Spring 5-21-2022

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Recommended Citation

Barthelmess, Grace Hope, "SURVIVORSHIP OF COLUMBIAN BLACK-TAILED DEER IN A PREDATOR-FREE ENVIRONMENT" (2022). *Honors Projects*. 163.
https://digitalcommons.spu.edu/honorsprojects/163

SURVIVORSHIP OF COLUMBIAN BLACK-TAILED DEER IN A PREDATOR-FREE ENVIRONMENT

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A project submitted in partial fulfillment of the requirements for the Bachelor of Arts degree in Honors Liberal Arts

Presented at the SPU Honors Research Symposium
Date: May 21, 2022

ABSTRACT

Future management of Columbian black tailed deer (*Odocoileus hemionus columbianus*) populations requires an understanding of survivorship and potential drivers of mortality. Little is currently known about the survivorship of *O. h. columbianus,* specifically in a predator-free environment. Analyzing the survivorship of deer in these contexts may be crucial for wildlife conservation efforts throughout the United States, as it could provide insight into how deer populations may be impacted by lack of population control by predation. Here, I present age analysis of *O. h. columbianus* based on the cementum annuli of the lower first molar in 489 males and females from Blakely Island, WA. Juvenile survivorship was found to be lower than that of the adult population. Sex-specific annual survival differed between males and females but overall average annual survivorship did not differ. The survivorship of *O. h. columbianus* on Blakely island was determined to be a Type 1 curve. As there are no predators present on the island, our results give further evidence that other factors besides predation, such as food availability, may be impacting *O. h. columbianus* survivorship.

INTRODUCTION

Predators can impact prey via predation, which can create trophic cascades that help mediate the size and survivorship of prey populations. Given that there has been widespread population decline of apex predators, especially by anthropogenic influences, predicting and understanding the associated ecological consequences of predator absence is a priority. Predator loss or absence can especially impact herbivore population dynamics, and in turn, impact plant life abundance and health. In recent research, the absence of top predators in a Brazilian Atlantic Forest landscape led to capuchin monkey population overabundance in a habitat fragment (Portela & Dirzo 2020). This population outbreak in turn led to notable decline of a dominant and keystone plant species, palmito. The decline in palmito abundance has both ecological and economical consequences, and therefore has importance in both conservation and natural resource management. Without predators, capuchin monkeys were no longer mediated by top down control, and resulted in notable drops in plant abundance.

Unfortunately, in the United States, human influences have led to similar problems with loss of top down control (carnivores) on herbivore abundance. Trophic cascades that have kept ecosystems more or less in balance historically are being tampered with, both indirectly and directly, and could potentially lead to entire ecosystem collapse if not managed properly

(Beschta & Ripple 2009). In the U.S., concentrated efforts to reduce predator populations led to extensive trapping, poisoning, and hunting between the 1800s and the early 1900s by federal agencies and Euro-American communities, which greatly reduced gray wolf *Canis lupus* and cougar *Puma concolo*r ranges (Laliberte and Ripple, 2004), two key predators of common herbivores, the ungulates. The impacts of predator loss on ungulates has been evaluated in the U.S. National Parks, with many showing significantly high rates of browsing intensity in forests by ungulates, leading to unprecedented decreases in native plant species (Beschta & Ripple 2009). Foraging by native ungulates in the absence of large predators can alter the function, composition, and structure of native plant communities, and therefore the overall health and resource output that forests can provide.

Cervids are a particular type of ungulate, and are prominent herbivores throughout U.S. forests, including in Washington State. Predation has historically been among one of the greatest causes of death for cervids on the mainland (Ballard et al. 2001). For example, in five deer populations studied in the 1990s in a western region of the United States, the greatest causes of mortality for mule deer were predation and human-induced death (Bleich & Taylor 1998). In a population of white-tailed deer in eastern Canada, coyote predation was the greatest cause of mortality for fawns throughout their first year of life (Ballard et al. 1999). In these studies, all deer populations were top down regulated. Although predation still drives much of the mortality of cervids throughout Washington, there is evidence that predator populations are decreasing on the mainland (WDFW 2016). This decrease in predator population may lead to effects similar as those seen in other parts of the U.S., such as native plant species decline. It's vital that current forest management considers cervid population life history for future projections of how predator declines may indirectly lead to increased grazing intensity, which may threaten the health of Washington State lands.

Survivorship is one tool to analyze cervid population life histories in different ecological contexts. Survivorship can be distinguished into three curve categories: Type 1, Type 2, and Type 3. In a Type 1 curve, population mortality occurs mostly in old age, and usually is indicative of a population with low number of offspring and high parental care. Type 2 curves represent populations with steady mortality in each age interval. On the other hand, Type 3 curves show populations that have high mortality in the juvenile stage, and are usually indicative of populations with high offspring numbers and low parental care- very few individuals make it to old age (Pinder et al. 1978).

In areas where predation dictates the life histories of cervids, survivorship has been reported to resemble a Type 1, with significantly different survival rates between males and females (Forrester & Wittmer 2012). With this in mind, less deer make it to old age, which may mean decreases in reproduction of adults, and therefore, lower grazing intensity by cervids on native plant species. Unfortunately, although survivorship of cervids has been analyzed in areas with high human activity and with predation, little is known about the survivorship of cervids in a predator free environment.

In this study, we analyzed the cementum annuli of the third molar in Columbian black-tailed deer (*Odocoileus hemionus columbianus*), a subspecies of cervids present on Blakely Island, Washington (Stoneberg & Jonkel 1966; Prilepskaya et al. 2020; Azorit et al. 2002). Blakely Island is a predator-free island and has highly managed human activity, leaving the majority of the habitat undisturbed for the deer population. We predicted that the deer population on Blakely Island would have a Type 1 survivorship curve due to the lack of predation and human activity (hunting, car accidents, etc.) on the island, with males having a lower survival rate due to intraspecific competition, venturesome behavior, and larger body size as compared to females. We also expected that the deer survivorship would be higher on Blakely Island as compared to survivorships on the mainland, due to the lack of predation and human impact.

METHODS

Study Site:

Male and female Columbian black-tailed deer from Blakely Island (48.55°N, 122.81°W) were analyzed. Located in the San Juan Archipelago of Washington state, Blakely Island is a midsized (16.8-km^2) island 8 km from the mainland, with an elevation ranging from 0 to 318 meters and a mild, temperate climate with little snowfall. The current forest consists of second growth Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). On the island is a high density of black-tailed deer population with limited hunting and lacking predators. Climate on the island is temperate and seasonal with cool, wet winters (mean winter minimum=0.04 C) and warm, dry summers (mean summer maximum=26.6 C). Historically, winter snow cover is rare but has been increasing in recent years.

Lab Methods:

Tooth extraction, preparation, and analysis were done as outlined in work by Wall-Scheffler (Wall-Scheffler 2007). The first molar, M1, of black-tailed deer was examined due to its presence since birth to accurately determine age at death. A Dremel Multi-Pro 395 high-speed rotary saw (Dremel, Racine, WI, USA) with a circular blade was used to extract the teeth from the jaw. Two sagittal cuts in the mandible surrounding the tooth were made along with a transverse cut along the bottom of the jaw between the sagittal cuts.

The teeth were vacuum-impregnated in Epo-Thin epoxy (Buehler, Lake Bluff, IL, USA). A thin layer of silicone release spray was used when the molds were applied to ensure easy removal of the hardened resin. The hardener (20g) and resin (50g) were mixed slowly to ensure no air bubbles were created. The mixture was allowed to sit (5 min). During this time, the teeth were placed into the molds. Once 5 to 6 molds were prepared, they were placed into the vacuum chamber with the pressure set to 25 pascals while the resin was poured into the molds. After 3 minutes, the pressure was released and remained so for an additional 3 minutes. The pressure was then returned to 25 pascals for a final time of 3 minutes whereupon the pressure was released and the samples remained to harden overnight.

Once hardened, the disks of resin with the embedded teeth were removed from the molds and engraved with an identification number using a diamond pen. The disks were then cut longitudinally through the center using an Isomet 1000 saw (Buehler, Lake Bluff, IL, USA) using a 17.78cm diameter diamond-tipped blade with the speed set to 200-300 RPMs and the weight of the arm set to 250-300g.

Slices of the teeth were then ground using a Buehler variable speed grinder-polisher (Buehler, Lake Bluff, IL, USA). Initially, the teeth were ground with the 800 and 1200 grit paper with duration varying depending on the sample. The teeth were then ground using 2400 grit paper until smooth. Following, the teeth were polished using a white felt polishing cloth and alumina oxide diluted with distilled water.

Polished teeth were adhered to a frosted microscope slide washed with acetone using epoxy (20g hardener, 50g resin). After applying resin to the microscope, the teeth were placed on the slide and held firmly to prevent the formation of bubbles. They were then left overnight to dry at which point they were ground to a thickness of 50-90 µm and polished using the same methods as above. Cementum annuli were counted using a Leica DM EP polarizing microscope (Meyer instrument, Houston, Texas, USA) equipped with a 180mm rotating state and rotating swing in/out polarizer and centerable condenser.

Statistical Analysis:

Cementum rings were counted to estimate the age of death. By assuming a 1:1 sex ratio of survivorship for juveniles, a static life table, and survivorship curve were constructed by plotting the age of death against the number of individuals (Gaillard et. al. 1997). To determine the juvenile survivorship, the proportion of naturally killed juvenile skulls over the total number of naturally killed skulls in the database was calculated. Sex-specific survivorship was calculated using a Kaplan-Meier LogRank test as detailed in a publication by Pollock (Pollock et al. 2010). A comparison of overall survivorship between males and females was done using a two-tailed t-test.

RESULTS

A total of 658 skulls were collected, of which, 489 were not killed by hunters and had enough material to determine the age range. Of the 489 skulls, 297 adult skulls had enough material to determine sex, and 192 were determined to be juveniles (with juvenile mortality being 39%). The female to male sex ratio was close to a 2:1 ratio. Out of the total 297 sexed adult skulls, 68 females, and 51 males were aged. Based on a Kaplan Meier LogRank test, the median age of survival for females was 5 years (95% CI: 4 - 6) and for males was 4 years (95% CI: 3 - 7) for males, with maximum ages of 15 years and 10 years, respectively (Figure 1). There was no significant difference in survival between males and females (p-value 0.33), although there was evidence that females might live longer. Combined annual survivorships for adult males and females resulted in a median age of 5 (95 % CI: 6).

Because no significant differences were found between the sexes for mortality and survivorship, females and males were combined into a single life table, with a total of N=132. Survivorship for adult male and females was determined to be a Type 1 curve (Figure 2), using piecewise regression.

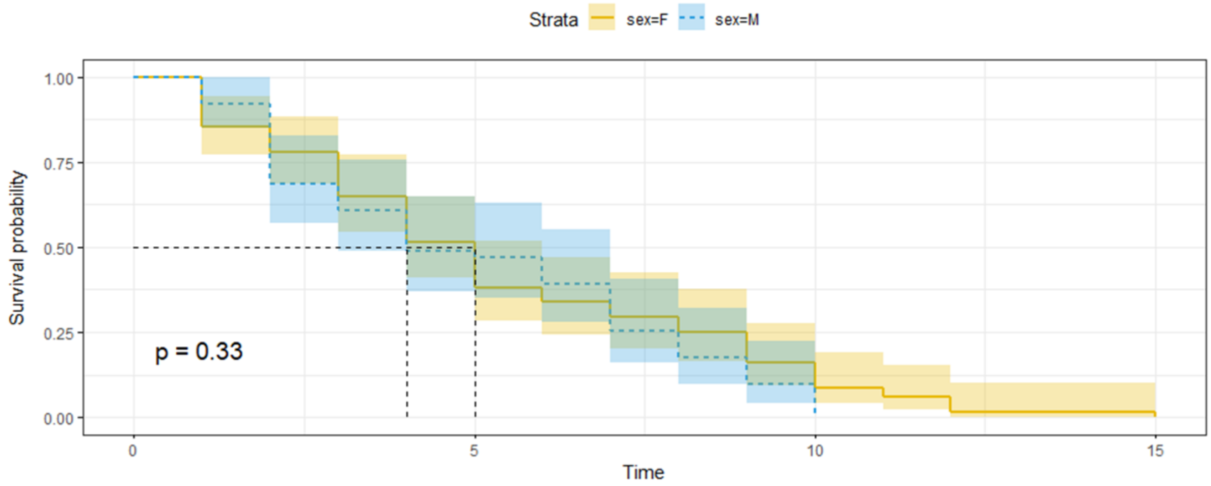

Figure 1: Sex-specific annual survivorship (±95% CI) of adult (≥1 year) male (M) and female (F) Columbian black-tailed deer on Blakely Island, WA.

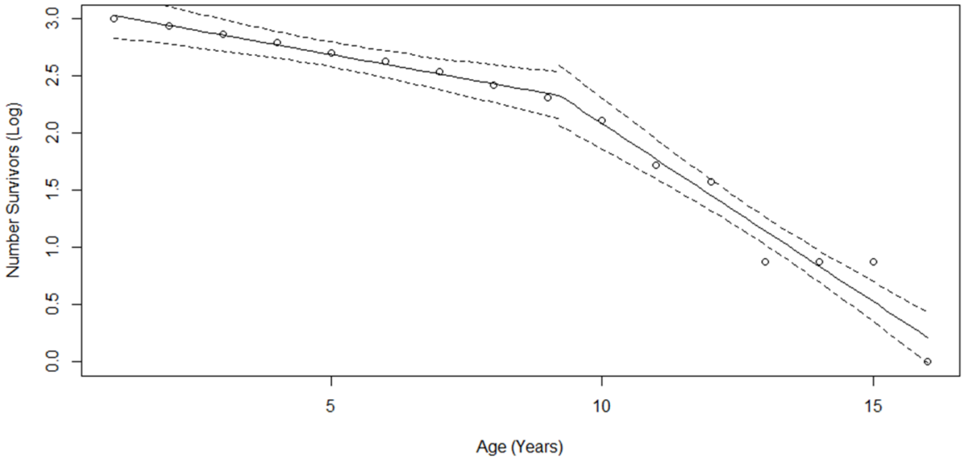

Figure 1: Adult survivorship modeled with a significant break in slope at the age of 9 years old. When modeled this way we have an Rsq of 0.98. Annual survival from ages 1 to 9 is 82% (75%-91%), from ages 9-15 annual survival drops to just 48% (42%-56%).

DISCUSSION

Juveniles experiencing lower survivorship than adults were consistent with results from previous cervid studies. Juvenile survivorship of the deer on Blakely Island was greater than that of mainland populations in Washington (Forrester & Wittmer 2012), and the same was true when comparing average adult survivorship on Blakely to the mainland (Farmer et al. 2006, McCoy et al. 2014). Within the mainland population, predation was the leading cause of mortality of juveniles (74%) with a small proportion caused by other natural causes (19.4%) and a nearly inconsequential proportion being anthropogenic (2.3%; McCoy et al. 2014). While we are not able to definitively determine cause-specific mortality of the Blakely Island black-tailed deer population further than natural causes, we are able to speculate that a lack of such causes an increase in juvenile survivorship.

Additionally, Blakely Island has a relatively low impact from human interactions. In an urban environment in Washington state, trauma from car accidents was the greatest cause of death for black-tailed deer (Bender et al. 2004). In rural areas also on the mainland, hunting and predation contributed the most to the mortality rate of juvenile and male deer (Bleich & Taylor 1998). While there is a small amount of hunting occurring annually on the island, we can see that the reduced human impact increases the survivorship of juveniles and adults.

Interestingly, average annual survivorship and survival did not differ significantly between males and females. In a study looking at populations of deer across the U.S., sexes do usually differ significantly in survival. For example, in southwest WA, annual survival of adult females averaged at 0.82, and annual survival of males averaged at 0.50 (McCorquodale 1999). The survivorship of the Blakely Island male and female deer was shown to be very close to a type 1 survivorship curve (Figure 2).

As there are no predators inhabiting Blakely Island and human activity is limited, the survivorship of deer on Blakely Island is likely dictated by other factors. Juvenile and young adult deer are extremely sensitive to low resource availability and habitat quality as they need nutritive resources to support their growth and development (Parker et al. 2009). Surviving the increased pressure from climate during the winter increases the energetic cost of living and further limits resource availability; therefore, that especially increases the nutritional stress on juvenile populations and is a probable cause in controlling their survival (Long et al. 2013). Blakely Island is occasionally subject to snowfall in the winter months. Additionally, the Blakely Island deer population is high-density, so resource availability per individual is relatively low year-round (Long et al. 2013). The survival rates of both juveniles and adults could be due to malnutrition caused by limited food resources on Blakely Island.

In another population of Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) in Heceta Island, Alaska, annual survivorship of juveniles was found to be 7.4% lower than the Blakely Island population (Farmer et al. 2006). Interestingly, predation was found to be the second-highest cause of mortality of juveniles on Heceta Island with malnutrition being the leading cause. Because the survivorship of juveniles on both islands are very similar and Blakely Island lacks predators, we can assume malnutrition has a greater impact on Blakely Island and more than compensates for the lack of predation.

For a population of black tailed deer in Southeast Alaska, predation by wolves accounted for the most death of adult females, and hunting was the greatest cause of death for adult males (Farmer et al. 2006), resulting in an annual survivorship of 0.69. Although malnutrition was one of the greatest causes of death for juveniles, such as what we speculate with the juvenile deer on Blakely Island, predation and hunting still led to a lower overall annual survivorship for the adults. On Blakely, no predation occurred, and hunting is highly limited, so adult survivorship is not impacted by either of those factors, resulting in a higher survivorship than what was seen in Alaska. For a population of black tailed deer on the mainland of Washington state, in Klickitat county, annual survival of adult females averaged at 0.82, and annual survival of males averaged at 0.50 (McCorquodale 1999). Annual survival rates of males was most impacted by hunting for this population, while females were most impacted by malnutrition during winter periods. Annual survival for the males on Blakley was higher compared to this mainland population, again due to the absence of hunting, but female annual survival looked similar between these populations. This leads us to further speculate that malnutrition may be one of the greatest sources of adult mortality for the deer on Blakley.

In the future, more research needs to be done on juvenile male and female survivorship. Unfortunately, with the methods presented here, juveniles are not able to be definitely labeled as male or female. Also, the Blakely Island population has other interesting demographics that may also be worth looking into, such as the skewed sex ratio. Overall, this research may help form educated predictions for mainland management decisions of deer, by providing a natural experiment of how predator absence can shape a population.

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RESEARCH AS SERVICE: CULTIVATING CARE OF NEIGHBOR AND CREATION

Historically, scientific research has focused on exclusive ecosystems and has been conducted by an exclusive set of individuals. However, being human involves embracing an inclusivity to care for all peoples, animals, and plants. How might contemporary inquiry be reconstructed to serve all communities involved in knowledge acquisition? This panel will explore a variety of ways in which scientific research can inform how to meaningfully care for creation, both human and nonhuman.

APPENDIX

Hello everyone, my name is Grace Barthelmess, and I am a senior ecology, honors, and ecotheology student here at SPU. I can't wait to talk to you about my research. But before I do, I want to give some background information on how I ended up where I am today.

Long before I knew what ecology was, as a young girl, I was deeply interested in the interactions and relationships between organisms and their environment. My idea of a hobby was sitting for hours in the farm field behind my house hoping to catch a glimpse of my wild neighbors- the geese, the coyotes, and the deer. I loved imagining what they were trying to communicate, and would often wonder how they came to be in the first place. At the time though, ecological and evolutionary knowledge was not accessible to me, even throughout high school. I grew up in a small town here in Washington, with deeply conservative Christian roots where matters of evolution, climate change, and conservation were not positively discussed.

As I would bring up my questions to family, friends, and church members about my observations and growing interest in biology, I was often met with concern and criticism. I was told that science and God could not work together, science was the path to hell, and I was getting much too close to that path. Those hurtful conversations, among many others, threatened to weaken the voice of my childhood curiosity. How could people I trusted tell me that the very thing that made me feel most connected to God, was actually pushing me further away? But thanks to the love of the Creator and my high school science teachers, I did not lose hope. I sat with my Bible in one hand and my biology text book in the other, and decided that I would settle for both. I was Eve, curiosity the snake, science the forbidden fruit.

Now, years later, I get to proudly declare that I am an ecologist, although it was far from easy to get here. By studying ecology at Seattle Pacific University, I had the honor and privilege of visiting our field station on Blakely Island, up north in the San Juans. Blakely Island is nothing short of a magical place. It's an island with a rich ecological and evolutionary history.

Although it is only a few miles away from the mainland, that distance still is enough to make it considered an isolated natural community. And as an ecology student, it has also created a space for me to study conservation issues in tangible ways, specifically with insular biogeography in mind. Insular biogeography or island biogeography is a field that examines the factors that affect the species richness and diversification of isolated natural communities. These island communities, including Blakely, in many ways present a sort of natural lab experiment. On them, ecologists can look at how populations are impacted by different factors that might not be the same on the mainland. Of particular interest to me on Blakely were the Columbian black tailed deer.

Columbian black tailed deer are the largest animals on Blakely (besides humans), although they are actually quite small compared to other deer in the world. They display island dwarfism- meaning that over time, their body sizes and brain sizes have significantly decreased, for a number of reasons we are still discovering. There are no predators to deer on the island, and even human activity, such as hunting, is quite limited. On the mainland, the main cause of death of black tailed deer is predation (although in urban areas, death due to human activity such as car collisions is also common), so information looking at deer populations at carrying capacity, or without top down control, is actually quite limited. Why does this matter?

As some background, predators can impact prey via predation, which can create trophic cascades that help mediate the size and survivorship of prey populations. Given that there has been widespread population decline of apex predators in the U.S., especially by anthropogenic influences, predicting and understanding the associated ecological consequences of predator absence I believe is a priority. Predator loss or absence can especially impact herbivore population dynamics, and in turn, impact plant life abundance and health. In recent research, the absence of top predators in a Brazilian Atlantic Forest landscape led to monkey population overabundance in a habitat fragment (Portela & Dirzo 2020). This population outbreak in turn led to notable decline of a dominant and keystone plant species, palmito. The decline in palmito abundance has both ecological and economical consequences, and therefore has importance in both conservation and natural resource management. Without predators, monkeys were no longer mediated by top down control, and resulted in notable drops in plant abundance.

Unfortunately, in the United States, human influences have led to similar problems with loss of top down control (carnivores) on herbivore abundance. Trophic cascades that have kept ecosystems more or less in balance historically are being tampered with, both indirectly and directly, and could potentially lead to entire ecosystem collapse if not managed properly (Beschta & Ripple 2009). In the U.S., concentrated efforts to reduce predator populations led to extensive trapping, poisoning, and hunting between the 1800s and the early 1900s by federal agencies and Euro-American communities, which greatly reduced gray wolf *Canis lupus* and cougar *Puma concolo*r ranges (Laliberte and Ripple, 2004), two key predators of common herbivores, the ungulates, which is a broader taxonomic term used for the group the Blakely Island deer belong to. The impacts of predator loss on ungulates has been evaluated in the U.S. National Parks, with many showing significantly high rates of browsing intensity in forests by ungulates, leading to unprecedented decreases in native plant species (Beschta & Ripple 2009). Foraging by native ungulates in the absence of large predators can alter the function, composition, and structure of native plant communities, and therefore the overall health and resource output that forests can provide.

For my research project, I specifically looked at survivorship of the Blakely deer. Survivorship is one tool us ecologists like to use to analyze population life histories in different ecological contexts, and is often displayed graphically. It represents the proportion, or fraction, of individuals that make it to each age category in a population. Survivorship can be distinguished into three curve categories: Type 1, Type 2, and Type 3. In a Type 1 curve, population mortality occurs mostly in old age, and usually is indicative of a population with low number of offspring and high parental care (humans display this curve, as an example). Type 2 curves represent populations with steady mortality in each age interval, which includes a lot of bird species. On the other hand, Type 3 curves show populations that have high mortality in the juvenile stage, and are usually indicative of populations with high offspring numbers and low parental care- very few individuals make it to old age (Pinder et al. 1978), such as with some frogs.

In order to determine survivorship of these deer, there was only one reliable method that I could use to look at their age of death. I had to extract the first molar from the lower jaw, and then use it to create thin microscope slides to count the cementum bands on the tooth. Cementum is a layer of tissue that slowly grows over time on the tooth, and the bands grow with a 1:1 ratio of band to a year of life. In other words, a deer that has three dark cementum bands for example would have been about 3 years old when it died. It's comparable to how trees have tree rings that represent how long the tree has been alive. With deer, the first molar is the only tooth that can be used to accurately determine their age at death because it is the only tooth that is present from birth into adulthood.

In my sample of 489 skulls, 297 adult skulls had enough material to determine sex, and 192 were determined to be juveniles (with juvenile mortality being 39%). Out of the total 297 sexed adult skulls, 68 females, and 51 males were aged. Using piecewise regression, survivorship for adult male and females was determined to be a Type 1 curve, with the average age being about 5.

There are many implications of this research. Type 1 survivorship indicates that the deer make it to older age (and in fact, we aged a female deer to be much higher than what is usually seen in mainland deer). This possibly shows they are foraging longer, which means there is even less nutrient availability for the young juveniles. It also might mean that the adults are better able to out-compete the juveniles because they know where the good foraging spots are, which could be leading to even faster decline of local plant life on Blakely. Both the deer, and the native vegetation, are suffering because of the deer being at carrying capacity. My research also is interesting from an evolutionary perspective. The actual life cycle of these deer looks different than what we would normally see- I found that male and female deer had no significant differences in their survival rate (although they do have a skewed sex ratio). With a longer life cycle and equal survival between males and females, behavior, competition, and reproduction of the population could also look different than mainland populations, each with different possible generational consequences.

By pursuing my passion for ecology, I was able to participate in this meaningful research, and learn more about the relationships between different organisms and their environment. Research is my form of service- I get to serve God and God's creation by utilizing my knowledge of ecology and evolution. Like I said, this didn't come easily. Thankfully though, in my first year here at SPU and in the Honors Program specifically, I was pushed outside of my comfort zone while also having my passions be validated.

Within the first few days of starting Honors, we all were challenged to consider the following question: what does it mean to be human? Four years ago, the only words I felt I had were the ones I was given by the people around me. Now, I have an answer that is my foundation. To be a human means to actively engage with and love our neighbors- both human and non human creation alike. In Genesis 1, on the sixth day, when God saw all that they had made, God declared that it was very good. It wasn't that humans were very good- it was that everything, together, was very good. Our earth is our common home.