Investigating the relationships between forest management strategy and terrestrial salamander populations in Northwestern Pennsylvania



By:

Anthony DeMarco

First Reader: Dr. Mark A. Kirk

Second Reader: Dr. Kelly Pearce

Department of Environmental Science and Sustainability

Allegheny College

Meadville, Pennsylvania

March 2025

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Acknowledgements

I would like to first thank my parents, my brother Jameson, and the rest of my family as this entire opportunity would not have been possible without them, for that I will always be grateful. All of my friends back at home, Evan, Michael, Park, Nolan, Connor, Markus, Kyle, Nate, Austin, Javion, Logan, Higgins, Luke, and all of your parents, you all have been a source of endless support in this long journey and for that I offer my thanks. I also want to thank Dr. Kirk and Dr. Pearce for advising and helping me along through my independent research and my comp, you both made the process feel easier for me and helped me accomplish my goals here in the Environmental Science Department. I want to thank all of my coaches for pushing me to be my best both on and off the field. To the teammates I met here at Allegheny, to call you teammates would be a disservice. Over the past 4 years I've truly come to call you my brothers, sharing the field and the classroom with you all has been one of the most rewarding experiences of my life, and I hope that these 4 short years will not be the extent of our friendship. Finally, I want to thank Lainee Swanson. You never failed to make me smile even in the most stressful of times. You support me whether it be through lacrosse or through my comp and I'm thankful for it every single day.

Name: *Anthony Reid DeMarco* Date: Spring, 202*5*
Major: Environmental Science
Thesis Committee: *Dr. Mark Kirk, Dr. Kelly Pearce*

Title: *Investigating the relationships between forest management strategy and terrestrial salamander populations in Northwestern Pennsylvania*

Abstract

Amphibian species are facing a decline as global anthropogenic impacts continue to progress. This is due to amphibians being climatically sensitive, and as a result, they are intolerant to environmental changes in temperature and moisture. In this study, we sought to investigate the relationship between different forest management strategies and terrestrial amphibian populations. This study was conducted in Northwestern Pennsylvania at three properties throughout the area. Collection methods included visual encounter surveys. The motivation behind this project was to provide insight into other potential stressors that terrestrial amphibians may face, while also looking at better ways to manage forests so as to keep biodiversity and amphibian populations intact. Among our surveys, 4 different species were captured. These were Eastern redback salamanders (*Plethodon cinereus*), Eastern newts (*Notopthalmus viridenscens*), 4-toed salamanders (*Hemidactylium scutatum*), and slimy salamanders (*Plethodon glutinosus*). Across these 4 species, we saw an overall trend towards higher densities and higher richness at our unmanaged forest stand (Bousson), than at the other two sites with active and passive forest management. We saw that there were no notable differences between the three sites when it came to body condition for eastern redback salamanders, however total length (mm) and mass (g) were highest at the actively managed stand compared to the unmanaged and passively managed stands. Our research holds implications for

the maintenance of Northwest Pennsylvania amphibian populations, as well as future sustainable forest management strategies not only for our study area, but for the rest of the world as well.

Introduction

As deforestation continues to impact the ecosystems of the planet, we are seeing more detrimental effects. Countless effects have been prevalent over the past few decades, but one of the main impacts of deforestation that has garnered mainstream attention is the global loss of habitat and biodiversity. Some of the factors that negatively affect biodiversity are comprised of interactions between exogenous (environmental) threats such as habitat loss, habitat degradation, habitat isolation, and interactions between species, as well as endogenous (physiological) threats such as changes in biology and physiology, and changes in behavior (Fischer and Lindenmayer, 2007). Of these many groups of organisms, amphibians are a group that have historically faced a myriad of challenges as a result of deforestation.

Amphibians are particularly vulnerable to deforestation due to the fact that their physiology and life-history attributes rely heavily on climatic conditions (Kirk et al, 2019). Amphibians, being ectotherms, are largely dependent on the climate around them to maintain bodily functions such as metabolism, metamorphosis, and other physiological necessities. Many amphibians are also dependent on climatic factors such as temperature and precipitation to trigger life history events that play crucial roles in their life cycles (Bartelt, 2010; Walls et al., 2013). These events include behaviors such as breeding migrations, overwintering, and juvenile dispersal (Bartelt, 2010; Walls et al., 2013). On an individual scale, previous studies have linked

the physiological performance of amphibians to the alteration and management of their habitat. One study in particular found that overall body size in male brownbelly leaf frogs (*Phyllomedusa tarsius*) was lower in open pastures and lighter undergrowth, than in a continuous stretch of forest (Neckel-Oliveira and Gascon, 2006). Amphibians, like many other groups of organisms, have been shown to have idiosyncratic responses to stimuli caused by deforestation among many different species (Bury, 1983; Toussaint et al., 2021, Hayden Bofill and Blom, 2024). This presents a clear challenge given that different species will likely react uniquely to stimuli caused by deforestation than other species, making the process of creating generalizations about responses to these stimuli difficult. Generalizations are also made difficult when considering that many changes that occur on a global scale, may not be seen on a local scale (Warren and Bradford, 2010).

The primary aim of this study is to analyze the potential effects of forest management on their resident amphibian populations. Studies of this nature have been conducted in the past. One in particular found that there were higher densities and higher species richness in the old-growth forests versus logged redwood forests (Bury, 1983). This study included species such as the California Giant salamander (*Dicamptodon ensatus*), Olympic Salamander (*Ryhacotriton olympicus*), and Tailed Frog (*Ascaphus truei*) being found only in old-growth plots, whereas the Pacific Treefrog (*Hyla regilla*) was only found in logged plots (Bury 1983). This foundational study's results added credence to the potential relationship between forest management level and amphibian densities. More recent studies have been conducted that support the correlation between forest management and amphibian densities. The retention of both coarse woody debris and overstory or canopy cover, are both positively linked to the success of amphibian populations (Moorman et al., 2011). Success could be defined here as having a higher abundance

of individuals and individual survival. A higher abundance of salamanders in a given area has been shown to indicate a higher habitat suitability (Lunghi et al., 2018). Individual survival of salamanders in a given area can also be attributed to habitat suitability, more specifically, the availability of shelters for optimal microclimates (Basile et al., 2017). The study conducted by Basile et al. (2017) uses trees as an overall proxy for shelter, however, things like coarse woody debris and canopy cover could both be used to represent shelter. All three of these factors, coarse woody debris, canopy cover, and tree species are directly linked to the management level of a forest.

Based on this prior research, my objective was to use visual encounter surveys in different forest management types to determine the species compositions of the three management levels. Within this objective, I make three explicit predictions. The first of these is that amphibian biodiversity will be lower when the forest has been more recently logged because amphibians are very sensitive to habitat change, pollution, and degradation (Piñon-Flores et al., 2021). The second main prediction is that there will be a higher density of individuals found in the forest stand with no form of management. Forests with little to no management have been shown to contain more suitable habitat for many of these amphibian species. The third and final prediction is that amphibians encountered in recently logged forests will be smaller both in length (mm) and weight (g). In prior studies, body condition, body size, and mass have all been linked to habitat suitability in other organisms (Johnson, 2007). It has also been suggested in prior studies that the strength of the relationship between habitat suitability and individual organismal performance should be investigated (Unglaub et al., 2018).

Materials and Methods

I sampled amphibians on three different forest types: an old-growth, unmanaged forest (Bousson Environmental Research Reserve), a new-growth, passively managed forest (Blooming Valley Forrest), and a freshly logged, actively managed forest (Thompsons' Wood). The Foundation for Sustainable Forests manages two of these properties, while Allegheny owns the old-growth forest. Our old-growth forest, Bousson Environmental research reserve is a mixed deciduous-conifer forest that has been left to grow and progress as part of Allegheny College research efforts. The passively managed forest, Blooming Valley Forest, is a heavily deciduous forest that experienced little activity over the past decade, while Thompsons' Wood is still forested and has had activity as recently as 2024.

Sampling sites were made up of three to four 5 x 50 meter transects in each of the three aged forests (Bury, 1982). Sites were designated using flags with neon markers for ease of visibility. Sites were selected based upon their suitability to amphibian habitat needs. We looked for things such as fallen logs, leaf litter piles, residual moisture, and adequate shade. Data was collected during the fall months before the first of the winter freezes.

Amphibian sampling was conducted using one primary method. The survey method that was utilized is simple encounter surveys using visual methods following established methods (Kerr 2023). These involved surveying the transect and flipping over logs, rocks, and other cover objects. While surveying, the number and type of cover object were written down. As the surveys were being conducted, the soil moisture (%), air temperature (F), and canopy cover (lux) were taken at the approximate beginning, middle, and end of the transect as indicators of microclimate (see Appendix 1 for summary of this data). When an amphibian was found, it was

carefully recorded according to its species. This was done for each of the transects. Any amphibians that were collected or encountered also had both their mass (g) and their total length (mm) taken on-site.

Data Collection and Analysis

Statistical analyses were conducted to assess the three response variables as they pertain to my study predictions: 1.) species richness, 2.) species density, and 3.) body size/condition. Body size was quantified with three different metrics: total length, mass, and body condition. Body condition was calculated using the formula (mass (g)/ total length (mm)). Body condition is an important performance trait to consider as a part of this study due to the implications it has towards overall salamander performance. Higher body condition leads to more success in life history events such as competition for resources, migration, and sexual fitness (Farooq, 2023). Statistical analyses were done using analysis of variance (ANOVA) tests. All relationships between forest management activity and response variables were considered significant when $p < 0.05$.

Results

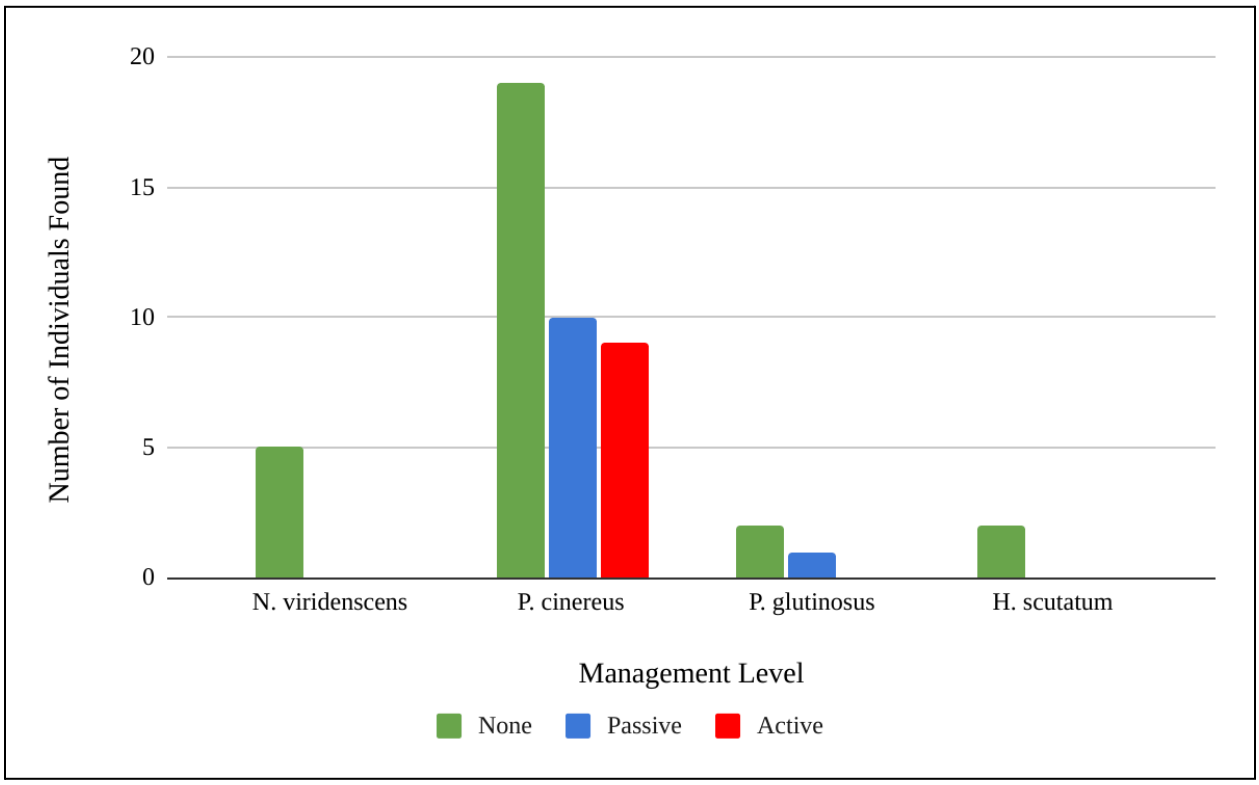


Figure 1: Total Number of Each Species Found in Each Management Level. This figure shows how many of each species were found at each respective management level.

We captured four different species across our surveys, which included Eastern redback salamanders (*Plethodon cinereus*), 4-toed salamanders (*Hemidactylium scutatum),* Eastern newts (*Notopthalmus viridescens*), and slimy salamanders (*Plethodon glutinosus*). As figure 1 displays, the property with no activity (Bousson) contained all four study species as well as the highest number of individuals for each species.

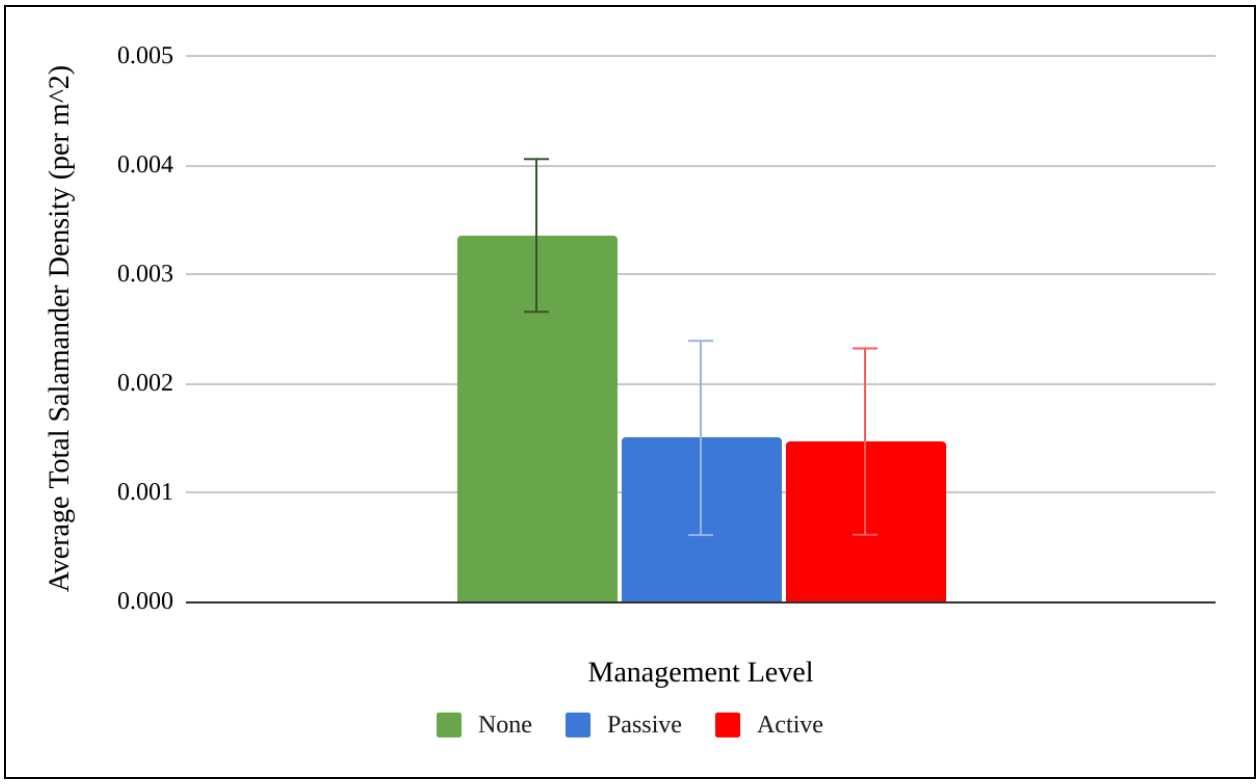


Figure 2: Average Total Salamander Density found at each Management Level. This test had an F-value of 1.481 and a p-value of 0.235, which does not support statistical significance.

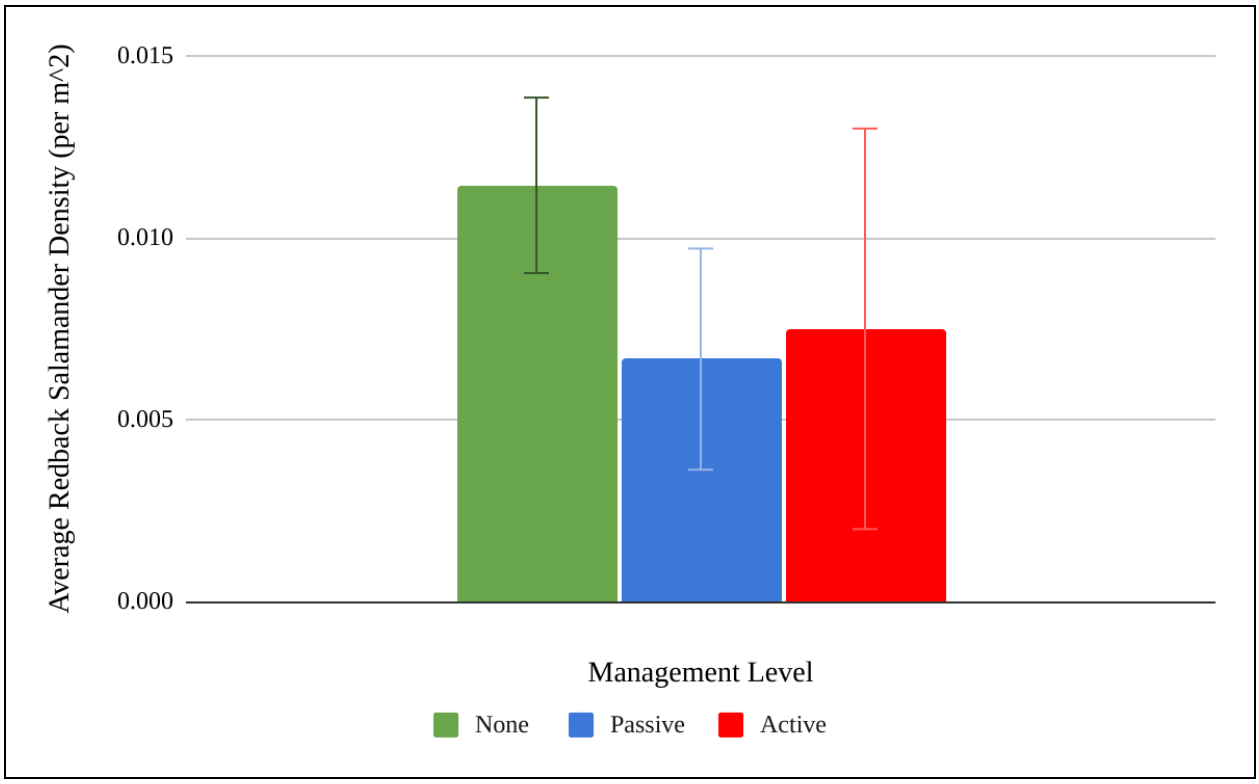


Figure 3: Redback Salamander Density as a Function of Management Level (n = 38 salamanders). This test had an F-value of 0.59 and a p-value of 0.57, indicating that there is no statistical significance

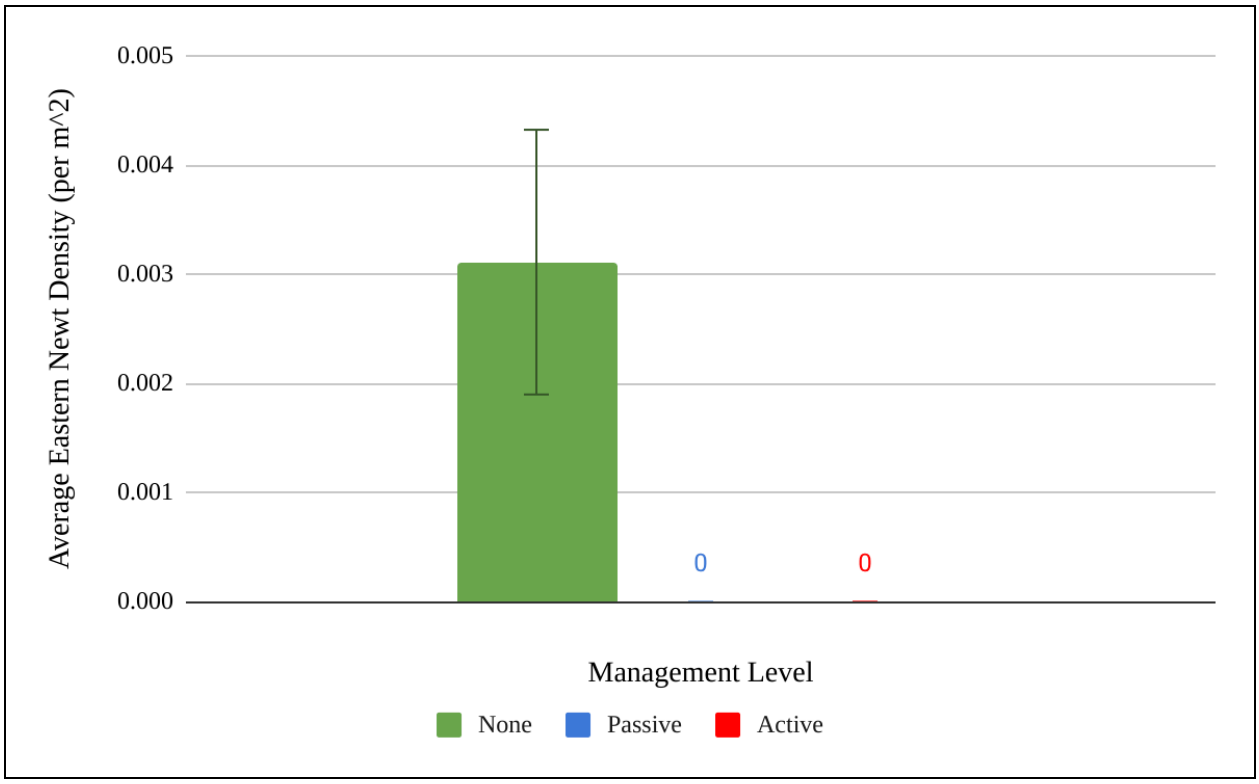


Figure 4: Eastern Newt Density as a Function of Management Level (n = 5 newts). This test had an F-value of 5.21 and a p-value of 0.0218, supporting the idea that these results are statistically significant.

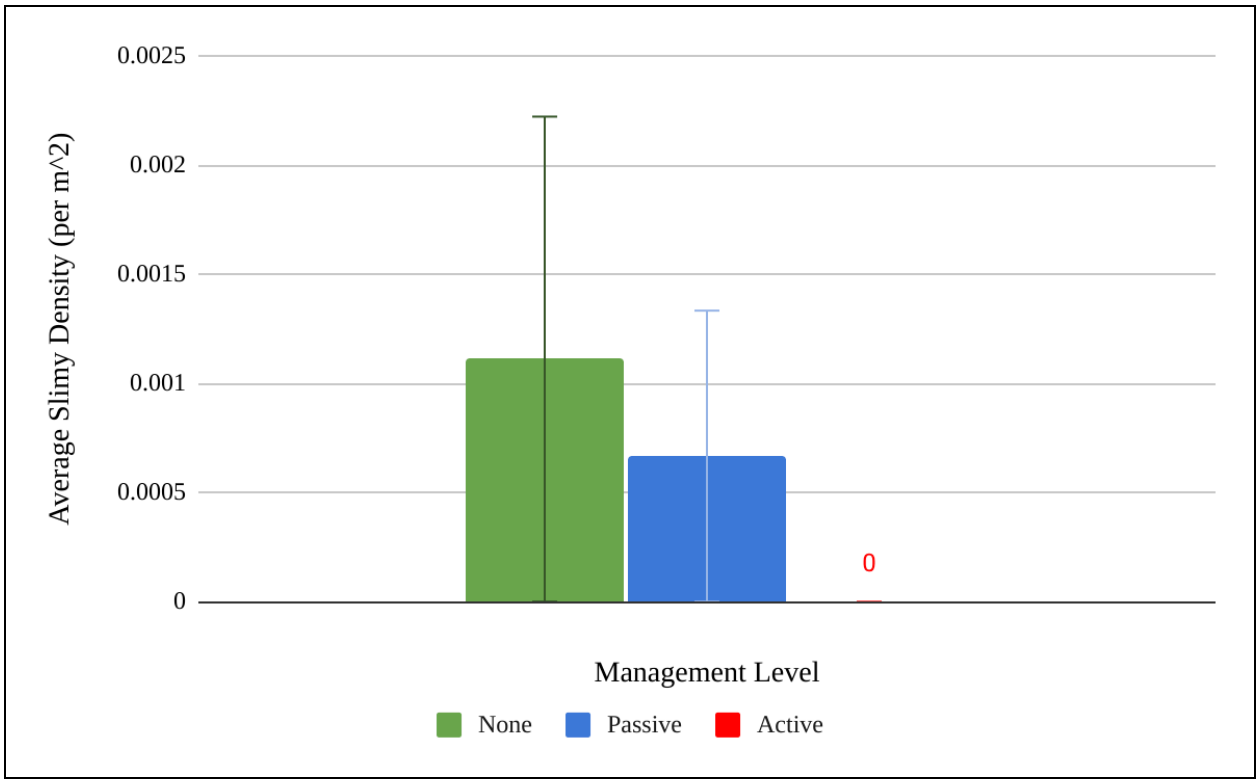


Figure 5: Slimy Salamander Density as a function of Management Level (n = 3 salamanders). This test had an F-value of 0.38 and a p-value of 0.69, which does not support statistical significance.

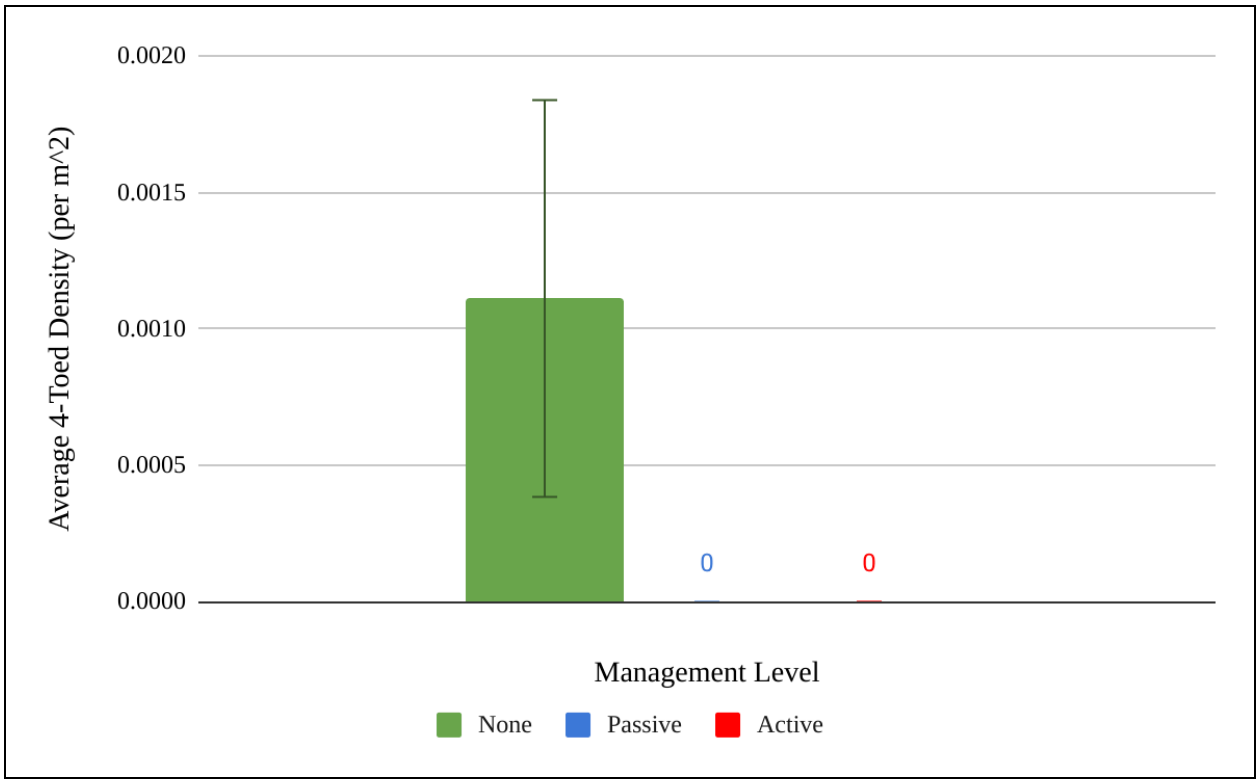


Figure 6: Average 4-Toed Density as a Function of Management Level (n = 2 salamanders). This test had an F-value of 2.04 and a p-value of 0.169, which does not support statistical significance.

The species-specific analyses show that overall, the lower the management level was, salamander densities were higher (figure 2, F = 1.481, p = 0.235). The densities were very similar between the passive (Blooming Valley Forest) and active (Thompson's Wood) management types (figure 2). Redback salamanders showed higher densities at the site with no management (Bousson) than at the other two sites (figure 3). Notably, redbacks were the only species to be found at all three locations. Eastern newts and 4-toed salamanders were only found at the property with no activity (figure 4, figure 6). Slimy salamanders were found in their highest densities at Bousson (figure 5). Redback salamanders accounted for roughly 79% of the data (n=38; 38 out of 48 total salamanders).

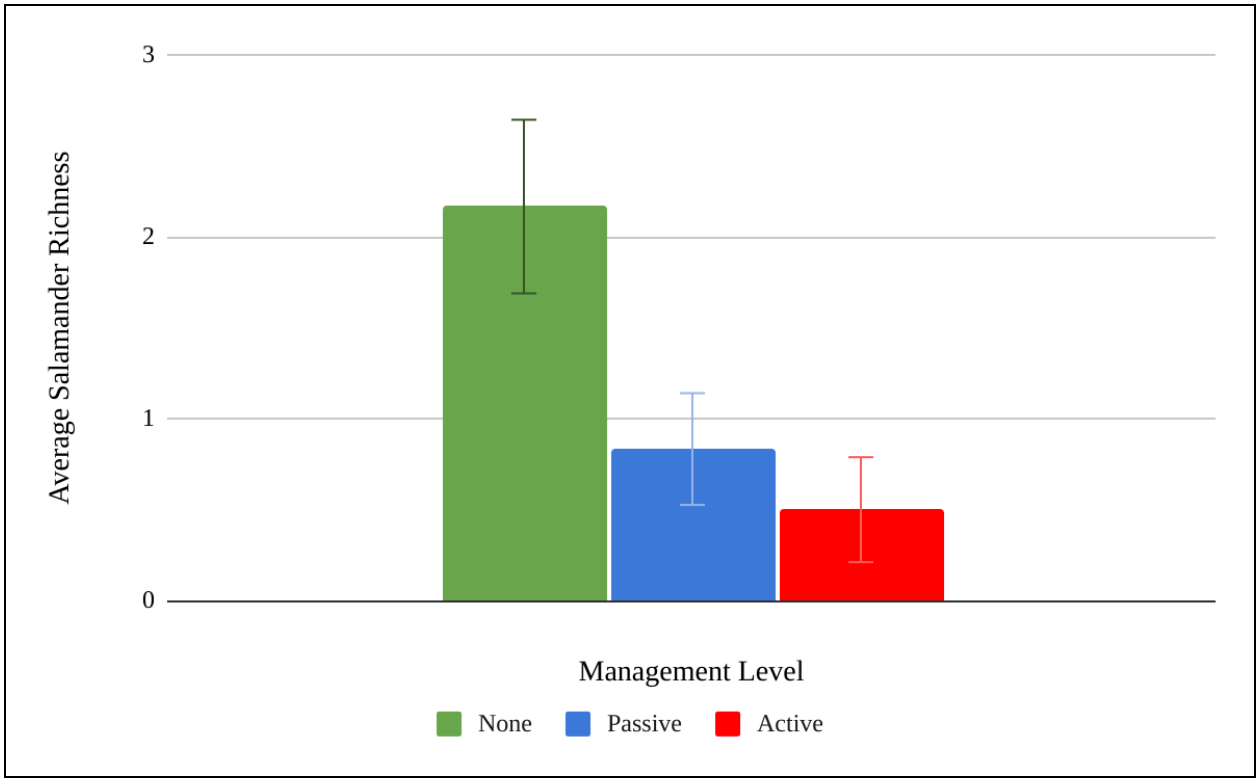


Figure 7: Richness as a Function of Management Level. This test had an F-value of 5.07852 and a P-value of 0.02345, which shows that this result is statistically significant.

Similar to the densities of salamanders, species richness was 3-4 times higher for control levels (mean = 2.16) compared to both management categories (passive mean = 0.83, active mean = 0.5; Figure 7). While the overall effect of forest type was significant ($F = 5.08$, $p = 0.023$), the error bars between passive and active are overlapping, suggesting that the relationship between these two management types is not significant.

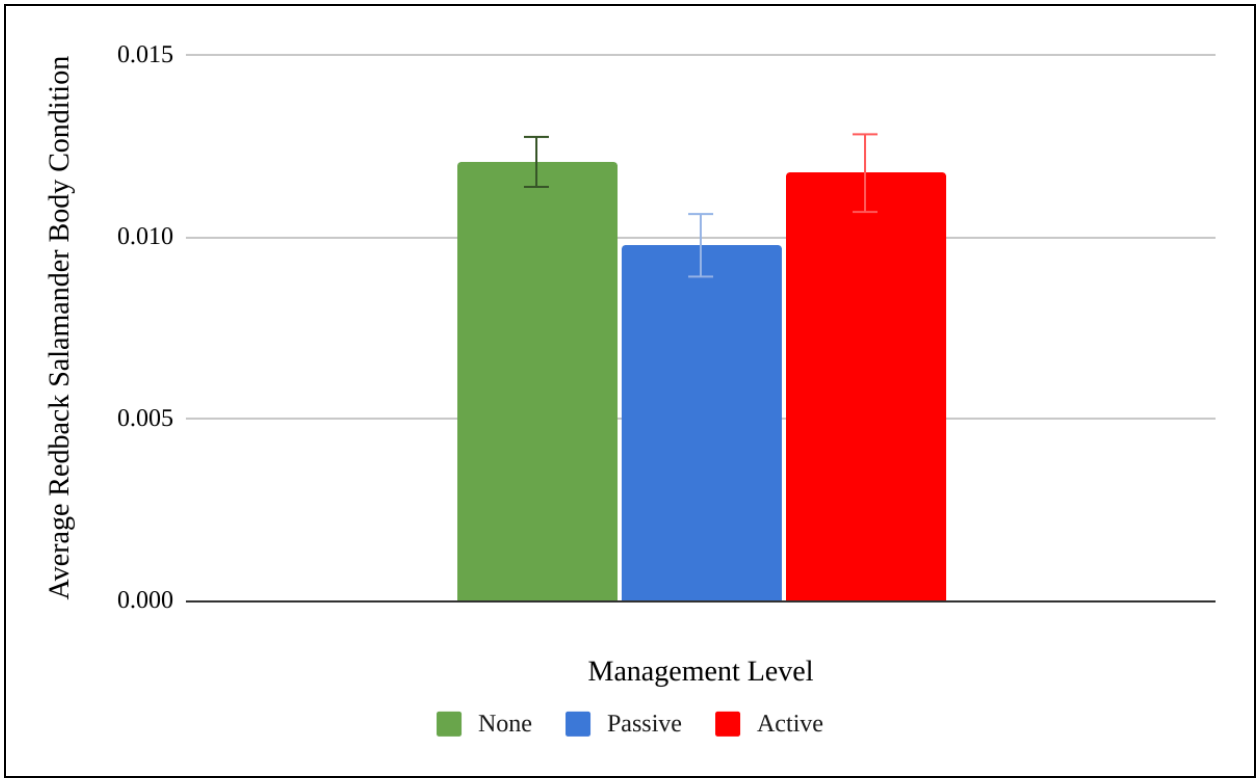


Figure 8: Relationship between Management Level and Redback Salamander Body Condition. This test had an F-value of 1.53 and a p-value of 0.23 which does not support statistical significance.

We assessed the relationship between the management level of each of the three forests and the average body condition of redback salamanders found in those stands. Redback salamanders were used for this test as they provided the largest amount of data. As figure 8 clearly shows, there appears to be no difference in the average body condition between the three sites. The relationship was not statistically significant ($F = 1.53$, $p = 0.23$). This is supported by the fact that the error bars for all locations are overlapping.

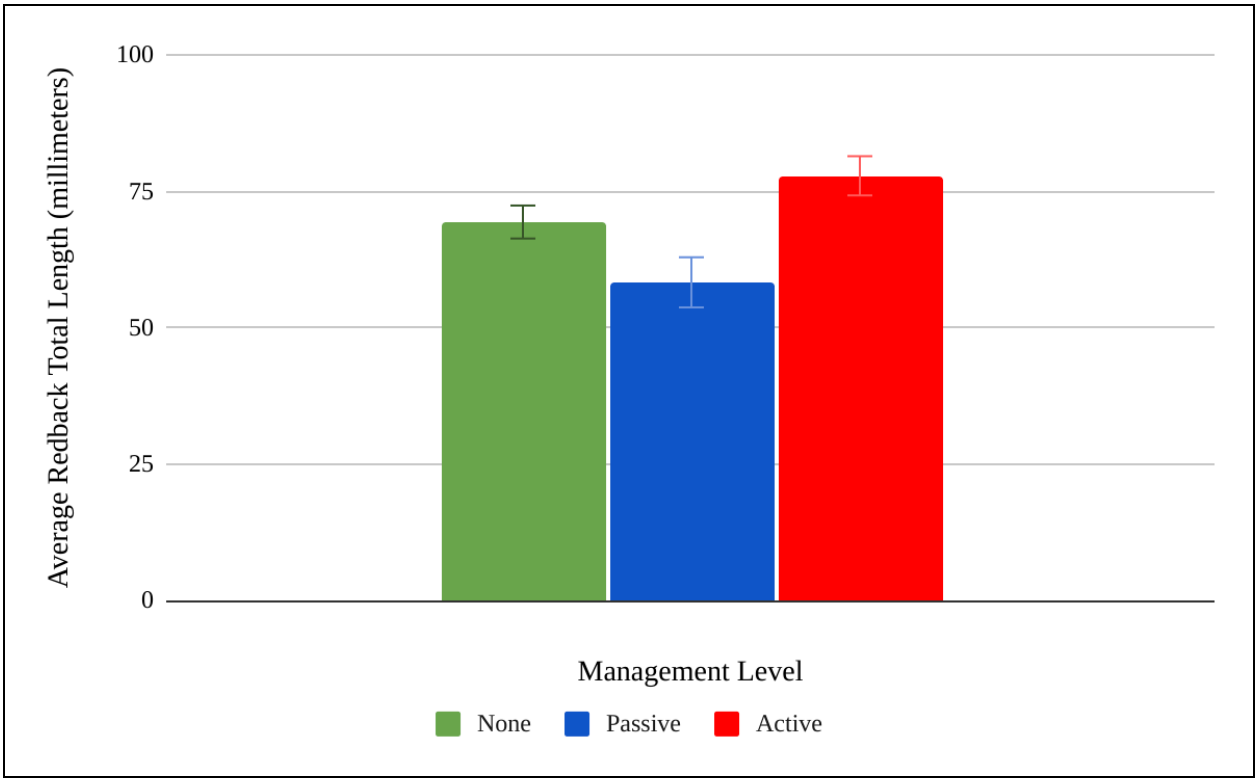


Figure 9: Average Redback Salamander Total Length (mm) as a Function of Management Level.

Similar to the body condition data, we only evaluated the relationship between redback salamander total length (mm) and the management level of the three different forests due to the plethora of data that redback salamanders provided. Average total length was notably higher at the actively managed site (Thompson's Wood) than the other two sites (Figure 9). There was roughly an 11mm difference between the averages of Blooming Valley (58.33) and Bousson (69.34), and roughly a 12 mm difference between Bousson and Thompson's Wood (77.85). The ANOVA yielded statistical significance ($F = 4.35$, $p = 0.023$), which is supported by the small error bars and the fact that none of them are overlapping.

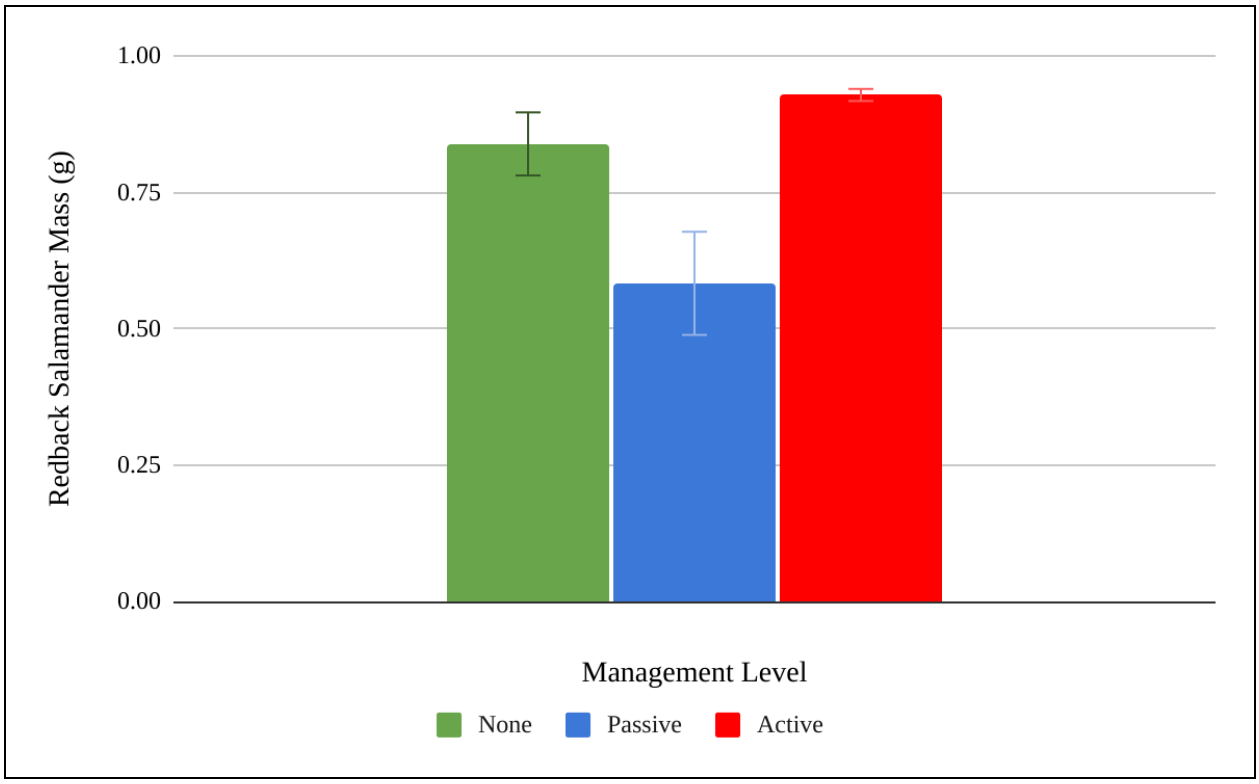


Figure 10: Average Redback Salamander Mass (g) as a Function of Management Level. This figure displays the relationship between management level and the mass (g) of redback salamanders

Redback salamanders were once again used in this test due to their aforementioned large sample size. We saw that overall average redback mass was highest in the active stand and stand with no activity and was lowest in the passive stand ($F = 3.27$, $p = 0.053$), however, this was only a marginally significant effect

Discussion

Looking at the results, there are a number of important things to note. The first of these is that my first initial prediction that the biodiversity of amphibians found would be higher in an old growth stand, was supported by our findings. I found that the property with no form of management (Bousson) had members of all four species while also containing the most

individuals from each species and that richness was 3 to 4 times higher than the other two sites (see Figure 1, Figure 7). It was also the only stand in which four-toed salamanders (*H. scutatum)* and eastern newts (*N. viridenscens)* were found. This was followed by Blooming Valley (passive management) and finally by Thompson's Wood (active management). This result aligns with prior findings from similar studies that also documented reduced amphibian biodiversity as a result of reduced canopy cover caused by clearcutting and the removal of coarse woody debris (CWD; Patrick et al., 2006; Bury 1983).

My results also partially support my second prediction, which was that salamander densities would be higher in the older growth stands. While we did see a greater overall density for all species of salamander in the old growth stand (figure 2), there was also higher density of redback salamanders at the actively managed stand than at the passive stand (Figure 3). For this particular species, our prediction was thus not supported. It is important to note that this test and several of the other density tests for the other species did not support statistical significance, having p-values that were greater than 0.05 ($p > 0.05$). This could have been attributed to a small sample size among a majority of the study species. Slimy salamanders (n=3), 4-toed salamanders (n=2), and eastern newts (n=5) all had 5 or fewer individuals recorded between all 3 sites. Despite a lack of statistical significance for several of the tests, these trends still show salamanders and newts as sensitive to changes in natural forests. As I previously mentioned, Eastern newts were found only at Bousson (no management), and presented a statistically significant result.

My third and final prediction stated that the mass and length of salamanders found in managed stands would be smaller than those found in an unmanaged forest. This prediction was not supported by the data. We saw that total length (mm) was highest at Thompson's Wood

(active), followed by Bousson (none), and finally Blooming Valley (passive). A similar result was seen when conducting the average mass statistic, although the relationship between mass and management level proved to be statistically insignificant. This result showed almost no difference between Bousson and Thompson's Wood, which again, did not support our prediction.

A potential explanation behind the lack of support for our predictions may lie in the tolerant nature and dispersal abilities of the redback salamander. Redback salamanders are a remarkably resilient and adaptable species (Gade et al., 2023). Prior research has shown that redbacks in successional forests showed higher growth rates, which subsequently lead to faster maturation and longer lifetime fecundity (Gade et al., 2023). This may help explain the larger total length and greater mass seen at the actively managed site. The redbacks found at Thompson's Wood (active) were potentially older or more mature than those found at the less managed sites, which would account for the greater length and mass.

It is also important to consider the time of year in which the salamanders were surveyed. Surveys were conducted from mid-to-late October until late November. Many species of salamander spend a large proportion of time in underground burrows (Jaeger, 1980). By this time, salamanders may have already moved into their burrows for the winter, thus avoiding any sampling that took place. This could have affected the densities and sample sizes of the study at the Thompsons Woods location because of this site being sampled the latest.

Another factor may have been the reliance of terrestrial salamanders on a microclimate. Large-scale forest management may actually play a more minimal role in the survival of these species compared to the role of a microclimate created by remaining cover objects or coarse woody debris. A study done by Patrick et al (2006), found that the retention of CWD may serve to mitigate the effects of a total clearcut for ambystomatid salamanders. A more recent study

conducted in 2019 by Mossman et al. (2019) studying redback salamanders and eastern newts, found that both species' abundances were heavily tied to the abundance of downed and decayed coarse woody debris. These findings suggest that microclimate and the presence of CWD is a more important factor to consider when identifying the presence and health of salamander populations than the management level of the forest itself.

Amphibians have been an under-researched group of species when it comes to studies regarding forest management strategies. This does not, however, mean that they are not important tools for understanding the effects of only forest management, but a multitude of ecological functions have on resident amphibian populations (Bury, 1993). Amphibians are highly sensitive to their environments, which allows us to use them as bioindicators of how healthy an ecosystem is. A prior study found that in the area of Eastern North America, terrestrial salamanders such as redback salamanders, likely account for more biomass than other primary and secondary consumers in many of the local forests (Grant et al., 2024). This lends merit to the idea that future research efforts should be focused not only on amphibians, but to their effects on overarching ecosystem processes. The practices being used to manage forests in Northwest Pennsylvania have proven to provide habitat for terrestrial salamanders along with other fauna. However, there are many ways to not only maintain, but also improve amphibian restoration practices. Retaining CWD and minimizing the loss of canopy cover, are all ways to adapt and keep redefining best practices for forest management.

My research indicates that next directions for future research could be repeating this type of study with a focus on different species. My study focused on terrestrial salamanders, but could be branched out to focus on stream-side salamanders, as well as different amphibian groups such as frogs and toads. Further investigation could be done on the different life stages and their

susceptibility to the effects of forest management. Many amphibians undergo a biphasic life cycle, beginning life as eggs and larvae that are confined to aquatic environments until they metamorphose into terrestrial juveniles and adults (Nolan et al., 2023). These drastic changes in habitat over the course of their life cycles means that they face different challenges as they progress. Another area of study could potentially be the differences between Spring and Autumn in regards to terrestrial salamander population health. Given that many salamanders undergo different behaviors during the Spring breeding migrations, Autumn would likely be a more accurate reflection of the condition of the health of the individuals and overall population.

Finally, an important future direction for research would be to investigate the differences in complexity between different species of salamander and their life cycles and life histories. As I mentioned before, there are many amphibians that are biphasic, meaning they undergo two distinct phases in their life cycles. This however, does not apply to all species. Redback salamanders are uniphasic, meaning that they do not undergo an aquatic larval stage (Fischer-Reid et al, 2024). In contrast, one could argue that the Eastern Newt is triphasic given that it begins life in an aquatic larval stage, metamorphoses into its terrestrial eft stage, until finally maturing in its aquatic adult stage. These complexities between species open the door to the potential susceptibility to a plethora of different environmental factors that could negatively affect their individual health, as well as the health of their populations.

Amphibians are declining at an alarming rate, as of 2023 40.7% of global species are threatened (Luedtke et al., 2023). It is vital to the continued survival of all amphibian species that these complexities be taken into further consideration when conducting further research and future forest management. However, the practices being implemented by the Foundation for Sustainable Forestry, coupled with the data from this study and others like it, provide hope for

the future of amphibian populations. Spreading awareness and spreading the influence of these practices can be a major step in the right direction for not only preserving the biodiversity of amphibians in Northwest Pennsylvania, but also around the world as well.

Appendix 1: Average microhabitat and microclimate conditions for each of the transect surveys performed at each of three different study properties.

	Average Soil Moisture (%)	Average Canopy Cover (lux)	Average No. Cover Objects Flipped	Average Air Temperature (°F)
None (Bousson)	38.50	4,469.66	26.33	59.66
Passive (Blooming Valley)	39.83	3,933.27	23.50	56.00
Active (Thompson's Wood)	53.83	1,002.33	16.25	56.50

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