature and windspeed at the time of observation were only recorded for survey years 2020 and 2021. The reason for the inconsistency in this aspect of the surveying methodology is unknown. As a consequence, the data used to address research question three includes only the years 2020 and 2021.

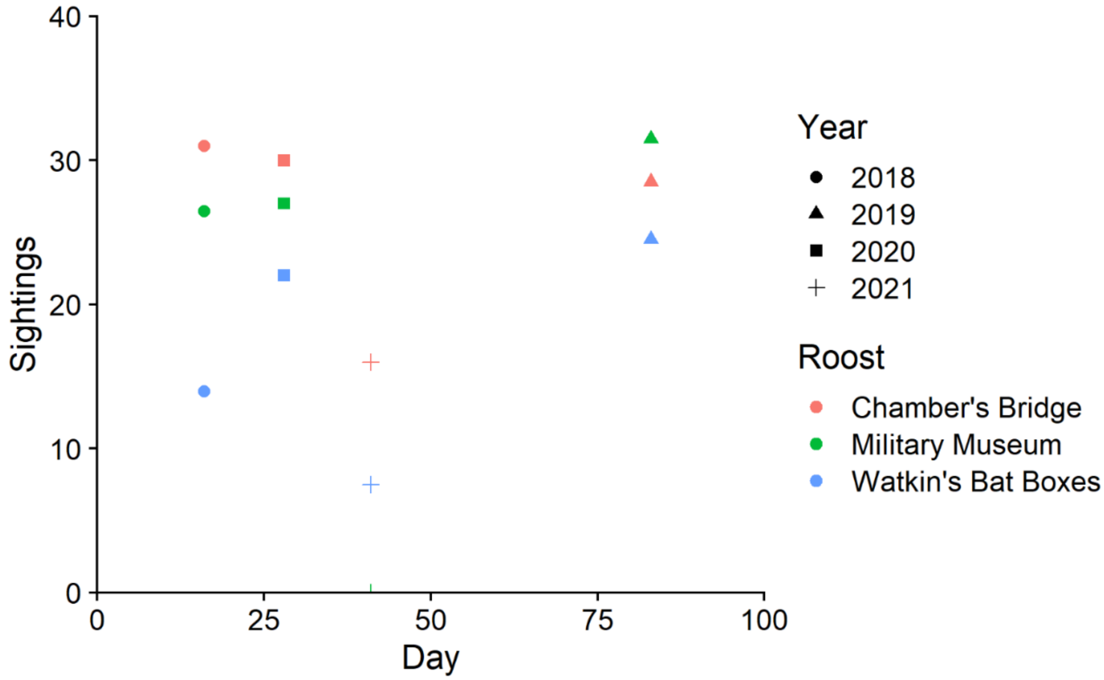
However, despite the data only being collected over the span of two years, survey year 2020 observed 7 roost sites and 2021 observed 8 roost sites as depicted in Table 2. The analyses in this section are organized according to the two types of weather conditions recorded at the time of observation: temperature and wind speed. Precipitation would be another meaningful metric that would be taken into consideration, however, it was not collected at the time of the surveys.

Research Question One

Are bat sightings affected by how early in the year the temperature regularly exceeds 40°F?

To determine whether there is a correlation between the variable First Day Above 40 Degrees (FDA40) and the number of bat sightings (Fig. 4), Spearman's correlation was calculated. All available data without missing values were used for this analysis: the years 2018 to 20201 and three roosts (n=12). Spearman's correlation was 0.02 with a 95% Confidence Interval (CI) of -0.56 to 0.59. The associated p-value was 0.95, indicating that the FDA40 and bat sightings are not correlated. Figure 4 shows the three different roosts represented using a different color for each roost: red for Chamber's Bridge, green for the Military Museum, and blue for Watkin's Bat Boxes. Each survey year is represented using a different symbol shown as a circle for 2018, a triangle for 2019, a square for 2020, and a plus sign for 2021. No statistically significant correlation between FDA40 and the number of annual bat sightings was identified. This could be interpreted in several ways: 1) the variables are not correlated, 2) the sample size is too low n=12 (statistically underpowered) to detect the true effect size, or 3) the variables FDA40 and bat sightings may not capture salient environmental factors or bat population size. In other words, FDA40 may not be a good indicator of when bats emerge from hibernation or torpor. Although this study has a small sample size (n=12), this is quite common for bat studies and points to the need for a coordinated, large-scale, and comprehensive monitoring effort.

First Day above 40°F (FDA40) and Bat Sightings



n=12

Figure 4. First Day above 40°F and Bat Sightings. Relationship between the FDA40 and number of bat sightings. The FDA40 indicates the first calendar day at which the 7-day average low temperature exceeded 40°F. Colors identify roosts and shapes identify observation year. The FDA40 and number of bat sightings were uncorrelated (p=0.95). Spearman's correlation was 0.02 with a 95% CI of -0.56 to 0.59. n=12. Image Credit: Erika Larson, 2021.

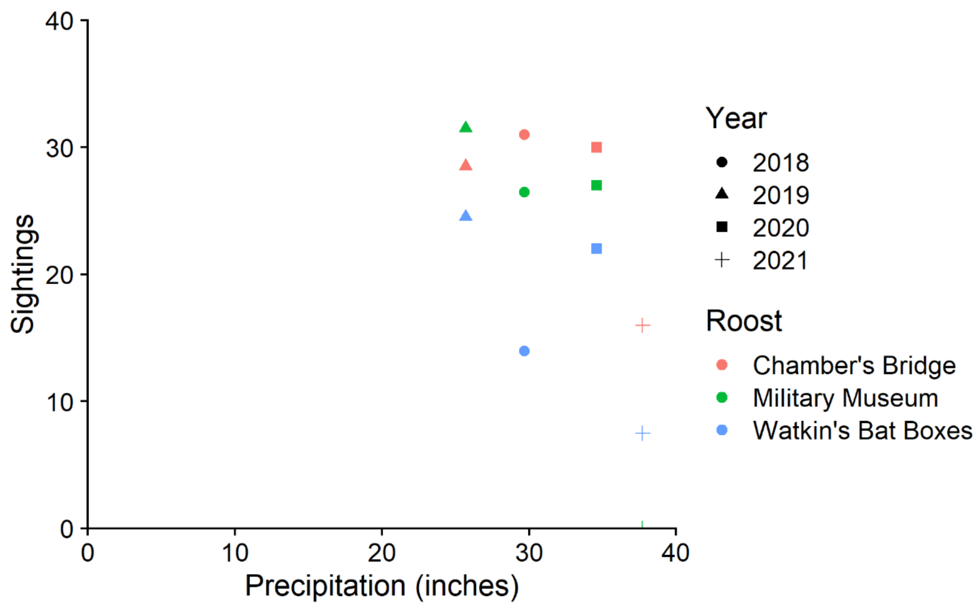
Research Question Two

Are bat sightings affected by total annual rainfall?

To determine if there was a correlation between precipitation and annual bat sightings (Fig. 5), Spearman's correlation was calculated. All available data were included in this analysis, including the years 2018 through 2021 and three roosts (n=12). Spearman's Correlation was -0.63 with a 95% CI of -0.88 to -0.08. The associated p-value was 0.029, indicating that total annual rainfall and bat sightings are negatively correlated, which is significant at the alpha=0.05 level. However, it should be noted that the confidence interval is very wide, highlighting that significant uncertainty remains as to the true size of this effect. Nevertheless, a statistically significant correlation of -0.63 suggests that total annual rainfall has a large impact on bat emergence behavior.

Figure 5 shows the three different roosts represented using a different color for each roost: red for Chamber's Bridge, green for the Military Museum, and blue for Watkin's Bat Boxes. Each survey year is represented using a different symbol shown as a circle for 2018, a triangle for 2019, a square for 2020, and a plus sign for 2021.

Annual Precipitation (inches) and Bat Sightings per Year



n=12

Figure 5. Annual Precipitation (inches) and Bat Sightings. Relationship between the annual precipitation (inches) and number of bat sightings. Colors identify roosts and shapes identify observation year. Total annual rainfall and the number of bat sightings were negatively correlated ($p=0.029$). Spearman's Correlation was -0.63 with a 95% CI of -0.88 to -0.08. n=12. Image Credit: Erika Larson, 2021

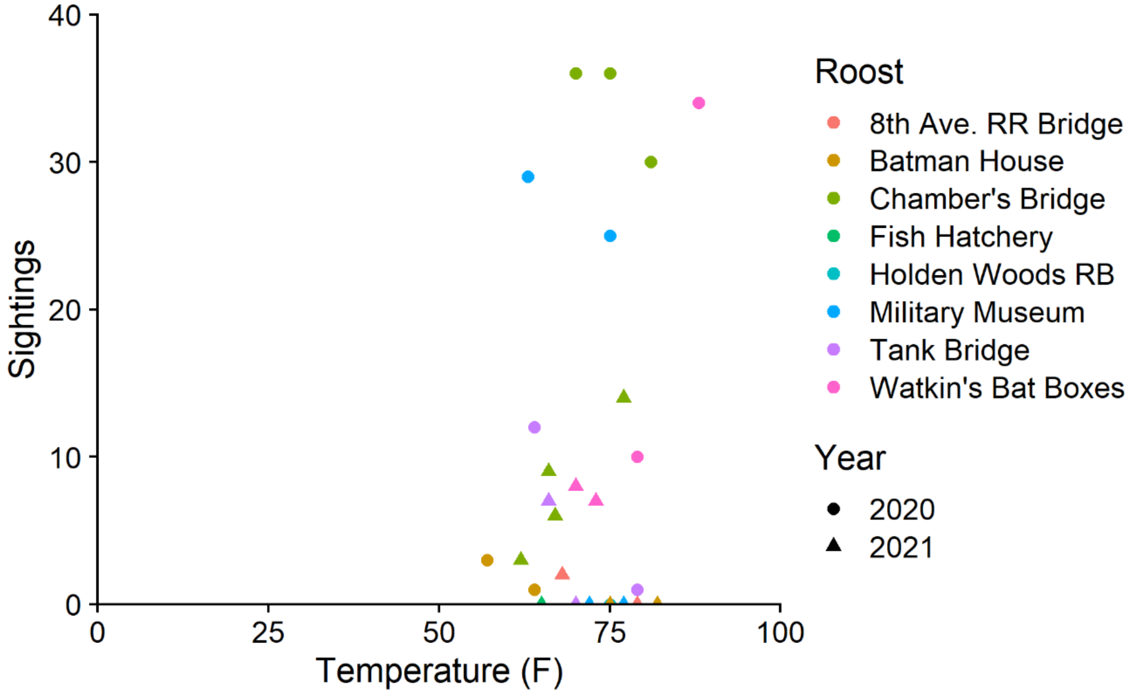
Research Question Three

Since day-to-day weather conditions can affect survey results, which conditions are important to consider when conducting surveys?

Temperature and windspeed recorded during bat surveys were analyzed to determine if they are associated with the number of bat sightings. While research question one addressed temperature, it did not consider temperature at the time of observation.

To determine if there was a correlation between temperature at the time of observation and bat sightings (Fig. 6), Spearman's correlation was calculated. Data from the years 2020 and 2021 were included which were 8 roosts 7 from 2021 due to inconsistencies in data collection. All the roosts in the 2020 and 2021 data were surveyed twice per year, except for Holden Woods RB from 2020 and Fish Hatchery from 2021 which were only surveyed once during those respective years (n=28). Spearman's Correlation was 0.01 with a 95% CI of -0.37 to 0.39. The associated p-value was 0.97 indicating, that temperature and the number of bat sightings are not correlated.

Temperature and Bat Sightings for 2020 and 2021

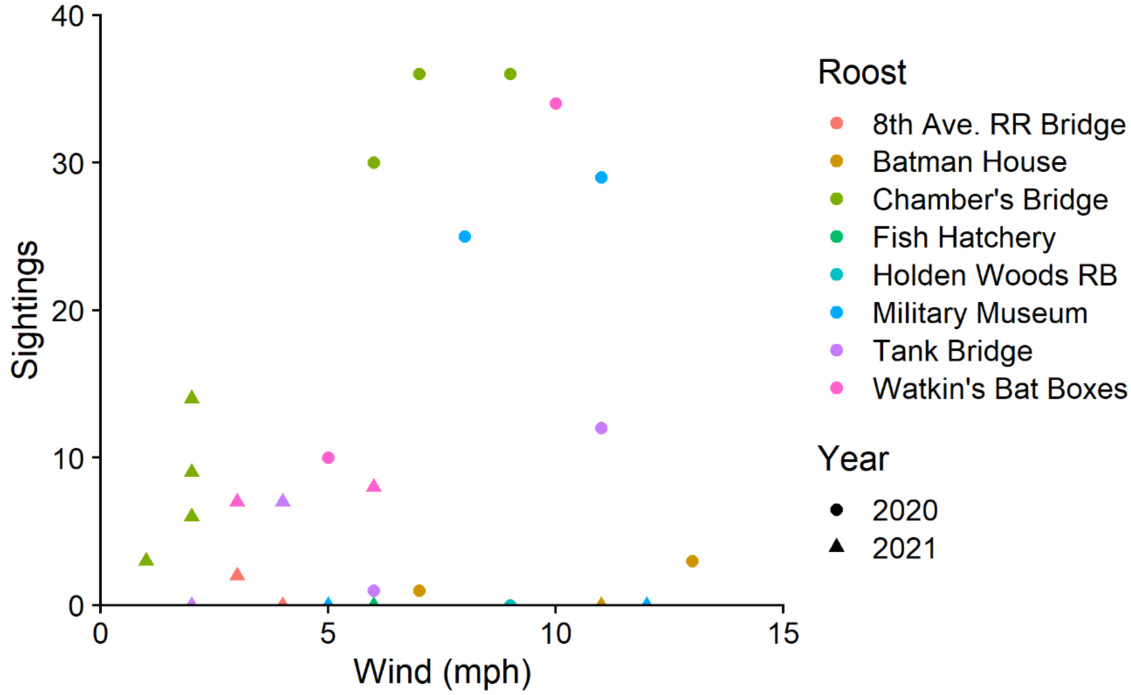


n=28

Figure 6. Temperature and Bat Sightings. Relationship between the temperature and number of bat sightings. Roosts are indicated by color and survey year is indicated by point shape (circle=2020 and triangle=2021). These data identified no correlation (p=0.97) between the temperature documented at the time of the survey and the number of bat sightings. Spearman's correlation was 0.01 with a 95% CI of -0.37 to 0.39. n=28. Image Credit: Erika Larson

To determine if there was a correlation between wind speed at the time of observation and the number of bat sightings (Fig. 7), Spearman's correlation was calculated. The same data and sample size (n=28) were used in this analysis as in the temperature analysis described above (Figure 6). Spearman's Correlation was 0.11 with a 95% CI of -0.28 to 0.47. The associated p-value was 0.60 indicating that wind speed and the number of bat sightings are not correlated.

Wind (mph) and Bat Sightings



n=28

Figure 7. Wind (mph) and Bat Sightings. Relationship between the windspeed and number of bat sightings. Wind speed was recorded at the time of the survey. Roosts are indicated by color and survey year is indicated by point shape (circle=2020 and triangle=2021). Wind speed and the number of bat sightings were uncorrelated (p=0.60) with a Spearman’s correlation of 0.11 (95% CI -0.28, -0.47). Image Credit: Erika Larson, 2021

VI. DISCUSSION

The objective of this study was to determine which weather metrics impact the number of bat sightings during surveys. Prior research suggested that there was an interplay of three different contributors to bat population decline: disease, habitat loss, and climate change. However, there were few studies that took into consideration weather metrics such as temperature, precipitation, and wind. These are important factors to evaluate since weather is predicted to change in the future due to climatic changes and global warming. This study attempted to fill that knowledge gap.

Question 1: Are bat sightings affected by how early in the year the temperature regularly exceeds 40°F?

It was predicted that bat sightings would be affected by how early in the year the temperature exceeded 40 degrees. Specifically, it was predicted that there would be more annual bat sightings for the years that saw a later day of emergence from the bat winter roosting sites or hibernaculum. To evaluate this prediction, the variable First Day Above 40 Degrees, or FDA40 was created to quantitatively define the time at which the temperatures of JBLM became amenable to bat emergence. Note that there is debate as to what specific temperature defines this criterion. Regardless, the present analysis failed to identify a correlation between the FDA40 and number of bat sightings at the respective roosts ($p=0.95$). Spearman's correlation was 0.02 with a 95% Confidence Interval (CI) of -0.56 and 0.59.

These statistical results agree with visual interpretation of the data. As illustrated in Figure 4, the variables FDA40 and the number of bat sightings are not visibly correlated. This result is surprising since the lack of correlation suggests that the changes in the temperature from the winter months to the spring does not impact bat emergence. So, either this is not the correct metric to be using to predict the occurrence of annual bat sightings, or there could be other factors in play. Reports in the literature indicate that if a bat emerges too early there could be limitations on the food that is available for foraging (Frick et al., 2012). On the other hand, bats survive the winter months by using their fat stores while hibernating, meaning that long hibernation times could also put them at risk. The short duration of this study (four years) could also be creating limitations necessary to detect climatic changes (Frick et al., 2012). According to the National Oceanic and Atmospheric Administration (NOAA), climate is the average of weather patterns in a location of 30 years or more (NOAA, 2016). Climate is slow to change over time, thus, a longer duration of study would be required to begin seeing the impacts of these changes on the hibernation times. So, extending the number of years included in this survey may be necessary to generate results that support the use of FDA40 to predict the number of bat sightings.

According to the U.S. Fish and Wildlife Service, bats that live in coastal and Puget sound lowlands could be active all year long (WDFW, 2020). Two species have been observed foraging in the winter months (Falxa, 2007; U.S. Fish and Wildlife, 2020). So, there is the possibility that the FDA40 is the wrong metric to be using. Pacific Northwest bats could be going into mild states of torpor instead of a full hibernation. For example, species such as the silver-haired bats (*Lasionycteris noctivagans*) and the California myotis (*Myotis californicusI),* both species which are located on JBLM (Table 2), go into a state of torpor during severe weather, and become active during good weather (WDFW, 2020). This suggests that it is possible that Pacific Northwest bats have acquired a type of adaptive emergence behavior (Frick et al., 2012).

It has also been reported that early emergence can lead to either: 1) an increased risk of predation and competition with other diurnal insectivores or 2) the forfeiture of optimum foraging opportunities during peak prey availability (Frick et al., 2012). If bats are capable of adaptive emergence behavior then it is possible that some of the species on JBLM migrate during the winter. In the 2008 survey, the hoary bat (*Lasiurus cinereus*) was identified on JBLM. This species of bat survives the winter by migrating more than 1,000 km (WDFW, 2020). However, the same species of bat has also been known to hibernate in the winter (Weller et al., 2016). The hibernation, torpor, and migratory strategies of bats in the Pacific Northwest are not well understood. This points to the need for more comprehensive surveys that include speciation.

Lastly, it is also possible that the short duration of the current survey (four years) could have caused this study to fail to detect associations between variables that are logically connected. For example, it is possible that the number of bat sightings could be related to events from the previous year such as the impact of temperature on food supply, lower annual summer or fall temperature. These are things that could potentially affect bat population size, thus, affecting the number of bat sightings in the subsequent year.

Question 2: Are bat sightings affected by total annual rainfall?

It was predicted that total annual rainfall would negatively impact the number of bat sightings. A negative correlation was identified between precipitation and the number of bat sightings ($p=0.029$). Spearman's correlation was -0.63 with a 95% CI of -0.88 to -0.08. This supports the prediction the number of bats sightings will decrease as total annual rainfall increases.

According to a study conducted by Voight *et al.*, when a bat becomes wet, its pelage and wings moisten, thus increasing their metabolic requirements for flight. It is unknown whether this is caused by the rainfall lowering their body temperatures and increasing their metabolisms or if it makes them less aerodynamic. For example, it has been proposed that rain induces clumping of their fur which could hinder flight and increase metabolic rates (Braconnier, 2011). While this study was conducted in Costa Rica, the bats are in the same suborder as the bats found on JBLM. Leaf Nosed Bats, such as those studied by Braconnier *et al.*, have similar physical characteristics and habitats as Vesper bats seen on JBLM, which suggests that their fur and skin could also share similar characteristics (Birkett et al., 2014; Braconnier, 2011). Voight *et al.* reported that aberrant flight during rain is due to moisture on the bat rather than disorientation due to the raindrops. Specifically, wet fur reportedly causes bats to have higher metabolic rates (Voight et al., 2011). These reports support the present study's findings.

The Colony Assessment Protocol that provides the surveying guidelines instructs that the surveyors are not to continue with the emergence counts if there is heavy precipitation or fog present (Washington Department of Fish and Wildlife, 2018). There is no information regarding why these guidelines were included. The guidelines did not provide a measurement guide to indicate how much precipitation is considered heavy or how much fog needs to be present to discontinue the survey. The duration of the bat surveys could also be a factor since the surveyors were only conducting emergence counts for 1-2 hours starting at dusk. However, there is no documentation or information provided to account for any survey cancellations or reschedules due to inclement weather events.

Question 3: Since day-to-day weather conditions can affect survey results, which conditions are important to consider when conducting surveys?

The goal of question three was to define the relationship between the number of bat sightings and specific weather metrics recorded at the time of observation: temperature and wind speed. The only two weather metrics documented during the bat surveys conducted during this study were temperature and windspeed, both of which were recorded at the beginning of the surveying session. A major limitation in evaluating these metrics is that they were only recorded for survey years of 2020 and 2021. There was no information provided as to why this change in protocol occurred or why these readings might have been left out for years 2018 and 2019. Although question three includes fewer years of data, it includes eight different roosts in 2020 and seven in 2021. Thus, the resulting sample size was 28.

Metric: Temperature

It was predicted that a higher temperature would increase the amount of bat sightings. Spearman's correlation was 0.01 with a 95% CI of -0.37 to 0.39 and a p-value of 0.97. Interestingly, the temperatures at the beginning of the observation periods were not correlated with the number of bat sightings. This suggests that an increase in temperature does not affect the number of bat sightings on JBLM. This is counter intuitive since bats have been reported to be more active in warm weather (Minnesota

Wild Animal Management, 2020). Many studies suggest that at moderate temperatures, activity levels are maximized (Anufriev et al., 2003; Dahl et al., n.d.; Frick et al., 2012). If this is the case, then Pearson's and Spearman's correlations would not be good metrics because they detect only strictly increasing or strictly decreasing relationships, and not those that increase then subsequently decrease. The latter relationship was not observed in this study, as illustrated in Fig. 6. Therefore, this observation supports the selection of statistical test used in this study. On the other hand, it is possible that this relationship exists but was obfuscated by the high variability in the number of bat sightings across the narrow temperature range - spanning from 57°F to 88°F. Since this is a typical temperature range for Western Washington, a substantially enlarged sample size may be required to detect such a relationship. While Hoeffding's D statistic could detect this kind of relationship, it 1) would be statistically underpowered and 2) is not easily interpretable ranging from -0.5 to 1 depending on whether there are ties in the ranked data (Harrell Jr. & Dupont, 2021; Hoeffding, 1948).

To gain a comprehensive understanding of the relationship between temperature and bat activity, observations would be required across a broader range of temperatures. This is important because models produced by the University of Washington predict that there will be temperature increases in the Pacific Northwest (University of Washington, 2020). While the present study failed to detect a correlation, other studies have identified correlations between bat sightings and temperature (Duvergé et al., 2000; Pettit & O'Keefe, 2017). These changes in temperature affect each bat species differently (Groc, 2021). The differential effects can be due to bat size, metabolism, behavior, and roosting location. For example, bats that roost in artificial roosts such as bat boxes are at risk for rapid heating, potentially leading to overheating and dehydration (Groc, 2021). As climate change progresses, these artificial roosts may no longer be safe. According to Cori Lausen from Wildlife Conservation Society of Canada, “Bats walk a tightrope because a few degrees can make a difference to whether they live or die” (Groc, 2021). Due to habitat loss, artificial roosts are becoming more common. If heat waves like the one experienced in Western Washington in June 2021 become more common, then bat mortality is likely to increase. Since bats have a slow reproductive rate it is difficult for their population to recover from these heat events (Groc, 2021).

To mitigate the impact of heat on bats roosting in artificial roosts, researchers have begun investigating different bat box designs and the impact of their installation locations. They have found that some bat boxes can reach a temperature of 52°C (Groc, 2021). Researchers have found that different modifications to these artificial roosts such as adding a chimney, water chamber, or painting the boxes a lighter color could be helpful in stabilizing the temperature inside these roosts (Groc, 2021). Interestingly, bats seem to choose their roosting site based on its location rather than these other factors. All of the above observations point to a substantial lack of information concerning: 1) Species specific responses to increased temperatures, 2) how bats select their roosting sites, and 3) how the impact of severe weather events involving bats can be mitigated.

Metric: Wind Speed

It was predicted that an increase in wind speeds would decrease the number of bat sightings. However, Spearman’s correlation was 0.11 with a 95% CI of -0.28 to 0.47 and a p-value of 0.60. Since the data were only documented for two years it was difficult to determine whether there was any significant trends over time. Wind speeds at the beginning of the observation periods during 2020 and 2021 were not correlated with the number of bat sightings. This suggests that wind speed does not affect bat activity. This is surprising, and contrasts with reports that bat activity is associated with wind speed (Bach et al., 2011). Moreover, there were no obvious non-monotonic relationships between the variables (e.g. increasing then decreasing) (Fig. 7). Thus, failure to detect a correlation cannot be attributed to improper use of statistical methods. In other words, the use of Spearman's correlation was justified for this analysis.

Previous studies have indicated that wind speed does affect the number of bat sightings (Bach et al., 2011; Pettit & O'Keefe, 2017; WINDExchange, n.d.). According to German Nature Conservation Organizations and Authorities, different species of bats show different tolerances to windspeed. This is at least in part due to bat size (Bach et al., 2011). Since bat species in the Pacific Northwest are small, they could be more susceptible to an increase in wind speeds than larger bats would be. The literature in this regard is limited with most studies focusing on the interactions between bats and wind turbines, not the wind itself. The lack of data in this regard is especially concerning since wind speeds can be highly variable. Interestingly, in the present study, there appears to be a substantial difference in wind speed readings between years, with 2020 having higher average wind speeds (8.5 mph) compared with 20201 (4.6 mph). The average number of bat sightings per roost in 2020 and 2021 were 18.08 and 3.73, respectively. These surprising results could potentially be an artifact of the method of data collection. However, that is difficult to discern, as there was no indication as to how the wind speed readings were collected by the volunteers conducting the surveys.

While these results do not support the hypothesis that these weather metrics are associated with the number of bat sightings on JBLM, they do highlight that more research needs to be conducted to include a larger sample size, longer duration of surveying practices, standardization of surveying practices, and consistent training of personnel. All of these could have had impacts on the underlying data and thus the conclusions for the research questions being evaluated during this study.

VII. CONCLUSION

The objective of this study was to determine which weather metrics impact the number of bat sightings. JBLM was used as a case study because the confounding factors that cause bat population decline elsewhere are minimal or absent. This strategy allowed for three key weather metrics (temperature, precipitation, and wind) to be evaluated using data collected between 2018 and 2021. These data were collected by surveyors with the Department of Fish and Wildlife, publicly available sources. Using these data, three questions were asked:

Question 1: Are bat sightings affected by how early in the year the temperature regularly exceeds 40°F?

Question 2: Are bat sightings affected by total annual rainfall?

Question 3: Since day-to-day weather conditions can affect survey results, which conditions are important to consider when conducting surveys?

A statistically significant association was detected for question two. No associations were detected for questions one and three. This points to the conclusion that bat sightings during the summer are less frequent in years when the total annual precipitation is high. However, these findings, both positive and negative, may have been impacted by the study's limitations: 1) metrics that inaccurately reflect the variable of interest, 2) small sample size, and 3) lack of standardization and training.

Weather data are widely available. However, the data are in a format that cannot readily be used to assess the impact of weather on the number of bat sightings. In addition, seasonal and daily trends complicate analysis. To relate the number of bat sightings to weather metrics, weather data must be aggregated into simple and interpretable values. In this study, an attempt was made to devise variables that are meaningful in the context of bat biology and robust to variation. For example, the variable First Day Above 40°F (FDA40) was used in this study. While it is defined as the first day in the calendar year when the seven-day average of daily low temperatures exceeds 40°F, it can be interpreted as the first day of the year on which daily lows regularly exceed 40°F. Though this temperature was selected because bats tend to emerge from hibernation or torpor at this temperature, bat species may be differentially affected by temperature. Therefore, FDA40 may be a good metric for some species but a poor metric for others. Weather metrics may also have impacted the data by introducing an unexpected bias. Specifically, the guidelines outlined in the Colony Assessment Protocol (CAP) concerning precipitation and wind are likely to introduce a bias. The CAP guidelines state that surveyors should stop an emergence survey if the following weather conditions are met: heavy precipitation or high wind speed (Washington Department of Fish and Wildlife, 2018). Since the guidelines do not specify exact thresholds for these conditions, the subjectivity of the surveyors is introduced.

To improve the quality of survey data, a protocol with more specific guidelines is needed. It should incorporate specific thresholds for rain and windspeed that identify when a survey should be terminated. These thresholds are needed for multiple reasons including the impact of these metrics on bat activity and the visibility of the bats to the surveyors. To overcome the latter issue, visual aids different could be used (e.g., infrared or cameras). Alternatively, a combination of methods could be employed. Mist-netting and acoustic sampling have proven to be the most effective for bat monitoring and should be considered for use in future studies on JBLM.

The second major limitation was sample size. The sample sizes used in this study were low. Thus, it was not surprising that this study failed to detect associations between variables that are logically connected (e.g. number of bat sightings and wind speed). Even though, there were four years of data collected, the fact that the survey conducted in 2019 only observed three roosts severely limited the data that could be analyzed. Consistency of site monitoring across survey years would improve the identification of factors that are associated with the number of bat sightings.

In addition to inconsistent observation of roost sites, some variables were missing in 2018 and 2019 data. Temperature and wind speed were only collected in 2020 and 2021. The inconsistent documentation of these metrics further limited the sample size, resulting in only two years of usable data. Two years is insufficient to identify a trend. It is recommended that these metrics be documented consistently at the start of each observation, period. More complete and accurate documentation of weather metrics expanding beyond just temperature, precipitation, and wind are also recommended (e.g. humidity, fog, pressure). This strategy would facilitate a conversation about the types of conditions that affect bat sightings. Importantly, it could facilitate the prediction of the impacts of climate change on bat population health.

The third major limitation is two-fold, a lack of standardization and a lack of training for surveyors. Standardization efforts should focus on bat speciation, counting, and recording weather conditions. Historically, three surveying strategies have been used: visual emergence counts, netting, and acoustic sampling. However, to incorporate these methods, more training needs to be provided to the volunteers conducting the bat surveys on JBLM. Ideally, this would involve a collaborative effort amongst bat monitoring organizations in the region such as the Washington Department of Fish and Wildlife, Bats Northwest, Western Bat Working Group, Cascadia Research, and the Nature Conservancy. Standardized training would go hand-in-hand with standardization of regional surveying methodologies. Sharing the expertise of representatives from these organizations could reduce biases resulting from the methods employed or lack of surveyor experience. Currently, JBLM only conducts emergence count surveys. While emergence count surveys are cost effective, they generate low quality data. Specifically, they produce unreliable data when the surveyors are inadequately trained. To circumvent this problem, it is recommended that future surveys incorporate acoustic sampling technologies and live capture tactics such as mist-nets. This will produce a more accurate representation of JBLM's bat population. While this would require more comprehensive training for surveyors, it would dramatically improve the resulting data.

In summary, this study identified a negative correlation between the number of bat sightings and total annual rainfall. The study's conclusions may have been impacted by 1) metrics that inaccurately reflect the variable of interest, 2) small sample size, and 3) lack of standardization and training. These findings and limitations lead to the following recommendations. 1) A combination of all three surveying methods should be utilized (emergence count surveys, live-capture, and acoustic sampling). This may require a long-term funding source since the upfront costs would include equipment and training. 2) Surveys should be conducted over a longer timeframe and at consistent roosting sites. This will enable the detection of the impacts of climatic changes. 3) Subject matter experts should carefully consider and devise weather metrics that are interpretable and meaningful in the context of bat biology. 4) The incorporation of data sharing and regional training tactics would create transparency among organizations in the area and increase awareness and communication. Overall, the implementation of these recommendations would significantly improve future research and conservation efforts by enabling important questions to be asked and ensuring that data are both high quality and comprehensive, incorporating all factors of interest.

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