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Bat activity over wetlands: temporal and spatial variation

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BAT ACTIVITY OVER WETLANDS:

TEMPORAL AND SPATIAL VARIATION

A Thesis

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By

Sarah Stankavich

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THESIS OF SARAH STANKAVICH APPROVED BY

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MASTER'S THESIS

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ABSTRACT

Foraging animals face decisions about when and where to forage based, in part, on prey availability, which can fluctuate temporally as well as spatially. For temperate insectivorous bats, wetlands are important forage habitats because they provide water and high abundances of insects. My overall objective was to identify abiotic and biotic factors that influence bat foraging activity over wetlands in the channeled scablands of eastern Washington. I surveyed 12 wetland sites at Turnbull National Wildlife Refuge (TNWR) in Cheney, Washington, 3 or 4 times during summer 2012. Ten stations were set up at each site to measure insect abundance using floating aquatic emergence traps and pan traps. Bat feeding activity was measured using ultrasonic recording devices. I measured vegetation abundance, water temperature and depth, presence/absence of fish, and wetland type at each site. I collected 3,127 aquatic insects from 5 different orders. I recorded calls from ten bat species, including two species that have not been previously detected at TNWR. Feeding buzzes were recorded at all 12 sites during at least one sampling period. There was spatial variation in water depth, cattail abundance, and calls from high-frequency bats. Water depth was deeper at one permanent wetland than at one permanent and one non-permanent wetland. Cattail abundance varied across sites. Calls from high-frequency bats were higher at one permanent wetland compared to one wetland that dried up during July. There was temporal variation in wetland characteristics, insect biomass, and bat activity. Water temperature, insect biomass, and bat activity (both total calls and total feeding buzzes) were highest during the first sampling period. Overall, my study showed that bats utilize wetlands as foraging habitat. Because wetlands exhibit temporal and spatial fluctuation, a broad-scale conservation effort to maintain quality wetlands would provide the greatest benefit to bat species at TNWR.

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As flying mammals, bats have high energy demands due to the costs of flight and endothermy. For example, the heart rate of a greater spear-nosed bat (*Phyllostomus hasatus*) in flight increases to 34 times the resting heart rate, compared to a 6 to 8-fold increase in similar sized terrestrial rodents during exercise (Thomas and Suthers 1972). The energy demand for many insectivorous bats is further increased because they typically locate and capture prey that is mobile (Barclay and Brigham 1994). To maintain the necessary level of energy, bats should forage in a manner that will allow them to maximize their energy intake while reducing costs. Because prey availability for insectivorous bats varies temporally and spatially, bats must make decisions about when and where to forage to optimize each foraging period (Anthony and Kunz 1977).

All of the bat species in the Pacific Northwest are insectivorous and belong to the family Vespertilionidae. In the winter, these bats hibernate in groups or migrate (Brack and Twente 1985; Cryan 2003). After emerging in the spring, the sexes separate (Cryan 2003). Females roost in maternity colonies or individually and males roost alone (Hamilton and Barclay 1994). Females give birth to one pup (rarely two) in late spring or early summer (O'Farrell and Studier 1973; Barclay et al. 2003). The young are dependent on milk from their mother until the fall, when they fledge (Kurta et al. 1989; Barclay 1989). Sexes reunite in the fall and mating takes place (Cryan 2003). During this time, both sexes begin preparing for winter hibernation or migration. Because the activity of Vespertilionidae bats is restricted to three seasons, they must forage efficiently in order to gain all the necessary energy.

Vespertilionidae bats show considerable plasticity in their feeding behavior and may utilize a mixture of foraging strategies depending on the habitat and prey available. Norberg and Rayner (1987) classified insectivorous bat foraging strategies into five categories. The first, hawking, is used by bats to catch insects in flight. They do this by using their wing to hit insects into their tail membrane before consuming them. Hawking is further divided into two groups, fast, long range hawking and slow, short range hawking. *Lasiurus cinerus,* the hoary bat is considered a fast hawker. These bats generally forage in uncluttered areas, often above canopy level, and are fast, agile fliers. They can detect prey at long ranges, about 3-5 m (Simmons et al. 1979). Slow-hawking bats, including those in the genus *Myotis,* are short range echolocators. Because of their slower flight they have better maneuverability than fast hawkers and generally forage in cluttered areas. Slow flying bat species also trawl for aquatic insects, catching them at the surface of the water with their hind limbs. Gleaning bats take non-flying prey from surfaces such as the ground (pallid bats, *Antrozous pallidus)*, vegetation, or water. Some species, such as *M. evotis* (long-eared myotis)*,* can actually hover for brief periods while gleaning. Flycatching, in which bats make short attack flights from a perch, is not a common strategy for vespertilionids and has only been noted in juvenile *M. lucifigus* (little brown bat) in our area (Buchler 1980).

Two main factors potentially influence where insectivorous bats forage – habitat type and insect abundance. Studies of bat habitat use have shown that bats spend a significant amount of active time over habitats associated with water (Vaughan 1997; Walsh and Harris 1996). During diurnal roosting, bats lose water through urination and evaporative water loss (Kurta et al. 1990). Although bats gain >66% of water through their food, 20-22% is obtained by drinking (Kurta et al. 1990). When bats emerge from their roosts in the evening, they seek out a water source to re-hydrate before they begin feeding (Adams and Hayes 2008). Finding a water source that also provides high numbers of insects is beneficial to a bat in order to maximize energy gained during foraging flights. Wetlands are therefore important habitat for bats because they provide both water and potential prey (Whiles and Goldowitz 2001; Szewczak et al. 1998).

Insect densities within wetland networks are typically unevenly distributed in time and space because species exhibit differential flushes in response to biotic and abiotic factors. Biotic factors such as predator abundance and the abundance of macrophytes can affect insect biomass. Zimmer et al. (2000) found a negative relationship between insect abundance and fathead minnow abundance. Duffy (1998) also found that predation by fathead minnows can impact invertebrate communities because they consume insect larvae in high numbers, often approaching the estimates of yearly invertebrate production in wetlands. In contrast, macrophyte abundance had a positive relationship on insect abundance (Zimmer et al. 2000). Batzer and Wissinger (1996) showed that litter from emergent plants can support high densities of insects. High abundance of macrophytes creates a more complex habitat, providing a place for insects to hide from diurnal predators and more food resources for them to utilize (Crowder and Cooper 1982). Abiotic factors that can affect insect abundance include water depth, water temperature, and wetland type. Zimmer et al. (2000) found negative relationship between insect abundance and water depth. Water temperature is another factor in emergence, with insects generally emerging earlier at higher temperatures (Gaufin and Hern 1971; Hogg and Williams 1996; Gregory et al. 2000). Wetland type can also influence the insect community composition found in wetlands. Permanent wetlands are covered by water all year while non-permanent wetlands can dry up during the summer. Mosquitoes (order Diptera) and beetles (order Coleoptera) are more abundant in non-permanent wetlands wheras midges (order Diptera) and odonates (order Odonata) are more common in permanent wetlands (Batzer and Wissinger 1996).

Since insect abundances vary between wetland sites, bats must be able to locate these resource flushes for optimum foraging success. In their study of big brown bats (*Eptesicus fuscus*) on Turnbull National Wildlife Refuge, Rancourt et al. (2007) radio tracked female bats and found that individual colonies switched roosts 3.6 during a 2-3 week tracking period and stayed an average of 3.7 days at each roost. They also looked at roost switching behavior for long-eared myotis (*Myotis evotis)*. *M. evotis* colonies moved 3.25 times and spent an average of 2 days at each roost during a 2-3 week tracking period (Rancourt et al. 2005). They suggested that one of the reasons colonies may move is to exploit patches of newly flushed insects. By evaluating how wetland characteristics can influence emerging insect biomass and bat activity, my study will help identify quality foraging habitat for bats for conservation purposes.

I examined the relationship between wetland characteristics (presence/absence of fish, macrophyte abundance, water depth, water temperature, and wetland type), insect abundance, and bat activity at Turnbull National Wildlife Refuge (TNWR) in eastern Washington. My questions were 1) does insect biomass vary between sampling period, site, and wetland type and is this variation explained by wetland characteristics, 2) does bat activity vary by sampling period, site, and wetland type and is this variation explained by wetland characteristics, and 3) is there a relationship between insect abundance and bat activity?

STUDY AREA

My research was conducted from 29 June to 24 September 2012, at TNWR, located in Spokane County 8.05 km south of Cheney, WA. The climate of the region is characterized by warm, dry summers averaging 21◦C and cool, moist winters averaging -1◦C (National Atmospheric Oceanic Administration 2013) (Fig. 1). The average annual precipitation is 42 cm (Fig. 2). TNWR encompasses 7,372-hectares of the Channeled Scablands on the eastern edge of the Columbia Basin Plateau. Volcanism, glaciation, and floods formed the unique environment that is composed of basalt outcrops, flood channels, grasslands, ponderosa pine and aspen forests, shrub-steppe habitat and over 130 bodies of water (U.S. Fish and Wildlife Service 2011). Wetlands comprise 20%, or 1,214-hectares, of TNWR's habitat (National Fish and Wildlife Service 2011) ranging in size from small (ca 9 m^2) vernal pools to large (>161 ha) permanent. There are 10 confirmed bat species (including several Washington priority species) found at TNWR (Table 1).

METHODS

I randomly chose 12 wetlands (Fig. 4) from a pool of 16 sites. The sites in the pool were close to an access road and reportedly free of stickleback fish (Michael Rule, TNWR, personal communication). Stickleback are voracious consumers of chironomid larvae and pupae and can significantly impact the numbers of insects emerging (Hynes 1950). Nine sites are classified by TNWR as permanent wetlands and the remaining 3 are non-permanent (either semi-permanent or seasonal ephemeral) (Fig. 4). Permanent wetlands contain measureable water throughout the entire year, while non-permanent wetlands can dry up during the summer depending on weather conditions (United States Environment Protection Agency 2013). All 12 sites were sampled 3 times during the summer and 5 sites were sampled 4 times. Sampling Period 1 was from 29 June-25 July, Period 2 was from 27 July-22 August, Period 3 was 23 August-13 September, and Period 4 was 15 September-24 September.

Wetland characteristics

I established transects along the edge of each wetland with one station every 50 meters, 10 stations in total. As the water receded between sampling periods, I moved my transects to be in water. I measured water depth (m) and water temperature (◦C) at each station during each sampling period. Once insect nets had been placed in the water (see: Methods, insect abundance) I counted the stems and species of vegetation that fell within a 20 × 50-cm PVC plot frame on all four sides of the trap. The vegetation measurements were later grouped into 4 categories: cattails (*Typha* species*)*, rushes (*Scirpus* species), reeds/sedges (*Eleocharis*, *Sparganium*, and other Cyperaceae species), or grasses (predominantly *Phalaris arundinacea,* reed canary grass). I surveyed for fish once at each site during the summer. I placed 3 fish traps in the water at each site for a 24 hour period to survey for presence/absence of fathead minnows, stickleback, or other fish. I used the classifications determined by TNWR managers to group wetlands into permanent and non-permanent categories.

Insect abundance

Each site had 10 insect stations set 50 m apart along the edge of the wetland. At each station, I placed an insect emergence net and a pan trap. The emergence nets were 1.65 m × 0.6 m floating traps constructed from midge netting and PVC pipe (Fig. 5) (modified from MacKenzie and Kaster 2004). They were placed in standing water and anchored to nearby vegetation. The pan traps were plastic plates filled with soapy water that were placed on the ground approximately 0.3 m away from the water's edge. Using a Summit Backyard Safari Bug Vacuum, I collected insects from all emergence traps after a 24 hour period and placed them in 70% ethyl alcohol. I strained the pan traps and preserved the contents in 70% ethyl alcohol. I identified the insects to family, measured total body length to the nearest mm, and used length-weight regressions from Sabo et al. (2002) to calculate biomass (mg). Only insects that had at least one aquatic life cycle stage were used in data analysis.

Bat activity

I used an Echo Meter EM3 Active Ultrasonic Bat Detector/Recorder (Wildlife Acoustics, Inc.) to monitor bat activity at my sites. Acoustic monitoring provides a non-invasive way to actively or passively monitor bats by recording their echolocation calls. Acoustic monitoring is a relative measure of bat activity and cannot be used to identify individual bats. I conducted preliminary monitoring at TNWR and found that bat activity was highest for a period of 2 hours after sunset and declined sharply after midnight, so I recorded activity from 9 p.m. to midnight during the study. I obtained information on lunar phase during sampling nights (The United States Naval Observatory 2013). The detectors were set to record in 20 second increments with a 12 kHz trigger. I imported these data into Kaleidoscope Pro (Wildlife Acoustics, Inc.) to count the number of overall calls and the number of feeding buzzes during each sampling period. Feeding buzzes are visible in a call sequence as areas with modulated frequency and a high repetition rate (Fig. 6). A feeding buzz is significant because it signifies a bat's final approach and capture of an insect. The Kaleidoscope software has an auto ID feature to identify bat calls to species, but the results are not always accurate. After running the calls through the auto ID, I visually verified the results using the sonograms. If identification to species was not possible (due to call quality or ambiguity), I sorted the call based on the minimum frequency into 3 frequency groups – low-frequency bats (<30 kHz), mid-frequency bats (30-47 kHz), and high-frequency bats (>47 kHz) (Table 1, Fig. 3) (O'Farrell et al. 1999).

Statistical analysis

My data included 1) five measures of wetland characteristics – average water temperature, average water depth, stem counts for emergent vegetation, presence/absence of fish, and wetland type, 2) insect abundance (biomass of insects/m^2), 3) number of bat calls/night, and 4) number of feeding buzzes/night. The bat call data were also broken down into number of calls per night by each frequency group (high, mid, and low-frequency) and number of feeding buzzes per night by each frequency group.

When comparing means between sampling periods, sites, or wetland type, I first used Levene's test to determine if the assumption of equal variance was met. As indicated in tables 1-7, if the variance was equal, I used one-way ANOVA and Tukey's test. If this assumption was not met, I used Welch's ANOVA and the Games-Howell post hoc test. In all analyses involving total number of calls or feeding buzzes, the variables were transformed using $\log_{10}$ to improve issues with equal variance. For all stepwise regressions, significant factors were left in the equation if the individual $p \leq 0.1$. All statistical analyses were completed using SAS 9.3. Means, standard error, and ranges for all analyses can be found in appendices 1-3.

For wetland characteristics, I compared both the mean water temperature and mean water depth of all 12 sites combined between the four sampling periods. I compared the mean stem counts for cattails, rushes, reed/sedges, and grasses between individual sites and wetland types. I also compared mean water temperature and depth across sites and wetland types.

For insect biomass, I compared mean biomass across sampling periods, sites, and wetland type. I used stepwise regression to determine which, if any, wetland characteristics explained variation in insect biomass.

For bat activity, I compared the mean number of total calls by sampling period, individual site, and wetland type. I also compared mean number of calls by frequency group, mean number of total feeding buzzes, and mean number of feeding buzzes by frequency group across sampling periods, individual sites, and wetland type. I used stepwise regression to examine the relationships between total bat calls and wetland characteristics, calls by individual species group and the wetland characteristics, number of feeding buzzes and wetland characteristics, and number of feeding buzzes from each species group by wetland characteristics.

Finally, I used a simple linear regression to examine the relationship between the total number of bat calls and insect biomass as well as the total number of feeding buzzes and insect biomass.

RESULTS

Wetland characteristics

Mean water temperature declined 10.6◦C throughout the summer (Fig. 7, Table 2), but did not vary significantly by site or wetland type. Mean water depth did not vary by sampling period or wetland type (Appendix 1). Site 105a, a small, non-permanent wetland had a significantly higher mean water depth than medium-sized wetlands 21a (non-permanent) and 54a (permanent) (Fig. 8). Although emergent macrophyte cover was variable between sites, only one site had a significantly higher abundance of reeds/sedges (Fig. 9). The ANOVA for cattails abundance by site indicated that there was a significant difference in the means, but Tukey’s post-hoc test did not separate means. Vegetation abundance did not vary by wetland type (Appendix 1). Although water noticeably receded at all sites throughout the summer, only one (21a) completely dried up during the course of the study. Juvenile Centrarchidae species, most likely bluegill, were present at one non-permanent and five permanent wetlands (Fig. 4). I did not find any fathead minnows or stickleback.

Insect abundance

I collected a total of 3,127 aquatic insects representing 5 different orders (Fig. 10). Chironomidae and Ephydridae, both belonging to the order Diptera, were the two most common families collected. Total insect biomass per site ranged from 0 to 8,837 mg between all sampling periods. Within a single site, total insect biomass could range from 0 mg to >1,000 mg from one sampling period to the next. Sampling Period 1 had significantly higher insect biomass than the fourth sampling period (Table 3, Fig. 11). There was no difference in overall insect biomass by site or by wetland type (Appendix 2). Insect biomass increased with increasing water temperature ($F_{1,35} = 4.56$, $p = 0.04$, $R^2 = 0.12$) (Appendix 3).

Bat activity

I recorded a total of 2,784 calls from 10 species (Table 1). I was able to identify approximately 24% of these calls to species and the rest I sorted into high, mid, or low-frequency groups. Calls were recorded at all 12 sites during the study. The mean number of bat calls by was variable between sampling periods (Table 4). There were significantly more calls recorded during sampling Period 1 than Period 4 (Fig. 12), but calls did not vary by wetland type or site (Appendix 4). There were significantly more calls from low-frequency bats during sampling Period 1 than Period 4 (Fig. 12). The mean number of calls from mid and high-frequency bats did not vary by sampling period (Appendix 4). The mean number of calls varied between sites (Table 5), one permanent wetland (LT1) had significantly more calls from high-frequency bats than the wetland that dried up (21a) (Fig. 13). There were no differences in calls from mid or low-frequency bats across all sites (Appendix 4).

There was a positive relationship between the total number of calls and water temperature ($F_{1,34} = 4.73$, $p = 0.04$, $R^2 = 0.12$). There was a significant positive relationship between high-frequency calls and water depth ($F_{1,37} = 10.63$, $p = 0.002$, $R^2 = 0.22$) (Appendix 3). There was a significant positive relationship between mid-frequency calls and rush and grass abundance ($F_{2,27} = 4.5$, $p = 0.02$, $R^2 = 0.25$). There was no significant relationship between low-frequency calls and any wetland characteristic. There was no relationship between total calls or calls from any species group and moon phase.

I recorded a total of 332 feeding buzzes. Feeding buzzes were recorded at least once at every site. There were significantly more feeding buzzes during Period 1 than Period 4 (Fig. 14). Feeding buzzes did not vary by site or wetland type (Table 6, Appendix 4). There was a significant positive relationship between the total number of feeding buzzes and water temperature ($F_{1,35} = 7.24$, $p = 0.01$, $R^2 = 0.17$).

More feeding buzzes from mid-frequency bats were recorded at one permanent site (UT1) than all other sites (Fig. 15). However, the mean number of feeding buzzes from high or low-frequency bats did not vary (Table 7, Appendix 4) and there was no variation between wetland type for any species group (Appendix 4).

There was no relationship between the number of feeding buzzes by high-frequency bats and any wetland characteristic. There was a significant positive relationship between the number of feeding buzzes by mid-frequency bats and rush abundance and presence of fish ($F_{2,28}$= 3.97, p = 0.03, R^2 = 0.22). Feeding buzzes by low-frequency bats increased as grass abundance increased ($F_{1,29}$ = 4.73, p = 0.04, R^2 = 0.14). There was no relationship between total feeding buzzes or feeding buzzes from any frequency group and moon phase. Complete regression results for bat activity during each sampling period are presented in Appendix 5.

I recorded calls from 10 different bat species during my study. Rancourt (2000) netted eight of these but also captured 2 additional *Myotis* species that I did not record, *M. thysanodes* and *M. volans*. However, I recorded calls from *Antrozous pallidus* and *Parastrellus hesperus* which have not yet been captured at TNWR. *A. pallidus* is classified as a priority species in Washington because they often congregate in large numbers, making them vulnerable to disturbance (Washington Department of Fish and Wildlife 2011). *A. pallidus* has been captured in Spokane County (Ella Rowan, Washington Department of Fish and Wildlife, Personal communication). They generally prefer areas with rocky outcrops and dry shrub or dry forest environments near water (Washington Department of Fish and Wildlife 2011). I confirmed calls from *A. pallidus* at one permanent wetland, UT2, and one non-permanent wetland, 21a. There were low basalt outcroppings to the south of site 21a that could provide roosting areas for the pallid bat and the surrounding area was dominated by dry shrubby grassland. Site UT2 was mostly surrounded by grassland habitat so it is unlikely that pallid bats are roosting near the site. Because UT2 is a permanent site, *A. pallidus* may frequent the area for feeding and drinking only. *P. hesperus* has not been documented in Spokane County, but has been found in neighboring Whitman and Lincoln counties (Washington Department of Fish and Wildlife 2011). *P. hesperus* is generally found in lowland arid habitats such as dry grasslands, shrub-steppe, and associated riparian zones (Washington Department of Fish and Wildlife 2011). I confirmed calls from *P. hesperus* at one non-permanent wetland, 105a. Site 105a was a lowland area that was surrounded by grasslands that occasionally flooded. Although recording multiple calls from these two species is strong evidence that they are found at TNWR, confirmation of their presence should be confirmed by capture before their known ranges are expanded.

Insect abundance and bat activity

There was a significant positive relationship between total number of calls and insect biomass ($F_{1,37} = 7.49$, $p = 0.01$, $R^2 = 0.17$) (Appendix 6). Likewise, feeding buzzes also increased with increasing insect biomass ($F_{1,38} = 7.03$, $p = 0.01$, $R^2 = 0.27$) (Appendix 6).

DISCUSSION

The wetland network at TNWR fluctuates spatially and temporally. These variations in wetland characteristics in turn impacted insect abundance and bat activity. The variation in insect abundance due to changing wetland characteristics also influences bat activity. The positive relationship between insect abundance and bat activity also suggests that bats are able to locate and exploit variable insect flushes.

There was spatial variation in both abiotic and biotic wetland characteristics. Mean water depth was significantly higher at one small, seasonal wetland, 105a, than at one permanent wetland, 54a, and another non-permanent wetland, 21a. Wetlands 54a and 21a have human-made drainage outlets that allow refuge managers to control water levels, whereas wetland 105a does not. Because there was an increase in precipitation in June, all the wetlands would have re-flooded. Drainage outlets could have lowered water depth at 54a and 21a but not at 105a. Macrophyte cover also varied spatially. The higher presence of reeds/sedges at site ET could be due to differences in soil chemistry and composition. Newman et al. (1996) found higher levels of potassium and nitrogen in one *Eleocharis* species than in one *Typha* and one *Cladium* species. McJannet et al. (1995) classified *Eleocharis* species as plants that prefer infertile soils such as sand or gravel.

Spatial differences in vegetation abundance can cause spatial variation in bat activity. The total number of bat calls and feeding buzzes were both positively affected by rush and grass abundance. Rush abundance was higher at permanent wetlands, so rushes could be indicators to bats of reliable water sources that will not dry up during the summer. High abundance of rushes and grasses could also provide habitat for insects. Although I did not find any relationship between insect biomass and vegetation abundance in this study, other studies have shown that insect abundance increases with macrophyte cover (Crowder and Cooper 1982; Batzer and Wissinger 1996; Zimmer et al. 2000).

Variation in wetland permanence across a landscape can also impact bat activity. There were significantly more calls from high-frequency bats at one permanent wetland than at one non-permanent wetland, 21a, which was completely without standing water by late July. *M. yumanensis* is a high-frequency bat whose habits are closely tied to water (Brigham et al. 1992; Evelyn et al. 2004). Herd and Fenton (1983) observed *M. yumanensis* foraging predominantly over water and feeding on aquatic insects such as Ephemeroptera and Trichoptera. The lack of water at 21a could have caused *M. yumanensis* individuals to abandon the site as a source of water and food, which would lead to a decrease in high-frequency calls at that site.

Additionally, there were more feeding buzzes from mid-frequency bats over one permanent wetland (UT1) than one non-permanent wetland. The mid-frequency group is made up mostly of *Myotis* species, which are smaller bats. To maintain their mass specific metabolic rate, small bats need to eat a relatively larger volume of insects compared to bigger bats. Because *Myotis* are morphologically limited to small prey items, they need to catch a large number of small insects to meet this required volume, which could account for the significantly higher number of feeding buzzes. I found a significant positive relationship between feeding buzzes by mid-frequency bats and rush abundance. Rushes were more abundant at permanent sites, which suggests that this wetland would be quality foraging habitat for mid-frequency bats.

Insects exhibited temporal variation in their abundance at TNWR, with abundance highest during sampling Period 1 and declining throughout the summer. The decrease in water temperature between early periods and late periods explains the temporal difference in biomass. Changes in mean water temperature throughout the summer could be due to cooler air temperatures in August and September. The mean low temperature during these two months was 5-10 ◦C cooler than in July, leading to the decreased water temperature. Insect development is closely tied to temperature

(Ward and Standford 1982; Hogg and Williams 1996; Gregory et al. 2000). Insects have a minimum threshold temperature that must be reached before development can begin and they must remain above this threshold for a certain number of “degree days” before the insect emerges (Byrd and Castner 2000). Because the average water temperature was highest during the first sampling period, insect larvae would reach the required number of degree days sooner than during the other sampling periods, leading to a greater emergence of insects.

Bat activity also varied temporally. The increased number of bat calls and feeding buzzes during sampling Period 1 coincides with the highest period of insect biomass. In addition to responding to the presence of more insects, many North American bat species give birth in late June or early July (Frick et al. 2009; Davis 1969; Christian 1956; Grindal et al. 1992). The juveniles generally do not leave the roost and forage on their own until late August or September, so the females would be foraging more frequently to produce enough energy for lactation. Female *M. lucifugus* use 32% of their energy for milk production during lactation, which amounts to 33.8 kJ/d^{-1} on the first day of lactation and 60.3 kJ/d^{-1} during peak lactation (Kurta et al. 1989). A 9-g lactating *M. lucifugus* will eat 5.5 g of insects a night to meet these energy requirements (Kurta et al. 1989). The significant increase in low-frequency bat calls could also be related to lactation energetics. The species that make up the low-frequency group are larger bats and thus would require a larger total amount of food to meet their own energy demands as well as those of their offspring. Barclay (1989) found that foraging time of *L. cinereus* females increased 73% between the beginning of lactation and the fledging of young but declined as the offspring became more independent. I did not see an increase in bat activity in August when the juvenile bats begin leaving the roost. As water temperature drops and water depth decreases over the summer, bats may begin to forage more often over terrestrial areas, which could account for the lack of increased activity when juveniles begin foraging independently.

Abiotic and biotic wetland characteristics vary temporally and spatially at TNWR. These differences can, in turn, lead to variation in insect abundance and bat activity. Insect abundance varied with changing seasonal water temperatures, which in turn led to temporal differences in bat activity. Bat activity also varied spatially, with high and mid-frequency groups showing significantly more activity at permanent wetlands. The overall goal of my study was to identify quality bat foraging habitat for conservation purposes. Since successful foraging bouts are critical for lactating females during June and July, wetlands that produce large numbers of insects during this time period are crucial. In this study, wetlands with higher mean water temperatures in late June-late July produced the highest abundance of insects during this time. Wetlands in areas with an open canopy will receive more sunlight and will thus have higher temperatures and produce more insects than wetlands in shaded areas. Although my results suggest that bats may utilize permanent wetlands slightly more than non-permanent wetlands, maintaining a mosaic of wetland types is important to promote the temporal and spatial variability of resources required by bats.

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Table 1 - Bat frequency group based on minimum call frequency in kHz. Low-frequency < 30 kHz, mid-frequency 30-47 kHz, high-frequency > 47 kHz. Species marked with R were captured by Rancourt (2000), S were recorded in this study, and B were found in both. Fig. 3 illustrates examples of calls from each frequency group.

Species group	Species	Common name	Study
Low-frequency	*Lasionycterus noctivagans*	Silver-haired bat	B
	Lasiurus cinereus	Hoary bat	B
	Eptesicus fuscus	Big brown bat	B
	Antrozous pallidus	Pallid bat	S
	Myotis thysandoes	Fringed myotis	R
Mid-frequency	*Myotis ciliolabrum*	Small-footed myotis	B
	Myotis evotis	Long-eared myotis	B
	Myotis lucifugus	Little brown bat	B
	Parastrellus hesperus	Canyon bat	S
	Myotis volans	Long-legged myotis	R
High-frequency	*Myotis californicus*	California myotis	B
	Myotis yumanensis	Yuma myotis	B

Table 2 – ANOVA results for wetland characteristics by sample period, site, and wetland type at TNWR in 2012. Significant results are in bold. Significant results are in bold. Variance test's marked with a "W" are Welch's test values. All other variance tests are Levene's test.

		$F_{(NDF, DDF)}$	**P**	**Variance test p**
Water temperature	**Sample period**	**$17.86_{3,33}$**	**<0.001**	**0.3**
	Site	$0.93_{11,25}$	0.94	0.62
	Wetland type	$0.09_{1,25}$	0.77	0.63
Water depth	Sample period	$0.49_{3,36}$	0.69	0.6
	Site	**$2.74_{11,28}$**	**0.02**	**0.03 W**
	Wetland type	$0.25_{1,38}$	0.62	0.02
Cattail abundance	**Site**	**$3.14_{11,19}$**	**0.014**	**0.25**
	Wetland type	$0.05_{1,29}$	0.83	0.63
Rush abundance	Site	$1.64_{11,19}$	0.16	0.20
	Wetland type	$0.67_{1,29}$	0.42	0.52
Grass abundance	Site	$1.14_{11,27}$	0.39	0.13
	Wetland type	$0.07_{1,37}$	0.79	0.34
Reed/sedge abundance	Site	$0.67_{11,27}$	0.42	0.52
	Wetland type	$1.74_{1,37}$	0.2	0.31

Table 3 – ANOVA results for insect biomass by sampling period, site, and wetland type at TNWR in 2012. Significant results are in bold. Significant results are in bold. Variance test's marked with a "W" are Welch's test values. All other variance tests are Levene's test.

	$F_{(NDF, DDF)}$	P	Variance test p
Sampling period	**$2.81_{3,36}$**	**0.024**	**0.56**
Site	$1.24_{11,28}$	0.31	0.001 W
Wetland type	$2.78_{1,38}$	0.10	0.15

Table 4 – ANOVA results for number of bat calls by sampling period, site, and wetland type at TNWR in 2012. Significant results are in bold.

	$F_{(NDF, DDF)}$	P	Levene's test p
Sampling period	$\mathbf{3.4_{3,35}}$	**0.03**	**0.79**
Site	$1.47_{11,27}$	0.2	0.08
Wetland type	$0.7_{1,37}$	0.41	0.82

Table 5 – ANOVA results for number of calls for each species group by sampling period, site, and wetland type at TNWR in 2012. Significant results are in bold. Significant results are in bold. Variance test's marked with a "W" are Welch's test values. All other variance tests are Levene's test.

		$F_{(NDF, DDG)}$	P	Variance test p
# calls – high-freq	Sample period	$0.28_{3,35}$	0.84	0.58
	Site	**$2.16_{11,27}$**	**0.05**	**0.02 W**
	Wetland type	$0.00_{1,37}$	0.9	0.07
# calls– mid-freq	Sample period	$2.73_{3,35}$	0.06	0.14
	Site	$0.94_{11,27}$	0.52	0.10
	Wetland type	$1.08_{1,37}$	0.37	0.38
# calls – low-freq	**Sample period**	**$3.54_{3,35}$**	**0.02**	**0.08**
	Site	$0.8_{11,27}$	0.64	0.15
	Wetland type	$0.75_{1,37}$	0.39	0.49

Table 6 – ANOVA results for number of bat feeding buzzes by sampling period, site, and wetland type at TNWR in 2012. Significant results are in bold. Significant results are in bold. Variance test's marked with a "W" are Welch's test values. All other variance tests are Levene's test.

	$F_{(NDF,\ DDF)}$	P	Variance test p
Sampling period	**$4.37_{3,36}$**	**0.001**	**0.06**
Site	$1.19_{11,28}$	0.33	0.25 W
Wetland type	$1.83_{1,38}$	0.18	0.79

Table 7 – ANOVA results for number of feeding buzzes for each species group by sampling period, site, and wetland type at TNWR in 2012. Significant results are in bold. Variance test's marked with a "W" are Welch's test values. All other variance tests are Levene's test.

		$F_{(NDF,DDF)}$	**P**	**Variance test p**
# buzzes – high-freq	Sample period	$1.32_{3,36}$	0.28	0.14
	Site	$0.81_{11,28}$	0.63	0.92 W
	Wetland type	$1.65_{1,38}$	0.2	0.55
# buzzes – mid-freq	Sample period	$1.08_{3,36}$	0.37	0.38
	Site	**$4.35_{11,28}$**	**<0.001**	**0.75 W**
	Wetland type	$2.22_{2,38}$	0.14	0.29
# buzzes – low-freq	Sample period	$1.63_{3,36}$	0.2	0.33
	Site	$0.92_{11,28}$	0.54	0.10
	Wetland type	$0.97_{1,38}$	0.33	0.49

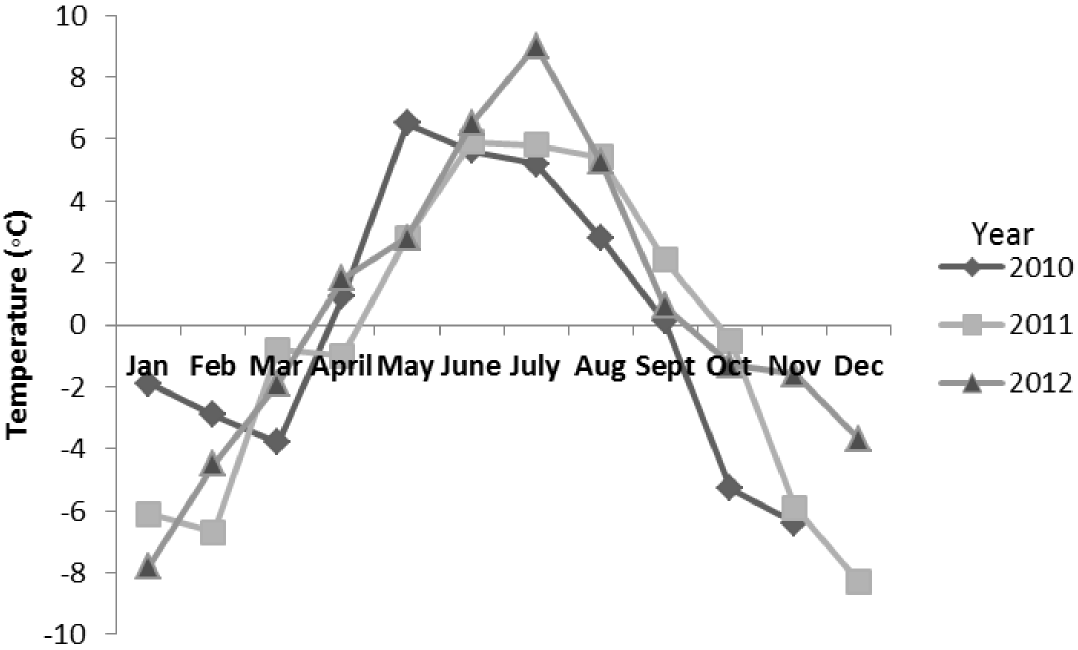

Figure 1 – Average monthly low temperature from 2010-2012 in Spokane, WA (NOAA 2013).

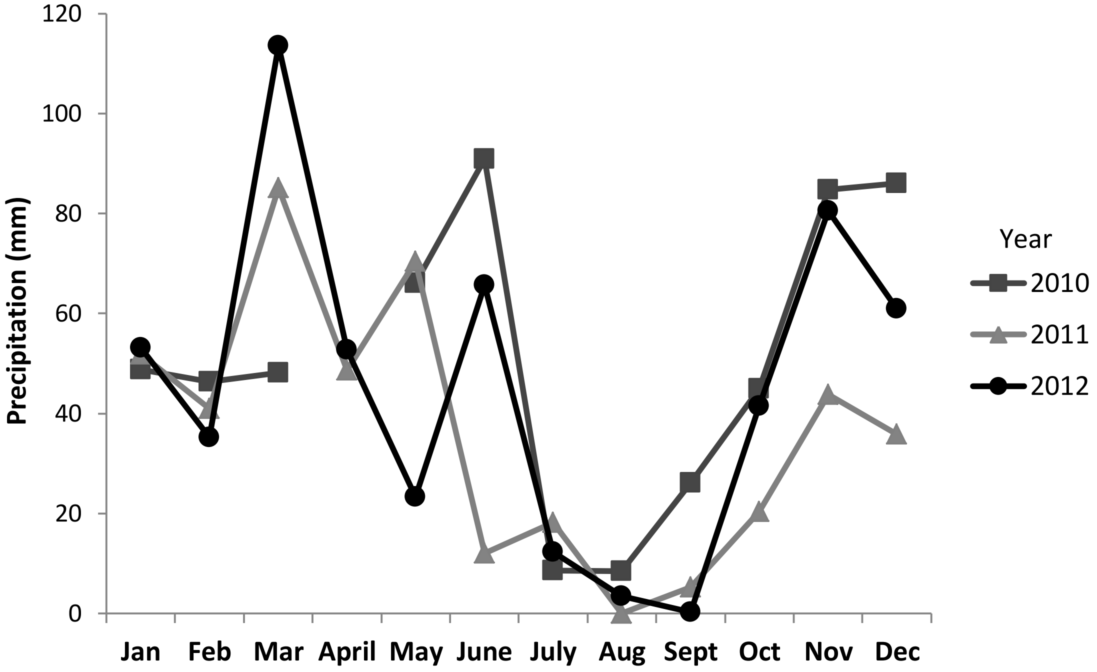

Figure 2 – Average monthly precipitation from 2010-2012 in Spokane, WA (NOAA 2013).

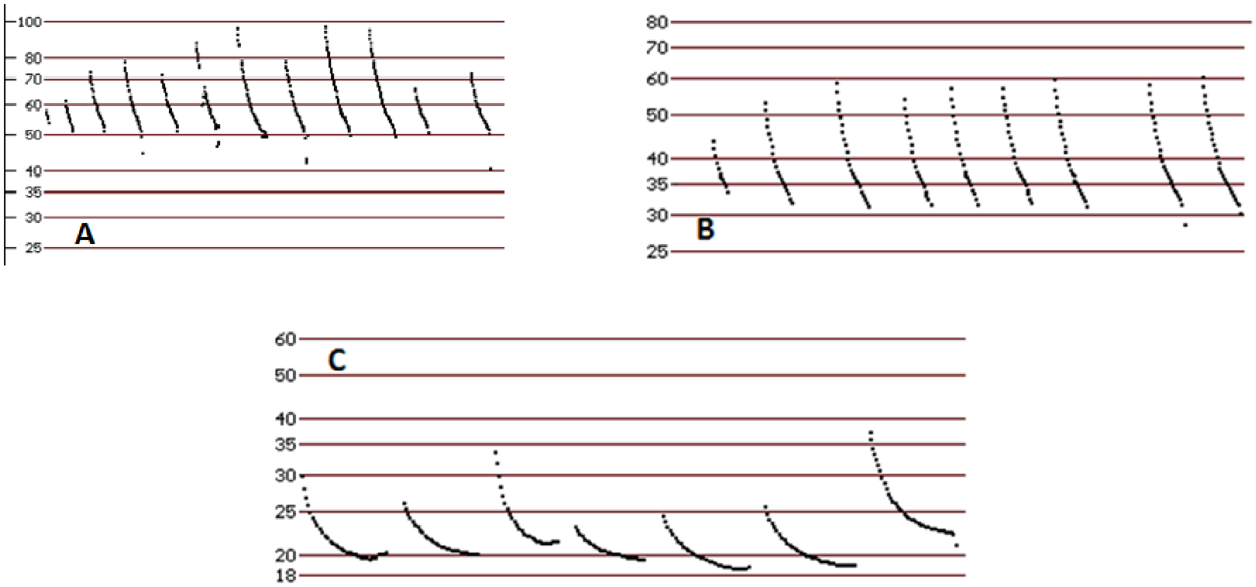

Figure 3 – Spectrographs illustrating calls from a high-frequency bat (A), a mid-frequency bat (B), and a low-frequency bat (C).

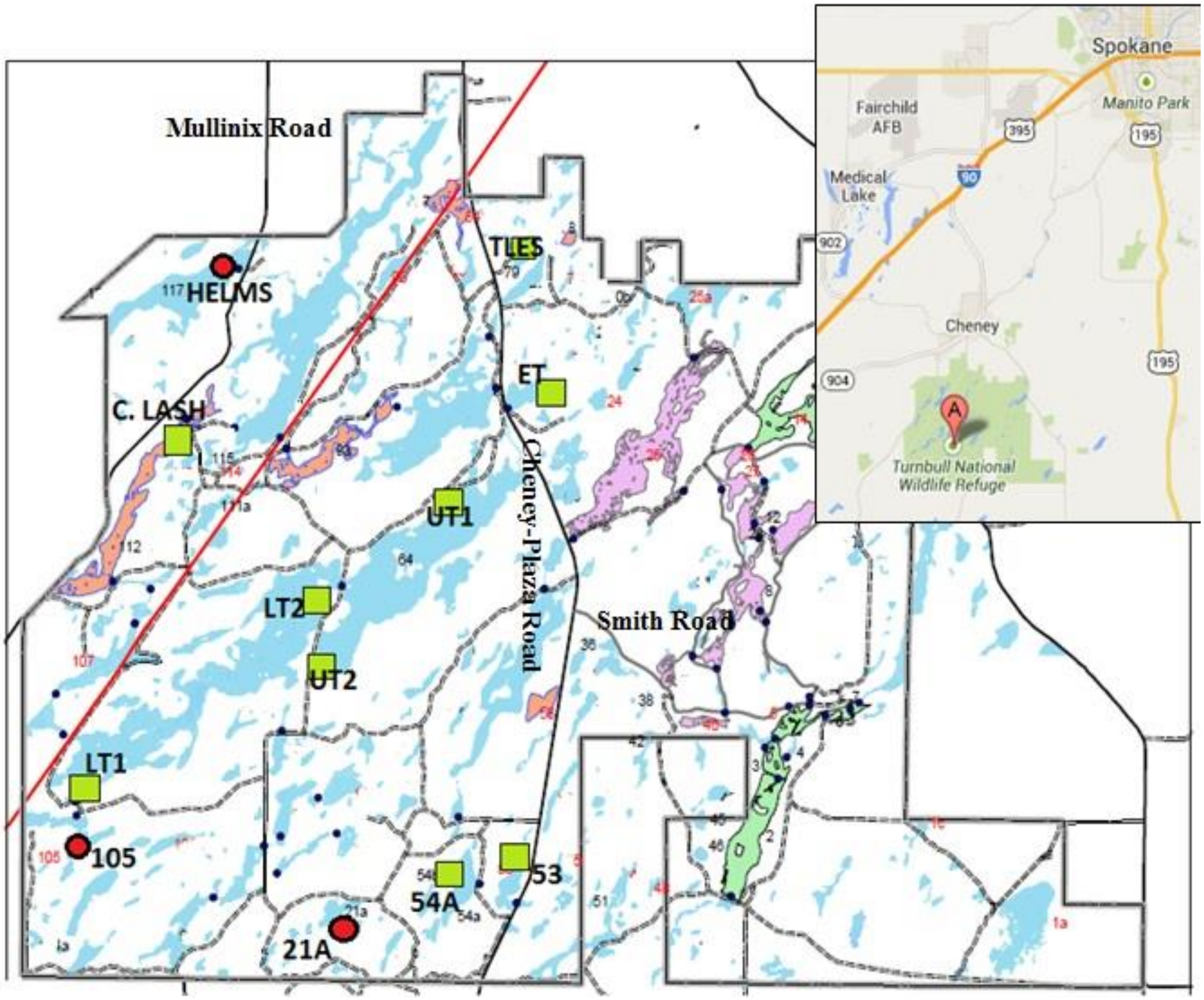

Figure 4 – Map of 12 study sites at TNWR. Non-permanent wetlands are indicated by circles and permanent wetlands are indicated by squares. Sites with fish: 105, 54a, LT1, TLES, UT1, and UT2.

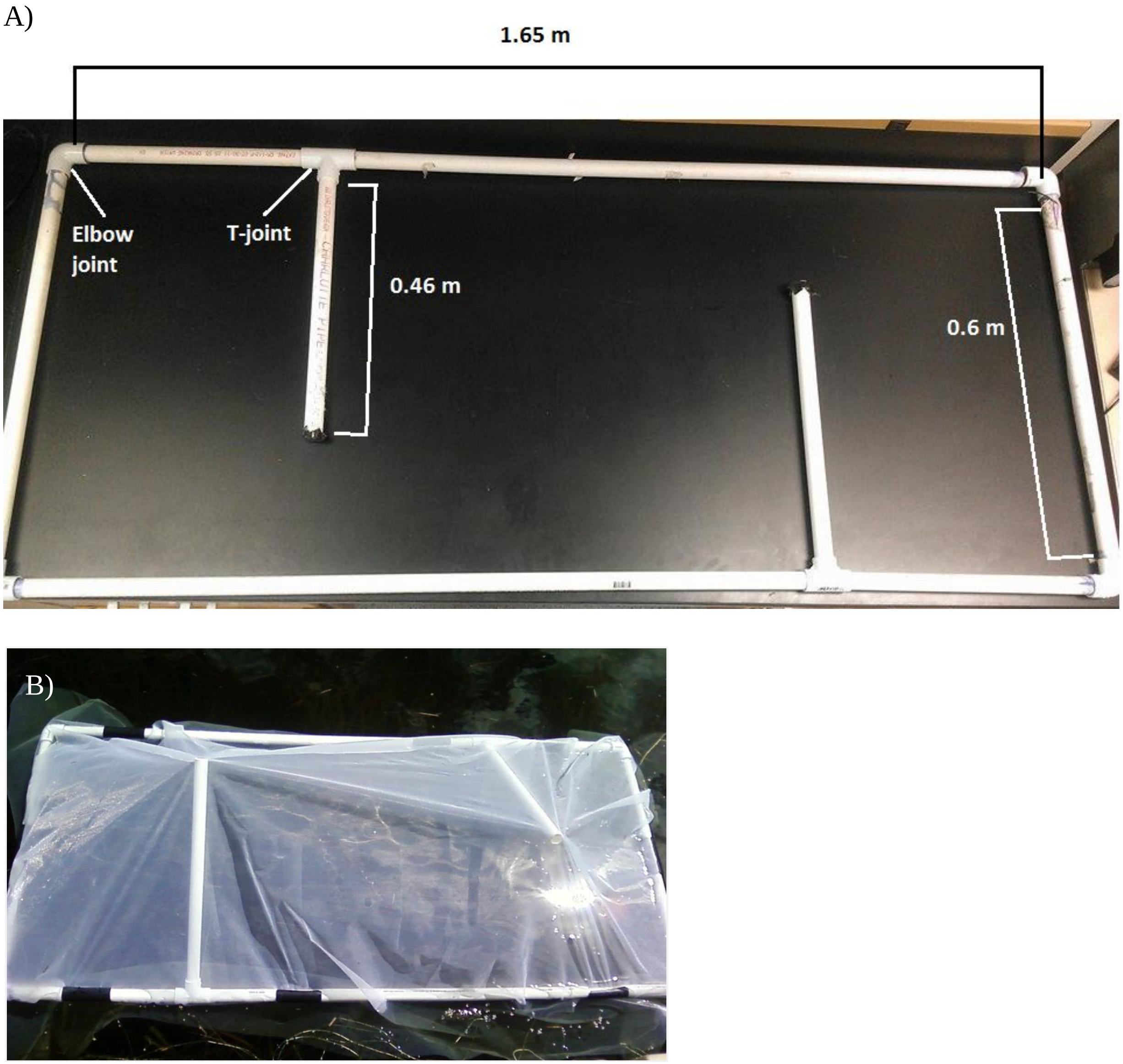

Figure 5 – A) Emergence trap frame built from PVC pipe. The 4 elbow joints were bonded using purple PVC primer. The T-joints were left un-bonded to allow the arms to fold flat for easier transport. B) Midge netting (1.5 m) was glued to the frame using waterproof silicon caulking and small pieces of PVC cut lengthwise to act as clips.

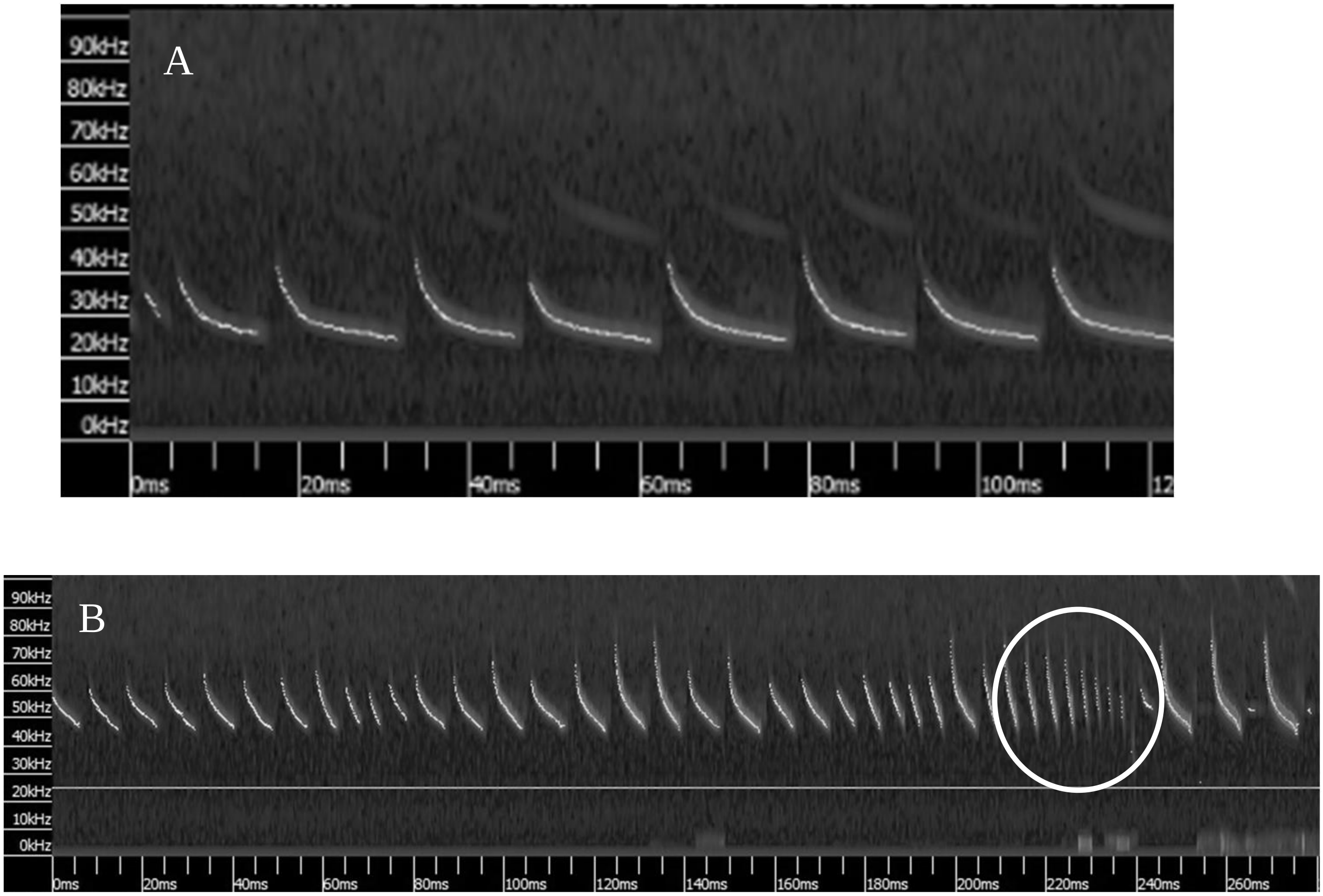

Figure 6 – A) A portion of an echolocation call from a low-frequency bat viewed in Kaleidoscope. B) A high-frequency bat call and feeding buzz (circled) viewed in Kaleidoscope

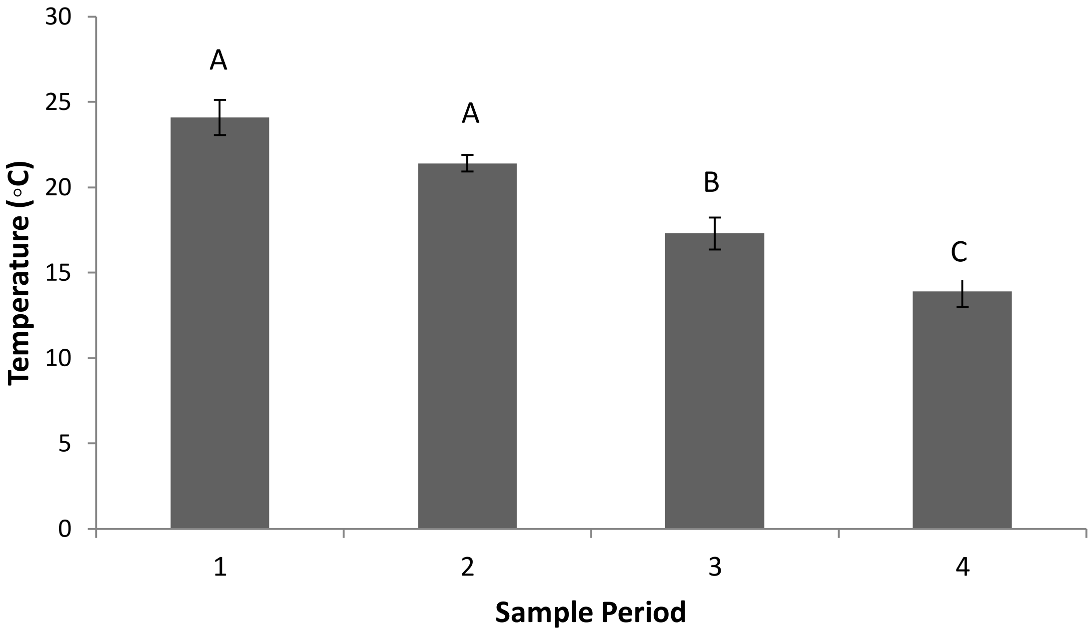

Figure 7 - Mean (±SE) water temperature of 12 wetland sites at TNWR across 4 sampling periods in 2012. Periods marked with the same letter are not statistically different.

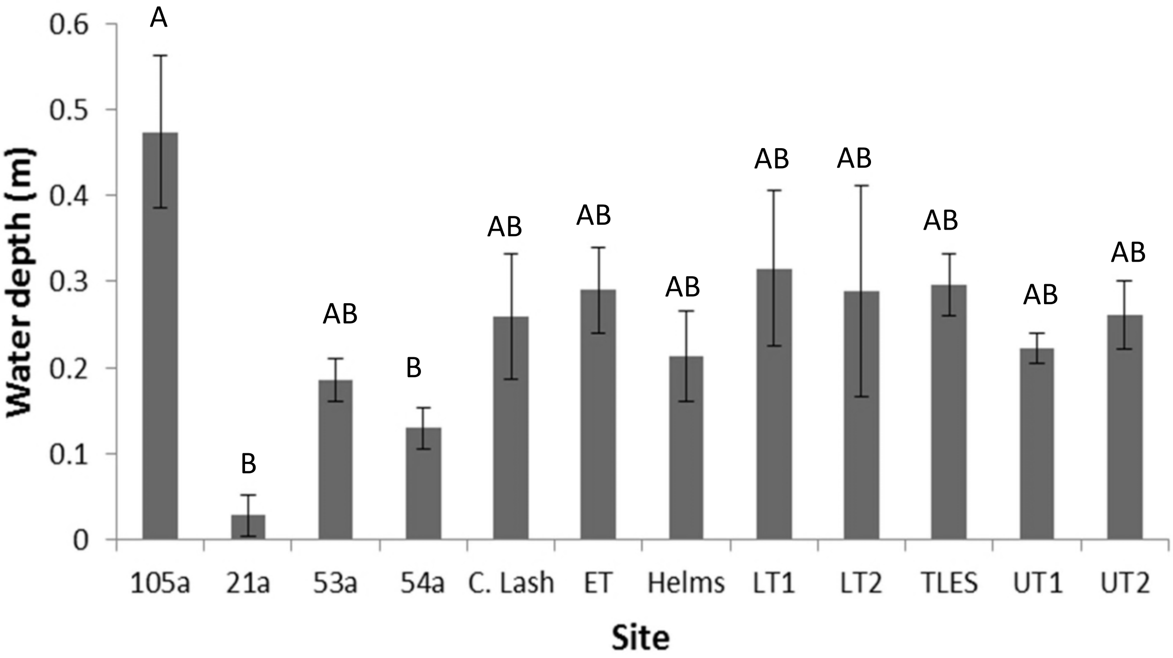

Figure 8 – Mean (± SE) water depth across 12 wetland sites at TNWR in 2012. Water depth at 105a was significantly higher than at permanent wetland 54a and non-permanent wetland 21a.

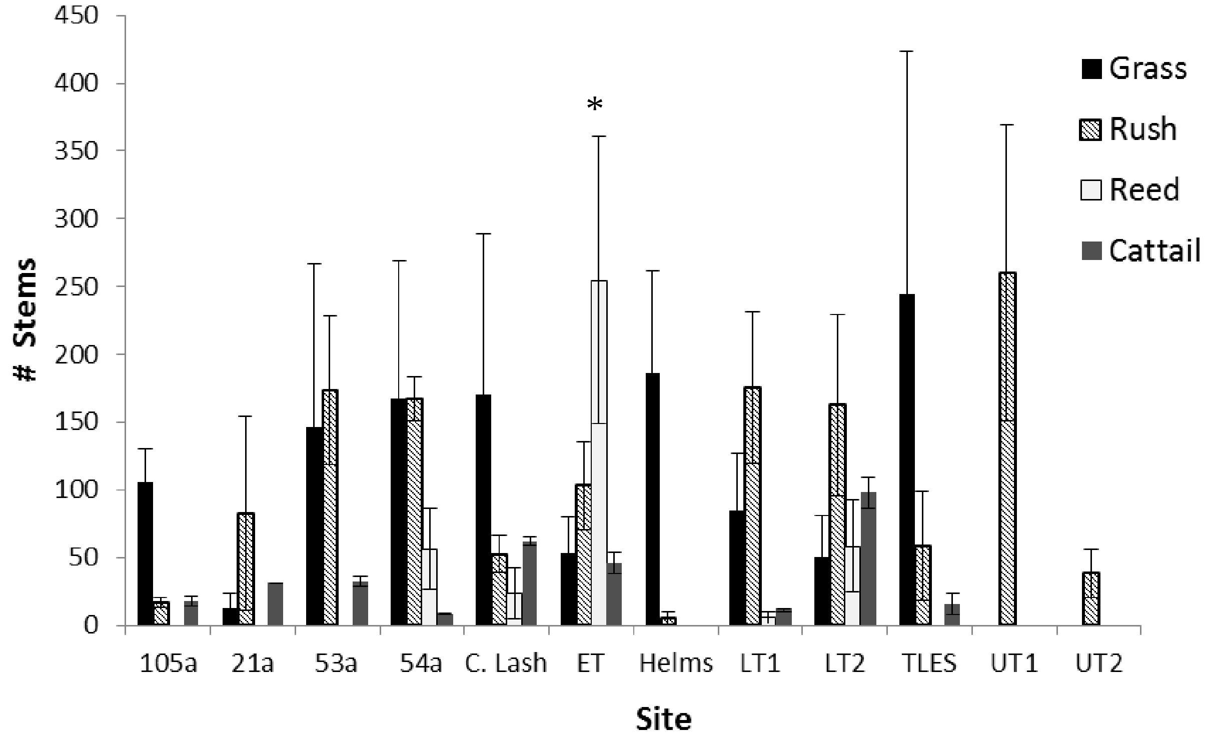

Figure 9 – Mean (± SE) abundance of grasses, rushes, and reeds/sedges at 12 wetland sites at TNWR in 2012. ET had a significantly higher abundance of reeds/sedge than any other site.

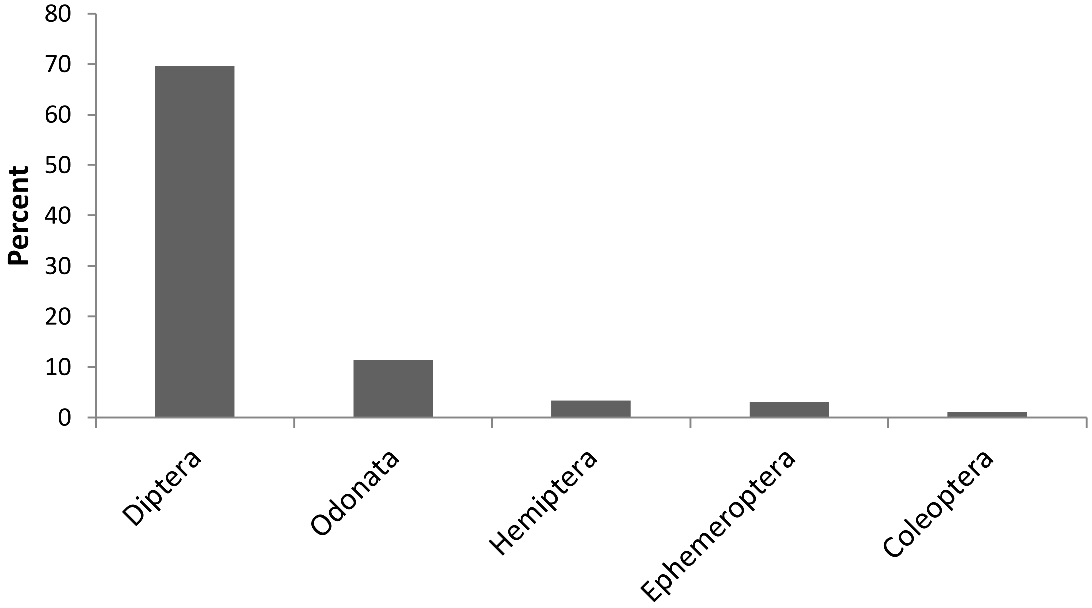

Figure 10 - Percent composition by order of 3,127 insects collected from 12 wetland sites at TNWR using emergence nets and pan traps in 2012.

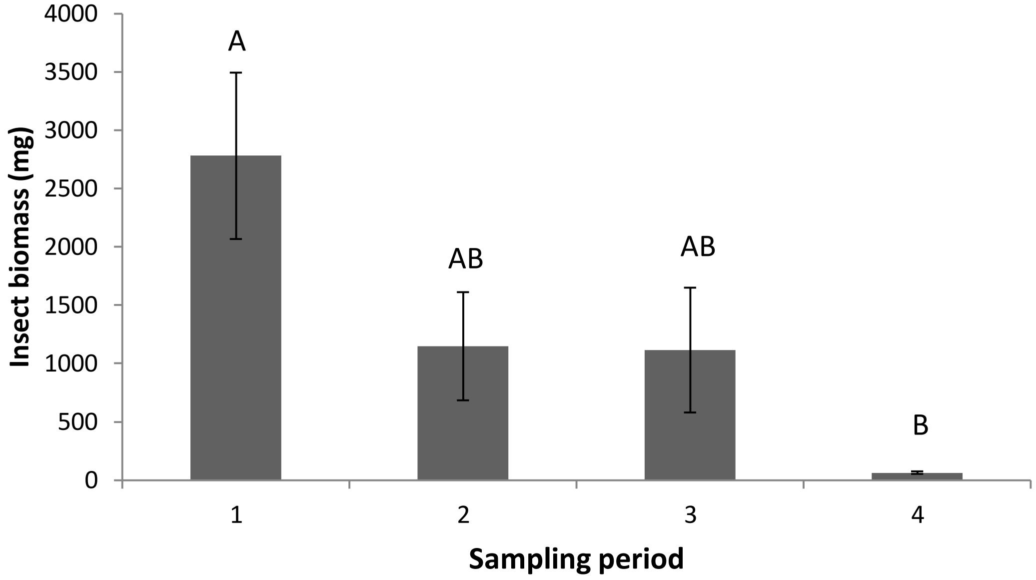

Figure 11 – Mean (± SE) insect biomass at 12 wetland sites at TNWR across 4 sampling periods in 2012. Biomass was significantly higher during sampling Period 1 than sampling Period 4.

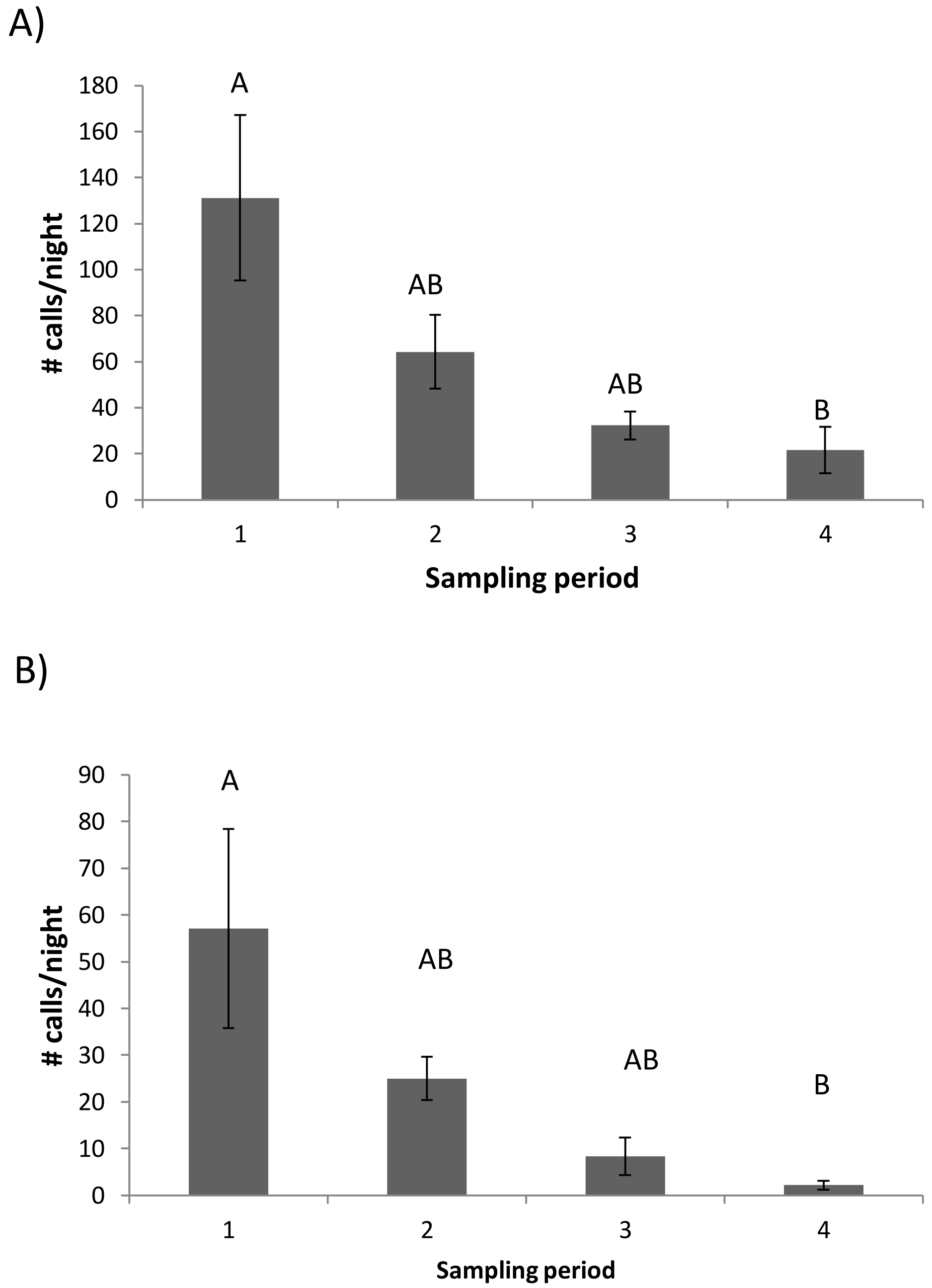

Figure 12 – A) Mean (± SE) number of bat calls per night recorded at 12 sites in TNWR during 4 sampling periods in 2012. Number of calls during sampling Period 1 was significantly higher than Period 4. B) Mean (± SE) number of low-frequency bat calls per night recorded at 12 sites in TNWR during 4 sampling periods in 2012. Number of calls during sampling Period 1 was significantly higher than sampling Period 4.

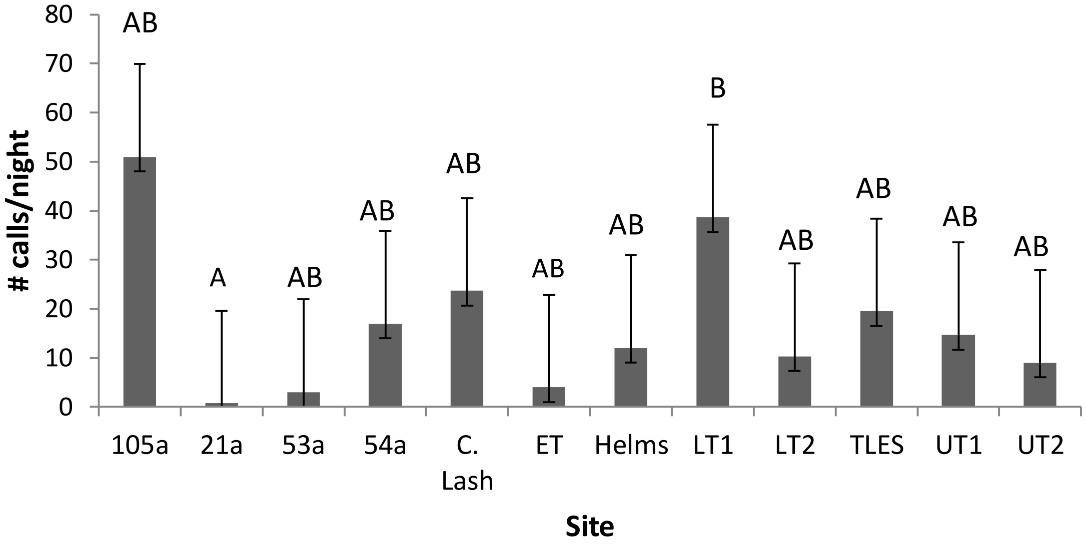

Figure 13 – Mean (±SE) number of calls from high-frequency bats at 12 wetland sites at TNWR in 2012. Site LT1 had a significantly higher mean number of calls than site 21A.

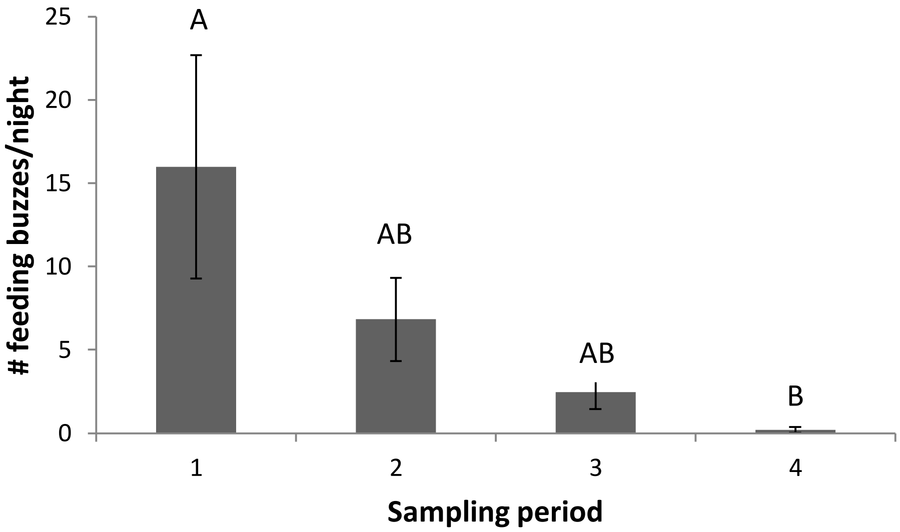

Figure 14 – Mean (±SE) number of feeding buzzes from 12 wetland sites at TNWR across 4 sampling periods in 2012. Sampling Period 1 had significantly a higher mean number of buzzes than sampling Period 4.

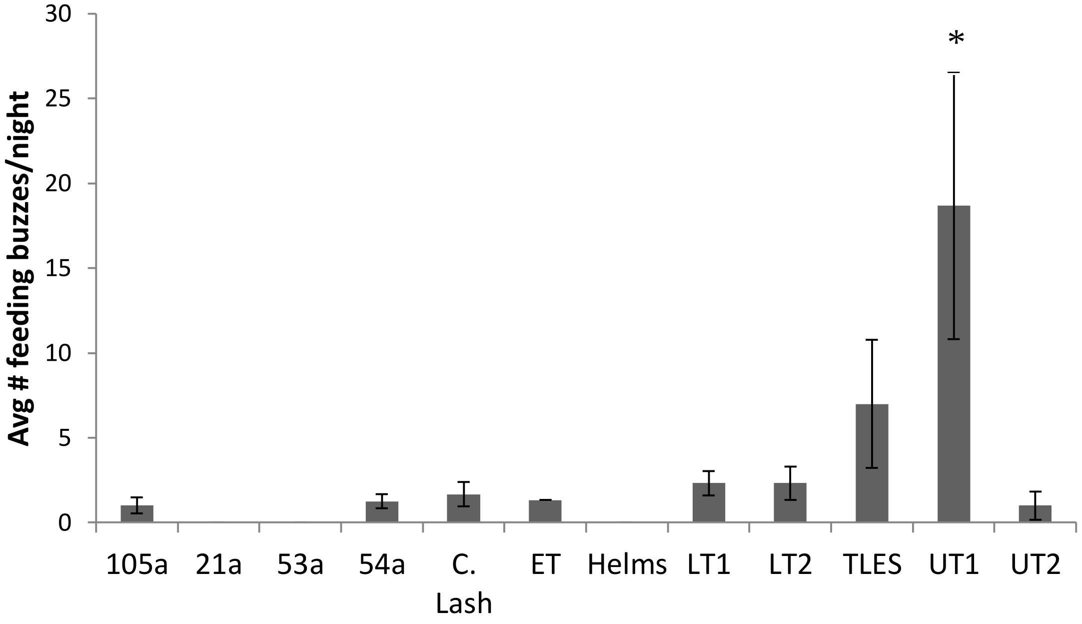

Figure 15 – Mean (±SE) number of feeding buzzes/night from mid-frequency bats at 12 wetland sites at TNWR in 2012. Permanent wetland UT1 had a significantly higher number of feeding buzzes than all other sites.

Appendix 1: Means, standard error, and ranges for wetland characteristics.

			x̄	**SE**	**Range |x|**
Water temperature (◦C)			21.83	0.22	12-33.5
	Sample period	1	24.19	0.97	19.72-32.35
		2	23.29	0.50	21.13-25.6
		3	19.09	0.67	16-23.25
		4	14.34	0.92	12.2-16.75
	Site	105a	22.35	2.46	16.4-26.2
		21a	23.20	0.00	23.2
		53a	18.60	2.42	12.2-24.7
		54a	19.16	1.96	12.4-21.88
		C. Lash	22.02	1.54	18.25-24.2
		ET	19.59	0.77	17.9-21.15
		Helms	21.10	1.78	16.75-23.5
		LT1	23.31	2.55	17.12-27.2
		LT2	22.26	1.75	19.25-26.4
		TLES	22.36	1.46	16-23.95
		UT1	21.75	1.38	19.35-25
		UT2	27.07	2.23	23.25-32.35
	Wetland type	Non-permanent	21.94	1.33	16.4-26.2
		Permanent	21.40	0.77	12.2-32.35

			Overall x̄	**SE**	**Range |x|**
Water depth (m)			0.25	0.01	0-1.7
	Sample period	1	0.27	0.04	0.11-0.64
		2	0.15	0.02	0-0.27
		3	0.32	0.05	0-0.58
		4	0.20	0.06	0-0.37
	Site	105a	0.47	0.09	16.4-26.2
		21a	0.03	0.02	23.2
		53a	0.19	0.03	12.2-24.7
		54a	0.13	0.02	12.4-21.88
		C. Lash	0.26	0.07	18.25-24.2
		ET	0.29	0.05	17.9-21.15
		Helms	0.21	0.05	16.75-23.5
		LT1	0.32	0.09	17.12-27.2
		LT2	0.29	0.12	19.25-26.4
		TLES	0.30	0.04	16-23.95
		UT1	0.22	0.02	19.35-25
		UT2	0.26	0.04	23.25-32.35
	Wetland type	Non-permanent	0.22	0.07	0-0.64
		Permanent	0.25	0.02	0.08-0.58

			Overall x̄	**SE**	**Range |x|**
Rush abundance (# stems)			100.61	15.84	0-340
	Site	105a	10.67	0.27	10-11
		21a	299.00	0.00	299
		53a	137.50	53.82	0-302
		54a	67.00	16.08	14-96
		C. Lash	31.00	10.84	8-54
		ET	88.33	31.45	32-162
		Helms	2.00	0.00	2
		LT1	169.00	54.84	48-280
		LT2	129.67	58.72	18-264
		TLES	79.50	30.75	18-141
		UT1	220.00	69.28	100-340
		UT2	57.50	10.10	40-75
	Wetland type	Non-permanent	97.44	26.99	11-280
		Permanent	101.91	18.63	0-340

			Overall x̄	**SE**	**Range |x|**
Cattail abundance (# stems)			9.76	2.29	0-52
	Site	105a	6.00	3.40	0-14
		21a	31.00	0.00	31
		53a	8.00	3.67	2-20
		54a	2.00	0.61	0-3
		C. Lash	20.67	3.31	14-28
		ET	15.33	7.85	2-34
		Helms	0.00	0.00	0
		LT1	3.67	1.36	2-7
		LT2	32.67	11.59	5-52
		TLES	8.00	4.00	0-16
		UT1	0.00	0.00	0
		UT2	0.00	0.00	0
	Wetland type	Non-permanent	7.33	80.97	0-34
		Permanent	10.67	105.39	0-52

			Overall x̄	**SE**	**Range |x|**
Grass abundance (# stems)			105	27	0-683
	Site	105a	106.00	23.80	50-148
		21a	12.50	10.83	0-50
		53a	173.00	121.17	0-586
		54a	167.00	86.46	0-417
		C. Lash	170.67	144.51	0-458
		ET	53.67	26.63	2-114
		Helms	185.67	75.93	0-288
		LT1	85.00	41.56	0-176
		LT2	50.00	30.47	0-123
		TLES	244.67	179.35	0-683
		UT1	0.00	0.00	0
		UT2	0.00	0.00	0
	Wetland type	Non-permanent	92.50	33.32	0-288
		Permanent	109.38	6.37	0-683

			Overall x̄	**SE**	**Range |x|**
Reed/sedge abundance (# stems)			32	14	0-428
	Site	105a	0.00	0.00	0
		21a	0.00	0.00	0
		53a	0.00	0.00	0
		54a	56.25	29.43	0-137
		C. Lash	23.33	23.33	0-70
		ET	254.67	106.20	0-428
		Helms	0.00	0.00	0
		LT1	5.33	4.35	0-16
		LT2	58.33	33.67	0-138
		TLES	0.00	0.00	0
		UT1	0.00	0.00	0
		UT2	0.00	0.00	0
	Wetland type	Non-permanent	0.00	0	0
		Permanent	43.10	3.47	0-428

Appendix 2: Means, standard errors, and ranges for insect biomass (mg).

		Overall x̄	**SE**	**Range |x|**
		1,457	1,487.49	0-8,837
Sample Period	1	2,781.02	713.59	3.49-8,837
	2	1,052.12	463.84	0-5,556
	3	1,113.85	536.31	0-6,717.1
	4	12.46	11.148	0-62.32
Site	105a	1,116.72	459.59	1.62-1,808.11
	21a	0.87	8.95	0-3.49
	53a	324.08	177.55	0-853.4
	54a	1,212.18	664.42	0-3,1943.31
	C. Lash	770.23	362.36	38.72-1,571.37
	ET	1,111.52	708.87	0-2,822.54
	Helms	570.93	430.04	0-1,623.05
	LT1	2,144.14	1566.77	0-5,972.73
	LT2	1,174.60	938.86	0-3,474.16
	TLES	3,614.71	1882.48	3.62-8,836.98
	UT1	4,083.81	1079.22	2,565.8-6,717.1
	UT2	1,596.34	632.11	423.27-3,058.06
Wetland Type	Non-permanent	506.64	239.12	0-1,808.1
	Permanent	1,774.86	420.62	0-8,836.98

Appendix 3: Complete regression results for overall insect biomass and overall bat activity with wetland characteristics. Only significant regressions are presented.

	Significant factors	**Relationship +/-**	**Individual R^2**	**Individual p**	**$F_{(NDF, DDF)}$**	**Model R^2**	**Model p**
Insect biomass	Water temperature	+	0.12	0.04	$4.56_{1,35}$	0.12	0.04
Total calls	Water temperature	+	0.122	0.04			
					$4.73_{1,34}$	0.122	0.04
Total feeding buzzes							
High-frequency calls	Water depth	+	0.22	0.002			
					$10.63_{1,37}$	0.22	0.002
Mid-frequency calls	Rush abundance	+	0.16	0.03			
	Grass abundance	+	0.09	0.09			
					$4.5_{2,27}$	0.25	0.02
Total feeding buzzes	Water temperature	+	0.17	0.01			
					$7.24_{1,35}$	0.17	0.01
Mid-frequency buzzes	Rush abundance	+	0.1	0.09			
	Fish presence	+	0.12	0.04			
					$3.97_{2,28}$	0.22	0.03
Low-frequency buzzes	Grass abundance	+	0.14	0.04			
					$4.73_{1,29}$	0.14	0.04

Appendix 4: Means, standard errors, and ranges for bat activity (number calls/night).

		Overall x̄	**SE**	**Range |x|**
Total calls		63.4	14	1-511
Sample Period	1	131.167	35.99	10-447
	2	64.2727	16.12	0-194
	3	32.2727	6.10	0-70
	4	21.6	10.14	0-60
Site	105a	136.5	73.03	10-263
	21a	17	5.30	0-29
	53a	17.75	12.05	0-59
	54a	71.25	37.21	25-200
	C. Lash	74	5.89	64-88
	ET	39.6667	13.30	20-72
	Helms	32	12.19	9-60
	LT1	114.667	25.72	55-162
	LT2	46.3333	17.72	15-88
	TLES	167.5	88.62	12-447
	UT1	113.667	35.75	54-199
	UT2	38.6667	16.23	0-66
Wetland Type	Non-permanent	48.5556	24.51	0-263
	Permanent	76.9	16.38	0-447

		Overall x̄	**SE**	**Range |x|**
High-frequency calls		15.38	3.03	0-98
Sample Period	1	19.42	0.49	0-98
	2	15.10	0.16	1-50
	3	12.73	0.33	0-44
	4	12.20	0	1-30
Site	105a	51	0.27	4-98
	21a	0.75	0	0-1
	53a	3	0	1-6
	54a	17	0.43	4-33
	C. Lash	23.67	0	13-31
	ET	4	0	2-8
	Helms	12	0	3-30
	LT1	38.67	0.27	22-50
	LT2	10.33	0.82	4-14
	TLES	19.5	0.83	2-39
	UT1	14.67	1.36	10-19
	UT2	9	0.82	0-16
Wetland Type	Non-permanent	51	9.62	0-98
	Permanent	0.75	2.5	0-50

		Overall x̄	**SE**	**Range |x|**
Mid-frequency calls		28.8	5.5	0-166
Sample Period	1	47.83	13.84	0-166
	2	31.73	8.39	4-114
	3	15.82	2.99	3-38
	4	5.6	3.76	0-22
Site	105a	43.5	23.38	3-84
	21a	9.25	2.81	0-15
	53a	11.5	4.80	1-26
	54a	13.5	5.15	0-28
	C. Lash	41.33	1.44	38-44
	ET	24.33	4.82	17-36
	Helms	10.33	4.77	5-22
	LT1	32	10.53	7-50
	LT2	25.67	11.47	4-52
	TLES	72.25	35.10	4-166
	UT1	55.67	22.21	26-110
	UT2	14.67	6.84	0-29
Wetland Type	Non-permanent	17.22	7.74	0-84
	Permanent	32.33	6.70	0-166

		Overall x̄	**SE**	**Range |x|**
Low-frequency calls		27.3	7	0-232
Sample Period	1	57.08	19.44	1-232
	2	25	4.22	3-49
	3	8.36	3.67	1-37
	4	2.2	1.34	0-8
Site	105a	42	22.52	3-81
	21a	7	3.50	0-18
	53a	7.75	5.32	0-26
	54a	50.5	25.76	1-137
	C. Lash	9	3.77	1-17
	ET	12.67	6.87	1-29
	Helms	10.33	4.12	3-20
	LT1	43	19.67	4-87
	LT2	10.33	5.36	1-23
	TLES	71.75	47.04	2-232
	UT1	42	17.44	2-75
	UT2	16.33	8.76	1-37
Wetland Type	Non-permanent	15.89	7.57	0-81
	Permanent	30.67	8.80	0-232

		Overall x̄	**SE**	**Range |x|**
Total feeding buzzes		7.55	2.4	0-82
Sample Period	1	16	6.70	0-82
	2	6.83	2.50	0-32
	3	2.45	1.02	0-12
	4	0.2	0.18	0-1
Site	105a	5.67	2.42	0-10
	21a	0.5	0.25	0-1
	53a	2.75	2.10	0-10
	54a	10.5	5.23	01-27
	C. Lash	4.33	1.66	1-8.
	ET	2.67	1.19	0-5
	Helms	0.33	0.27	0-1
	LT1	4.67	1.44	2-8
	LT2	3.67	1.19	1-6
	TLES	28.5	16.87	0-82
	UT1	19	10.03	0-42
	UT2	4	2.16	0-9
Wetland Type	Non-permanent	2	1.06	0-10
	Permanent	9.4	3.06	0-82

		Overall x̄	**SE**	**Range |x|**
High-frequency buzzes		0.53	0.19	0-5
Sample Period	1	1	0.49	0-5
	2	0.17	0.16	0-2
	3	0.64	0.33	0-3
	4	0	0	0
Site	105a	0.33	0.27	0-1
	21a	0	0	0
	53a	0	0	0
	54a	0.5	0.43	0-2
	C. Lash	0	0	0
	ET	0	0	0
	Helms	0	0	0
	LT1	0.33	0.27	0-1
	LT2	1	0.98	0-3
	TLES	1.5	0.96	0-4
	UT1	1.67	1.36	0-5
	UT2	1	0.82	0-3
Wetland Type	Non-permanent	0.1	0.09	0-1
	Permanent	0.67	0.25	0-5

		Overall x̄	**SE**	**Range |x|**
Mid-frequency buzzes		3	1.05	0-32
Sample Period	1	4	1.91	0-24
	2	5	2.73	0-32
	3	1.09	0.38	0-3
	4	0	0	0
Site	105a	1	0.47	0-2
	21a	0	0	0
	53a	0	0	0
	54a	1.25	0.41	0-2
	C. Lash	1.67	0.72	0-3
	ET	2	0.82	0-3
	Helms	0	0	0
	LT1	2.33	0.72	1-4
	LT2	2.33	0.27	0-4
	TLES	7	4.36	0-18
	UT1	18.67	7.85	0-32
	UT2	1	0.82	0-3
Wetland Type	Non-permanent	0.3	0.20	0-2
	Permanent	3.9	1.36	0-32

		Overall x̄	SE	Range |x|
Low-frequency buzzes		4.8	1.8	0-68
Sample Period	1	10.25	5.38	0-68
	2	4.08	1.18	1-12
	3	1.27	0.84	0-10
	4	0.2	0.18	0-1
Site	105a	4.33	1.78	0-7
	21a	0.5	0.25	0-1
	53a	2.75	2.10	0-10
	54a	8.75	4.51	1-23
	C. Lash	2.67	1.36	1-6
	ET	0.67	0.54	0-2
	Helms	0.33	0.27	0-1
	LT1	1.67	0.98	0-4
	LT2	0.33	1.19	0-1
	TLES	20	16.25	0-68
	UT1	7.67	3.21	0-13
	UT2	2	0.82	0-3
Wetland Type	Non-permanent	1.6	0.79	0-7
	Permanent	5.7	2.35	0-68

Appendix 5: Complete regression results for insect biomass and bat activity with wetland characteristics for sampling periods 1-3

SAMPLING PERIOD 1	**Significant factors**	**Relationship +/-**	**Individual R^2**	**Individual p**	**$F_{(NDF, DDF)}$**	**Model R^2**	**Model p**
High-frequency calls	Water depth	+	0.66	0.001			
					$19.8_{1,10}$	0.66	0.001
Mid-frequency calls	Fish presence	+	0.37	0.04			
	Water temperature	-	0.065	0.03			
					$8.28_{2,9}$	0.65	0.009

SAMPLING PERIOD 2

High-frequency calls	Water temperature	+	0.37	0.08			
	Grass abundance	+	0.38	0.07			
	Water depth	-	0.09	0.05			
	Fish presence	-	0.2	0.08			
					$13.93_{4,4}$	0.93	0.01
Mid-frequency calls	Grass abundance	+	0.57	0.007			
					$12.12_{1,9}$	0.57	0.007
Low-frequency calls	Water depth	+	0.47	0.04			
					$6.3_{1,7}$	0.47	0.04
High-frequency buzzes	Grass abundance	+	0.77	0.0002			
					$32.97_{1,10}$	0.77	0.0002
Mid-frequency buzzes	Rush abudance	+	0.1	0.09			
	Fish presence	+	0.12	0.04			
					$3.97_{2,28}$	0.22	0.03
Low-frequency buzzes	Grass abundance	+	0.47	0.04			
					$4.44_{2,7}$	0.47	0.04

SAMPLING PERIOD 3	Significant factors	Relationship +/-	Individual R^2	Individual p	$F_{(NDF, DDF)}$	Model R^2	Model p
Insect biomass	Cattail abundance	-	0.68	0.02			
					$10.83_{1,5}$	0.68	0.02
Total buzzes	Water temperature	+	0.92	0.0007			
	Cattail abundance	-	0.07	0.009			
					$0.02_{2,4}$	0.99	0.0002
Mid-frequency calls	Cattail abundance	+	0.89	0.001			
					$10.83_{1,5}$	0.89	0.001
Low-frequency calls	Water temperature	+	0.63	0.006			
					$13.52_{1,8}$	0.63	0.006
Low-frequency buzzes	Water temperature	+	0.71	0.01			
	Water depth	-	0.18	0.07			
						0.89	0.01

Appendix 6: Complete regression results for bat activity with insect abundance for the overall study and sampling periods 1-3. Because of the small sample size, sampling period 4 was not included.

OVERALL	$F_{(NDF, DDF)}$	R^2	**P**
Total calls	$7.49_{1,37}$	0.17	0.01
Total feeding buzzes	$7.03_{1,38}$	0.27	0.01

SAMPLE PERIOD 1

Total calls	$4.51_{1,10}$	0.31	0.06
Total feeding buzzes	$2.67_{1,10}$	0.13	0.13

SAMPLE PERIOD 2

Total calls	$0.64_{1,9}$	0.07	0.44
Total feeding buzzes	$2.3_{1,10}$	0.19	0.16

SAMPLE PERIOD 3

Total calls	$0.08_{1,9}$	0.009	0.78
Total feeding buzzes	$0.52_{1,9}$	0.05	0.49

VITAE

EDUCATION

The University of Akron, GPA 3.77 Dec 2010
BS in Biology, Akron, OH

TEACHING

Eastern Washington University 2011- 2013
Graduate teaching assistant, Cheney, WA

- Instructed laboratory courses in vertebrate zoology, mammalogy, ornithology, and human anatomy & physiology

PUBLICATIONS

Kurz, D., McGinty, N., Stankavich, S. and Smith, G. *In press.* Restored wetlands can support mammalian assemblages comparable to those in non-mitigated, reference wetlands. American Midland Naturalist 170: 260-273.

PRESENTATIONS

16th International Bat Research Conference & 43rd North American Symposium on Bat Research Aug 2013
San Jose, Costa Rica
Poster: Bat Abundance and Activity at Turnbull National Wildlife Refuge

16th Annual Creative Works Symposium May 2013
Eastern Washington University, Cheney WA
Poster: Bat Abundance and Activity at Turnbull National Wildlife Refuge

15th Annual Creative Works Symposium May 2012
Eastern Washington University, Cheney, WA
Oral presentation: Factors Affecting the Foraging Activity of Bats over Wetland Habitats

POSITIONS

Upper Columbia United Tribes Jul 2013-Present
Field technician, Spokane, WA

- Worked as part of a team to monitor and evaluate habitat restoration projects on tribal lands

Metro Parks, Serving Summit County
Natural Resource Management Intern, Akron, OH Aug 2010-Aug 2011
Volunteer May 2010-Aug 2010

- Assisted with park inventories for small mammals, insects, endangered bats, and invasive plants and also participated in wildlife management operations

The University of Akron Summer 2009 & 2010
Tiered Mentoring program, Akron, OH

- Helped design and conduct a study to compare small mammal communities in natural wetlands versus restored wetlands
- Mentored a student in telemetry techniques

AWARDS

- Herman & Jean Swartz and Nate Narrance Graduate Fellowship - 2013
- EWU Graduate Assistantship – 2011-2013
- Ohio Academic Scholarship recipient - 2007
- Scholarship for Excellence recipient - 2007
- Christian Stinner Memorial Scholarship recipient - 2010
- EWU Department of Biology Minigrant research funding - 2012
- EWU Department of Biology travel grant - 2013
- EWU Department of Graduate Studies travel grant - 2013
- EWU Graduate Affairs Council student representative – 2012-2013