

Effects of Pond Permanence on Avian Behaviors

Laura Braun

Mentor: Amanda Klemmer

Rocky Mountain Biological Laboratory
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Abstract

As global temperatures rise due to climate change, aquatic ecosystems, such as alpine ponds, become more at risk of drying earlier than normal. These changes in pond hydrology have the potential to alter not only the aquatic ecosystems, but also terrestrial and riparian ecosystems, through resource subsidies provided by the ponds. Vernal ponds (temporary ponds) are particularly vulnerable to these changes due to their size, therefore making the surrounding terrestrial ecosystems susceptible as well. Through observing avian behaviors around both permanent and temporary ponds, our study strived to gain insight on how terrestrial predators react to the change of aquatic hydrology. Our preliminary results indicate that avian predators spend more total time near semi-permanent ponds, but further inclusion of habitat variables, such as pond size, may change these results. Understanding the causes and effects of climate altered hydrology are important in building conservation strategies for aquatic and terrestrial ecosystems as global warming persists and grows in influence.

Introduction

The Intergovernmental Panel on Climate Change released a special report in 2018 reporting that the Earth has warmed around 1°C above pre-industrial levels due to anthropogenic activities and that it is predicted to continue to increase at a rate of around 0.2°C per decade (Allen et al., 2018). The resulting higher global temperature has already resulted in global phenomena such as extreme weather, sea level rise, and biodiversity loss, all of which are causing multiple species and populations to face unprecedented risks. One of the most sensitive and dramatic consequences of climate change is the enhanced global evapotranspiration rates, which lead to an increase in loss of surface water and the increased isolation of ponds (Brooks,

2009). Specifically, as climate change progresses and the world continues to warm, less winter precipitation is predicted to fall as snow and the snow is predicted to melt earlier in the spring (Barnett, Adam, and Lettenmaier, 2005). This leads to a shift in peak river runoff away from the summer and autumn to winter and spring and a change in the hydrology of both temporary and permanent ponds. Precipitation rates are also becoming more variable and unexpected as global warming persists. These global changes in hydrology will have the most dramatic effects on areas with a high density of smaller bodies of water and a multitude of ecosystems and food webs which depend on these bodies of water (Brooks, 2009).

The Colorado Rocky Mountain ecosystems have a high density of smaller lentic ecosystems which were created by the retreat of glaciers around 12,000 years ago. These bodies of water are often oligotrophic environments and experience relatively short growing seasons with low productivity (Epanchin, Knapp, and Lawler, 2010). These ponds can be permanent, semi-permanent, or temporary, depending on their hydrology and drying potential. Previous research has found that even though temporary ponds have a lower number of aquatic species, when compared to permanent ponds, they had similar rarity indices (Collinson et al., 1995). Specifically, permanent and temporary ponds in the Colorado Rocky Mountains both contain species such as Caddisflies (family Limnephilidae) and other planktonic and benthic invertebrates, as well as both submergent and emergent plant life. Invertebrates are influenced by the permanence of an aquatic system; vernal ponds contain large predatory aquatic insects and amphibians which can escape drying habitats, whereas permanent ponds contain larger invertebrates such as different species of fish and the Tiger Salamander (*Ambystoma tigrinum nebulosum*), which do not need to leave an aquatic environment before a drying season (Wissinger, Whiteman, Sparks, Rouse, and Brown, 1999). Moreover, permanent ponds contain

caddisfly species such as *Hesperophylax occidentalis* and *Agrypnia deflata*, which are restricted in distribution due to their aquatic oviposition, desiccation intolerance, and/or their lack of ovarian diapause. Caddisfly populations in vernal/temporary ponds (*Asynarchus nigriculus*, *Limnephilus externus* and *L. picturatus*), however, contain the characteristics of rapid larval growth, ovarian diapause, and terrestrial oviposition of desiccation-tolerant eggs, all of which facilitate the usage of both temporary and permanent ponds (S.A. Wissinger, Brown, and Jannot, 2003). Additionally, semi-permanent ponds and wetlands often contain large-bodied copepods, large dysticid beetles, midges, and mosquito pupa, with salamanders as the top predator. Small vernal basins are dominated by zooplankton, mosquitos, beetles, caddisflies and corixid water boatmen and predaceous diving beetles (*Dyticus dauricus*) are the primary predator (Scott A. Wissinger, Bohonak, Whiteman, and Brown, 1999; Scott A. Wissinger, Whissel, Eldermire, and Brown, 2006).

No matter the hydrology and permanence of the pond, both types of ecosystems are often closely linked to neighboring riparian zones. This allows for a system in which resource inputs from aquatic systems have an important influence on terrestrial consumers and the terrestrial ecosystem's structure (Epanchin et al., 2010). Freshwater systems contain a large amount of biologically available energy in the form of cross-ecosystem resource subsidies. A resource subsidy is a flow of fixed energy between two different ecosystems. Between neighboring aquatic and terrestrial ecosystems, there are both passive and direct flows of energy (Richardson, Zhang, and Marczak, 2010). Passive flows take the form of leaf litter and terrestrial invertebrate inputs, and direct flows are flows of energy that goes directly from the source to the consumer. Many consumers rely on these direct resource subsidies, and the availability and timing of these

energy resources can affect the growth and livelihood of the consumers (Richardson and Sato, 2015).

Aquatic insects are important components of avian diets in the landscapes surrounding freshwaters in mountainous environments, making up on average 26% of the annual energy budget for the local avian species (Nakano and Murakami, 2001). Therefore, the abundance and distribution of these avian populations are directly influenced by the availability of aquatic prey and reflects adult aquatic insect fluxes (Piovia-Scott et al., 2016; Richardson et al., 2010).

Flycatchers and other aerial feeders are specifically dependent upon emergent aquatic insects, but other avian populations and species are also directly affected by aquatic ecosystem dynamics (Iwata, Nakano, and Murakami, 2003). For example, the passerines can feed aquatic invertebrates to their young due to their protein-richness and high assimilation efficiency instead of their usual diet of seeds (Díaz, 1996).

Due to the close relationship between aquatic invertebrates and avian populations surrounding wetlands, understanding how increasing rates of evapotranspiration and changes in precipitation will affect aquatic insects is not only important for aquatic ecosystems, but also the avian populations that are dependent upon the aquatic resource subsidies. The aim of our study was to investigate if pond permanence has an effect on avian behaviors and presence, which gives insights on how birds will react to the changing hydrology of temporary ponds and permanent ponds. We predicted that as insects that have yet to emerge become trapped in drying temporary ponds, scavaging and opportunistic birds (birds which find food mainly through foraging techniques) will become more attracted to these ponds. However, aerial predatory birds (birds which primarily get food while in flight) will become more prevalent around permanent ponds where the insects emerge as adults.

Methods

Ponds/research sites

There are a multitude of smaller ponds surrounding the Gothic townsite that range in permanence, ensuring a range of survey locations. A group of ponds south of Gothic, CO called the Kettle Ponds, which refers to the glacial holes in which the ponds lie, contain multiple semi-permanent and temporary ponds (Figure 1). There are also other groups of ponds near Mt. Crested Butte, which are referred to as the Shooting Range ponds and the Snodgrass ponds. The Shooting Range ponds consist of 4 temporary ponds, and the Snodgrass Ponds consist of two temporary ponds and one semi-permanent pond (Figure 1). For my experiment, we observed patterns in all four of the Shooting Range's temporary ponds, all three of the ponds on Snodgrass, two of the Kettle Ponds' temporary ponds, and four of the Kettle Ponds' semi-permanent ponds, one of which is a marsh and will be divided into two sites due to its large size. There were more temporary pond sites than semi-permanent pond sites because the natural ratio is tilted towards temporary ponds in these locations and we wanted to ensure we have temporary pond sites at all of the locations.

Bird Surveys

At each of the ten pond sites, we performed two 10-minute bird surveys each week for a 6-week period, with a total of 12 surveys at each site. The ponds were divided into three zones to specify bird counts; a riparian zone (0-3 meters from the pond), a terrestrial zone (>3 meters) and a pond zone which is further divided into above or on the water (Figure 2). During each survey, we waited five minutes until starting the 10-minute window to allow for the local wildlife to become somewhat accustomed to our presence. The surveys included the recording of entrance

and exit time of a bird in any of the three zones, the identity and behavior that each individual exhibited (ground foraging, aerial feeding, calling, flying over, or loafing), and the weather/cloud cover observed on each day.

Insect Quadrats

In order quantify stranded invertebrate biomass in the ponds, we collected stranded invertebrates from three 20x20cm quadrats in three semi-permanent ponds and five temporary ponds at places in which the ponds have dried. Specifically, the invertebrates in each quadrat were counted and identified to Order where possible. The collections will be further analyzed to get a total biomass at each quadrat. Not every pond was sampled since some sites dried up before sampling could occur or others were simply unavailable for sampling.

** Note: Total Biomass has not yet been collected.*

Data analysis

The collected data on avian identities, behaviors, and time spent in pond (response variables) were then analyzed with linear models when appropriate using the statistical programming software R (need R citation here). These models will include predictor habitat variables, such as size, permanence, hydrology, weather, but have currently not been added to the models. Furthermore, when analyzing the quadrats in the future, the response variable will be dry biomass (g) and the predictors will be hydrology and date of drying. We also plan to use the R package Distance for the bird analysis to account for distance from pond, size of pond, and detection probability, as well as any natural variation or human errors which may lie in the bird surveys. ** Note: Many environmental variable tests have not yet been run.*

Results

Bird surveys at selected sites near Gothic revealed that some bird species were more selective of the types and locations of the ponds in which they frequented (specialist species), whereas others were more universally observed (generalist species). For example, the Red-Winged Blackbird and the American Robin had nesting sites near some of the ponds, resulting in a visitation rate higher at select ponds. On the other hand, Lincoln Sparrows, White-Crowned Sparrows, and Broad-Tailed Hummingbirds were observed at all of the sites on a regular basis. Moreover, there was a significantly larger amount of bird counts in general around the semi-permanent ponds, and birds tended to spend more time around semi-permanent ponds ($F\text{-ratio} = 3.827$, $p = 0.0424$; Figure 3). There was also a significantly greater amount of observed ground-feeding behaviors at semi-permanent ponds (Figure 4; $F\text{-ratio} = 5.1904$, $p = 0.0166$), and Aerial Feeding was only observed at semi-permanent ponds (Figure 5). When observing the amounts of time in which birds spent time in the temporary pond study system throughout the season, the minimum amount of time seems to remain constant, whereas the maximum amount of time spent seems to increase as the summer progresses (Figure 6). In contrast, the semi-permanent avian visitation times at all of the ponds seems to be consistently more variable and random as a whole (Figure 7).

Laboratory analysis of the stranded invertebrate counts from the quadrats revealed higher densities of stranded invertebrates in temporary ponds, and the density of stranded invertebrates in both types of ponds decreased throughout the season. *Diptera* sp. (i.e., chironomidae and tipulidae) and *Coleoptera* sp. (i.e., different beetle species) were observed to be the most populous in these quadrats. Surprisingly, only 1 stranded caddisfly (*Trichoptera* order) was found, and many stranded vertebrates (frog tadpoles) were found in one site.

Discussion

Even though there was significantly more of a bird presence at Semi-permanent sites, the conclusion that all avian populations generally gravitate towards more permanent ponds cannot be made. More permanent ponds do often have more diverse and populous invertebrate communities, which could give avian predators more of a prey selection (Scott A. Wissinger, Bohonak, et al., 1999), but more permanent ponds also tend to have larger surface areas and riparian zones, which could also be a huge factor in avian visitations. Thus, until analyses take into consideration surface areas and different geographical elements, it is impossible to make conclusions on the reasonings behind the significant differences in visitation times based on pond hydrology.

Weather and seasonal factors could have also impacted the results, requiring us to also do further data analysis taking those factors into consideration as well. It could be possible that different bird populations gravitate towards ponds with different pond hydrologies and food webs, as was predicted, so despite the fact that birds spent more time at semi-permanent ponds as a whole, this picture might change a bit once bird visitations are separated to only include scavenging bird species/aerial feeders. Moreover, even though aerial feeding behaviors were only observed over semi-permanent ponds, this was not significant ($p = 0.145$), probably due to the small amount of aerial feeding behaviors observed in general.

In addition to taking into consideration different environmental factors, it is also important that we take into consideration human error when performing bird surveys. Previous research shows that an observers variability in their ability to detect/identify birds has is a large source of error when performing terrestrial bird surveys (Diefenbach, Brauning, & Mattice,

2003). To help account for this error it is important that we utilize a Program Distance R program to further analyze our own survey data.

The time in which birds spent near temporary ponds throughout the season became more variable as the season progressed (Figure 6), which could be a reflection of the temporary ponds drying and therefore providing different scavengers and opportunistic bird species more chances to interact with the aquatic food web. The growing maximum amount of time spent in the system could also be reflective of the different life histories of aquatic invertebrates within the pond ecosystem. Further analysis on the avian times in system could be performed to gain a clearer picture on how the progression of the summer season impacted avian behaviors. Alternatively, the time in which birds spent near semi-permanent ponds throughout the season is seemingly random and consistent (Figure 7). This image changes when pond surveys are isolated by pond, and more trends are visible in which reflect things like invertebrate emergence periods and drying trends. More analysis is needed, however, to further understand these results.

A wide range of invertebrate taxa were stranded in the ponds, ranging from beetle larva to amphibious tadpoles and mayfly larva. The data hint at the idea that more invertebrates are in dried areas of temporary ponds than in semi-permanent, which could be because invertebrates in temporary ponds have nowhere to escape to when the pond dries, whereas invertebrate in semi-permanent and permanent ponds can simply move away from the drying areas of the pond as the water constricts. However, further statistical analyses are required to further clarify the significance of these observations. Once more concrete conclusions can be made, this information can shed light on what types of nutritional resources/prey were available at these sites, which would directly impact observed avian presences and speciation.

There are a multitude of steps that can be taken besides further analyses that can build upon our understandings of avian reactions to changes in aquatic phenologies and food webs. For example, caging areas of drying ponds in order specify the ways in which bird predation affects dry pond ecosystems could be beneficial in further understanding how terrestrial and aquatic ecosystems interact once ponds have dried. It would also be beneficial to put up cameras to record the few days of pond drying and bird visitations since it is hard to observe how birds are interacting with the ponds as they are drying by just performing 10-minute bird surveys once every two days. Through recording the full drying period of the pond, it would be easier to observe the presence or lack of presence of birds and bird predation. Finally, this study did not take into consideration elevation, since the higher elevation sites were inaccessible at the beginning of the experiment, but it would be nice to understand how elevation is altering these ecosystem interactions in addition to permanence.

Bird use and preference of ponds is important to understand as hydrology changes affect the respective resource subsidies. Previous research has cemented the idea that aquatic and terrestrial ecosystems are tied through a number of subsidies. Specifically, aquatic emergent insect adults are vital sources of food for terrestrial predators such as birds (Baxter, Fausch, & Saunders, n.d.). Thus, as we continue to discern how climate change affects aquatic systems, it is important that we also continue to discover how these changes will affect concurrent and tied systems. Through further analysis in of this study, we can further understand the ways in which avian populations react to differential pond hydrologies.

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Tables and Figures

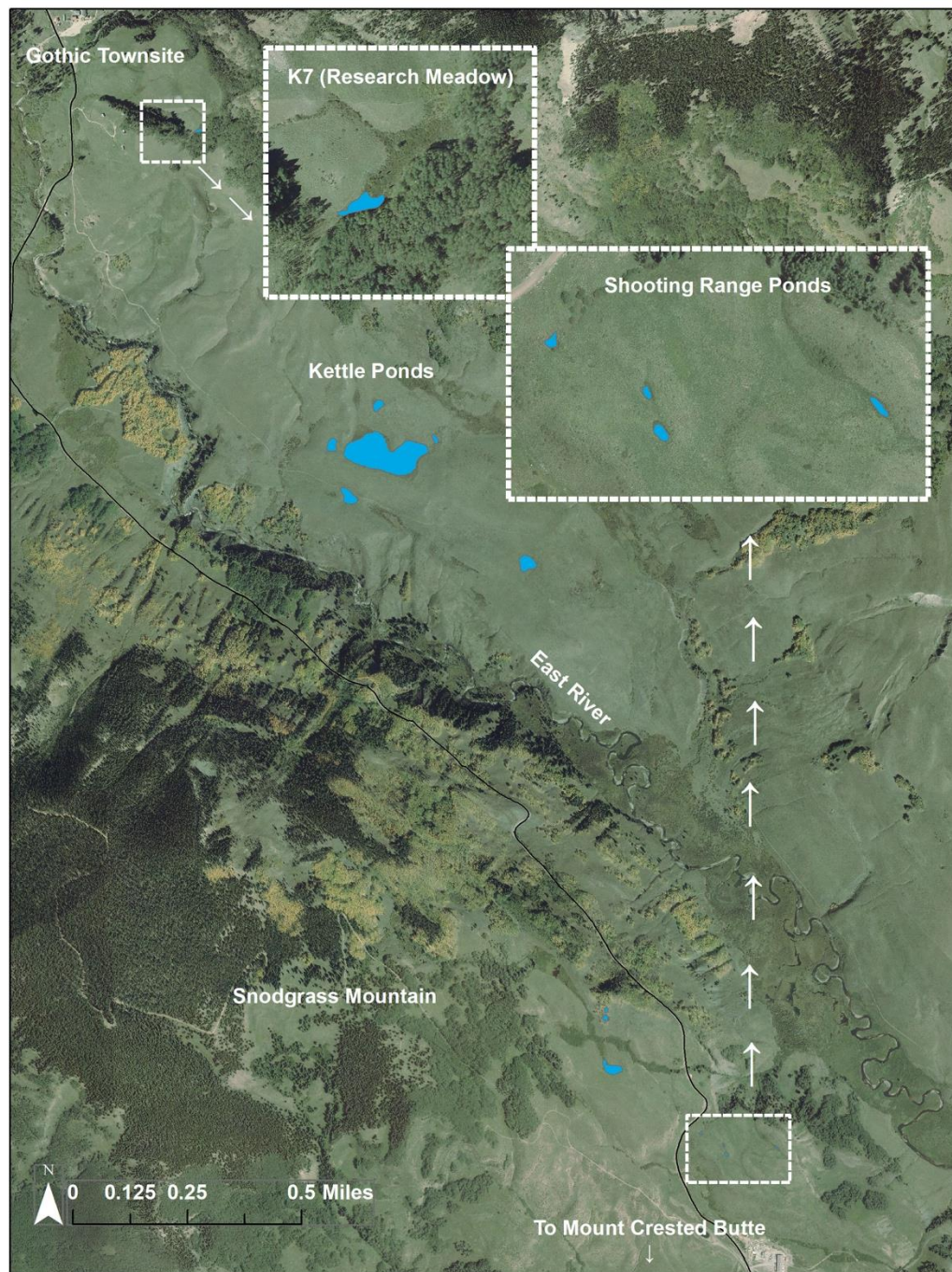


Figure 1: Aerial map of the different pond locations utilized in this study.

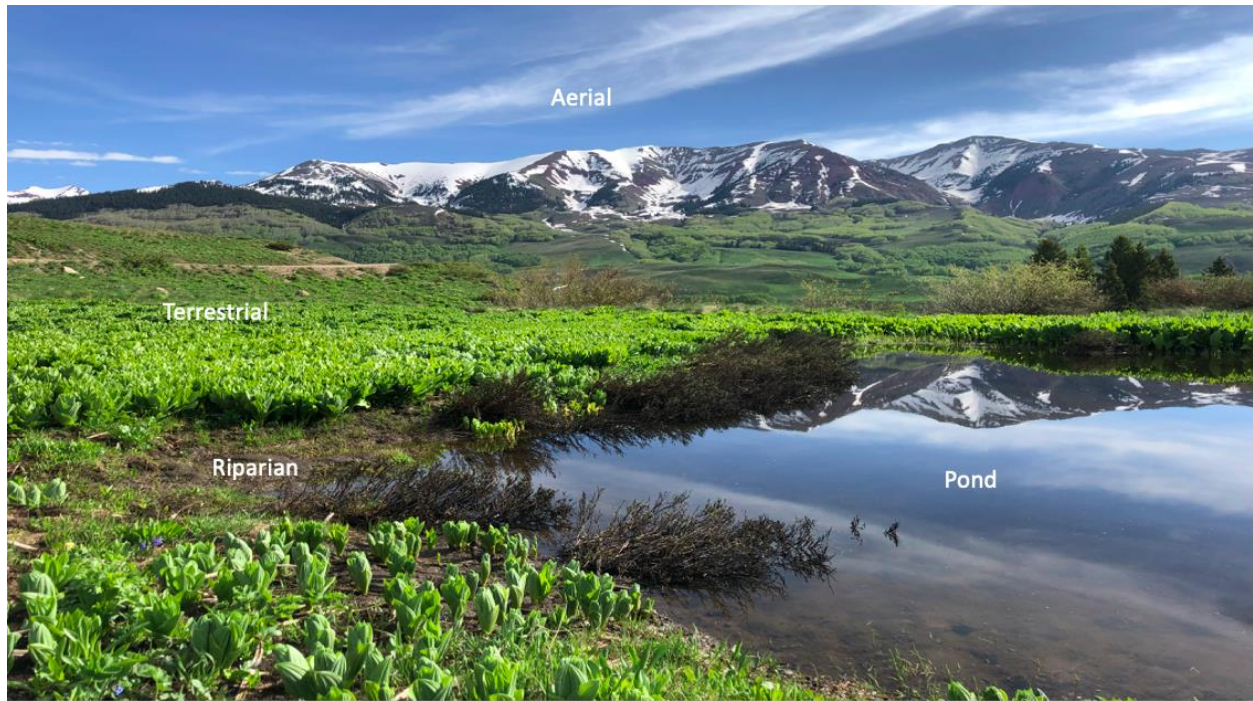


Figure 2: Depiction of the zones in which the ponds were divided into (aerial, riparian, terrestrial and pond)

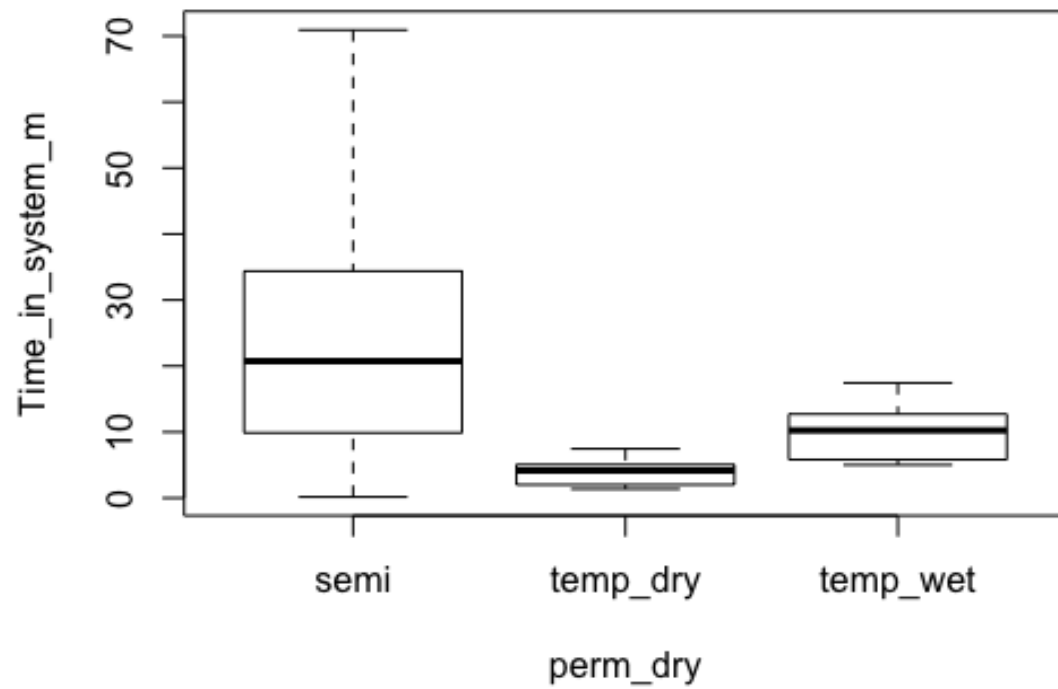


Figure 3: Comparison of total amounts of time there was an avian presence at semi-permanent ponds, wet temporary ponds and dry temporary ponds. ($p = 0.04244$)

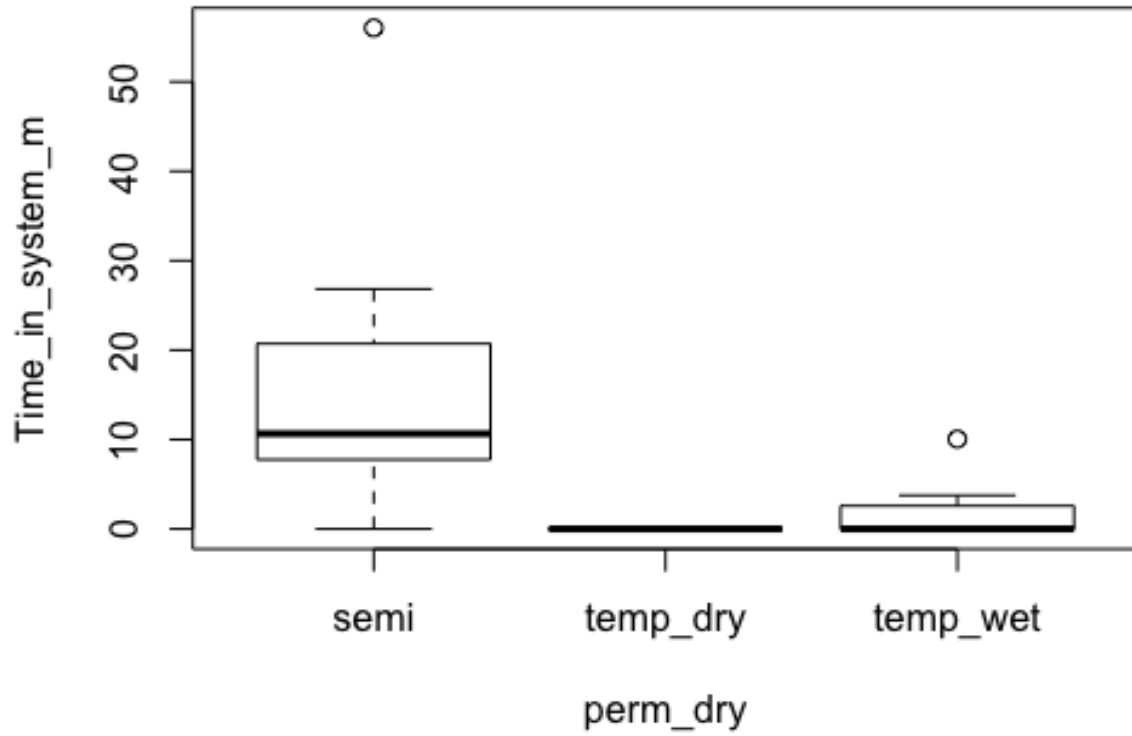


Figure 4: Comparison of total counts of avian ground foraging behaviors at semi-permanent ponds, wet temporary ponds and dry temporary ponds. ($p = 0.0166$)

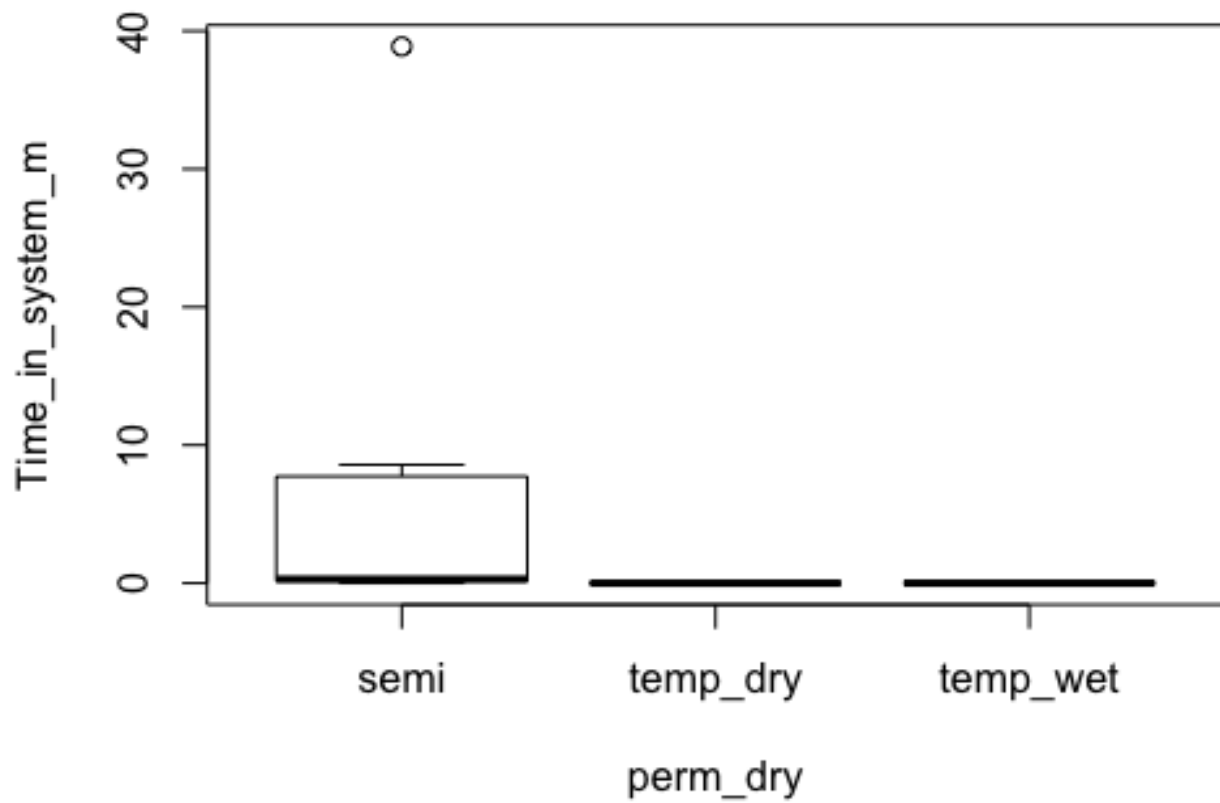


Figure 5: Comparison of total counts of avian aerial feeding behaviors at semi-permanent ponds, wet temporary ponds and dry temporary ponds. ($p = 0.0166$)

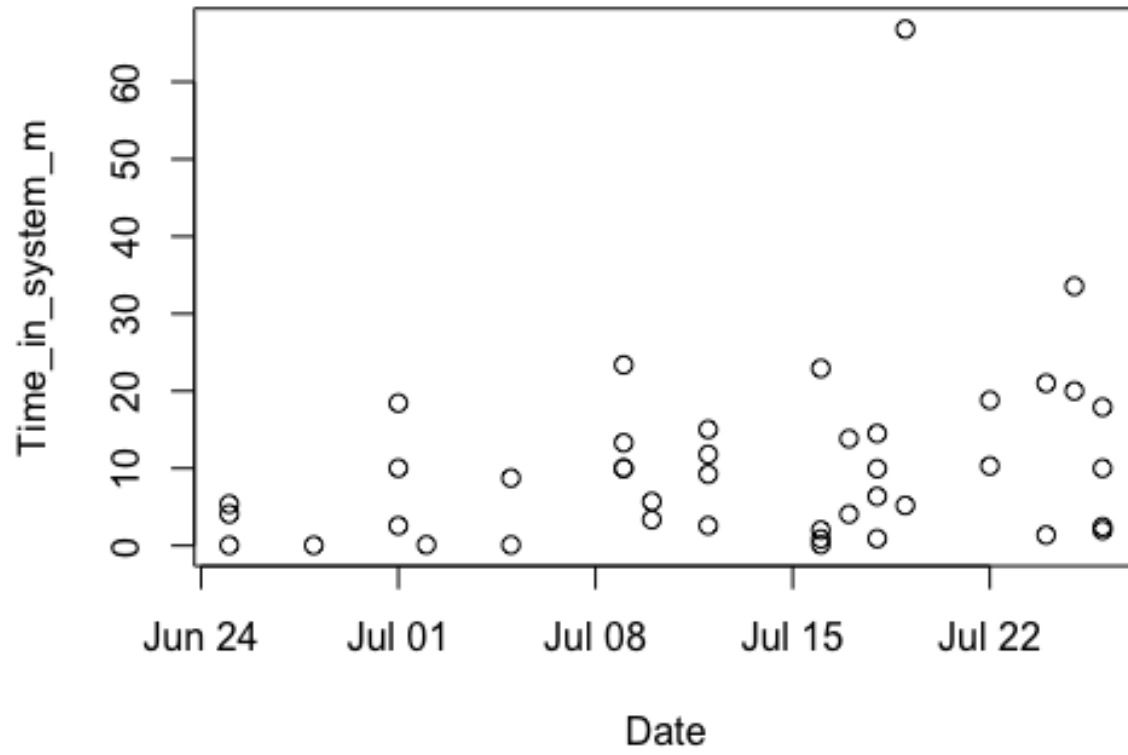


Figure 6: Amount of time spent in the aquatic systems with temporary hydroperiods by birds through time.

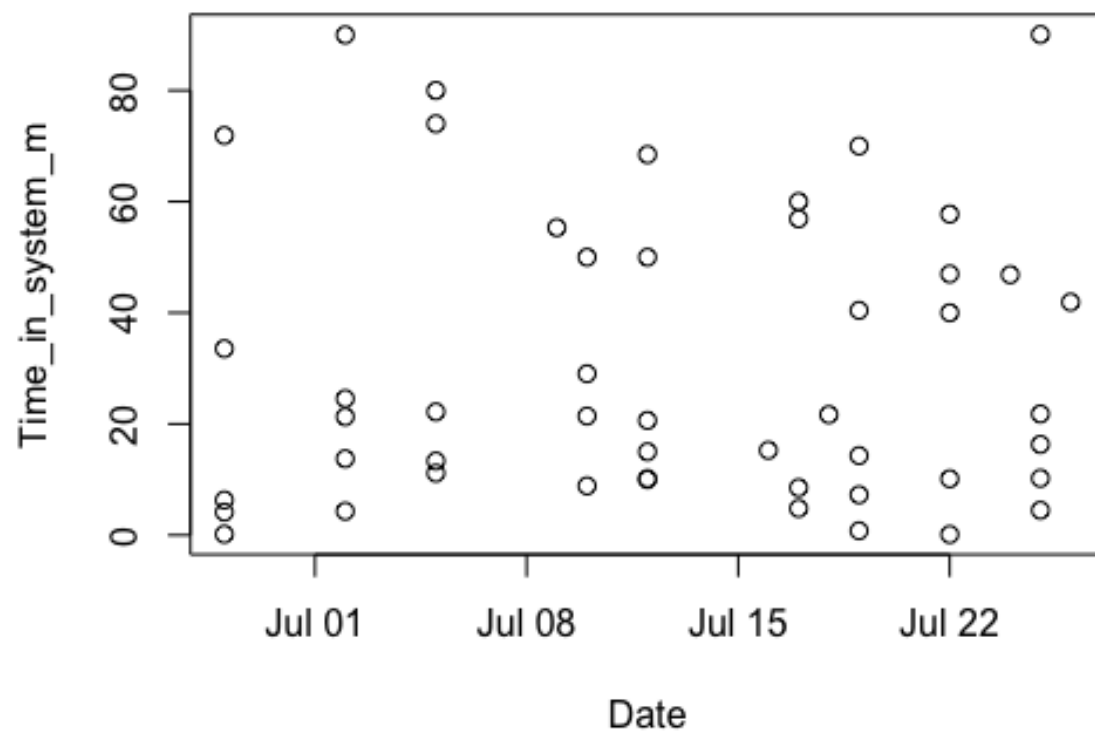


Figure 7: Amount of time spent in the aquatic systems with semi-permanent hydroperiods by birds through time.

Pond	Pernance	Quadrat #	dry/wet	collection date	Diptera #	Coleoptera #	Anura #	Hemiptera #	Haplotaixids #	Trichoptera #	Amphipoda #	Ephemeroptera #	Hymenopterans #	Trombidiformes #
WP	temp	1	dry	7.5.19	60	16	0	0	0	0	0	0	0	0
WP	temp	2	dry	7.5.19	13	8	0	0	0	0	0	0	0	0
WP	temp	3	dry	7.5.19	10	3	0	0	0	0	0	0	0	0
LP	temp	1	dry	7.5.19	17	10	8	0	0	0	0	0	0	0
LP	temp	2	dry	7.5.19	7	14	2	1	0	0	0	0	0	0
LP	temp	3	dry	7.5.19	20	30	51	0	0	0	0	0	0	0
SN3	temp	1	dry	7.24.19	119	8	0	0	0	0	0	70	28	0
SN3	temp	2	dry	7.24.19	14	5	0	0	0	0	0	50	0	1
SN3	temp	3	dry	7.24.19	4	0	0	0	0	0	0	15	0	0
SN1	semi	1	wet	8.7.19	15	4	0	0	0	0	0	0	0	0
SN1	semi	2	wet	8.7.19	3	0	0	0	0	0	0	0	0	0
SN1	semi	3	wet	8.7.19	0	1	0	0	0	0	0	0	0	0
SN2	temp	1	dry	8.7.19	6	1	0	0	0	0	0	0	0	0
SN2	temp	2	dry	8.7.19	27	6	0	0	0	0	0	0	0	0
SN2	temp	3	dry	8.7.19	60	65	0	102	0	0	0	0	11	1
KP7	temp	1	dry	8.12.19	0	0	0	0	0	0	0	0	0	0
KP7	temp	2	dry	8.12.19	0	0	0	0	0	0	0	0	0	0
KP7	temp	3	dry	8.12.19	0	0	0	0	0	0	0	0	0	0
KP5	semi	1	wet	8.12.19	4	1	0	0	58	0	0	0	0	0
KP5	semi	2	wet	8.12.19	3	0	0	0	11	1	0	0	0	0
KP5	semi	3	wet	8.12.19	7	4	0	1	2	0	0	0	0	0
M	semi	1	wet	8.12.19	1	4	0	0	0	0	0	0	0	0
M	semi	2	wet	8.12.19	11	2	0	0	0	0	0	0	0	0
M	semi	3	wet	8.12.19	4	1	0	0	1	0	0	0	0	0

Figure 8: Dry pond quadrat analyses' raw data