Fall 12-2023

How Beavers (*Castor canadensis*) Affect Habitat Availability for Two Native Oregon Turtles: *Actinemys marmorata* and *Chrysemys picta bellii*

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Actinemys marmorata* and *Chrysemys picta bellii

by

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An undergraduate honors thesis submitted in partial fulfillment of the

requirements for the degree of

Bachelor of Science

in

University Honors

and

Environmental Science

Thesis Adviser

Dr. Cat de Rivera

Portland State University

2023

Introduction:

Oregon is home to two native turtle species: the northwestern pond turtle (*Actinemys marmorata*) and the western painted turtle (*Chrysemys picta bellii,* the western subspecies of painted turtle*, C. picta*). Both turtles are experiencing population declines and have been listed as Oregon Conservation Strategy Species with a status rating of "sensitive" (*Northwestern Pond Turtle – Oregon Conservation Strategy*, n.d.; *Western Painted Turtle – Oregon Conservation Strategy*, n.d.). Much of this decline has been caused by habitat loss and degradation due to urbanization (Barela & Olson, 2014; Marchand et al., 2018; Spinks et al., 2003). No studies concerning *A. marmorata* or *C. picta,* have yet to examine how American beaver (*Castor canadensis*) could be affecting turtle habitat.

Castor canadensis is a known ecosystem engineer and has also been shown to facilitate populations of several species including waterfowl (Nummi et al., 2019; Nummi, Arzel, et al., 2021; Nummi & Holopainen, 2014), amphibians (Romansic et al., 2021), water beetles (Nummi, Liao, et al., 2021), reptiles (Metts et al., 2001), and small mammals (Fedyń et al., 2022). This study investigated the possible relationship between *C. canadensis, A. marmorata* and *C. picta bellii* by measuring important turtle habitat requirements at beaver-dammed ponds and control (not beaver-dammed) ponds. Previous work has shown that turtles will use beaver-impounded ponds (Markle & Chow-Fraser, 2014; Metts et al., 2001; Yagi & Litzgus, 2013), but these studies were not specific to *A. marmorata* and *C. picta bellii* nor have they attempted to quantify the potential mechanism behind how beavers could be creating beneficial habitat.

Castor canadensis is well-known for its engineering prowess of felling trees and damming rivers (Wright et al., 2002). Although their populations have begun to recover from their near extinction in the 1800s, their current numbers are only about 10% of their pre-colonization numbers (Wilson & Reeder, 2005). As beaver populations increase, they are inhabiting urbanized areas and coming into conflict more often with people living in these areas (Bailey et al., 2019). Under certain conditions, *C. canadensis* will dam streams and create ponds. They change hydrologic regimes by creating reservoirs, which also change flora and fauna compositions of the area (Rozhkova-Timina et al., 2018). Beavers utilize these ponds for escaping predation (Petro et al., 2020). In the Pacific Northwest, *C. canadensis* dam most actively between September and October, when water levels are at their lowest (Petro et al., 2020).

Although there are many reasons to suspect that *C. canadensis* could be creating beneficial habitat for turtles, this relationship is understudied. Even in a meta-analysis of the effects of beavers on 29 species across taxa, only one of those included effects of beaver damming on turtles (Stringer & Gaywood 2016). Another study focusing on the relationship between home range size of Spotted Turtles before and after beaver damming yielded inconclusive results (Yagi & Litzgus, 2012). Although the turtles did exploit newly created aquatic habitat once flooding from beaver damming occurred, it was unclear whether this flooding negatively affected nesting habitat in the area and new recruitment into the population (Yagi & Litzgus, 2012). This study builds upon previous findings by investigating if *A. marmorata* and *C. picta bellii* use beaver-impounded ponds in Oregon and quantifying how they may be using this habitat and what benefits it provides.

Beavers have the potential to impact turtle habitat in several ways. I have outlined three main areas where beavers could potentially have the largest effect on the primary habitat needs of Oregon's two native freshwater turtles.

Thermoregulation

Turtles are ectotherms that greatly depend on their surrounding environment to control their temperature levels, which drive growth rates and metabolic processes (Gervais et al., 2009; Snover et al., 2015). One of the primary ways turtles regulate their body temperature is through basking. During basking, turtles sun themselves using their carapace, or upper shell, to harness heat from the sun's rays (Snover et al., 2015). Large wood and emergent vegetation provides basking habitat, which is critical for ectotherms such as turtles, especially if they are living in an area with cold water (Spinks et al., 2003). Since *C. canadensis* eats mostly vegetation such as softwoods (Rozhkova-Timina et al., 2018), they decrease canopy cover surrounding dammed ponds (Weber et al., 2017). The increased sunlight at these ponds has the potential to provide more basking opportunities for turtles such as *A. marmorata* and *C. picta bellii*, a process necessary for thermoregulation. Since turtles' metabolic functions, physiological functions, and sex are temperature dependent, they could be sensitive to future consequences of climate change (Bodensteiner et al., 2019; Gervais et al., 2009).

In addition to basking, turtles can depend on water temperature for thermoregulation. If water temperatures are warm enough, turtles have less need for basking; temperature regulation is so important for ectotherms that water temperature is a key predictive variable in locating potential habitat for *A. marmorata* (Ruso et al., 2017). Therefore, warmer waterways in urban areas can be used to turtles' advantage if the waterways are managed with this goal in mind (Spinks et al., 2003). The upper temperature threshold for *A. marmorata* and *C. picta bellii* has not yet been established, but a recent study found that at higher temperatures two native turtles in China were outcompeted by invasive red eared sliders (*Trachemys scripta elegans*), a species also invasive to Oregon. This study suggests that higher water temperatures that may occur due to climate change could favor invasive species, such as red-eared sliders (Zhang et al., 2023). Sites dammed by *C. canadensis* experience more heterogeneous water temperatures than undammed sites (Weber et al., 2017). This thermal variety is proposed to be caused by two reasons. The first is that beaver damming increases the surface area of the water, which causes the surface water to receive more thermal radiation and heat up. This increase in surface area also causes benthic water to come into contact more with the ground, increasing hyporheic groundwater exchange, which allows cooler groundwater to be added to the beaveardammed pond (Weber et al., 2017). This relationship helps dammed locations buffer extreme temperatures especially in the summer, which could benefit *A. marmorata* and *C. picta bellii* in the face of climate change (Weber et al., 2017).

Nesting and Juvenile Habitat

Habitat for nesting and juvenile protection is critical for stabilizing or even increasing turtle populations. This is especially true in Oregon since both *A. marmorata* and *C. picta* have been shown to have smaller clutch sizes and slower growth rates when in northern latitudes and colder climates, such as found in Oregon (Lindeman, 1996; Germano et al., 2022). Beaver-dammed sites have also been shown to support more emergent vegetation than sites that are not dammed (Romansic et al., 2021), which could benefit juveniles (Spinks et al., 2003). Turtle hatchlings will exploit emergent vegetation to avoid predation, especially when first entering aquatic environments after leaving the nest (Rosenberg & Swift, 2013).

Turtles require terrestrial habitat with fewer large shrubs and trees and more grasses and herbs and limited canopy cover to successfully nest and reproduce (Spinks et al., 2003). A study involving the Eurasian beaver, *Castor fiber*, found that ponds dammed by beavers had lower canopy cover and higher percentages of ground vegetation and grasses than sites where beavers were not present (Fedyń et al., 2022). It is therefore likely that *C. canadensis* would have a similar effect and could create beneficial nesting habitat by felling trees near aquatic habitat, allowing bare ground and ground vegetation in the area to receive full sun exposure (Fedyń et al., 2022).

Aquatic Habitat

Deep pools and low water velocities are ideal habitat for *A. marmorata* and *C. picta*, although *A. marmorata* is a habitat generalist and can be found in both lentic and lotic waters (Ernst & Lovich, 2009; Horn & Gervais, 2018; Reese & Welsh, 1998; Ruso et al., 2017; Snover et al., 2015; Zaragoza et al., 2015). The creation of beaver dams slows water velocity (Johnston & Naiman, 1987), and *C. canadensis* dams can increase water levels by about one meter when compared to pre-dammed levels (He et al., 2023). Deep water is exploited by *C. canadensis*, *A. marmorata*, and *C. picta bellii* to avoid predation (Petro et al., 2020; Reese & Welsh, 1998; Snover et al., 2015). The reduction in water velocity in a beaver pond causes sediment accumulation behind the dam (Demmer and Beschta, 2008). These sediments have the potential to act as over-wintering habitat for *C. picta bellii,* which prefer fine sediments, or soft pond bottoms, to dig into during colder months (Gervais et al., 2009). Ponds impounded by beaver have shown to have a strong relationship to invertebrate biomass (Nummi & Holopainen, 2014). At times, beaver-dammed ponds have shown a seven-fold increase in invertebrate abundance when compared to ponds not dammed by beaver (Nummi & Holopainen, 2014). This increase in invertebrates could increase food availability for *A. marmorata* and *C. picta bellii* as they have been found to eat both aquatic and terrestrial invertebrates as well as aquatic vegetation (Marchand et al., 2018).

The aim of this study is to increase the understanding of how beavers could be facilitating turtle habitat in Oregon. This contributes to existing published knowledge about *A. marmorata* and *C. picta bellii,* which are relatively understudied in this bioregion. I tested the hypothesis that beaver impounded ponds create habitat for turtles that is more beneficial than control ponds. To do this, I took physical measurements of habitat characteristics necessary for turtle thermoregulation at impounded and non-impounded ponds.

Methods:

Study Site:

To measure the effects of beavers on native turtle habitat, I compared study sites across the Portland area. These study locations were recommended by regional managers in the Portland Metro area, and have been filtered to only include lentic, permanently beaver-dammed locations with a matching control pond. Control ponds were chosen based on proximity to beaver-dammed ponds, but they typically were not fed by the same stream. In most (6/7) cases, the non-beaver-dammed pond closest to a beaver-dammed study site was paired with that site as its control. Due to the urban setting of this study, many of the ponds have long and complex histories, with all the ponds having some degree of human alteration. The locations of the study sites span the length of Beaverton to Gresham, Oregon, including sites in Portland proper (Figure 1) (Appendix A).

Portland is located within the Willamette Valley, Oregon, which is historically characterized by grasslands, oak savannas, and wet prairies (*Willamette Valley – Oregon Conservation Strategy*, n.d.). However, now the Willamette Valley is known as the most urban ecoregion in the state of Oregon (*Willamette Valley – Oregon Conservation Strategy*, n.d.). The historic development in the area by agriculture, industry, and urban development has detached the Willamette River from its floodplain and fragmented the habitat for many at-risk wildlife species including *A. marmorata* and *C. picta bellii* (*Willamette Valley – Oregon Conservation Strategy*, n.d.).

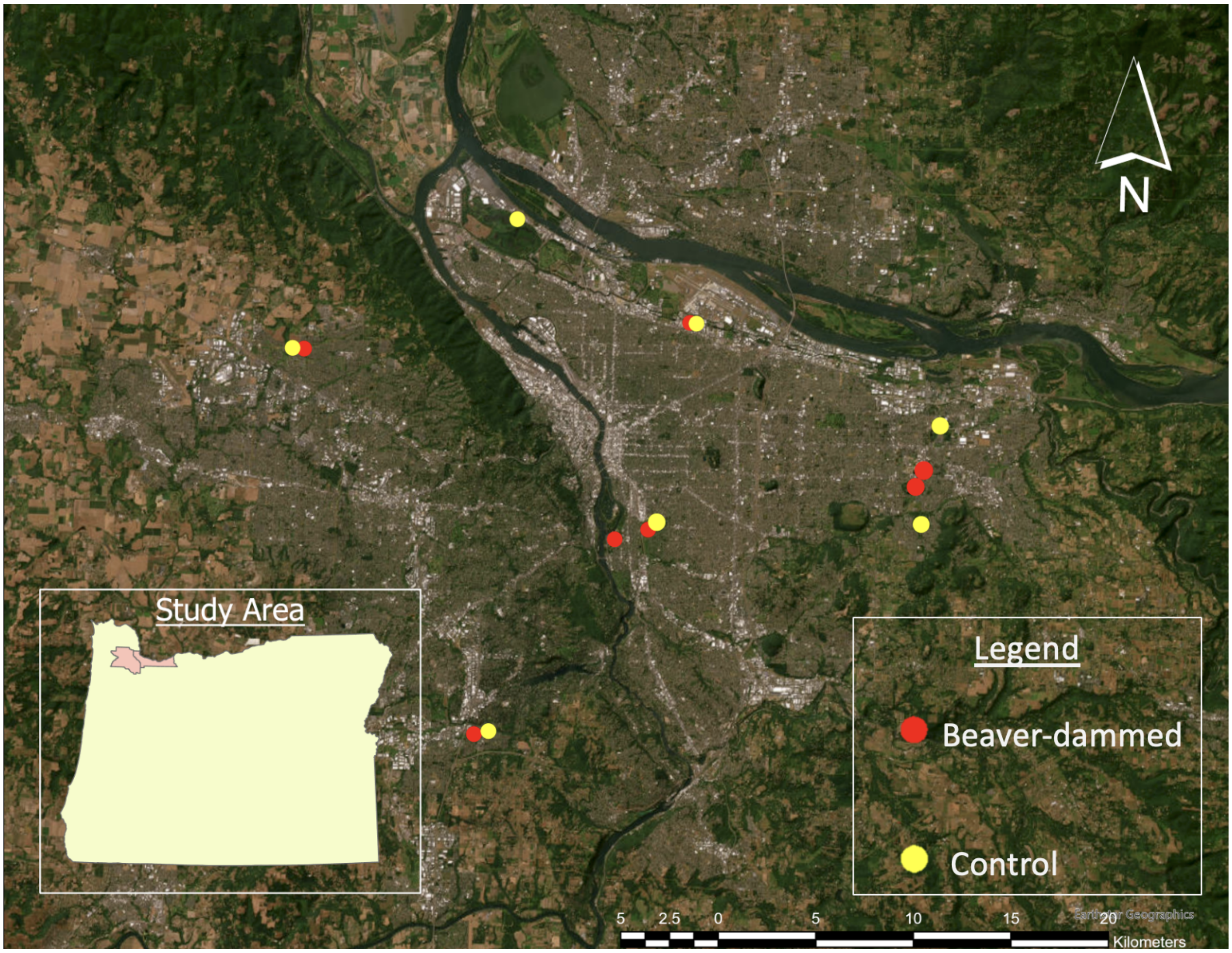

Figure 1. A map showing locations of control (no beaver damming present, yellow) and treatment (beaver damming present, red) locations across the metro Portland area. (n=7)

Water Temperature Loggers:

At each study site, temperature loggers were deployed in the deepest area of the pond. To find the maximum depth at each pond, the longest side of the pond was measured and divided so that there were ten evenly spaced depth measuring points in the pond. Once the maximum depth at the pond was identified, a line (either monofilament or braided nylon) was tied to a brick to a buoy. The line was the length of the pond depth plus about 0.5 meter added to create slack on the line. For 3 of the sets of ponds, one logger was fastened to the buoy using a zip tie, and another logger was either fastened onto the brick or 0.25 m up on the fishing line or up to 0.5 m up if there was fine sediment build-up in the bottom of the pond. This allowed for the logger attached to the buoy to be recording water surface temperatures and the logger attached to the brick to record benthic water temperatures. Loggers were deployed in early spring and summer and then retrieved in late summer, early fall.

Due to limited access to water temperature loggers, loggers differed among sites and in the deployment scheme. For three of the study sites, Fairview Creek Headwaters, Binford Pond, and Majidi Acres, Onset UTBI-001 HOBO TidbiT v2 Water Temperature Data Loggers were deployed at the surface and the bottom of each pond. For all other sites, iButton thermacron dataloggers were dipped in Plasti Dip® for waterproofing and then deployed (Roznik & Alford, 2012). Within the sites that had iButtons deployed, seven of the sites had iButtons deployed at the surface and the bottom of the pond, and four sites had an iButton deployed at the bottom of the pond creating the potential to acquire surface water data using GIS analysis in the future. Due to a variety of unforeseen circumstances, such as human interference and the curiosity of local wildlife, loggers in four sites were lost.

Habitat Assessments

At the end of summer, mid to late September, 2023, basking habitat surveys and general turtle habitat surveys were conducted at each study site.

Basking habitat surveys were conducted by counting the total basking structures present observable from the water by boat. All types of basking structures were counted such as rocks, logs, and dirt piles, but man-made basking structures were not counted. Logs were only counted if they were greater than six inches wide, at least one foot long, and less than 50% decomposed (Kutschera 2010). Each type of basking structure was categorized to describe whether it was completely emergent and only surrounded by water, emergent, but connected to the shore, or completely on the shore with the potential of becoming basking habitat in the future such as when water levels are higher (Kutschera 2010).

A general habitat assessment for northwestern pond and western painted turtles was conducted using the "Turtle Habitat Survey Sheet" developed by Rachel Kutschera in 2010 (Appendix B)(Scott, 2023; ODFW 2015). The survey sheet focuses on five main features important for turtle habitat: water body, bottom substrate, basking habitat, vegetation, and nesting/juvenile habitat. The responses recorded in each section are ranked based on a point system detailed in the instructions for using the sheet (Kutschera 2010).

Statistical analysis:

Excel was used to visually represent how water temperature changed over time. The daily maximum, daily minimum, and seven-day averages of both maximum and minimum daily temperatures were calculated and displayed on a line graph. A student's t-test in SPSS was used to test for difference in basking habitat between beaver-impounded and control sites. Although a paired sampling design was generally followed, the nearby ponds did not have much in common, including often having different sources of water. Therefore, after looking at the large variation in values between any selected pair versus all the other values, pairing was not used in the analysis for the assessing the Turtle Habitat Survey results. R studio, Version 2023.06.1+524 (2023.06.1+524), was used to create bar graphs, stacked bar plots, box and whisker plots, and to calculate summary statistics.

Results

Water temperature

Benthic temperature loggers for beaver-dammed sites Fairview Creek Headwaters, Majidi Acres, Rhododendron Garden, Rock Creek, and Whitaker Pond were able to be located and data could be retrieved from temperature loggers. Benthic temperature loggers that were usable from control ponds include: Binford Pond and Whitaker. The benthic temperature logger at Nyberg Pond was placed in a pond outside of the beaver-dammed area, and so is considered a control pond only during benthic temperature analysis, but is considered a beaver-dammed pond for basking habitat and turtle habitat survey analysis. All other loggers were either lost on site or data was not retrievable from the logger.

Since temperature logger data does not follow the paired-control study design due to unforeseeable data loss, no statistical tests were performed. However, trends were still visually displayed using line graphs (Figure 1 and 2).

From the usable benthic temperature data, I found that the three control ponds had the highest benthic temperatures overall (Figure 1). All beaver-dammed ponds displayed cooler benthic temperatures than control ponds for most of the summer. Three of the five beaver-dammed ponds showed steady temperature throughout the whole summer, with only minor oscillations displayed in their temperatures (Figure 1).

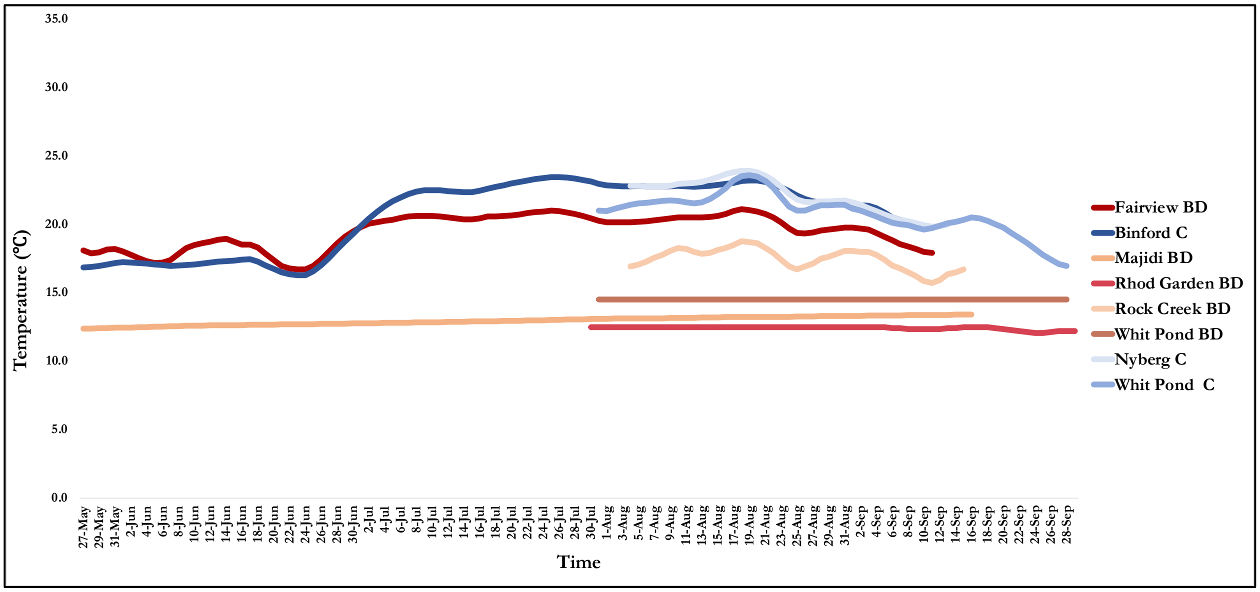

Figure 1. Seven-day average of daily, minimum, benthic temperatures. Temperature (°C) is shown on the y-axis, and days from May 27 to September 28 are shown on the x-axis. Shades of orange indicate control pond data, and shades of green indicate beaver-dammed pond temperatures.

Surface temperature loggers usable across beaver-dammed sites included Fairview Creek Headwaters, Majidi Acres, and Whitaker Pond. For control sites, usable loggers were from Binford Pond and Whitaker. Fairview Creek Headwaters had the highest surface temperatures for most of the summer. All surface temperatures peaked on August 18, 2023 (Figure 2).

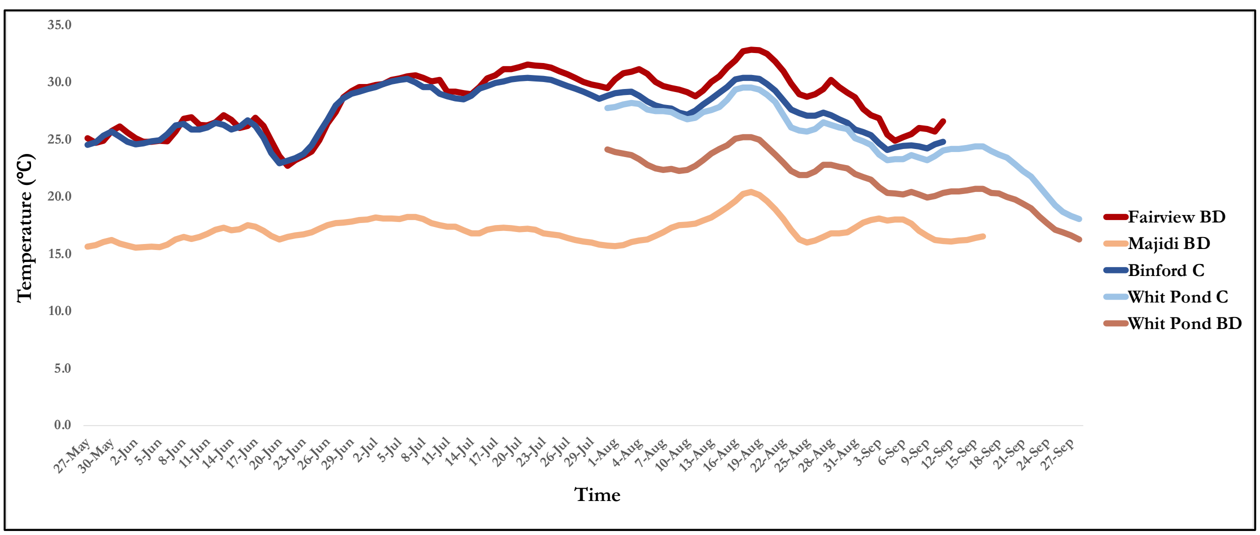

Figure 2. Seven-day average of daily, maximum, surface temperatures. Temperature (°C) is shown on the y-axis, and days from May 27 to September 28, 2023 are shown on the x-axis. Shades of blue indicate control pond data, and shades of red indicate beaver-dammed pond temperatures.

The greatest difference in surface and benthic temperatures on this day was a beaver-dammed site, Fairview Creek Headwaters with a difference of 12 degrees. The next greatest difference was another beaver-dammed site, Whitaker Pond with a difference of 11 degrees. The next biggest difference was the same for beaver-dammed site Majidi Acres and control site Binford Pond at 7 degrees, and the smallest difference was a control site, Whitaker with a 6-degree difference (Figure 3). Beaver-dammed sites Fairview Creek and Whitaker Pond had greatest difference between benthic and surface temperatures throughout the summer. Majidi Acres, a beaver-dammed sites, at the smallest differences between surface and benthic temperatures, until August 18th where it began to match differences in temperature with control sites Whitaker Pond and Binford Pond (Figure 3).

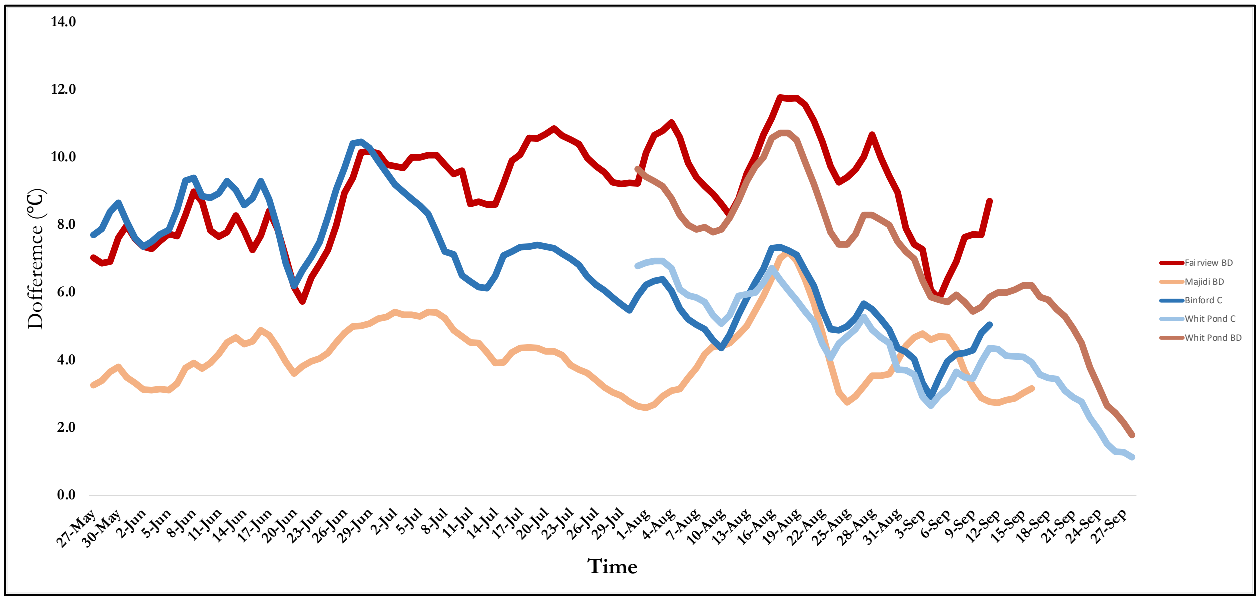

Figure 3. The difference between the seven-day average of daily, maximum, surface temperatures and seven-day average daily minimum benthic temperature from all sites that had both benthic and surface temperature loggers. Temperature (°C) is shown on the y-axis, and days from May 27 to September 28 are shown on the x-axis. Shades of red indicate beaver-dammed pond data, and shades of blue indicate control pond temperatures.

Habitat Assessments

I did not find a statistically significant difference between basking habitat available in beaver-dammed and control sites. However, analysis showed that there was, on average, more basking habitat available at beaver-dammed study sites (Figure 4). Beaver-dammed sites had an average of 21 structures per pond, and control sites had an average of 17 structures per pond. Variation in beaver-dammed sites was also higher (SD=57) while control sites (SD=38).

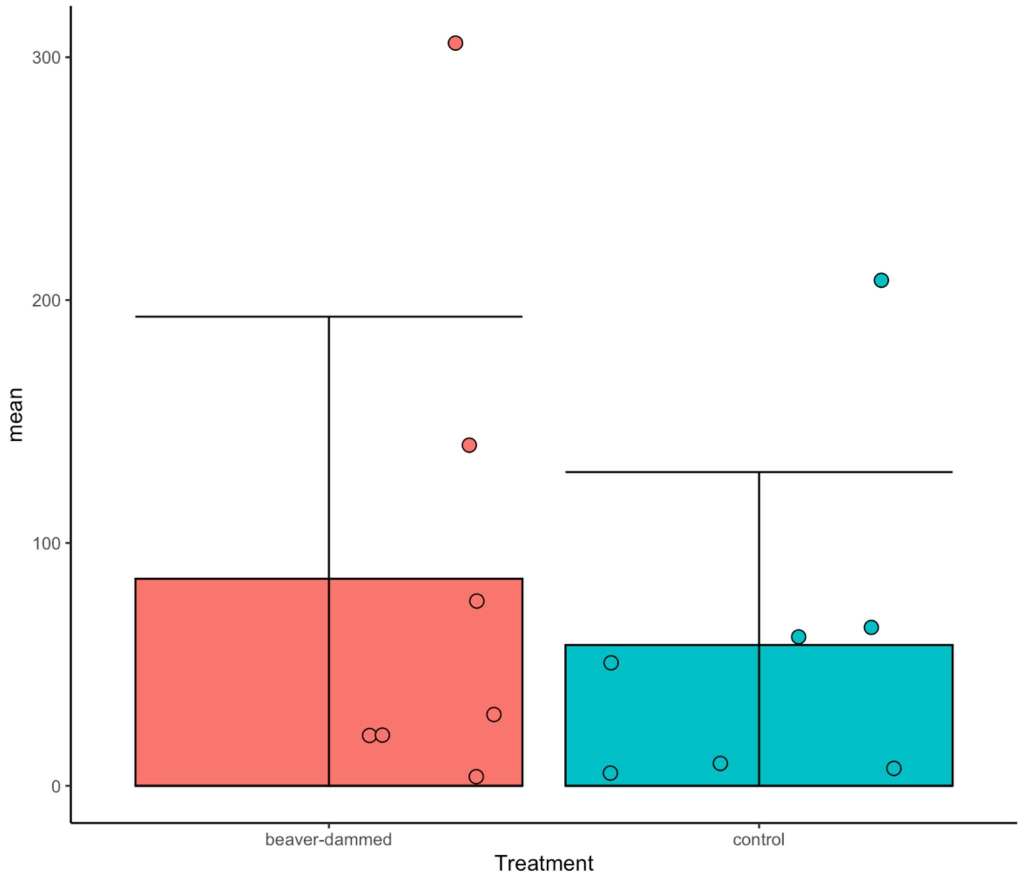

Figure 4. Average basking structure at beaver-dammed versus control ponds. Error bars indicate +1 standard deviation. Circles indicate individual data points; points are offset from each other for visual clarity.

Beaver-dammed study sites also had a higher, though not significantly higher, total number of basking sites, and greater number of different basking structures available for turtles to use (Figure 5). For both sites, the most common basking structure was emergent logs connected to the shore. For beaver-dammed sites, the least common basking structure that was present were beaver lodges that were connected to the shore. For control sites, the least common basking structure present were rocks.

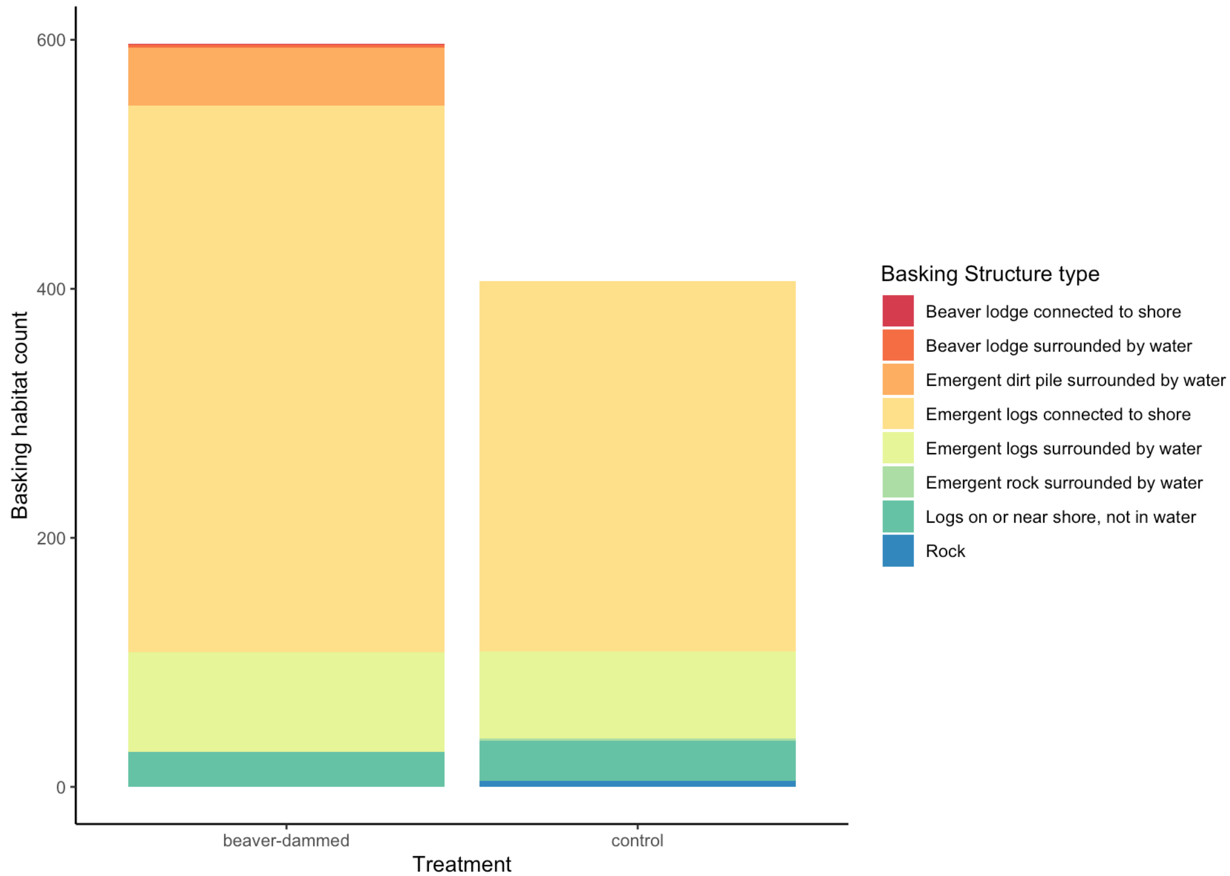

Figure 5. Total number of basking structures counted at beaver-dammed and control ponds. Each color corresponds with a different basking structure type.

The Turtle Habitat Survey by Rachel Kutchera showed that beaver-dammed ponds had higher mean (16) and median scores (16) than control ponds (12, 13) (Figure 6). The results of the t-test showed statistical significance (p=0.038, df=12, t=-2.34). The maximum scores for beaver-dammed ponds were higher (19) than the maximum scores for control ponds (16). Minimum scores for beaver-dammed ponds were also higher (12) than minimum scores for control ponds (9).

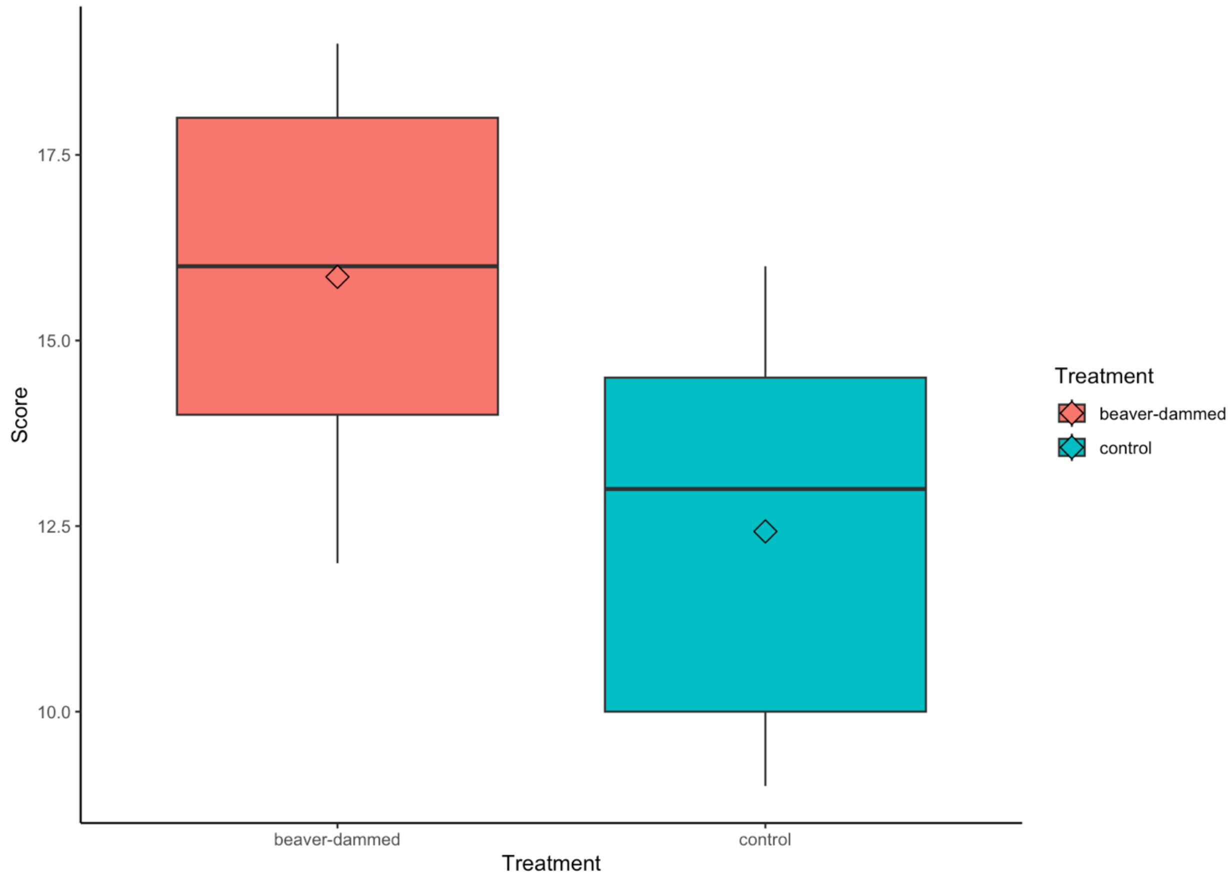

Figure 6. Box and whisker graphs for beaver-dammed (n=7), and control (n=7) ponds. Lower whiskers represent minimum values, lowest bars represent the 25th quartile, the middle bar represents the median, the upper bars represent the 75th quartile, and the top whisker represents maximum values. Diamonds represent the mean.

When looking at the average scores based on the survey category, beaver-dammed ponds received the same score as control ponds for the "Water Body" section (Figure 7), which records the size and permanence of a water body (Appendix B). Beaver-dammed ponds had an average score of 2.1 for the "Bottom Substrate" category, while control ponds had an average of 1.4 score. For "Nesting/ Juvenile Habitat" beaver-dammed ponds scored an average of 2.3 and control ponds scored an average of 2.0. In the "Vegetation" category which scores aquatic and terrestrial vegetation in and surrounding the ponds, beaver-dammed sites scored a 3.1 on average and control ponds scored a 2.6 on average (Figure 8).

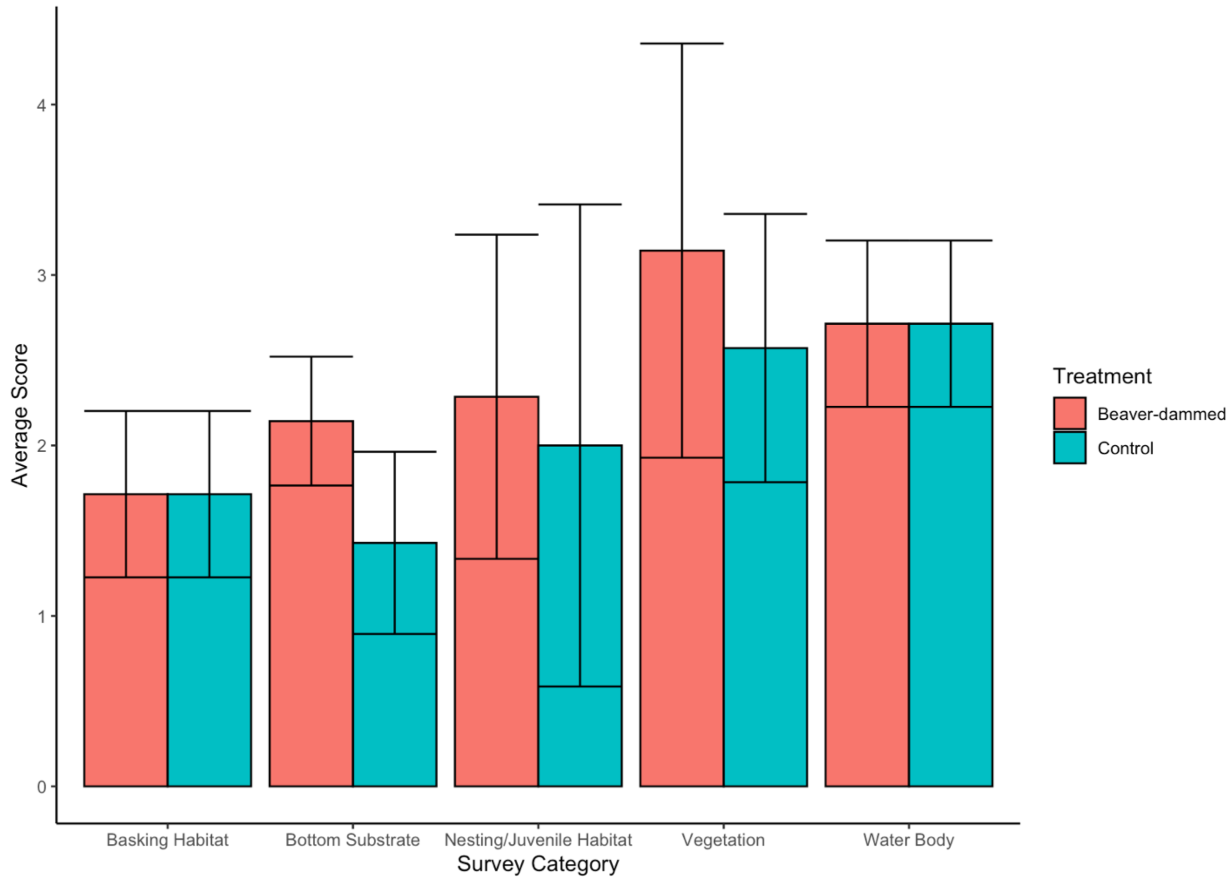

Figure 7. Bar graphs for beaver-dammed (n=7), and control (n=7) ponds. Bars represent the average score, and each bar is sorted by survey category and whether it is a beaver-dammed or control pond. Bars represent +/- 1 standard deviation.

Discussion:

My findings show general trends that support the hypothesis that beavers create habitat that is usable by Oregon's native turtles. However, only one of these trends was statistically significant. The high variability found in basking habitat surveys indicate there is a lot of variation between ponds. This could be due to the different histories of alteration and human influence on ponds in urban areas. Therefore, a future study would need a sample size much higher than 7 beaver-dammed and 7 control ponds to be able to properly answer the question of whether beaver-dammed ponds provide more turtle basking habitat than control ponds.

Although, I could find no hypothesis-driven research looking at whether beavers create more basking structure for turtles, one meta-analysis noted that beavers could be providing extra basking habitat through their creation of lodges (Stringer & Gaywood, 2016). During my fieldwork, I did not see turtles actively using lodges as basking habitat, but two beaver-dammed sites had emergent beaver lodges present that met the criteria for being usable basking habitat because they contained logs that were greater than 6 inches in diameter and less than 50% decomposed (Kutschera, 2010). My findings support government literature stating that beavers do create more basking habitat for turtles (Gervais et al., 2009). However, the source for this fact was not cited, so I was not able to directly compare my findings to another study's findings to see if statistically significant differences were found by other researchers.

The Turtle Habitat Survey results had a p-value of 0.038 which provides evidence to reject the null hypothesis that there is no difference in scores between beaver-dammed and control ponds. Given the high variability between ponds, and the small to moderate sample size in this study, a p-value of 0.038, and t-stat of -2.34 provide a strong signal that beaver-dammed ponds could be creating more suitable habitat for *A. marmorata* and *C. picta bellii* than control ponds. When looking at the components of the Turtle Habitat Survey separately, most variables had higher, though not significantly higher scores than control ponds. However, when these separate variables were all considered as a whole, the beaver-dammed ponds ranked much higher, and significantly so. Therefore, future research must consider all the components of how beaver-damming can affect turtle habitat because focusing on one aspect of beaver-damming or turtle habitat will likely not show large differences between beaver-dammed and control ponds. This also reveals that beaver-damming impacts turtle habitat in many, important ways and not just in one big way.

The Turtle Habitat Survey is beneficial to quickly get a general sense of if a site could potentially be used as turtle habitat, or if a site already hosts turtles, how the habitat can be improved (Scott, 2023). However, much of the survey is based on visual estimation, and the scoring method is broad. Most categories are scored on a scale of 0-2 with one category with a potential score of 4. This system was helpful in determining which areas of research should be focused on in the future, but it does not show detailed results. For instance, my detailed basking surveying method revealed all the different types of basking structures available, total number of basking habitat present, and detailed averages and variation across sites. When transferring my data to the survey scoring structure, the data lost a lot of detail as the only options for scoring each pond were: 0 = it had no basking structure, 1= it had at least one log connected to the shore, 2 = it had at least one emergent log surrounded by water. Because the protocol in the Turtle Habitat Survey is fairly general and does not rely on complex instrumentation or equipment, this method would be appropriate to use in a community science context. However, the Turtle Habitat survey protocol would be less conducive to finding significant differences or conducting multivariate analyses. With this in mind, I would strongly recommend future research focusing on habitat categories provided by the survey, but to use more detailed, quantitative methods, rather than rely on the visual estimates provided by the Turtle Habitat Survey protocol.

Despite the data loss in water temperature analysis, trends in the data support the findings of Weber et al. (2017), which found that temperatures in beaver-dammed ponds were more heterogeneous than temperatures in control ponds. This provides support for the proposed mechanism behind the temperature heterogeneity, which is that beavers increase hyporheic exchange, cooling lower portions of ponds, and also increase surface area of the water, warming the upper portions of ponds. Based on the findings in Yagi & Litzgus (2013) turtles can exploit this thermal heterogeneity by selecting different portions of a pond to maintain the optimal internal body temperature to help regulate metabolic function. Future research should focus on deploying temperature loggers at the surface and bottom at a greater number of beaver-dammed and control sites than seven. It would also be interesting to see how temperature differences vary throughout the entire year versus just the summer. The average difference between surface and bottom temperatures can then be compared statistically between the two types of sites.

Based on the findings in this study, I would recommend managers to continue working with the public to encourage co-existing with beavers, when possible, instead of opting for removal options. The Turtle Habitat Survey results suggest that beavers could be creating usable habitat for turtles, but the results from the basking habitat survey suggests that it is not likely due to increased basking habitat availability. Therefore, future research should focus on other important features of turtle habitat that beavers could be influencing such as nesting/ juvenile habitat, bottom substrate, or terrestrial and aquatic vegetation (Figure 7). Additionally, future studies should investigate the possibility of training volunteers to conduct Turtle Habitat Surveys "blind" to the beaver-damming hypothesis to reduce bias in the data collection process and to see if results coincide with results found in this study.

Turtles' long-lived nature provide a unique niche within ecosystems (Ernst & Lovich, 2009), and they also act as a charismatic megafauna to help engage the public and encourage interest in conservation of waterways and wetland-areas within urban spaces (ODFW 2015). Their survival depends on continued research, especially in under-researched areas within their range such as Oregon, and collaboration with regional managers to preserve current populations as well as increase the recruitment to ensure future generations of *A. marmorata* and *C. picta bellii*.

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Appendix A. Study Site Names and Locations

Table 1. All the study sites listed next to their paired control

Site Name	Coordinates	Treatment
Nyberg Creek	45.3820170, -122.744922	Beaver impounded
Browns Ferry Park	45.3832507,-122.7371997	Control
Rock Creek	45.556693, -122.864194	Beaver impounded
Bethany Lake	45.557191, -122.871717	Control
Oaks Bottom	45.4730813,-122.6580985	Beaver impounded
Smith Bybee Pond	45.6190993, -122.7269602	Control
Rhododendron garden	45.477874,-122.635900	Beaver impounded
Reed Lake	45.4828023,-122.6292970	Control
Whitaker Ponds Nature Park	45.5744161, -122.6127700	Beaver impounded
Whitaker Pond Control	45.573517,-122.6113820	Control
Fairview Creek Headwaters	45.5004939,-122.4613555	Beaver impounded
East Salish Pond	45.5292611,-122.4468052	Control
Majidi Acres	45.5099623, -122.4541299	Beaver impounded
Binford Pond	45.4831309, -122.4606996	Control

Appendix B. Turtle Habitat Survey Sheet and Scoring Parameters (Kutschera, 2010)

Turtle Habitat Survey Sheet		**Name:**
Date:	**Site Name/Address:**	**Time:** AM / PM
Water Body	Circle: Flowing (Creek/River/Channel/Slough, etc.) Stagnant (Pond/Lake/pool,etc.) Inlet or Outlet present Y / N Site is man-made or altered Y / N Check one: Intermittent _______ Perennial_______ Acreage________	**Notes and Comments** Include: Turtles seen (#, sex, age group-hatchling/juvenile/adult), behavior observed (nesting, basking, terrestrial movement and direction), animal sign (scat, tracks, predated nests, invasive species), Human use (trails, roads, trash).
Bottom Substrate	Estimate Percent of Each: Mud ___________ Rocks___________ Sand___________ Other (bottom not visible, obscured by aquatic vegetation, etc.)___________ Water Clarity (circle one): <1 ft. <2 ft. >2 ft.	
Basking Habitat	Indicate Number of Each (approximate if many) that are at least 6 in. wide, 1 ft. long, and less than 50% decomposed. Emergent logs surrounded by water___________ Emergent logs connected to shore___________ Logs on or near shore, not in water___________ Boulders, man-made surfaces, sandy/rocky shoreline present Y / N	
Vegetation	Estimate Percent of Each:	
Aquatic	Open water___________ Floating veg.___________ Emergent veg._________	
Terrestrial	Trees/Shrubs (>2 ft.)___________ Distance from shore (ft.)__________ Forbs/Grasses(<2ft.)___________ Distance from shore (ft.)__________ Bare ground/moss___________ Distance from shore (ft.)__________ Litter layer: Distance from shore (ft.)__________ Depth of litter (in.)___________	**Aquatic Vegetation Types Present** **Terrestrial Vegetation Types Present**
Nesting/Juvenile Habitat	Applies only if bare/mossy ground or vegetation <1ft. tall is present and has no canopy Estimate area (sq. ft)___________ Degree of Slope___________ Aspect___________ List any barriers to vegetation types or nesting areas (fencing, vertical slopes, etc.): ____ % shoreline water < 2 ft. deep_________ % with aquatic vegetation____________	**Photo Documentation** List photos and compass bearing of each.
Other	Riparian Zone: (shortest distance from shore to a disturbance): ________ft. Connected by water to other habitat? Y / N If N, distance to nearest aquatic habitat outside site boundary (if applicable)______ft./mi.	

Instructions and Definitions

Use the following guidelines in the order listed to help you fill in the survey form. If you are not sure, leave the space blank or indicate with a "?"

1. If there are multiple water bodies on the site, fill out one form for each. Size/acreage is recorded once for the site.

2. On the aerial photo of the location provided, sketch, mark, or highlight main components. Use "x" for basking logs, hash marks for aquatic vegetation, and circle nesting areas.

3. Walk perimeter of the property and the water body (if dense vegetation is in the way, observe from other side or as closely as possible).

4. Note anything listed in the "Notes and Comments" section with anything else you think is relevant. A summary of the area, descriptions, interesting elements (an abundance of one plant type, high or low water, etc.). More is better than less!

5. Acreage can be determined by the aerial photograph, maps, or the site owner.

6. Circle the type of **aquatic habitat (water body)** found at the site; elaborate if you are able. **Intermittent** waters flow only during certain times of the year, and **perennial** waters are permanent.

7. **Basking** is a turtle behavior of lying in the sun on logs, boulders, or occasionally a sandy shoreline.
Emergent logs are any that are partially in the water but extend out to form a potential basking surface.

8. **Floating vegetation**, such as lily or duckweed, is not attached to the bottom. **Emergent vegetation**, such as cattail and reed, grows out of the water but is rooted in the substrate.

9. The **litter or duff** layer is composed of dead leaves and grass, pine needles and cones, sticks, and other humic materials under the forest canopy. Take an average of 5 litter measurements around the site, or 5 from each separate forested area.

10. **Canopy** is the topmost layer of the forest, composed of the crowns of trees.

11. The **riparian zone** is the land directly adjacent to the water body. A **Disturbance** can be trails, roads, fishing platforms, houses, walls/fences, etc. within the site boundary.

12. A **connection** to other habitat would be undisturbed similar vegetation or landscape that would allows turtles to move between habitats without crossing roads or traversing large areas of open space where they could be easily viewed or harmed by humans or animal predators. Can also be connected by water (stream/creek, wetland) or human constructs such as undercrossings or greenways

13. **Photo documentation** can be digital photos of habitat components surveyed or notable findings and the direction you were standing when the picture was taken.

Habitat Component Values

1. Water
   0 = No water present
   1 = Water present intermittently; dries or is drained completely at some point annually
   2 = Water present perennially

2. Bottom Substrate
   0 = No water present or substrate is man-made (i.e. concrete)
   1 = Rocks, sand, or mixed substrates
   2 = Mud or organic materials

3. Basking
   0 = None (no surfaces emergent from or adjacent to water)
   1 = Logs present are <6" wide and 1' long, >50% decomposed, connected to shore (not isolated in water), OR basking habitat is composed of boulders, sand banks or other material
   2 = Logs present are >6" wide and 1' long, <50% decomposed, and isolated within the water body

4. Aquatic Vegetation
   0 = None (all open water or no water present)
   1 = Floating OR emergent vegetation present on at least 5% of water or shoreline.
   2 = Floating AND emergent vegetation present on at least 5% of water and shoreline.

5. Terrestrial Vegetation
   0 = None (soil or man-made substrate only)
   1 = At least two types of vegetation present with 5% coverage or more, OR a litter layer is present.
   2 = All types at least 5% present with a litter layer of at least 2 cm (.075 in), but separated from water by a barrier (fence, steep slope, etc.)
   3 = All types with at least 5% coverage and a litter layer present and accessible from some part of shoreline

6. Nesting
   0 = None (no bare ground or vegetation <1' tall and without canopy cover)
   1 = Present, but on a slope of >25°, not SE facing, or barrier to it is present
   2 = Present on slope of <25° and SE facing with no barriers between water and habitat

7. Hatchling and Juvenile
   0 = None (No water <2 ft deep)
   1 = Shoreline has water <2 ft deep, but with little accompanying aquatic vegetation, or access in and out of water is limited.
   2 = Shoreline has water <2 ft deep with emergent or floating vegetation and easy access in and out of water (low slopes from shoreline or other emergent structures nearby)

Appendix C. Supplemental Information

Turtle Trapping:

Approval for Oregon's STP and PSU's IACUC was achieved, and turtle trapping was conducted at Fairview Creek Headwaters (treatment) and Binford pond (control) during one week in late May. The traps were deployed continuously for four days. Traps were checked daily once deployed. Twelve hoop net traps were deployed at Fairview Creek Headwaters, and two were deployed at Binford Pond. When a turtle was trapped it was: sexed, weighed, carapace and plastron length measured, checked for gravidity, notched, and marked with fingernail polish, following standard protocols (Susan Barnes, personal communication). Turtles smaller than 110mm were not notched and their sex was marked as unknown. Sex was determined using primary physical characteristics such claw length and plastron shape. Secondary characteristics such as the position of the cloaca on the tail was used to affirm initial sex determination.

GIS analysis:

Aerial photos from 2014 to 2022 of Fairview Creek Headwater were provided by City of Gresham. The aerial photos for Fairview Creek Headwaters were taken around August and September every year, which is at the end of the summer and the driest time of the year in Oregon. Once the aerial photos were digitized into ArcPro, the coordinate system NAD 1983 State Plane Oregon North FIPS 3601 (Intl Feet), which was specified in the file names of the photos, was projected onto the map.

For Fairview Creek Headwaters, I wanted to measure how the reservoir behind a beaver dam can change over time. To do this, I created a new polygon feature class for each year's aerial photo. Then I used the create feature under the "Edit" ribbon to outline the reservoir behind the beaver dam for each year. I used the streaming feature to outline the reservoir as it has a unique and smooth shape (Figure 1). After the shape was outlined, I calculated the area of the polygon in square meters by adding an "area" column to the attribute table, right-clicking the column, and pressing "calculate geometry". This data was exported into Excel, where a linear regression model was fitted to the data in order to identify if there was a relationship between dam age and reservoir size.

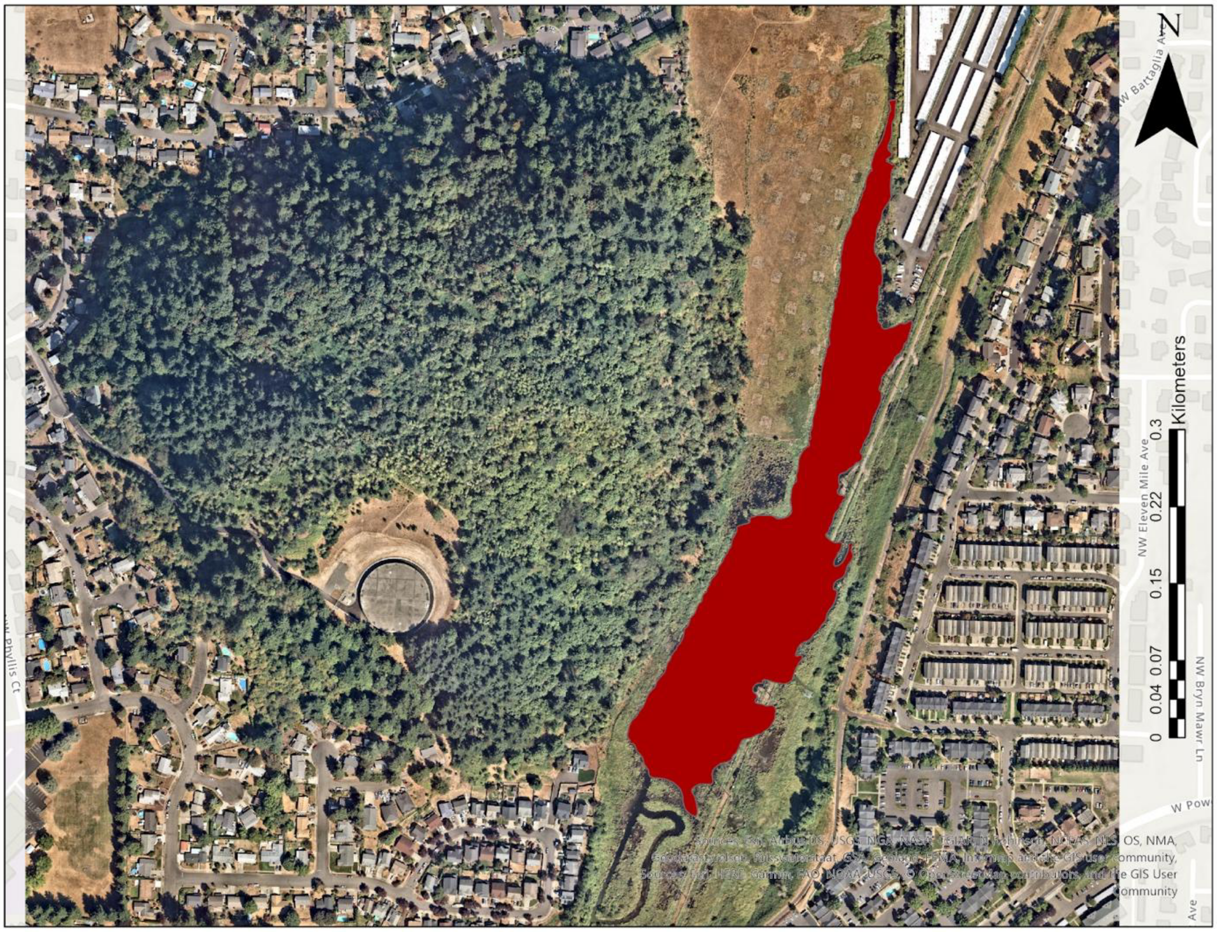

Figure 1. Aerial photo of Fairview Creek Headwaters 2021. The red indicates where the create a polygon tool was used to measure the area of the beaver pond.

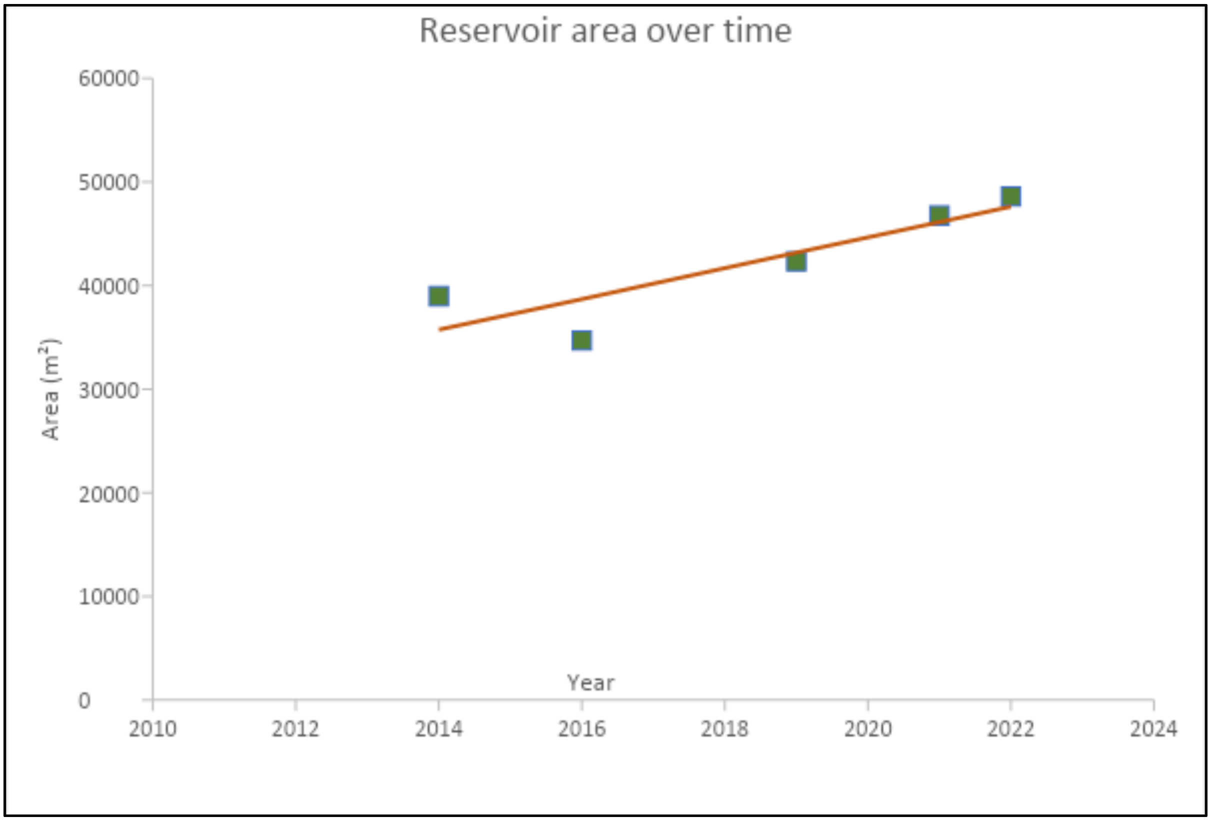

Figure 2. Linear regression model comparing the relationship between the ariel photo year and the area measurements at Fairview Creek Headwaters. N=5 as there was no data captured in 2017 or 2018.

Figure 2 represents the results from how the reservoir area behind the beaver dam at Fairview Creek Headwaters has changed over time. A slope of 1485.4 m^2/yr indicates that the relationship between time and area is positive. An r^2 value of 0.78 indicates that the relationship is fairly strong- 78% of the variation in the data can be explained by the relationship between time and area of the reservoir.

Beavers in urban areas often conflict with humans residing in the area as beaver damming can be seen as a nuisance to residents (Bailey et al., 2019). However, results from the linear regression in Figure 2 begin to shine some light on the possible benefits of co-existing with beavers in urban spaces. With an r^2 value of 0.78, these results suggest that as beaver dams get older, they store more water. As Figure 3 shows, beaver dams have the ability to store water at even the driest times of the year, which could provide beneficial habitat to all wildlife in the area, especially semi-aquatic ones such as turtles.

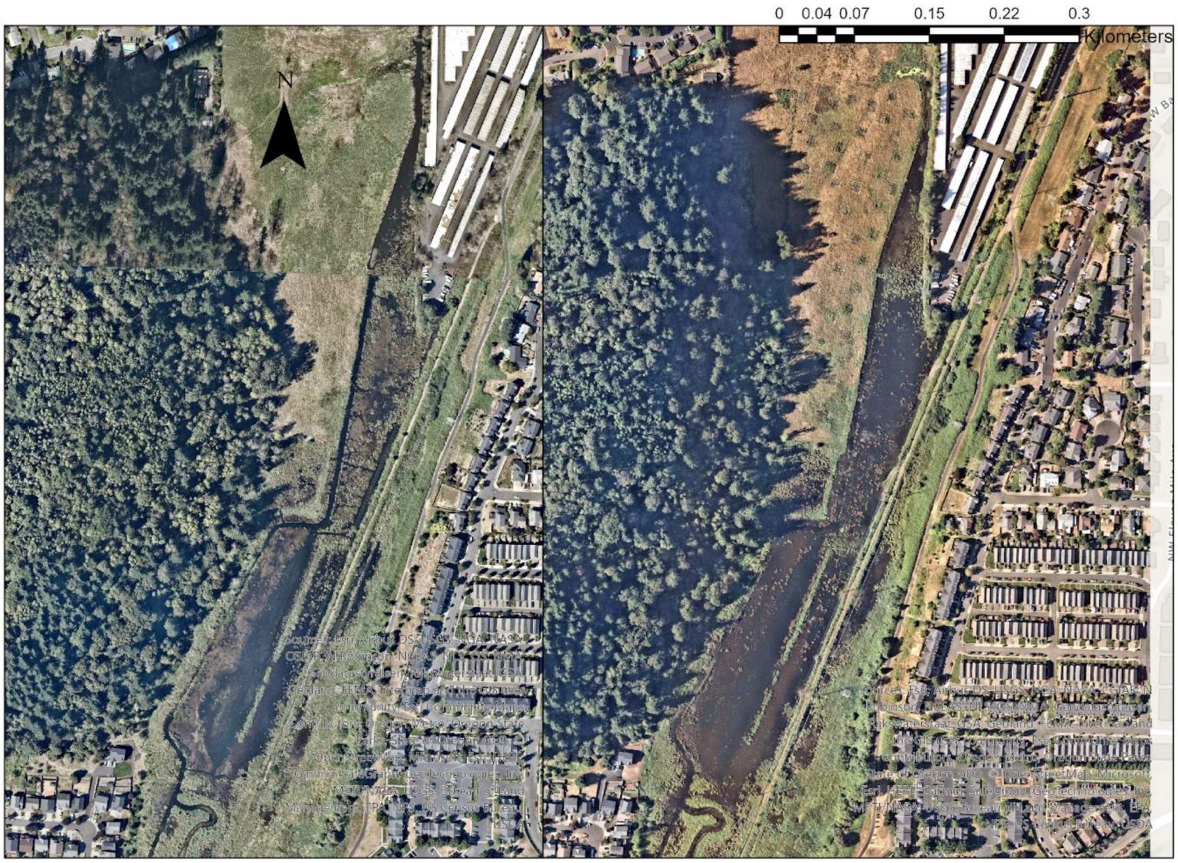

Figure 3. Two aerial photos of Fairview Creek headwaters. The photo on the left is from 2016 while the photo on the right is from 2022. It appears like the water is less deep in the 2016 photo as more land and greenery is showing. While the photo on the right from 2022 shows more surface area covered in water, and deeper water generally.

Overall, I recommend future, long-term research into the relationship between beaver dam age and water retention. I also recommend that this information be provided to wildlife managers in urban areas as an educational tool for the public. In order to better age beaver dams, I suggest using change in forest structure as a potential tool to identify when beaver began damming in an area.