AGE DISTRIBUTION AND SURVIVAL OF COYOTES AND GRAY FOXES IN WESTERN TEXAS

by

Cassie A. Kirk

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ABSTRACT

The coyote (*Canis latrans*) is one of the top predators in the state of Texas. They have been able to adapt to urbanization and continue to thrive in the wild. The coyote is also considered a top down keystone species. As such, coyote management can influence how other species are managed. Female coyotes can become sexually mature once they experience their first estrus cycle in the first year of life. Gray foxes (*Urocyon cinereoargenteus*) occur throughout Texas. Both male and female gray foxes can attain sexual maturity at an early age. Females on average breed for the first time at about 9-10 months of age. A better understanding of the age structure and survival rate of both species, we can better understand how many possible individuals we have that will be in prime breeding age, and how exploitation of the species may be effecting structure of the population. Given that both species are harvested in predator hunts and nuisance animal situations, I wanted to explore age structure and survival of coyotes and gray foxes in western Texas. I collected the lower canine tooth from 378 coyotes from the Panhandle and southwest areas of Texas. I also collected 288 lower canine teeth of gray fox samples from the Edwards Plateau and the Trans Pecos ecoregion. The teeth were processed for cementum annuli to access age for each individual. I then developed age distributions and used these distributions to calculate annual survival rates using a-structured regression. The overall survival of coyotes in Texas was 0.659. For females in total, annual survival was 0.709. Males annual survival was 0.686. The annual survival of all the gray foxes together is 0.650. Females annual survival was 0.647. Male’s annual survival was 0.643.

The coyote and gray fox are adaptive species and can survive in different habitats and situations. The age structure in both species does suggest that exploitation is changing the age structure towards a younger dominant composition. However, these age structures also suggest that all of the populations I examined have not been over-harvested. Shifting populations to younger age classes can reduce age at maturity and increases litter sizes. Thus, the demographic strategy of these species apparently allows them to be resilient to current exploitation levels in this region.

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Approved:

Richard T. Kazmaier, PhD — Date
Chairman, Thesis Committee

J. Brad Johnson, PhD — Date
Member, Thesis Committee

Brad Simpson — Date
Member, Thesis Committee

Head, Department of Life, Earth And Environmental Sciences — Date

Dean, College of Agriculture and Natural Sciences — Date

Dean, Graduate School — Date

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CHAPTER I

VARIATION IN AGE DISTRIBUTION AND SURVIVAL OF COYOTES IN THE PANHANDLE AND SOUTHWEST TEXAS ECOREGIONS

INTRODUCTION

The coyote (*Canis latrans*) is one of the largest native predators in Texas (Nelson and Lloyd 2005). This animal has a keen sense of smell, sharp vision, and excellent hearing. All of these attributes are used to hunt their prey and scavenge for food. Coyotes have omnivorous diets and are opportunistic feeders (Kamler *et al.* 2004). In fact, coyotes demonstrate plasticity in diets, behaviors, activity, and spatial patterns (Young *et al.* 2006). This plasticity can lead to an increase in human-wildlife conflict.

Having an up-to-date knowledge on reasons why a species is being hunted, where they are being harvested, and the age structure of the population, gives managers more information in making decisions to better regulate the population. Until recently, management of the larger North American carnivores has been oriented toward removal of animals where their presence appeared to jeopardize human safety or toward economic or sporting interests (Knowlton 1972). The role of coyotes as a predator of domestic livestock is frequently cited as a justification for control of this species (Wapenaar *et al.* 2012).

Coyotes are territorial with territories spaced contiguously across the landscape like pieces of a puzzle (Knowlton *et al.* 1999). Variation in territory size of coyotes is generally attributed to the abundance and dispersion of food resources (Wilson and Shivik 2011). Inside of each territory, a dominant breeding pair is normally established. Field observations in Texas suggest that the percentage of female coyotes that successfully whelp in the first year of estrus is 35%, and the remainder that do not in the first year become sexually mature at 20-22 months of age (Knowlton 1972). Coyote litter sizes are typically between 4-6 pups. The average lifespan of a coyote is 10-12 years, but some have been known to live to 15 years in the wild. The factors regulating the frequency of pregnancy among coyotes also influence litter size, and the conditions that lead to higher pregnancy rates probably also factor larger litter sizes (Knowlton 1972). These factors include, but are not limited to, abundance and availability of food, shelter, and availability of water sources. This reproduction cycle of coyotes benefits in their ability to survive while being heavily exploited or unexploited. Populations that are heavily exploited tend to have larger litter sizes and an increase of yearlings reproducing (Knowlton *et al.* 1999).

With the extirpation of other large native predators throughout Texas, the coyote has become what is considered a keystone predatory species (Henke and Bryant 1999). The predator-mediated coexistence hypothesis suggests that when frequency-dependent predation and preference occur, prey abundance distributions tend to become more even, resulting in increased diversity over ecological time (Henke and Bryant 1999). This evenness occurs because selective predation reduces competition in the lower trophic levels by preventing the dominant competitors from monopolizing space and resources, thus maintaining high diversity (Henke and Bryant 1999). Such a keystone predator can highly influence the evenness and diversity of an ecosystem. Coyotes are generalist and opportunistic feeders, whose diets often reflect the abundance and availability of local food resources (Kamler *et al.* 2014). The predation by coyotes can reduce competition in the lower trophic levels by preventing dominant competitors from monopolizing space and resources, thus maintaining high diversity (Henke and Bryant 1999)

Coyotes are also considered a top-down predator. This infers that the management of a coyote population will influence species of the lower trophic levels significantly. Top predators are important in controlling herbivore populations, which in turn affect producers (Henke and Bryant 1999). Extirpation of coyotes can increase the mesopredators and microherbivore populations considerably (Henke and Bryant 1999). For example, a study conducted in Andrews and Martin counties in Texas (located in the High Plains Ecoregion), the removal of the coyote on the study site shifted the food chain into a different direction. In this study, 4 sites were chosen. On 2 of the sites, coyote populations were unchanged, and on the other 2 sites, the coyote population was removed. The 2 sites where the coyotes were removed, there was an abundance of lagomorphs. This led to an increase of foraging on local plants and crops. This increase in lagomorphs, led to a decrease in available forage for livestock and wildlife, and a higher predation rate on crops. Along with the extirpation of coyotes in this study, was that the species richness declined on the study site as well. After several months, one species of rodent overwhelmed the study area. This species was the culprit in the highest damage to crops and grasslands and became the only dominant species. In the 2 sites where coyotes were not removed, the area kept a higher species diversity and a lower abundance of lagomorphs. This supported the notion that keystone species that are top-down predators can have a effect on other species in their ecoregion. This also supports the need to understand the mechanism of a population more clearly when it comes to age distribution.

Multiple factors contribute to the survival and recruitment of coyotes. Reproduction rates, size of territory, and how many individuals are found in the territory are aspects that are important to explore. A relationship between human exploitation and coyote survival should not be implied without considering other demographic and environmental variables (Windberg *et al.* 1985). Population structure is not static, and any population sampling over an extended period of time is biased towards the more mobile segments of the population (Knowlton 1972).

Food availability is one factor that can also affect coyote populations. What types of food, and the abundance, that is available can influence reproduction, survival, dispersal, home range patterns, and territory densities. The diets of coyotes can vary seasonally and annually. With the coyote being opportunistic, they eat what is available at the time. In a study in Knox and King counties, Texas, it was made apparent how wide of a variety they can have in their diet. The coyotes sampled, fed on local native plants and animals, and did not kill livestock that could also be food (Meinzer *et. al.* 1975). The diet was diverse and included juniper cones (*Juniperus* spp.), plums (*Prunus* sp.), wheat (*Triticum* sp.), lagomorphs, deer (*Odocoileus* sp.), insects, turtles, bird eggs, calf (*Bos taurus*) manure, and other plants and animals inside the stomach and scat remains (Meinzer *et al.* 1975). This study supported the idea that coyotes select foods that require the least amount of energy to obtain. This goes hand in hand with an opportunistic omnivore behavior. A study in Dallam County, Texas (High Plains ecoregion), there was evidence of consumption of cattle, pronghorn (*Antilocapra americana*), birds, and crops (Kamler *et al.* 2014). Depredation can also occur on newborn calves and lambing and sheep (*Ovis aries*) pastures (Knowlton *et al.* 1999). In most cases though, it was because of a single individual, and once the individual was removed, the issue was temporarily alleviated (Knowlton *et al.* 1999).

It is also important to note that coyotes are often removed from ecosystems because of their predatory nature (Henke and Bryant 1999) or disease (Wapenaar *et al.* 2012). Hunting and trapping account for the majority of the mortality in coyotes (Knowlton *et al.* 1999). Coyotes are hunted for profit, sport, nuisance issues, and for trophies. In some regions of Texas, a hunter can take home over $40,000 for winning a hunting competition. There can be a noticeable effect, because of high hunting or trapping rates, on the population structure of coyotes. Unexploited populations typically have older age structures, high adult survival rates, low reproductive rates, and low recruitment into the adult population (Knowlton *et al.* 1999). Under heavy exploitation, populations tend to have younger age structures, lower adult survival rates, increased percentages of yearling reproducing, increased litter size, and relatively small group sizes (Knowlton *et al.* 1999). This suggests that the degree of exploitation of populations can affect the overall survival of coyote individuals and the population.

Coyote removal can also be because of disease. If an individual is showing symptoms of a contagious disease, it may be necessary to remove that individual. This can be because of the hazard they pose to humans or livestock. Red foxes (*Vulpes vulpes*) and coyotes can be carriers of pathogens, such as the rabies virus and the zoonotic parasites *Toxocara canis* and *Echinococcus* spp. (Wapenaar *et al.* 2012). Furthermore, red foxes and coyotes can play a role in transmitting diseases, such as *Sarcocystis* spp. and *Neospaora caninum* (Wapenaar *et al.* 2012). They can also be carriers for heartworm, canine distemper, canine parvovirus, or mange (Wapenaar *et. al.* 2012). All of these can have an effect on humans and livestock.

These reasons and more, are why it is important to understand the dynamics of coyote populations in Texas. If a population needs to be controlled and reduced, or controlled and promoted to increase, it will depend on a case by case basis. If a population needs to be controlled, the manager needs to look at the nature of the problem. Knowing the general age structure and survival rate of the population will help in making the most accurate decision. Additionally, given current levels of exploitation of the species, it is desirable to evaluate the impacts of such exploitation on populations. The current ambiguity presents a duality in management that can be achieved only through a better understanding of the entire spectrum of species values, more intimate biological knowledge, and more precise techniques (Knowlton, 1972).

STUDY AREA

I collected coyote specimens from counties in the Rolling Plains, High Plains, Edwards Plateau, Trans-Pecos, and South Texas Plains ecoregions (Gould et al. 1960; Figure I.1).

The North section consists of approximately 17,806,168 hectares of gently rolling to moderately rough topography (Correll and Johnson. 1979). Elevation is 244 - 1372 meters and annual rain fall ranges from 56 - 76 centimeters (Correll and Johnson 1979).

The land is split up between tradition range land, cow-calf operations, and crop usage. Original prairie vegetation included tall and mid-grasses, mesquite (*Prosopis glandulosa.*), shinnery oak (*Quercus havardii*), western ragweed (*Ambrosia psilostachya*), and Texas croton (*Croton texensis*) (Correll and Johnson 1979). Grasses included a variety of bluesteams (*Andropogon sp.*), blue grama (*Bouteloua gracilis*), buffalo grass (*Bouteloua dactyloides*), and switchgrass (*Panicum virgatum*; Correll and Johnson 1979).

The Southwest section consists of 25495195 hectares (Correll and Johnson 1979). This sections elevation is 305 - 914 meters in most areas, and 760 - 2,590 meters in the mountainous areas. Topography includes adobe hills, shallow uplands, rough stony hills, and deep valley soils. The vegetation of this area includes patches of mesquite, cacti, white brush (*Aloysia gratissima*), cat claw (*Acacia greggii*), and other small shrubs and trees. Grasses include switchgrass, buffalo grass, bluestems, and Indian grass (*Sorghastrum nutans*; Correll and Johnson1979). Average rainfall is between 41 - 76 cm in most areas, and less than 41 cm in the desert areas. Large cattle and deer operations are a common sight.

METHODS

Lack of a reliable technique for determining age has hampered studies of population dynamics and productivity in coyotes (Linhart and Knowlton 1967). As such, age determination of various mammals by counting the annuli found in the tooth cementum recently has become a popular tool in the study of population dynamics (Roberts 1978). The cementum-layer technique is the only one presently available for coyotes that provides a quantitative measure of age (Linhart and Knowlton 1967). I collected coyote carcasses, and lower canine teeth, from a variety of places from August 2015-April 2017. These carcasses and teeth came from Texas Wildlife Services, roadkill, predator hunts, and nuisance animal hunts. Date of collection, sex, and location were also recorded.

If a whole carcass was collected, I would only keep the head of the animal. Once I had the head collected, I would then skin and clean the head. Once the head was cleaned of all excess material, I then took two paths to finish cleaning down to the bone. The first way was using a dermestid beetle colony to clean the remaining flesh off. Depending on the health of the beetles, this would take one to two days to be accomplished. Once all the flesh was cleaned, I would then soak the lower jaw in warm water until the canine tooth was loose enough to pull out. The jars were kept outside in the sun. Depending on overall temperature, this process would take three to four days on average. The other path used to clean the head, involved submerging the whole head into a warm jar of water. Since there was still flesh on these heads, the process to clean them took longer than the previous method. These heads would soak for a week on average, and the water needed to be replaced every day or two to keep the process as quickly as possible.

Once I had the lower canine tooth out, I placed them into coin envelopes and placed individual codes on each envelope for identification. The teeth were then shipped to Matson's Laboratory LLC in Manhattan, Montana for the age analysis. Once the lab completed their process of getting to the cementum annuli, they then shipped the teeth back on slides that allowed you to see the cementum annuli (Figure I.2). The lab also provided the estimated ages for each tooth. I also sent in blind doubles, to evaluate the precision. In a previous study, Matson's Laboratory LLC was also used to test the accuracy and precision of captive coyotes with known ages. With 93% of teeth accurately aged and ages based on right and left canines consistent 89% of the time, we (the previous study) concluded that aging of coyotes using cementum annuli analysis is both accurate and precise (Scrivner *et al.* 2014)

For my analysis, I group samples into North and Southwest sections because of individuals being culled in counties with overlapping ecoregions, and the overall distribution of samples. The North section included samples in the High Plains and Rolling Plains ecoregions. The Southwest section included samples in the Edwards Plateau, Trans-Pecos, and South Texas Plains ecoregions. Within each section of for the samples pooled across all regions, I summarized individual ages into age distributions of all coyotes within each region as well as sex-based age structures for each region. From this age distribution, I then calculated a regression between the log of the frequency against age. I then used the anti-log of the slope to estimate annual survival.

RESULTS

I analyzed 378 coyote samples representing 169 females and 209 males (Figure I.3). Annual survival rates ranged 64.9-76.4% across all analyses (Table I.1). The age range was 0-13 years old (Figure I.4A). Ages 0 and 1 had the largest number of individuals. The annual survival of all coyotes in the study was 0.659 ($r^2 = 0.924$; Figure I.3B). Females as a group maintained the pattern of being dominated by individuals under 1 year of age (Figure I.5A). The annual survival of all females in the study was 0.709 ($r^2 = 0.895$; Figure I.5B). The age distribution of all males in the study shows the majority of individuals are under the age of 2 years old (Figure I.6A), and the annual survival was 0.686 ($r^2 = 0.868$) (Figure I.6B).

In the north section of which I collected 320 total coyotes, 144 were female and 168 were male (Table I.1). The trend of having less individuals over the age of 2 years old continues in the north section for both sexes and as a whole (Figure I.7A, Figure I.8A, Figure I.9A). The annual survival rate for all individuals in the North section was 0.669 ($r^2 = 0.896$; Figure I.7B). The females in the north section had an annual survival rate of 0.719 ($r^2 = 0.873$; Figure I.8B). The males in the north section had an annual survival rate of 0.692 ($r^2 = 0.803$; Figure I.9B).

In the southwest section of Texas, I collected 58 total samples (25F:27M:6 unknown; Table I.1). The majority of individuals sampled were under the age of 1 year old (Figure I.10A, Figure I.11A, Figure I.12A). The annual survival rate for all individuals in the southwest section was 0.701 ($r^2= 0.703$; Figure I.10B). For females only, annual survival was 0.672 ($r^2= 0.673$; Figure I.11B). For males in this area, annual survival was 0.764 ($r^2= 0.673$; Figure I.1B).

I sent in 10 paired, blind samples to Matson's Laboratory LLC to compare their precision. Eight of these pairs were aged to the same year by the lab. The other 2 samples had 1 year difference. This suggests a relatively high degree of precision by the laboratory.

DISCUSSION

Coyote population reduction has been, and will continue to be, an important element of programs attempting to protect domestic livestock, agricultural crops, and other wild species from coyote depredations (Windberg and Knowlton 1988). In order to make informed management decisions, it is beneficial to know the survival rate of the population. Connolly and Longhurst (1975) developed a simulation model and determined that a minimum annual removal of 75% of the breeding population of coyotes was needed to consistently lower coyote density (Henke and Bryant 1999).

In general, coyotes have an extended period of reproductive activity. Juvenile coyotes < 12 months of age can be reproductively active in their 1st winter, but available evidence suggests that juvenile and yearling (12-24 months) females are less fecund than adult females ≥ 2 of age (Carlson and Gese 2008). Older females ≥ 10 years of age gradually pass into reproductive senescence, whereas a male coyote was reported to have sired pups when ≥ 12 years of age (Carlson and Gese 2008).

Coyotes may alter their social organization based on annual reproductive success, and seasonal changes in prey availability (Young *et al.* 2006). Data reported by professional trappers who routinely examined reproductive tracts suggested that average litter size may be inversely related to population density (Knowlton 1972). In a study looking at the population mechanics of coyotes, it was assumed a 40% mortality of adults on an annual basis, and a net survival of 33% of those under 1 year old, is sufficient to maintain a stable population (Knowlton 1972). Under extremely favorable conditions, such as an abundance of food or mortality rates are accelerated, populations may triple during the whelping season (Knowlton 1972).

If we are able to have a better understanding of age structure, and we apply the knowledge of optimal breeding age. This will aid managers in determining if a population is growing, declining, or consistent. If we look at total females sampled in this study, due to them contributing the most to the next generation, we can see that 29% are within optimal breeding age (2 years to 9 years). Female coyotes under the age of 2 was 70% of the female population, and females over the age of 9 was only 1%. This suggests that the population of coyotes has a higher possibility of increasing. There are a large number of individuals coming up to that optimal breeding age, and there is a strong number of individuals already there.

When we look at just the northern section, we find 68% are under the age of 2 years old, 31% are between 2 years and 9 years, and 1% is over the age of 9 years old. This also supports the idea that the population has a high chance of growing in numbers. In the southwest section, 80% of the females are under the age of 2 years, and 20% are between 2 years and 9 years. The total number of females sampled from this area was low when compared to the north section. However, it still supports that the population has a higher possibility of increasing in the next several years.

Food availability, especially in winter, is a major factor regulating coyote survival, reproduction, dispersal, and territory densities, mediated through social dominance and territoriality (Knowlton *et al.* 1999). This regulation is shown in a reduction of ovulation rates, litter sizes, and percentage of coyotes that breed (Knowlton *et al.* 1999). A secondary effect related to competition for access to food can be contributed to human activities such as hunting, trapping, and vehicle collisions (Knowlton *et al.* 1999).

Annual survival of coyotes is a deciding factor for several aspects of a population as well. It can influence home ranges, recruitment after birthing season, pack size, and social organization of the pack (Young *et al.* 2006). Coyotes are frequent targets of control programs, creating unstable environments in which coyotes must exhibit behavioral and spatial plasticity to thrive (Young *et al*. 2006). Combining the information from previous studies, and comparing it to this study, the population I sampled has younger age structure with lower adult survival rate. This age structure could in turn produce an increase in yearlings reproducing with larger litter sizes.

In Webb County, Texas, territoriality in coyotes was expressed as 2 “behavioral” classes in populations that are not heavily exploited. The first one is that territorial individuals spent most of their time within restricted areas without general contact between coyotes outside their immediate social group (Windberg and Knowlton 1988). The other behavior class was that transient individuals were usually younger and spent most of their time around the periphery and interstices among territorial sections (Windberg and Knowlton 1988). Social organization provides the basis for territorial spacing mechanisms, and undoubtedly varies with mortality rates within the populations (Windberg and Knowlton 1988). The annual survival in this area was between 0.54 - 0.84 for adult coyotes, and 0.37 - 0.60 for coyotes under the age of 2 years old (Windberg *et al*. 1985). My annual survival rates of 0.64 - 0.76 fall within the range reported by Windberg *et al.* (1985). This study also had a high number of individuals under the age of 2 years old. This structure of a higher number of juveniles than adults could be changing the social organization to more transient individual than territorial individuals.

On the Tallahala Wildlife Management Area in Mississippi, the primary cause of mortality in coyotes was anthropogenic, especially related to trapping, hunting, and vehicles (Chamberlain and Leopold 2001). There was no difference in survival or cause specific mortality between sexes or between breeding season and winter. The survival during these times was 0.936 (Chamberlain and Leopold 2001). However, survival during breeding season was 0.84. Whereas survival during pup-rearing season was 0.98 (Chamberlain and Leopold 2001). Lower probability of survival was also reported in more intensively exploited populations (Chamberlain and Leopold 2001). The annual survival in the Mississippi example was higher than the annual survival in my study, which could reflect a higher exploitation rate in Texas relative to the population sampled in Mississippi.

Several studies have demonstrated that removal of coyotes results in changes in the local faunal community (Lemons *et al.* 2010). If it is determined that coyotes do need to be managed more closely in order to control the population, we have to consider about how it will affect the community where the removal is occurring. Removal could have a negative, positive, or neutral outcome. Coyote populations are dynamic and resilient; however, removal of individuals could cause responses in recolonization, increased breeding among younger females, increased litter, and increased survival rates (Knowlton *et al.* 1999). Like every management scheme, animal control must have specific objectives; the more precisely they are identified, the more effectively they can be met (Knowlton 1972).

I do believe that having more consecutive years to compare would also allow for more refined results. The first year of collecting was a trial year on how to efficiently collect and process samples. The second year was much more successful, and the more contact we had with the hunters, the more likely they would help us. It might have also been beneficial to go to more than just the Big Bobcat Hunt in San Angelo, Texas. However, this was one of the largest hunts in the state of Texas, and we did collect samples from both the north and southwest sections. It would also be interesting to get samples from the rest of Texas and add in more ecoregions and diversity. Also, in the second year of processing samples, I was able to get the technique improved when it came to how quickly I could get samples ready to send to the lab.

Ultimately, the application of species biology will provide the finesse that will allow us to alleviate hazards to other human endeavors and yet provide ample opportunity for the recreational and aesthetic pursuits that coyotes offer (Knowlton 1972). More samples from each region, and/or county, would be more beneficial to coming to a stronger conclusion on how to handle the coyote population in Texas.

If control and management of the coyote is needed, then this is a task that may take years to achieve what the manager is looking for. It could be a case by case situation when it comes to the issue of if a population should be controlled in a select region. However, since the population structure is uniform in these two studies sites, a uniform management strategy could work as well. Management could be a combination of removal techniques, and non-removal techniques. Removal techniques could include just removing the individuals that pose an immediate risk to humans or livestock, placing Livestock Protection Collars on at risk animals, M-44 devices, or snares and traps (Knowlton *et al.* 1999). Non-removal techniques would include, creating physical barriers, confining livestock to protected pens during peak foraging hours of coyotes, use of electronic frightening devices to scare predators away, and use of guard animals (Knowlton *et. al.* 1999).

The two regions generally had the same outcome on age range of the coyotes. I originally thought there would be more variation. As of right now, I conclude that the population of coyotes is surviving equally as well with the variation in regions and human activity levels and interaction. Additionally, although the age structures I documented do seem suggest that these populations are being exploited, there does not appear to be evidence that current levels of harvest are leading to over-exploitation and disruption of the coyote populations I examined.

LITERATURE CITED

Carlson, D. A., and E. M. Gese. 2008. Reproductive biology of the coyote (*Canis latrans*): integration of mating behavior, reproductive hormones, and vaginal cytology. Journal of Mammalogy 89: 654-664.

Champerlain, M. J., and B. D. Leopold. 2001. Survival and cause-specific mortality of adult coyotes (*Canis latrans*) in central Mississippi. The American Midland Naturalist 145: 414-418.

Correll, D. S., and M. C. Johnston. 1979. Introduction. Manual of the vascular plants of Texas. The University of Texas at Dallas. Richardson, Texas, USA.

Connolly, G. E., and W. M. Longhurst. 1975. The effects of control on coyote populations. Bulletin of the Division of Agricultural Sciences, University of California, Berkeley, California, USA.

Gould, F. W., G. O. Hoffman, and C. A. Rechenthin. 1960. Vegetational areas of Texas. Texas Agricultural Experiment Station, College Station, Texas, USA.

Henke, S. E., and F. C. Bryant. 1999. Effects of coyote removal on the faunal community western Texas. The Journal of Wildlife Management 63: 1066-1081.

Kamler, J. F., U. Klare, W B Ballard, M. C. Wallace, and P. S. Gipson. 2014. Comparison of coyote (*Canis latrans*) diets in continuous and fragmented short-grass prairie in the Texas Panhandle. Texas Journal of Science 66:25-41.

Kamler, J. F., W. B. Ballard, R. L. Gilliland, and K. Mote. 2004. Coyote (*Canis latrans*) movements relative to cattle (*Bos taurus*) carcass areas. Western North American Naturalist 64: 53-58.

Knowlton, F. F. 1972. Preliminary interpretations of coyote population mechanics with some management implications. The Journal of Wildlife Management 36: 369-382.

Knowlton, F. F., E. M. Gese, and M. M. Jaeger. 1999. Coyote depredation control: an interface between biology and management. Journal of Range Management 52: 398-412.

Lemons, P. R., J. S. Sedinger, M. P. Herzog, P. S. Gipson, and R. L. Gilliland. 2010. Landscape effects on diets of two canids in northwestern Texas: a multinomial modeling approach. Journal of Mammalogy 91: 66-78.

Linhart, S. B., and F. F. Knowlton. 1967. Determining age of coyotes by tooth cementum layers. The Journal of Wildlife Management 31: 362-365.

Meinzer, W. P., D. N. Ueckert, and J. T. Flinders. 1975. Foodniche of coyotes in the rolling plains of Texas. Journal of Range Management 28: 22-27.

Nelson, T. A., and D. M. Lloyd. 2005. Demographics and conditions of coyotes in Illinois. American Midland National 153: 418-427.

Roberts, J. D. 1978. Variation in coyote age determination from annuli in different teeth. The Journal of Wildlife Management 42: 454-456.

Scrivner, J. H., C. A. Johnson, and C. A. Sego. 2014. Use of cementum annuli and eye-lens weight for aging coyotes. Wildlife Society Bulletin 38: 874-877.

Wapenaar, W., F. De Bie. D. Johnston, R. M. O'Handley, and H. W. Barkema. 2012. Population structure of harvested red foxes (*Vulpes vulpes*) and coyotes (*Canis latrans*) on Prince Edward Island, Canada. The Canadian Field-Naturalist 126: 288-294.

Wilson, R. R., and J. A. Shivik. 2011. Contender pressure versus resource dispersion as predictors of territory size of coyotes (*Canis latrans*). Canada Journal of Zoology 89: 960-967.

Windberg, L. A., and F. F. Knowlton. 1988. Management implications of coyote spacing patterns in southern Texas. The Journal of Wildlife Management 52: 632-640.

Windberg, L. A., H. L. Anderson, and R. M. Engeman. 1985. Survival of coyotes in southern Texas. The Journal of Wildlife Management 49:301-307.

Young, J. K., W. F. Andelt, P. A. Terletzky, and J. A. Shivik. 2006. A comparison of coyote ecology after 25 years: 1978 versus 2003. Canada Journal of Zoology 84: 573-582.

Table I.1 Sample size, age-structured regression statistics, and annual survival estimates of coytoes collected from western Texas, 2015-2017. Independent variable is the age categories and the dependent variable is age of each individal.

Region	Sex	N	Regression Equation	r^2	Survival
Pooled	Pooled	378	y= -8.2374x + 80.543	0.924	64.9%
	Female	169	y= -3.8132x + 36.857	0.895	70.9%
	Male	209	y= -4.4242x + 43.686	0.868	68.6%
North Section	Pooled	320	y= -6.9319x + 67.914	0.896	66.9%
	Female	144	y= -3.2088x + 31.143	0.873	71.9%
	Male	168	y= -3.5912x + 35.343	0.803	69.2%
Southwest Section	Pooled	58	y= -1.3055x + 12.629	0.703	70.1%
	Female	25	y= -0.6044x + 5.7143	0.673	67.2%
	Male	27	y= -0.556x + 5.5429	0.673	76.4%

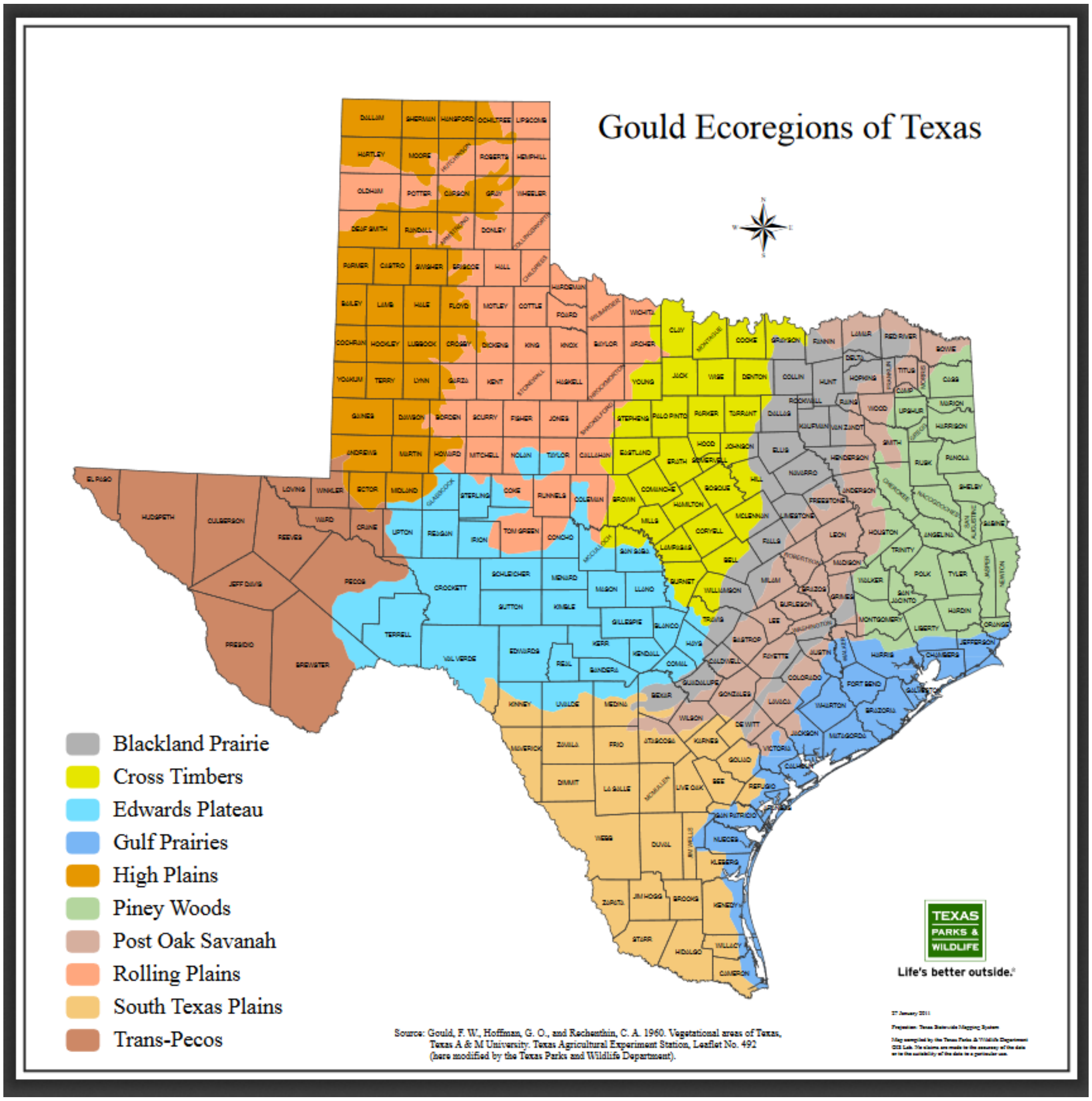


Figure I.1 A map reperesenting the Gould Ecoregions in the state of Texas. Coyote specimens from counties in the Rolling Plains, High Plains, Edwards Plateau, Trans-Pecos, and South Texas Plains ecoregions.

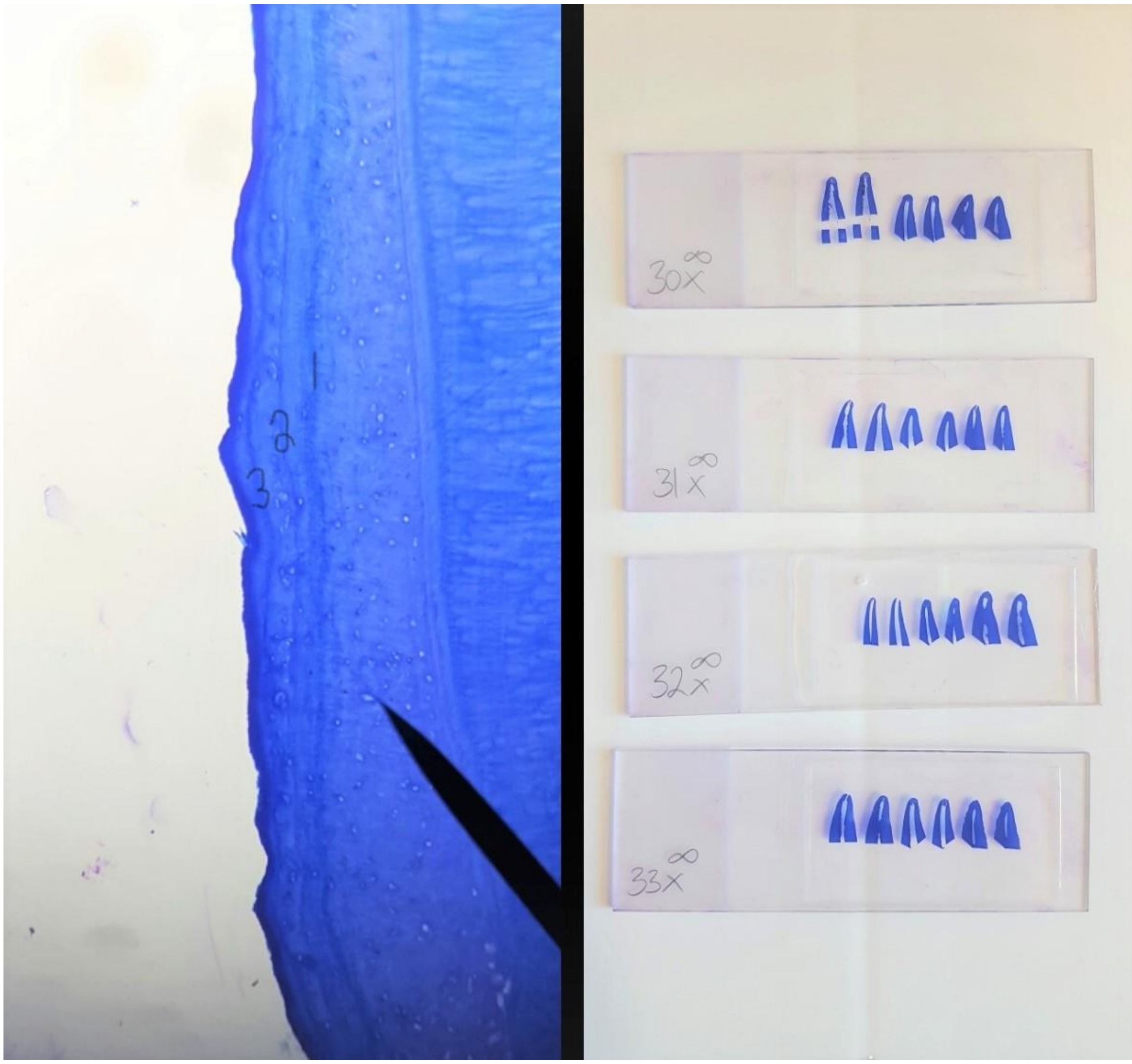


Figure I.2 An example of the microscope slides with the cementium annuli. The picture on the left represents a three year old individual. The picture on the right represents three individuals on each slide.

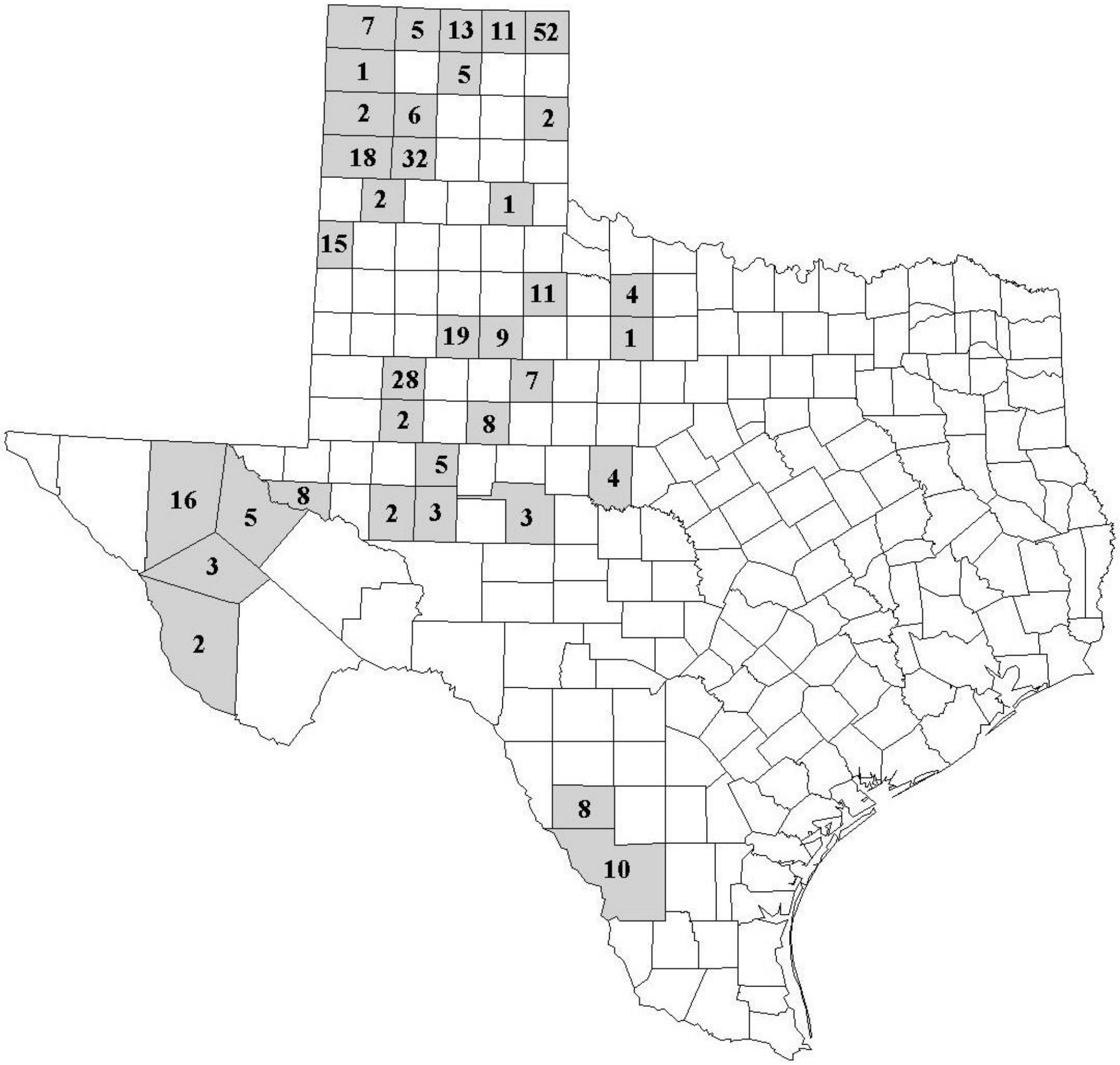
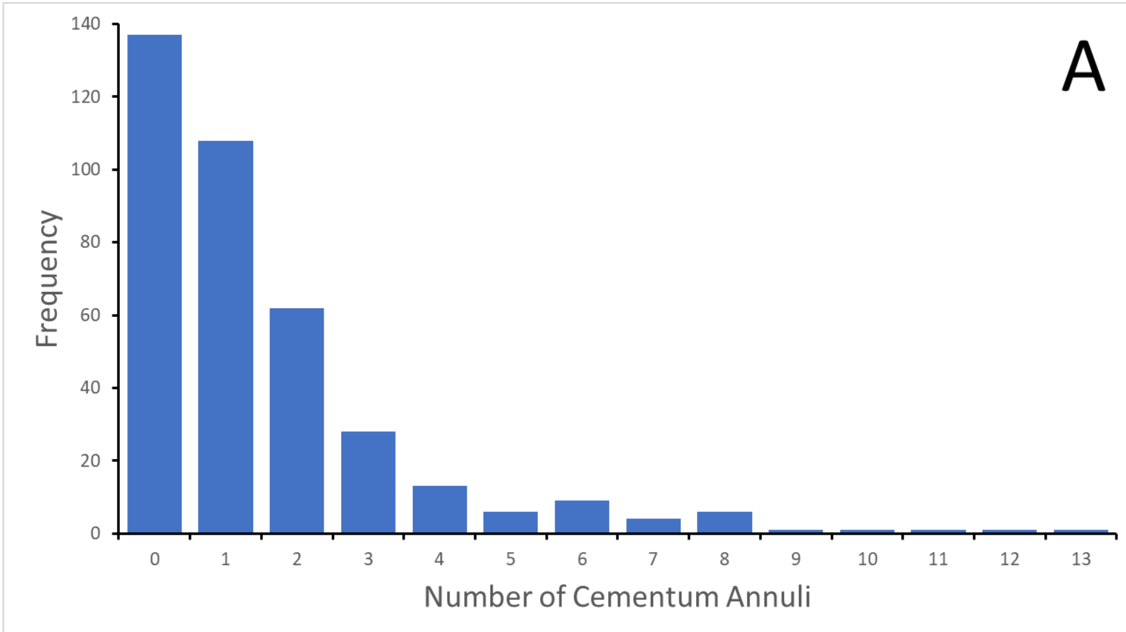


Figure I.3. The distribution of coyotes by county for samples used in the evaluation of age structure in western Texas, 2016-2017. An additional 45 samples of uncertain county origin but definitely from the Rolling Plains/High Plains ecoregions were used in both the overall and regional age analyses. Another 6 samples of uncertain county origin were used only in the overall age distribution.



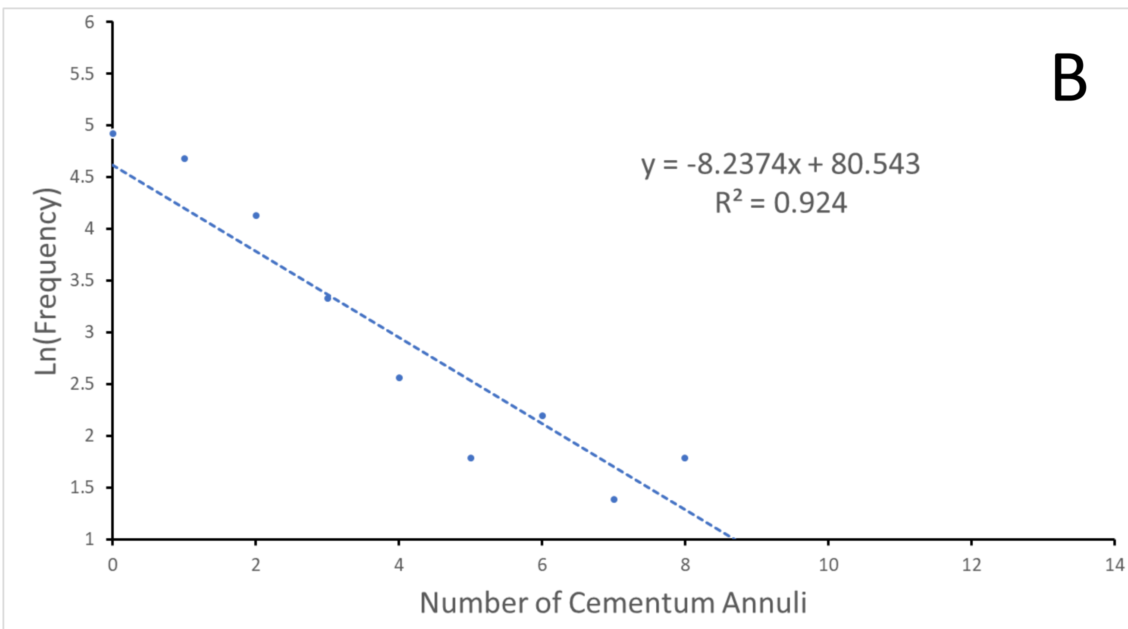
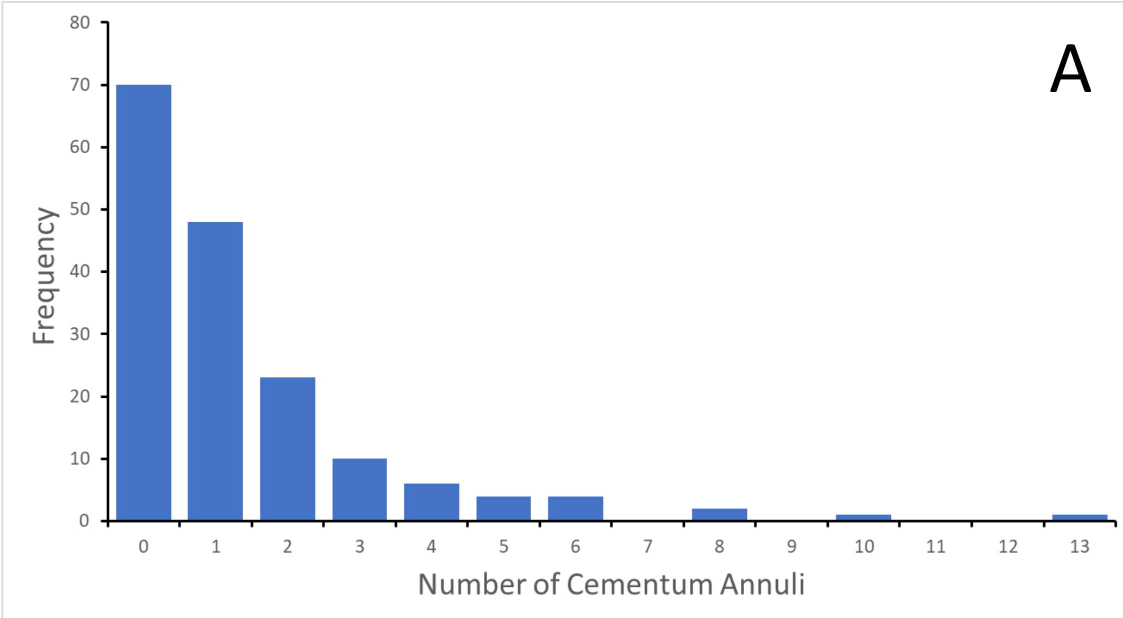


Figure I.4. Age distribution (A) and age-structured regression (B) of all sampled coyotes derived from cementum annuli analysis (n = 378), western Texas, 2015-2017.



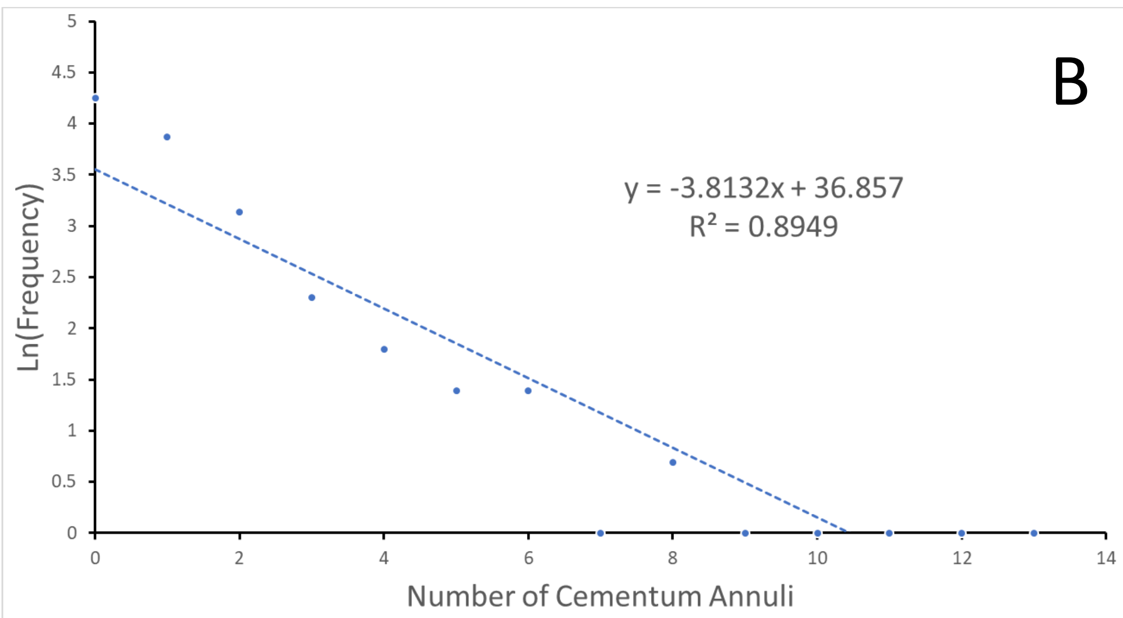


Figure I.5. Age distribution of all female coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 169), western Texas, 2015-2017.

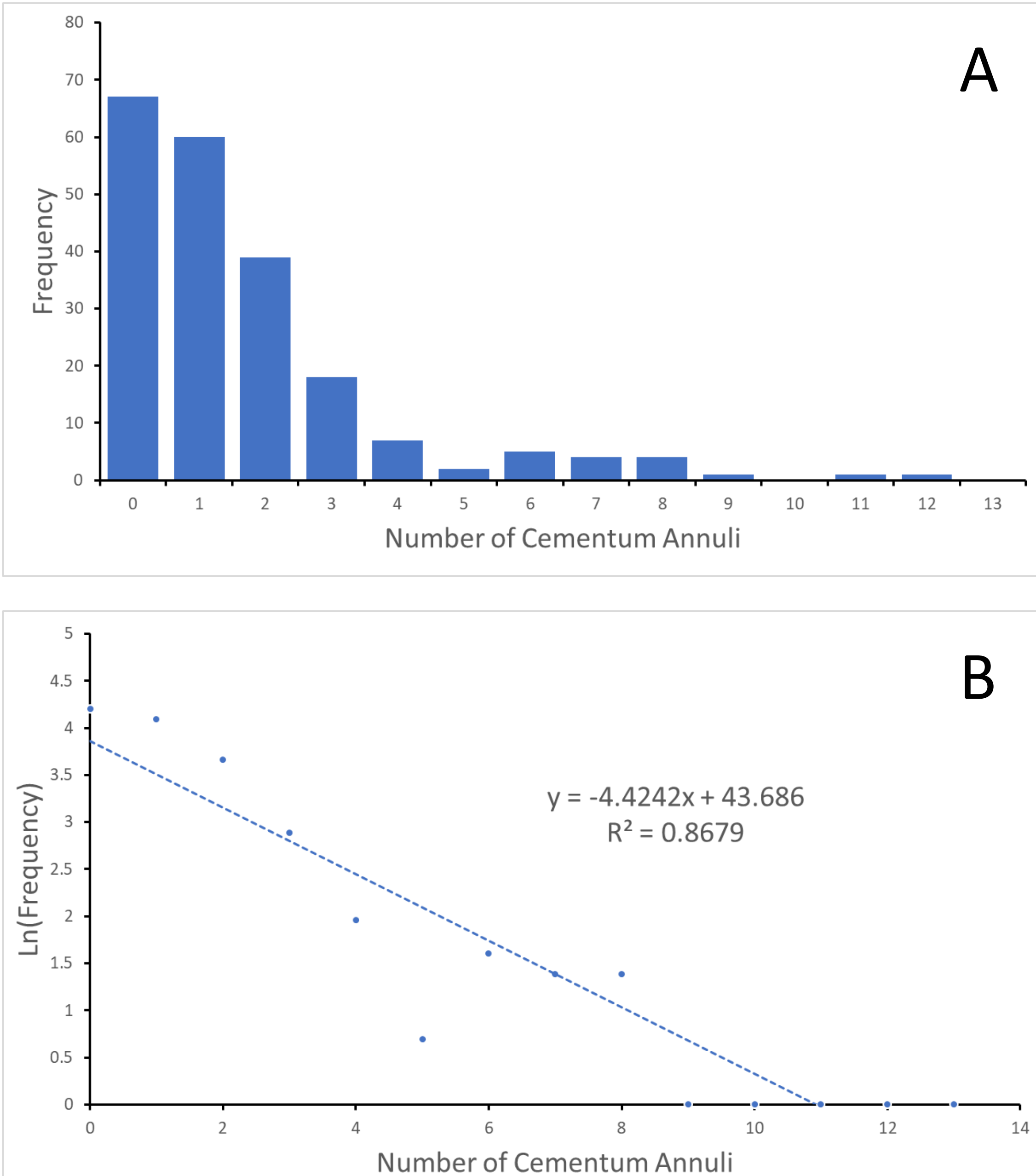
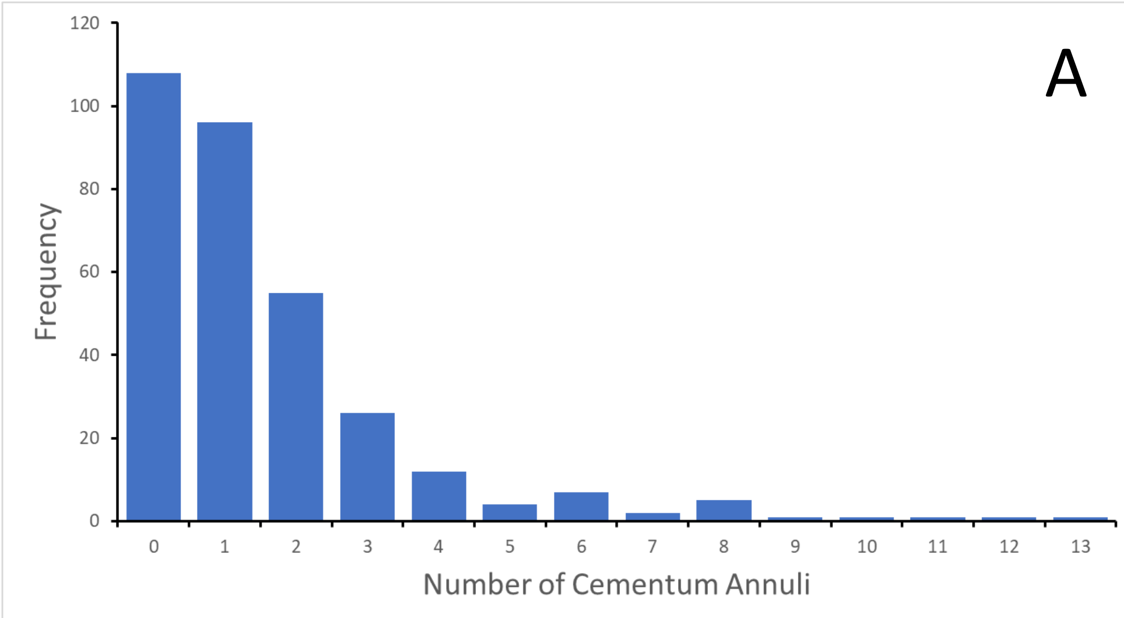


Figure I.6. Age distribution of all male coyotes (A) and age structured regression (B) derived from cementum annuli analysis (n = 209), western Texas, 2015-2017.



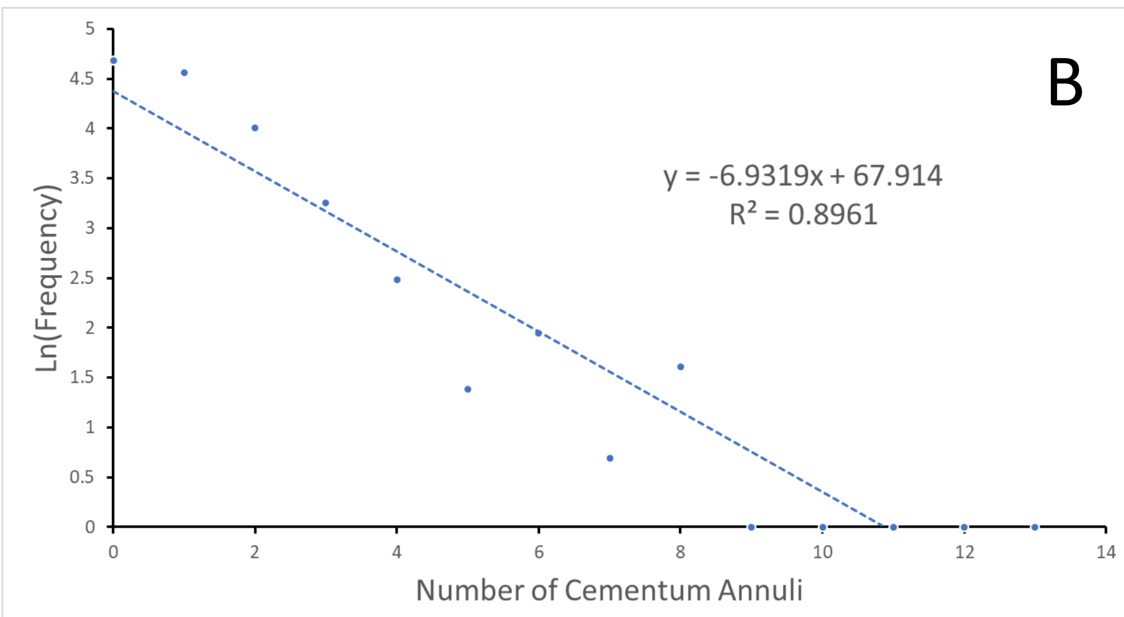
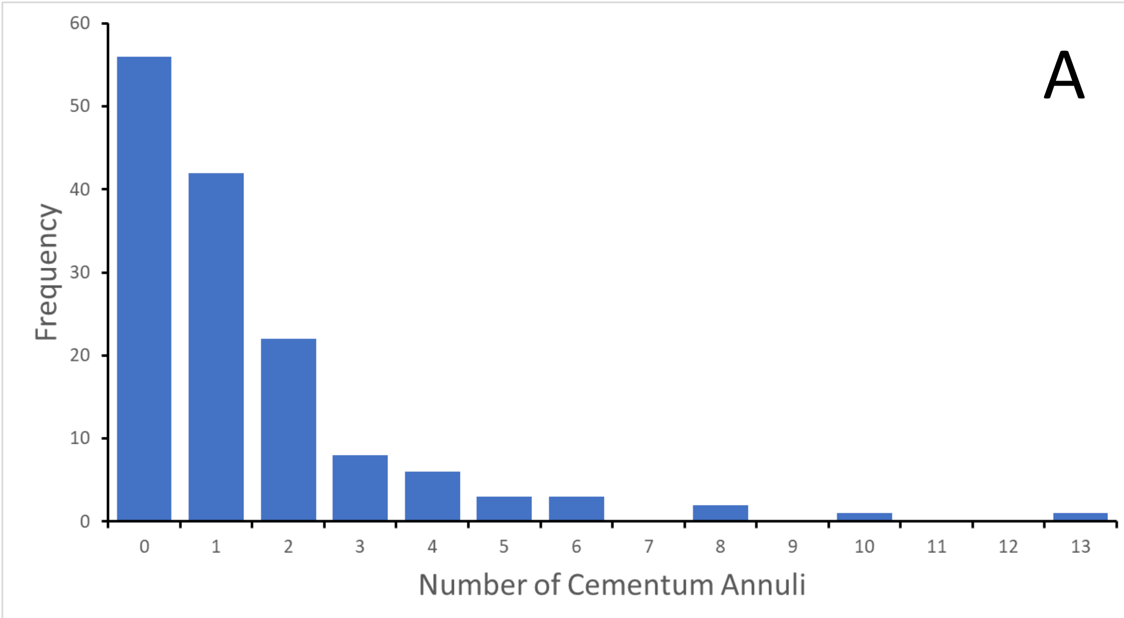


Figure I.7. Age distribution of all north coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 320), western Texas, 2015-2017.



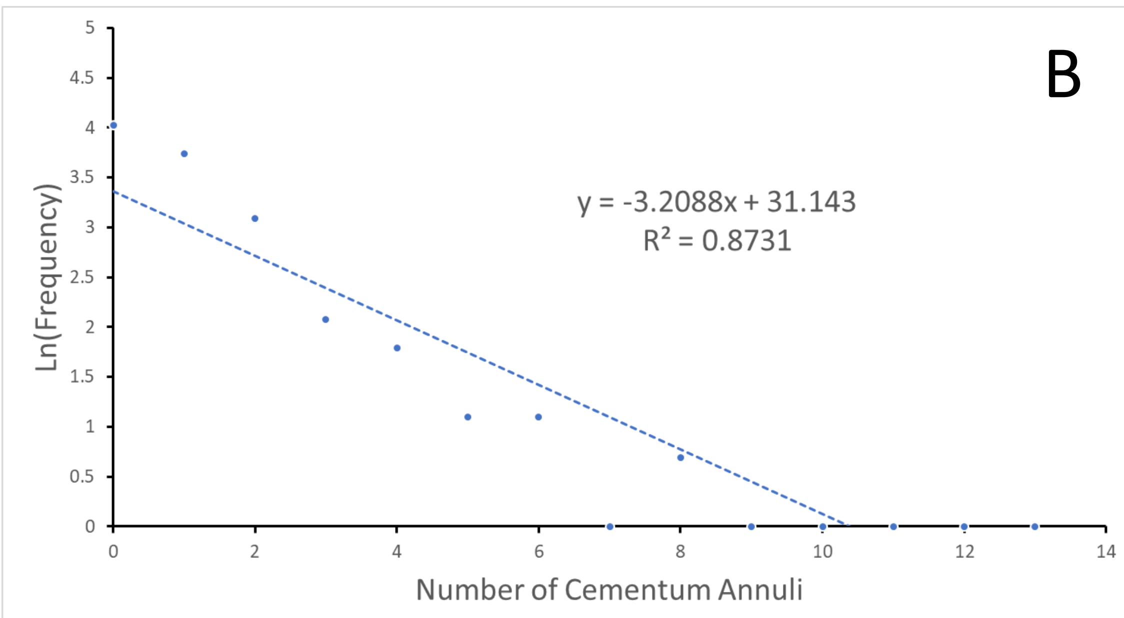


Figure I.8. Age distribution of North female coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 144), western Texas, 2015-2017.

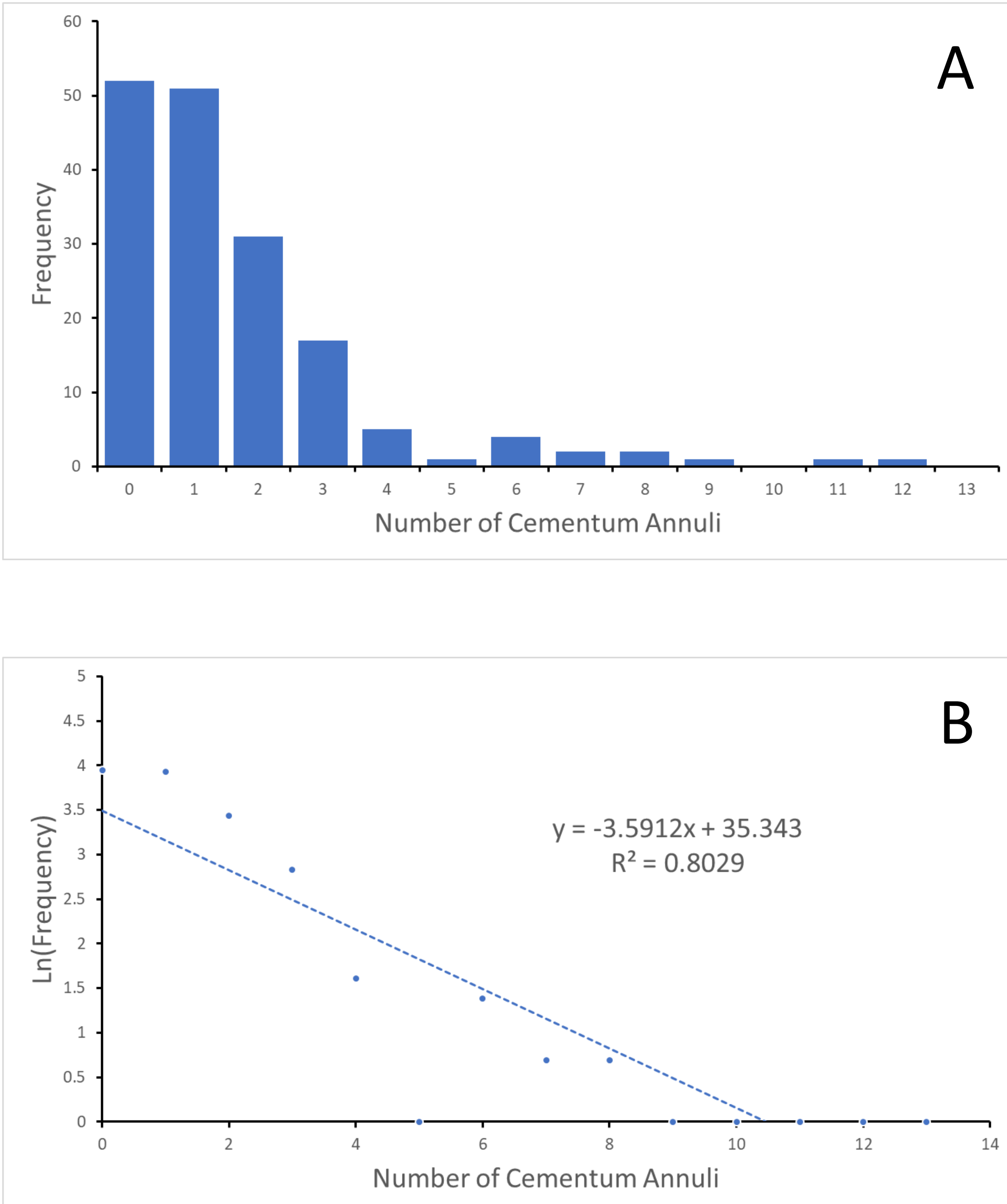


Figure I.9. Age distribution of North male coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 168), western Texas, 2015-2017.

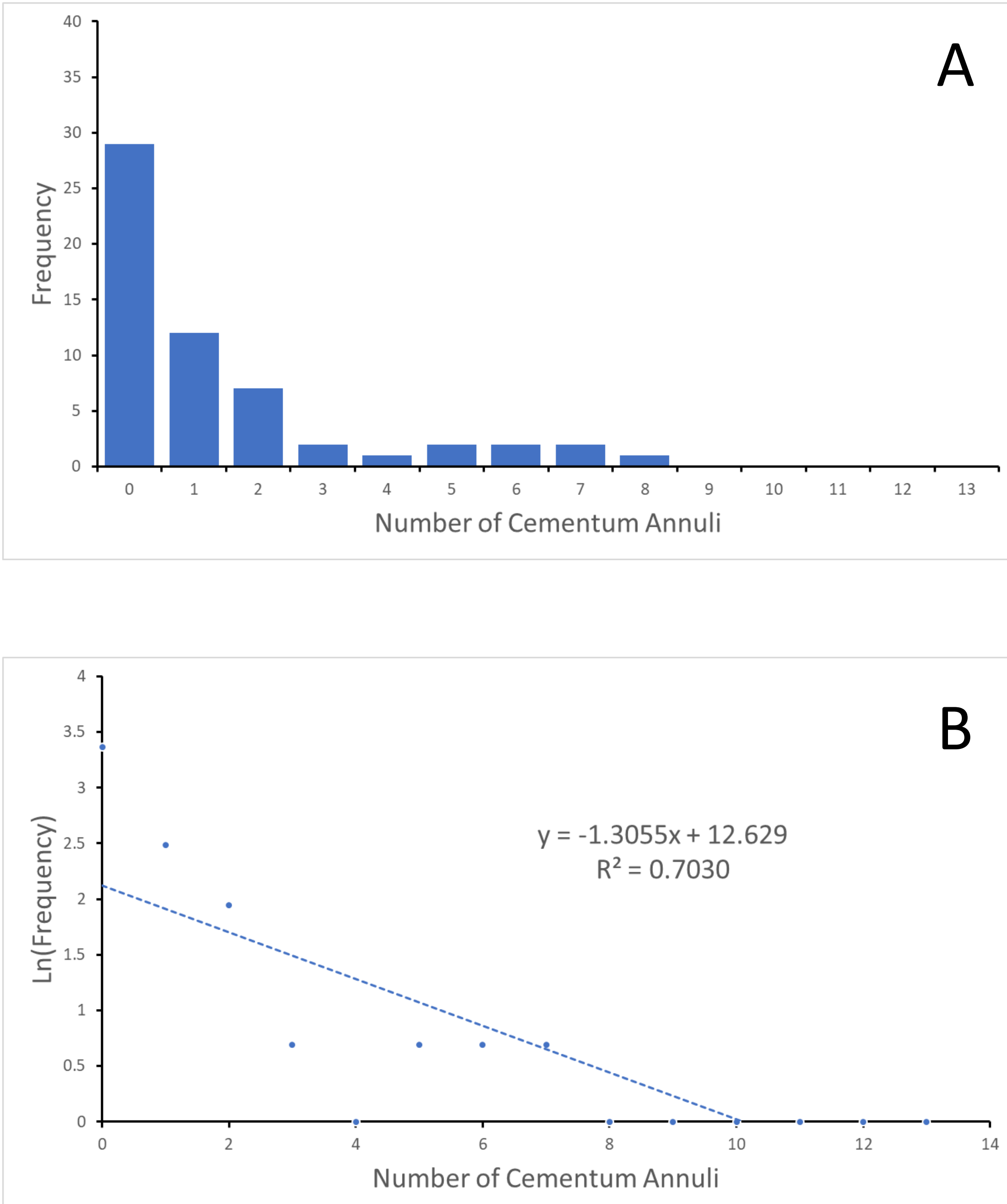
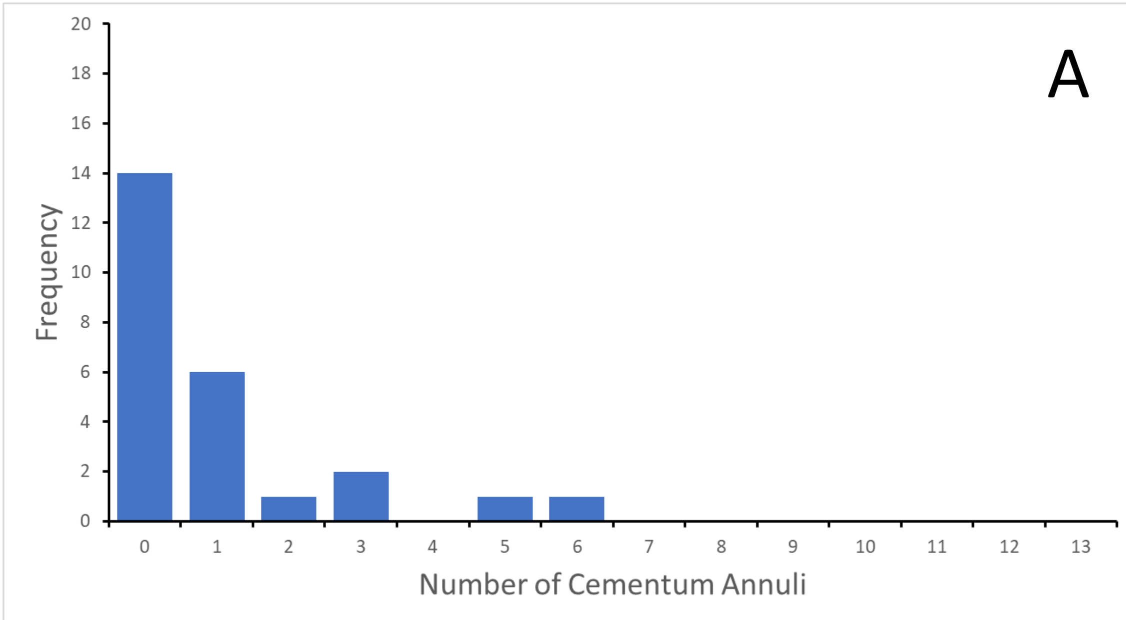


Figure I.10. Age distribution of Southwest coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 58), western Texas, 2015-2017



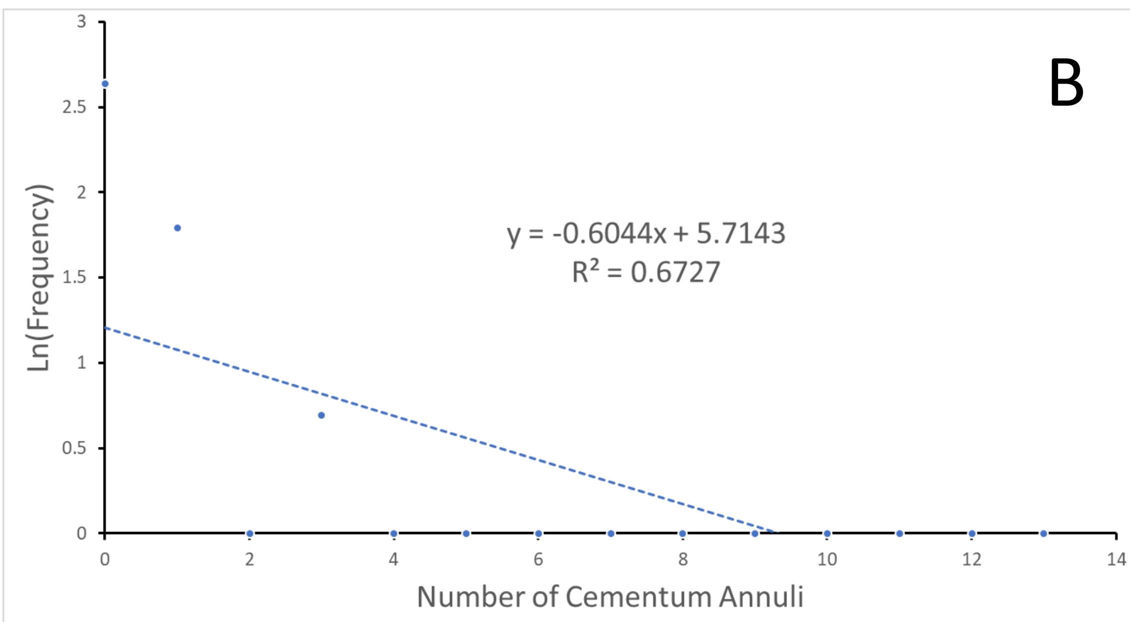


Figure I.11. Age distribution of Southwest female coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 25), western Texas, 2015-2017.

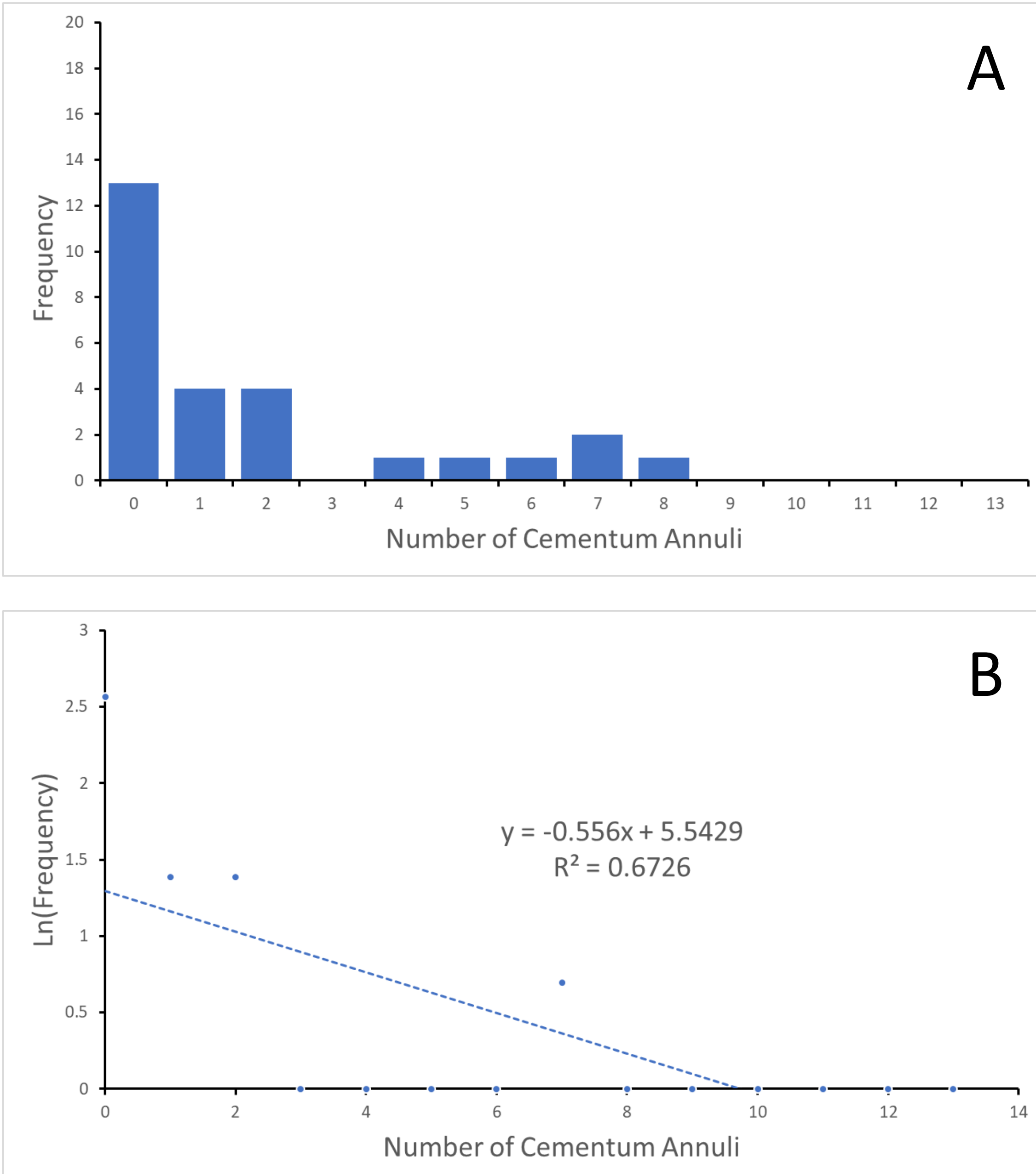


Figure I.12. Age distribution of Southwest male coyotes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 27), western Texas, 2015-2017.

CHAPTER II

AGE DISTRIBUTION AND SURVIVAL OF GRAY FOXES IN THE EDWARDS PLATEAU AND TRANS PECOS ECOREGIONS OF TEXAS

INTRODUCTION

Gray foxes (*Urocyon cinereoargenteus*) are distributed statewide in Texas, although in some areas they are locally excluded because of competitive interactions with more dominant coyotes (*Canis latrans*) and bobcats (*Lynx rufus*; DeYoung *et al.* 2009). Gray foxes inhabit wooded, brushy, and rocky habitats (Fritzell and Haroldson 1982). Annual home range sizes of gray foxes are variable across their geographical range, ranging from 75 ha to 676 ha, with most studies reporting estimates ranging from 100 ha to 350 ha (Deuel *et al.* 2017). Although gray foxes lack significant sexual dimorphism, home range sizes of males are generally slightly larger than females (Deuel *et al*. 2017).

Gray fox diets vary among temperate zone locations and seasons, and fox are generally considered more omnivorous than other canids (Cunningham *et al.* 2006). The gray fox will eat a variety of invertebrates, fruit (apples [*Malus* spp.], grapes [V*itis* spp.], corn [*Zea mays*]), birds, squirrels (Sciuridae), opossum (*Didelphis virginiana*), lagomorphs, and carrion (Cunningham *et al.* 2006, Fritzell and Haroldson 1982).

Gray foxes use dens at any time of the year, but most use occurs during the whelping season (Fritzell and Haroldson 1982). The gray fox will also use urban dens (i.e. under houses) in areas where a natural den cannot be found. They are also known to climb trees very well for foraging or shelter. Gray foxes are primarily nocturnal or crepuscular (Fritzell and Haroldson 1982). Gray fox populations appeared weakly structured and genetically non-independent across a broad geographic extent, suggesting high rates of movement or dispersal (DeYoung *et al.* 2009).

Foxes typically live as mated pairs or mated pairs with helpers, and larger canids form groups of related or unrelated individuals with only the dominant pair breeding (Glenn *et al.* 2008). Males attain sexual maturity at an earlier age than do females (Layne 1958). Testicular activity begins at about 4 months of age for males (Fritzell and Haroldso 1982). Females breed for the first time at about 9-10 months of age and give birth about 53 days later (Root and Payne 1984). The largest portion of the sexually mature population is animals in their first breeding year (less than 12 months of age) with a steady decline for successively older ages (Wood 1958). Litter size is between 3-5 young. Gray foxes can live up to 14 years in the wild, and they are able to survive equally as well during the breeding season and non-breeding season (Temple *et al.* 2010).

Undoubtedly the most important modern predator of the gray fox is man (Fritzell and Haroldson 1982). The gray fox is a fur bearing animal, and their fur can be sold throughout the state of Texas. There is no bag limit or closed season. Most of the individuals taken for the sale of fur are taken during the winter months when the fur is at its thickest. There are several predator hunts throughout Texas that in order to enter, you have to have a minimum amount of gray foxes killed. It is definitely a sporting event to see how many individual foxes you can kill, and there is a prize for the most killed in the time frame established. Fur traders are also present at these hunts looking for any coats that can be sold. The West Texas Big Bob Cat (WTBBC) hunt in San Angelo Texas is an example of this type of hunt (WTBBC 2019).

In populations that are not trapped, gray foxes may more commonly be killed by other carnivores and raptors or by disease, which can cause local population reductions (Farias *et al.* 2005). Gray foxes are susceptible to rabies, ticks, and fleas, but are not as susceptible to mange, as coyotes. The removal of larger predators has resulted in increases in the numbers of gray foxes, suggesting that predation limits some fox populations (Farias *et al.* 2005). In north-western Texas, coyote predation on swift foxes (*Vulpes velox*) was relatively higher where coyote density was higher, and subsequent removal of coyotes in one area resulted in increased survival, density, and recruitments of swift foxes (Kamler *et al.* 2003). There is a trade off in populations of gray foxes where there is not a strong presence of a predator to control the population. If there is an abundance of gray foxes in an area, this could affect the abundance of animals and plants they consume. Intraguild predation is a common cause of mortality for gray foxes, and in a Texas population, 92% of gray foxes sampled were depredated by either coyotes or bobcats. This supports the idea that removal of larger predators can increase the survival of gray fox populations.

Habitat loss and fragmentation is a primary threat to biological diversity and urbanization is a leading agent of fragmentation (Larson *et al.* 2015). Alteration and loss of natural habitat may be because of the construction of housing, roads, utility infrastructure, agriculture, commercial and industrial development, and natural resource extraction (Haverland and Veech 2017). Gray foxes appear to be tolerant of, and perhaps benefit from, residential development until residence density exceeds a threshold beyond which gray foxes avoid residential areas (Harrison 1997). At the landscape scale, Texas gray foxes were continually distributed, with no discernable gaps in populations (DeYoung e*t al.* 2009). This suggests, that gray foxes are able to adapt well to the changing landscape of Texas.

A knowledge of the structure of a population is essential for the clarification of population characteristics (Wood 1958). By having a better understanding of the age structure of a population, we can better understand how many possible individuals we have that will be in prime breeding age. Likewise, for harvested species, it is beneficial to explore age structure and survival is being negatively impacted by that harvest. Thus, my objective was to evaluate age structure and survival of gray foxes in the Trans Pecos and Edwards Plateau of Texas.

STUDY AREA

I collected gray fox specimens from counties in the Edwards Plateau and Trans-Pecos ecoregions (Gould et al. 1960; Figure II.1). The Edwards Plateau is characterized by growth of ashe juniper (*Juniperus ashei)*, oaks (*Quercus* spp.), honey mesquite (*Prosopis glandulosa*), switchgrass (*Panicum virgatum*), buffalograss (*Buchloe dactyloides*), several species of grama (*Bouteloua* spp.), and bluestems (*Andropogon* spp.; Correll and Johnston 1979). Elevation ranges from 305 m to 914 m (Correll and Johnston 1979). Annual rainfall varies from 38-84 cm (Correll and Johnston 1979). The area is predominantly rangeland grazed by cattle, sheep, and goats, but local tracts are cultivated for domestic pasture and hay (Afandador *et al.* 2016).

The Trans Pecos region is characterized by diverse habitats and vegetation, varying from desert valleys and plateaus to wooded mountain slopes and summits of conifer and hardwoods (Correll and Johnston 1979). Elevation ranges from 762 m to 2,590 m (Correll and Johnston 1979). Average rainfall for the Chihuahuan Desert areas is less than 30 cm, and the non-desert areas average of 51 cm (Correll and Johnston 1979). Vegetation of this region includes creosote (*Larrea tridentata*)-tarbush (*Flourensia cernua*) desert shrubs, grama grasslands, juniper savannahs, oak forests, plains bristlegrass (*Setaria macrostachya*), chinograss (*Bouteloua ramosa*), and various cactus, particularly prickly pear (*Opuntia* spp.).

METHODS

Counting cementum annuli from teeth is believed to be the most accurate aging method in gray foxes (Fritzell and Haroldson 1982). I collected gray fox samples from predator hunts in the Edwards Plateau area from March 2016 and January-March 2017. At these hunts, we had hunters bring their carcasses to us and identify what county the animal was shot in. These hunts were 24-hour hunts, so the date of kill was already known. I then placed a label on each carcass to identify which county it came from. After carcass collection, I used a saw to quickly separate the head. Heads were then grouped into bags and labeled by county and sex for freezing and later processing.

Cleaning the gray fox skulls was a quick process because of the head size being smaller overall. For processing, heads were skinned and as much flesh as possible was removed by hand. Next the skulls either sat in a dermestid beetle colony to quickly clean them, or they were placed in jars of water sitting in the sun to soak for a few days to remove the remaining flesh off via maceration.

After soaking, lower canine teeth were extracted and placed them into coin envelopes labeled with sex and location. The teeth were then shipped to Matson's Laboratory LLC in Manhattan, Montana, for the age analysis. Once the lab completed their process of sectioning teeth, they then mounted the tooth sections on slides to allow counting of cementum annuli (Figure II.2). The lab also provided the estimated ages for each tooth. I also sent in blind doubles, to test the aging of the lab.

For my analysis, I group samples into Edwards Plateau and Trans Pecos regions. Within each region, I summarized individual ages into age distributions of all gray foxes within each region as well as sex-based age structures for each region. From this age distribution, I then calculated a regression between the log of the frequency against age, and used the anti-log of the slope to estimate annual survival.

RESULTS

In total, I collected 288 gray fox samples (126F:157M:5 unknown; Figure II.3). Annual survival rates ranged 64.3-84.1% across all analyses (Table II.1). The age frequency range was 0 years to 8 years old for all gray foxes sampled (Figure II.4A). Ages 0 and 2 had the largest number of individuals. The annual survival of all the gray foxes together is 0.65 ($r^2 = 0.92$; Figure II.4B). All the females in the study had a similar age frequency with the majority of individuals being under the age of 1 year old (Figure II.5A). Female annual survival was 0.647 ($r^2 = 0.797$; Figure II.5B). Male annual survival was 0.643 ($r^2 = 0.862$; Figure II.6B), and the majority of individuals were in the 1 year old age class or younger.

I had 202 individuals from the Edwards Plateau (86F:115M; Table II.1). There was 1 individual not able to be identified to sex. The trend continues with the majority of individuals being under the age of 1 year old (Figure II.7A). The annual survival rate for all the individuals in this region was 0.636 ($r^2 = 0.817$; Figure II.7B). The females in the Edwards Plateau had a survival rate of 0.670 ($r^2 = 0.92$; Figure II.8B), with the majority being under 1 year old (Figure II.8A). The males had as survival of 0.656 ($r^2 = 0.847$; Figure II.9B), with the majority being under 2 years of age.

In the Trans Pecos region, I collected 46 individuals (18F:28M; Table II.1) and the majority of individuals were 3 years and younger (Figure II.10A). The annual survival rate for all individuals in this region was 0.717 ($r^2 = 0.597$; Figure II.10B). For females only, the annual survival rate was 0.841 ($r^2 = 0.389$; Figure II.11B), and the majority were under the age of 2 years old (Figure II.11A). For males only, the annual survival rate was 0.771 ($r^2 = 0.425$; Figure II.12B), and the majority of individuals were between 1 and 2 years old (Figure II.12A).

DISCUSSION

In both the Edwards Plateau and Trans Pecos regions, the majority of the individuals sampled were of prime breeding age or going through their first breeding season (Wood 1958). Given that ~65% of my sample was under the age of 2 years old and ~31% were between 2-6 years old, the reproductive potential of these populations was exceedingly high. Female gray foxes can start breeding at 9-10 months of age. With a younger age structure representing the population sampled, there is a higher change of more individuals reproducing at this younger age as well.

The survival rate of gray foxes in my study (0.63 – 0.84) was higher than annual survival rate of gray foxes in a population in California (0.58-0.69; Farias *et al.* 2005). The main cause of mortality in the California study was predation of coyotes. This suggested that interference competition was a primary motivation factor as coyotes did not consume the foxes killed (Farias *et al.* 2005). The removal of larger predators can result in the increases in the number of gray foxes as well (Farias *et al.* 2005). Gray fox spatial distribution also appears to be relegated to habitats avoided by coyotes (Deuel *et al.* 2017) and bobcats (DeYoung *et al.* 2009). A lower predation on gray foxes by coyotes could be an explanation of why the survival rate was higher in my study.

In a study in Georgia, there was a 34% probability of a gray fox experiencing a human-induced mortality, an 11% chance of dying from unknown causes, and an 8% of dying from natural causes (Temple *et al.* 2010). During this 4 year study, the annual survival of the individuals 0.61 and it did not vary during different seasons (Temple *et al.* 2010). My annual survival rates were generally higher than those reported in this study from Georgia (Temple *et al.* 2010). There could be several factors that would cause this difference. In the Georgia study, only 23 individuals were sampled. We had a significant amount more in this study, and that higher amount could be a better representation of the actual population structure in the wild. However, the differences could also be because of higher rates of anthropogenic contact in Georgia relative to the more rural regions in Texas that I sampled.

Landscape features also have minimal effect on gray fox population structure (DeYoung *et al.* 2009). Gray foxes are distributed across Texas, with no physical barriers to hinder gene flow (DeYoung *et al.* 2009). The graphs in this study do show a similar trend between the regions. This similar trend could suggest that a uniform management technique could be used between the 2 regions, if a manager did decide to manage the overall population. At the landscape scale, management units that are defined too conservatively result in wasted effort, whereas failure to control the entire local population may render management ineffective (DeYoung *et al*. 2009). Gray foxes are an adaptive species and can survive in different habitats and situations (Harrison 1997), and they also have high rates of movement or dispersal (DeYoung *et al*. 2009).

It would be beneficial to have more sampling years. More sampling years would be beneficial due to being able to see how a previous year affected the following year. It would allow you to see if a management practice made an impact or not. Also collecting in successive years may allow you to see a cycle form on the structure and survival of the population. I collected gray foxes for two years, and collected so many samples, that I was not able to get all processed in time and sent to the lab for analysis. It would be valuable to have the rest of these sent to the lab to add a more robust group for the years we did ample, however more sample years and locations may be more beneficial for managers. It would be possible to get samples from across all of Texas, and this would give a more concise idea of what the gray fox age structure and annual survival is.

I originally thought there would be more variation between the 2 regions due to the diverse habitat found and the difference in human interactions. The data supports that the 2 regions are similar in the age structure and survival rate of the gray fox. I conclude that the gray foxes are thriving equally as well in these 2 regions.

LITERATURE CITED

Afandador, E. G., M.E. Kjelland, X. B.Wu, N. Wilkins, and W. E. Grant. 2016. Ownership property size, landscape structure, and spatial relationships in the Edwards Plateau of Texas (USA): landscape scale habitat management implications. Environment System & Decisions 36:310-328.

Correll, D. S., and M. C. Johnston. 1979. Introduction. Pages 1-15. Manual of the vascular plants of Texas. The University of Texas at Dallas. Richardson, Texas, USA.

Cunningham, S. C., L. Kirkendall, and W. Ballard. 2006. Gray fox and coyote abundance and diet responses after a wildfire in central Arizona. Western North American Naturalist 66: 169-180.

Deuel, N. R., L. M. Conner, K. V. Miller, M. J. Chamberlain, M. J. Cherry, and L.V. Tannenbaum. 2017. Gray fox home range, spatial overlap, mated pair interactions and extraterritorial forays in southwestern Georgia, USA. Wildlife Biology 2017:1-10.

DeYoung, R. W., A. Zamorano, B. T. Mesenbrink, T. A. Campbell, B. R. Leland, G. M. Moore, R. L. Honeycutt, and J. J. Root. 2009. Landscape-genetic analysis of population structure in the Texas gray fox oral rabies vaccination zone. The Journal of Wildlife Management 73: 1292-1299.

Farias, V., T. K. Fuller, R. K Wayne, and R. M. Sauvajor. 2005. Survival and cause-specific mortality of gray foxes. Journal of Zoology, London 266: 249-254.

Fritzell, E.K., K.J. Haroldson. 1982. *Urocyon cinereoargenteus*. Mammalian Species 189: 1-8.

Glenn J.L.W, D.J. Civitello, and S.L. Lance. 2008. Multiple paternity and kinship in the gray fox (*Urocyon cinereoargenteus*). Mammalian Biology 74: 394-402.

Gould, F. W., G. O. Hoffman, and C. A. Rechenthin. 1960. Vegetational areas of Texas. Texas Agricultural Experiment Station, College Station, Texas, USA.

Harrison, R.L. 1997. A comparison of gray fox ecology between residential and undeveloped rural landscapes. The Journal of Wildlife Management 61: 112-122.

Haverland, M.B., and J.A. Veech. 2017. Examining the occurrence of mammal species in natural areas within a rapidly urbanizing region of Texas, USA. Landscape and Urban Planning 157: 221-230.

Kamler, J.F., W.B. Ballard, R.L Gilliland, P.R. Lemmons II, and K. Mote. 2003. Impacts of coyotes on swift foxes in Northwestern Texas. The Journal of Wildlife Management 67: 317-323.

Larson, R.N., D.J. Morin, I.A. Wierzbowska, and K.R. Crooks. 2015. Food habits of coyotes, gray foxes, and bobcats in a coastal southern California urban landscape. Western North American Naturalist 75: 339-347.

Layne, J.N. 1958. Reproductive characteristics of the gray fox in southern Illinois. The Journal of Wildlife Management 22: 157-163.

Root, D.A., and N.F. Payne. 1984. Evaluation of techniques for aging gray fox. The Journal of Wildlife Management 48: 926-933.

Temple, D.L., M.J. Chamberlain, and L.M. Conner. 2010. Spatial ecology, survival and cause-specific mortality of gray foxes (*Urocyon cinereoargenteus*) in a longleaf pine ecosystem. The American Midland Naturalist 163: 413-422.

West Texas Big Bob Cat Hunt [WTTBC]. 2019. WTTBC homepage http://www.wtbbc.org/ . Accessed 9 September 2019.

Weston Glenn, J.L., D.J. Civitello, and S.L. Lance. 2008. Multiple paternity and kinship in the gray fox (*Urocyon cinereoargenteus*). Mammalian Biology 74:394-402.

Wood, J.E. 1958. Age structure and productivity of a gray fox population. Journal of Mammalogy 39: 74-86.

Table II.1. Same size, age-structured regression statistics, and annual survival estimates of gray foxes collected from western Texas, 2016-2017. Independent variable is the age categories and the dependent variable is age of each individal.

Region	Sex	N	Regression Equation	r^2	Survival
Pooled	Pooled	288	y= -11.517x + 78.067	0.919	65%
	Female	126	y= -5.2333x + 34.933	0.797	64.7%
	Male	157	y= -6.1197x + 41.911	0.862	64.3%
Edwards Plateau	Pooled	202	y= -8.1833x + 55.178	0.817	63.6%
	Female	86	y= -3.6833x + 24.289	0.921	67%
	Male	115	y= -4.45x + 30.578	0.847	65.6%
Trans Pecos	Pooled	46	y= -4.45x + 30.578	0.597	71.7%
	Female	18	y= -4.45x + 30.578	0.389	84.1%
	Male	28	y= -4.45x + 30.578	0.425	77.1%

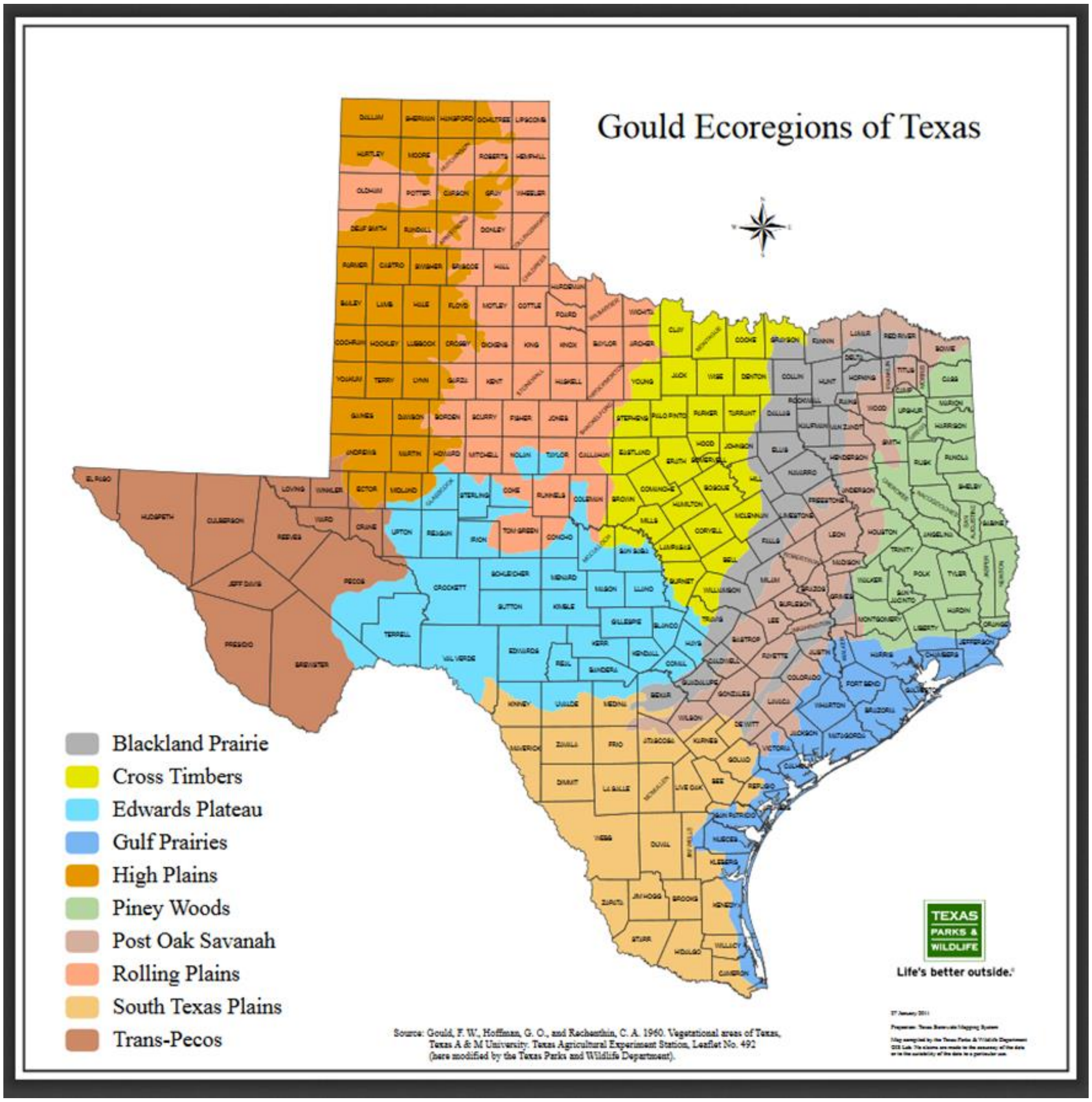


Figure II.1. A map reperesenting the Gould Ecoregions in the state of Texas. Gray fox specimens came from counties in the Edwards Plateau ecoregion and Trans-Pecos ecoregion.

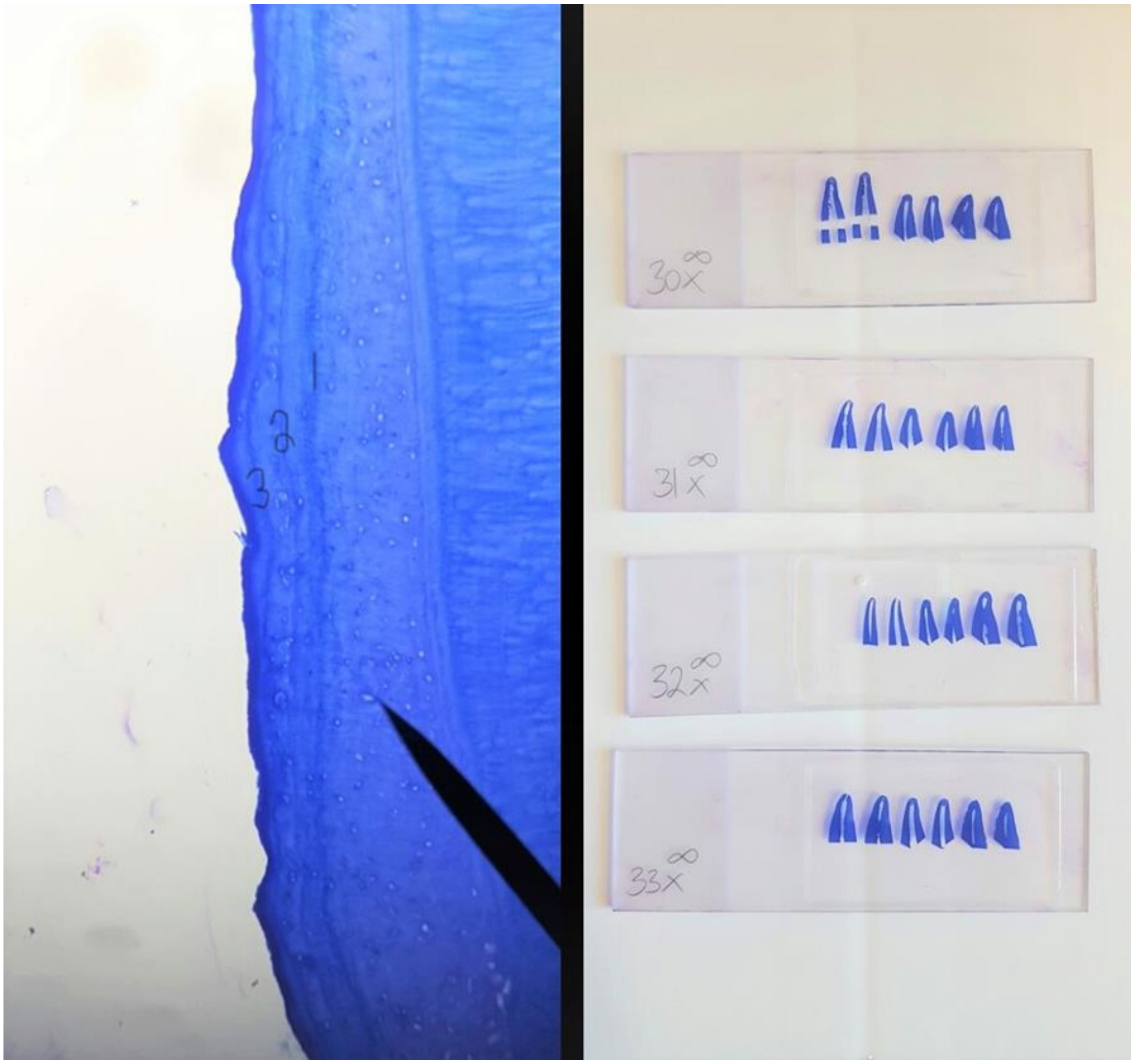


Figure II.2. An example of the microscope slides with the cementium annuli. The picture on the left represents a three year old individual. The picture on the right represents three individuals on each slide.

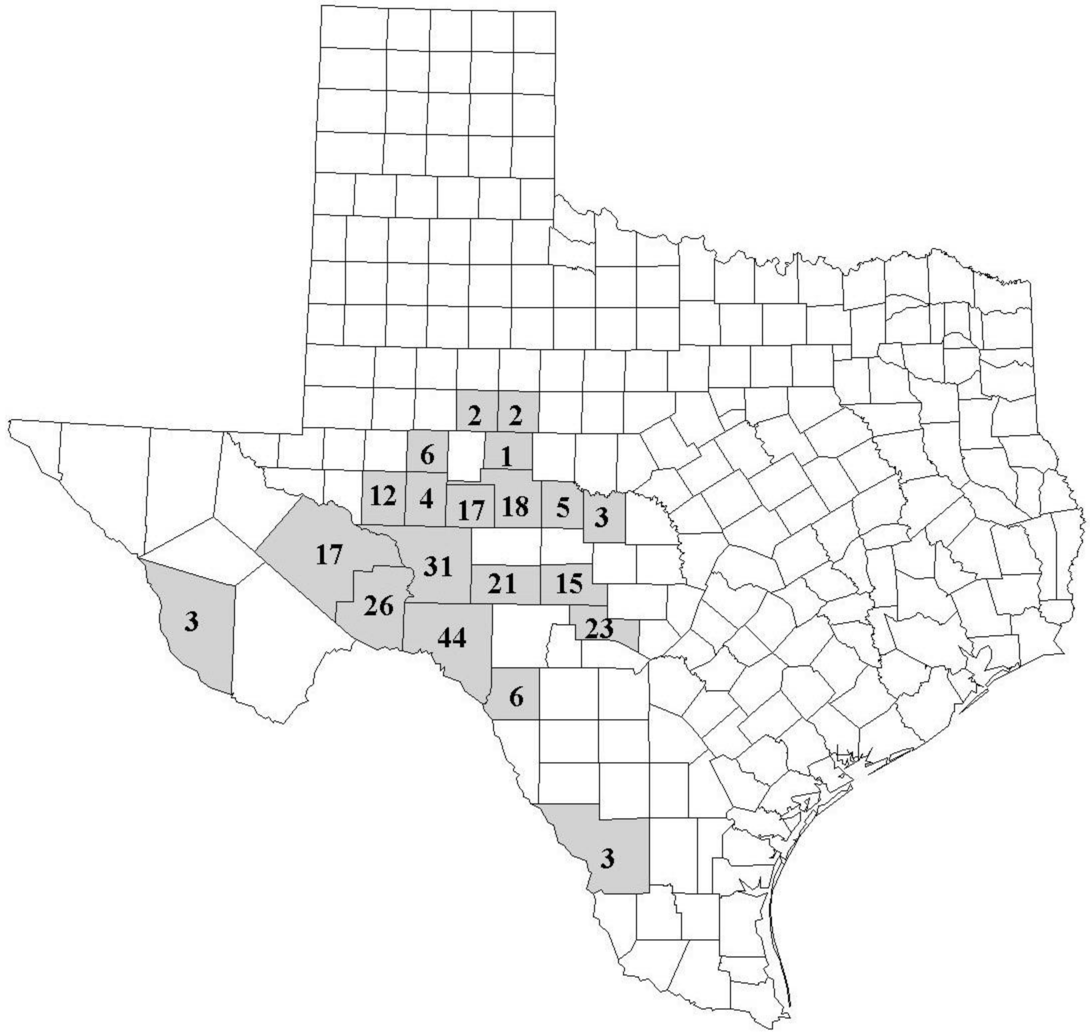


Figure II.3. Representaion of Texas with the number of gray fox samples collected in each county.

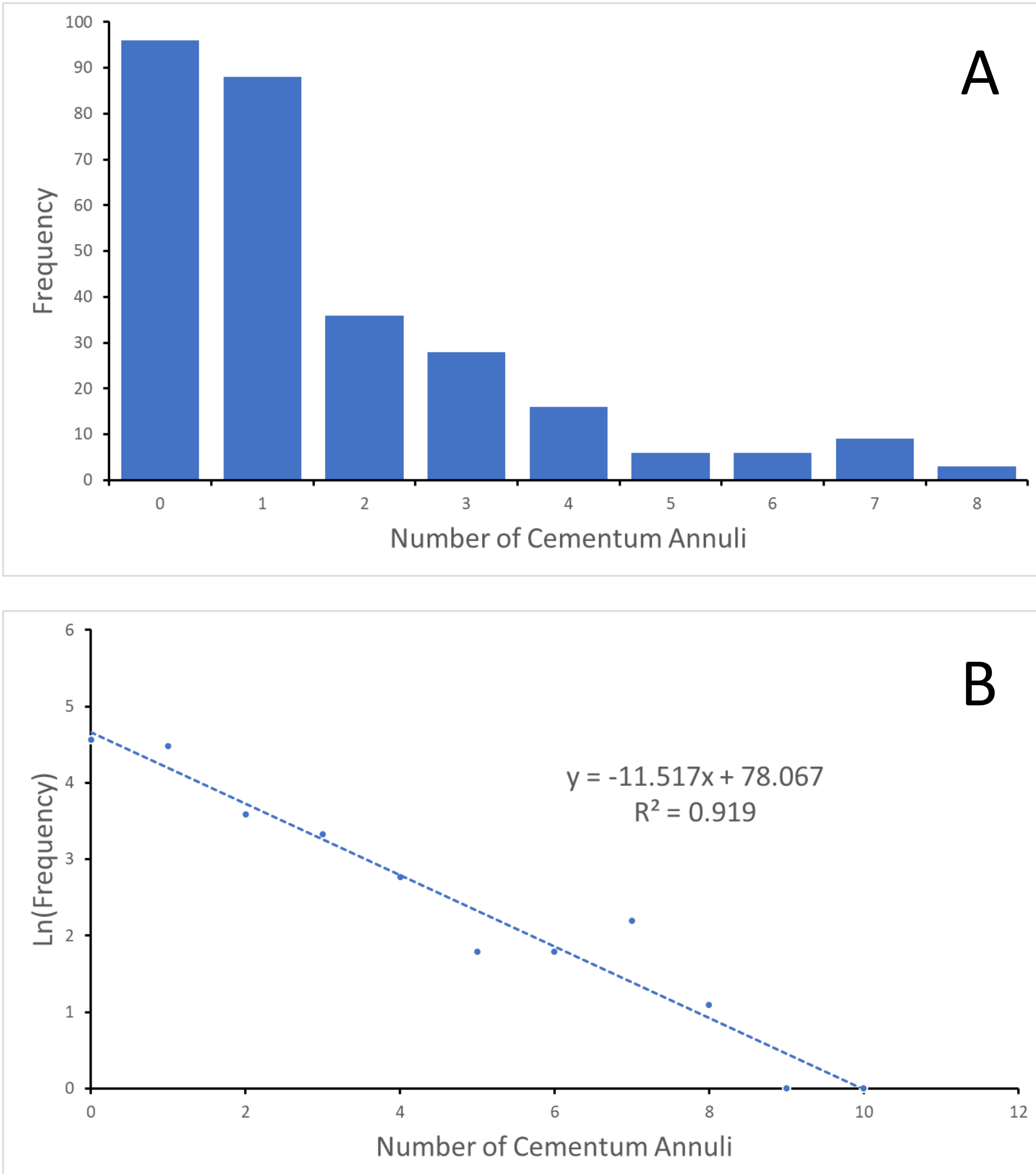
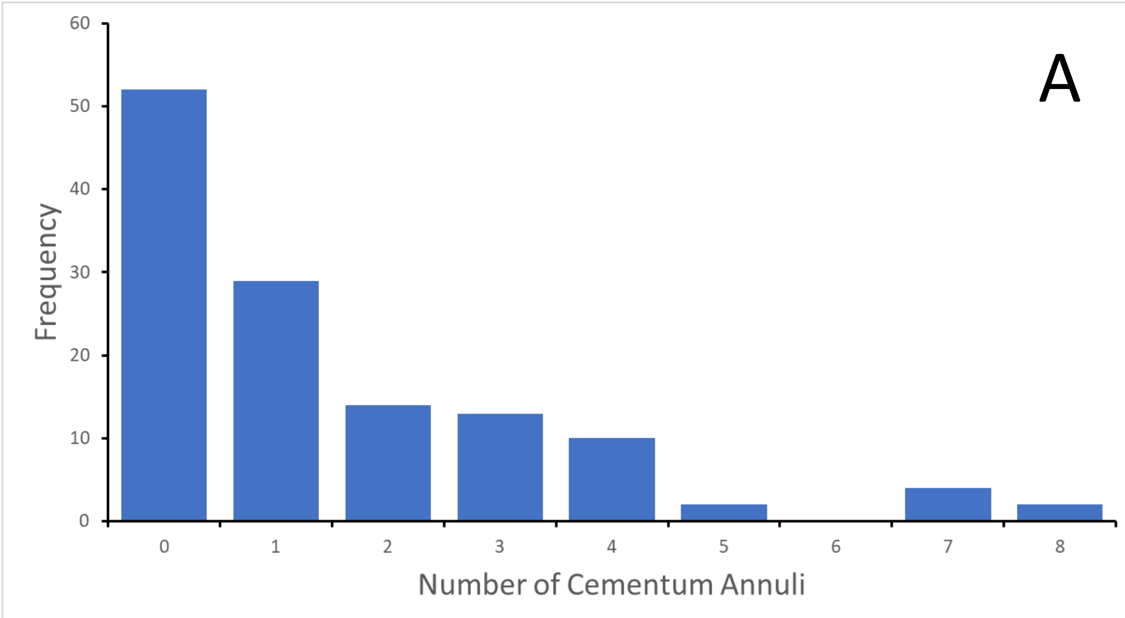


Figure II.4. Age distribution of all gray foxes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 228), western Texas, 2016-2017.



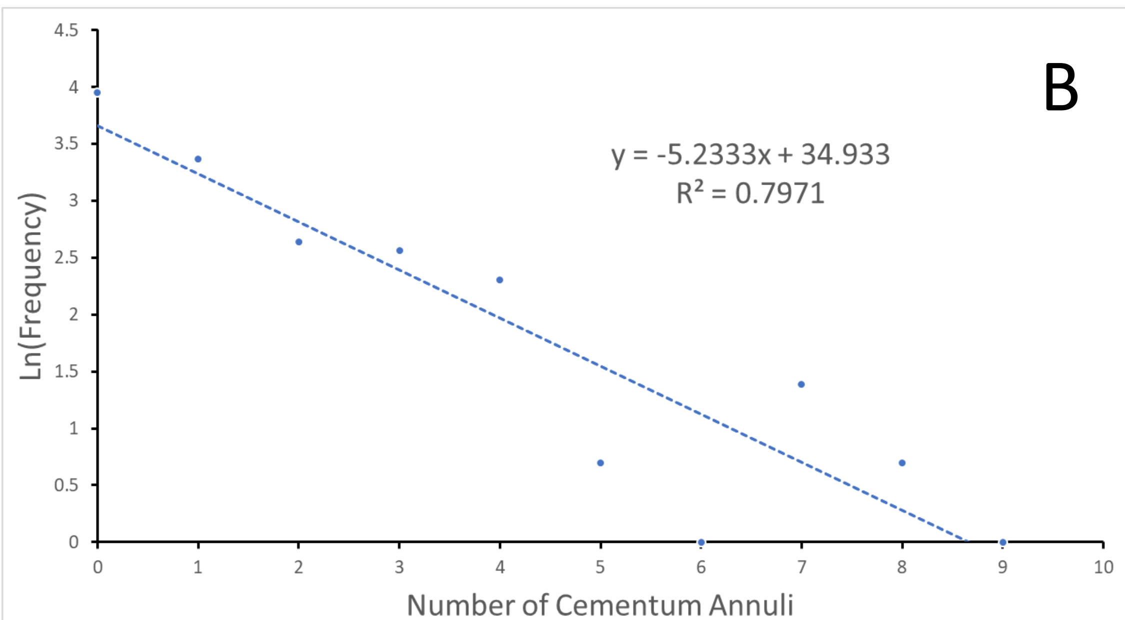


Figure II.5. Age distribution of all female gray foxes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 126), western Texas, 2016-2017.

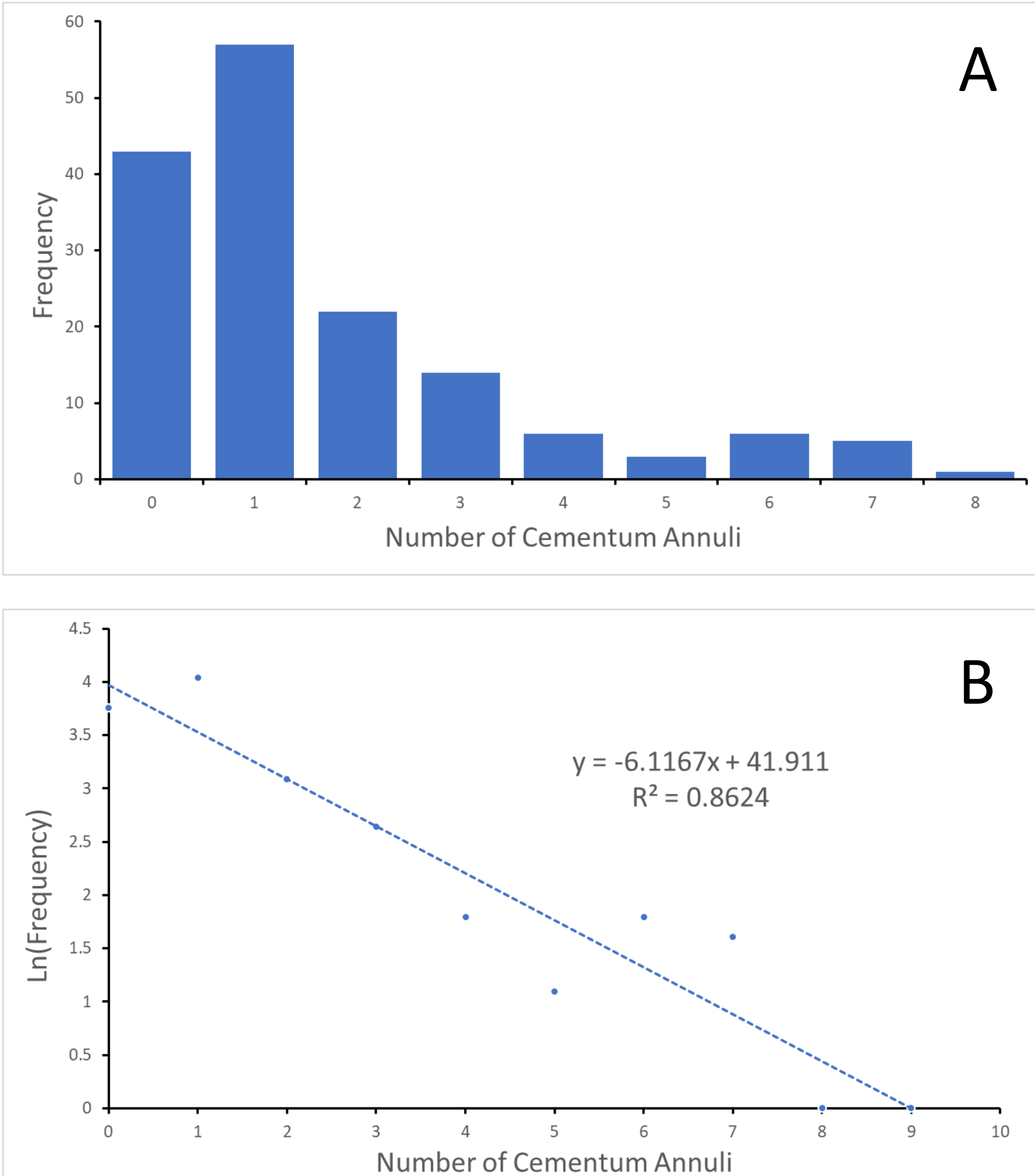


Figure II.6. Age distribution of all male gray foxes (A) and age-structured regression (B) derived from cementum annuli analysis (n = 157), western Texas, 2016-2017.

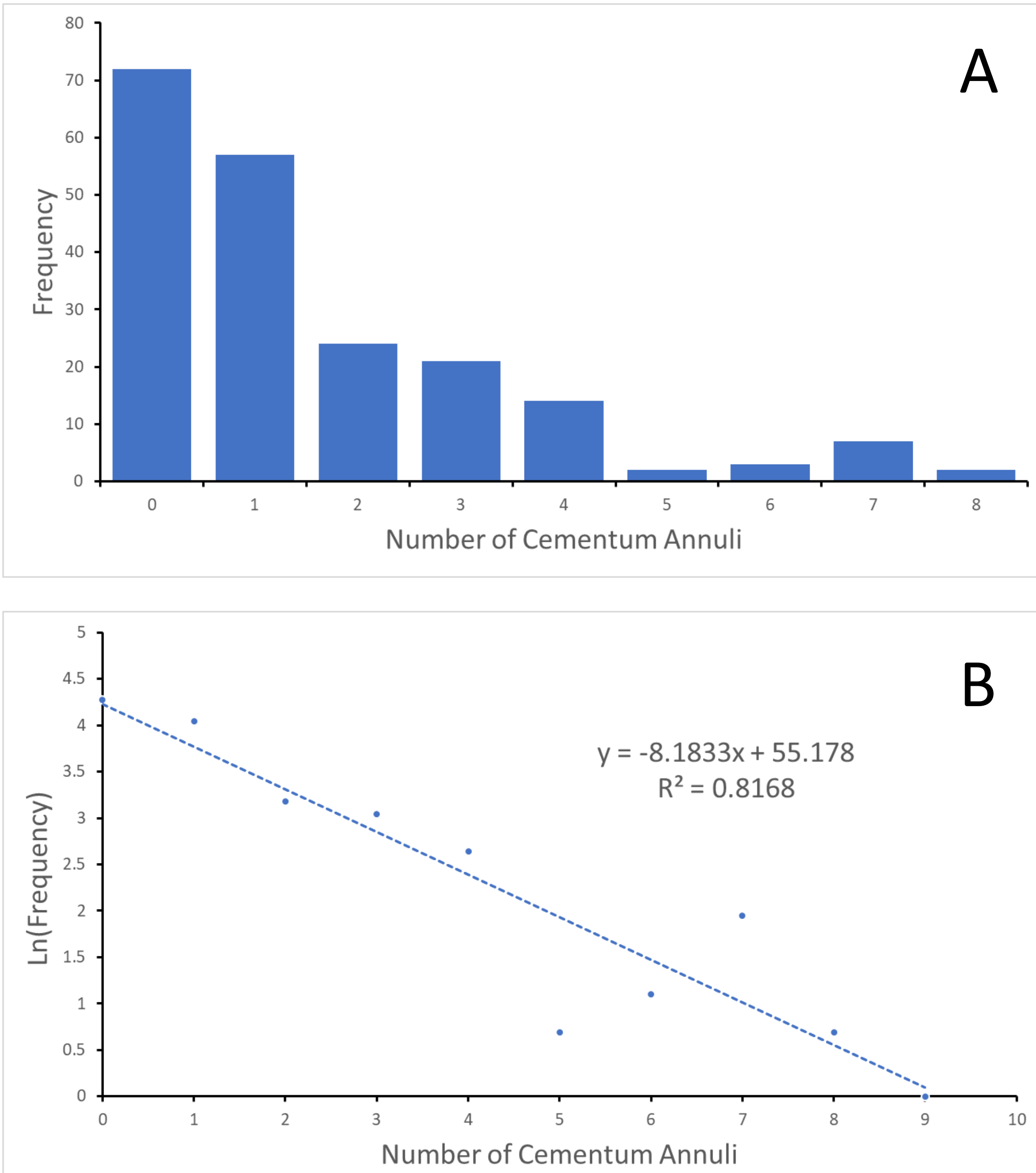


Figure II.7. Age distribution of gray foxes from the Edward's Plateau (A) and age-structured regression (B) derived from cementum annuli analysis (n = 202), western Texas, 2016-2017.

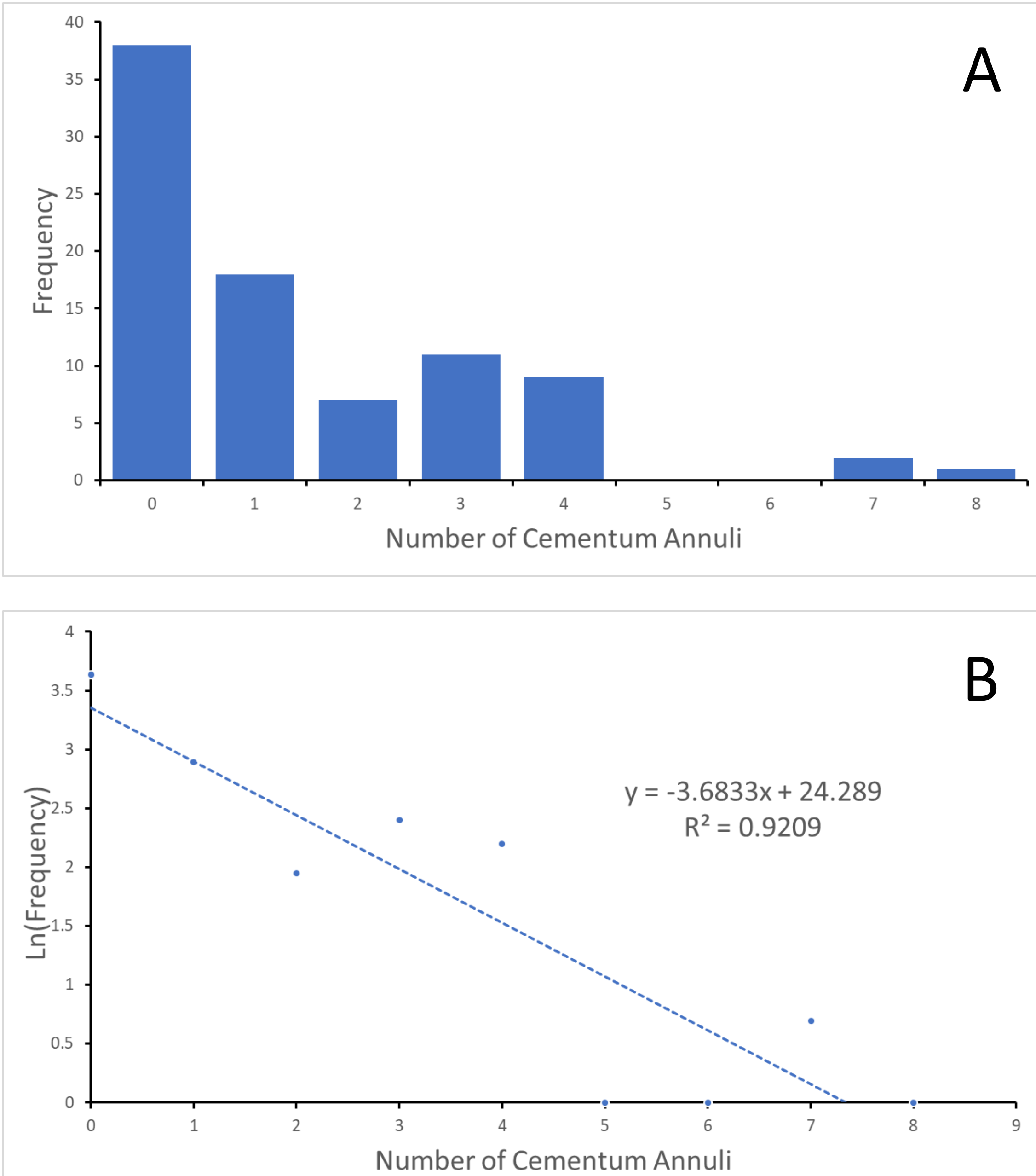


Figure II.8. Age distribution of female gray foxes from the Edward's Plateau (A) and age-structured regression (B) derived from cementum annuli analysis (n = 86), western Texas, 2016-2017.

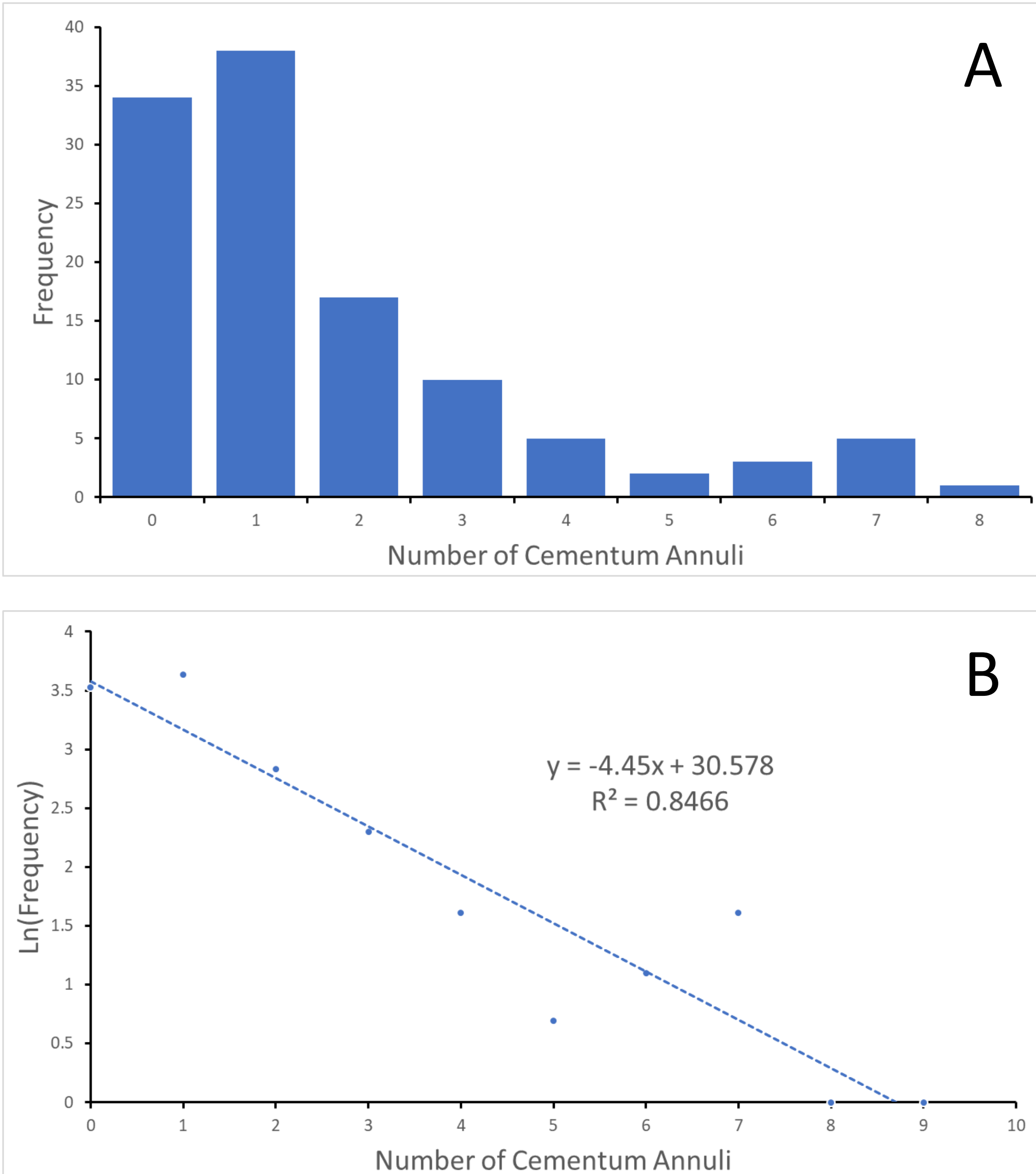
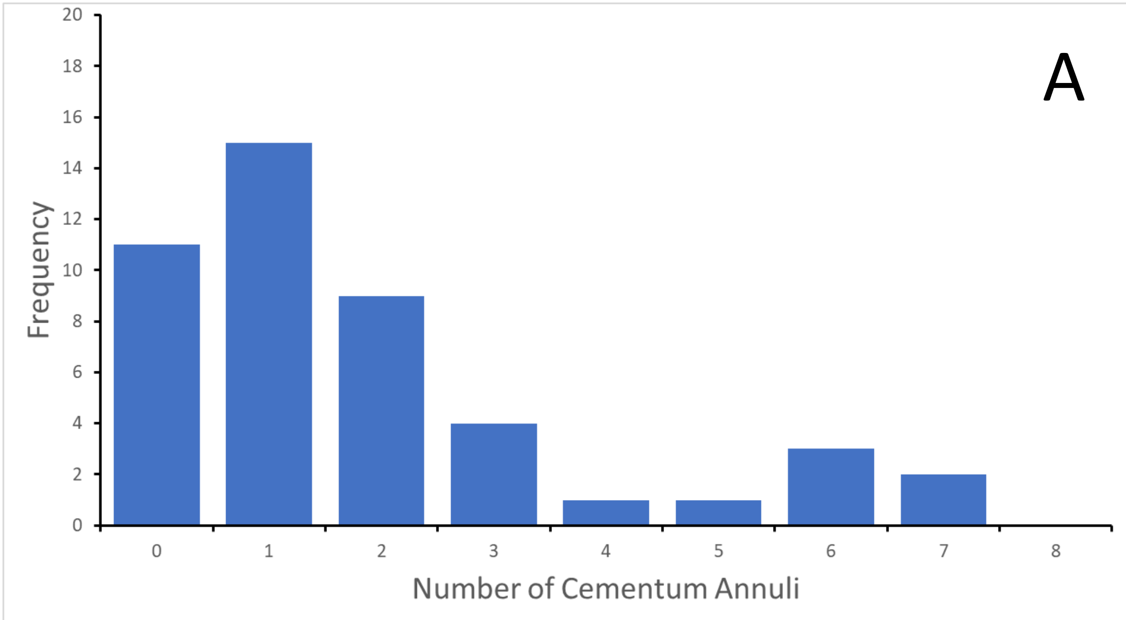


Figure II.9. Age distribution of male gray foxes from the Edward's Plateau (A) and age-structured regression (B) derived from cementum annuli analysis (n = 115), western Texas, 2016-2017.



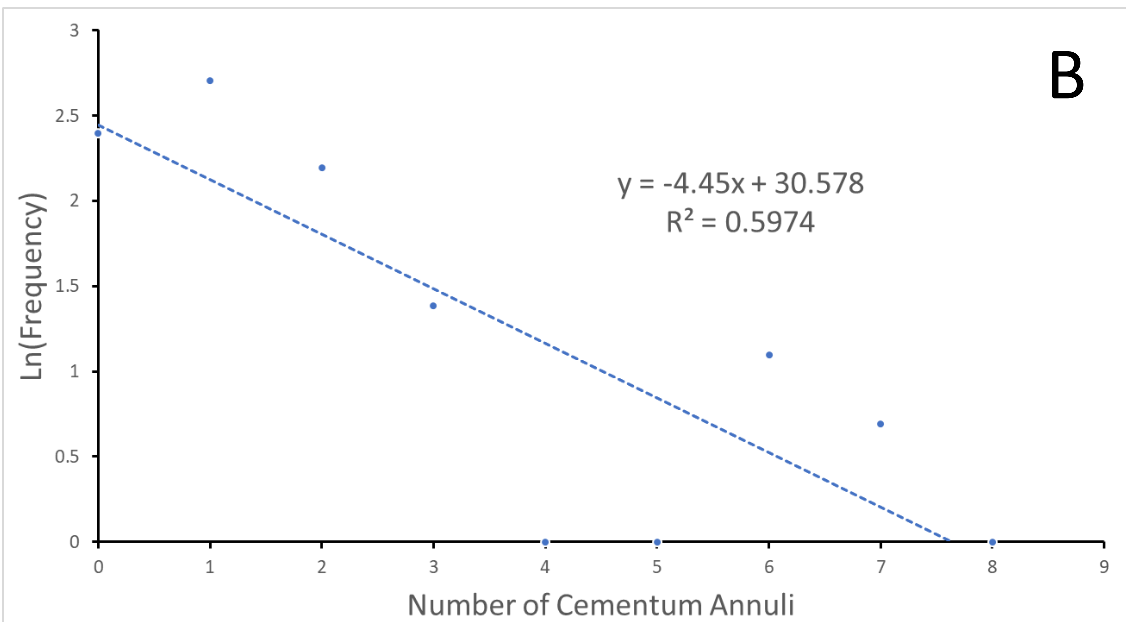
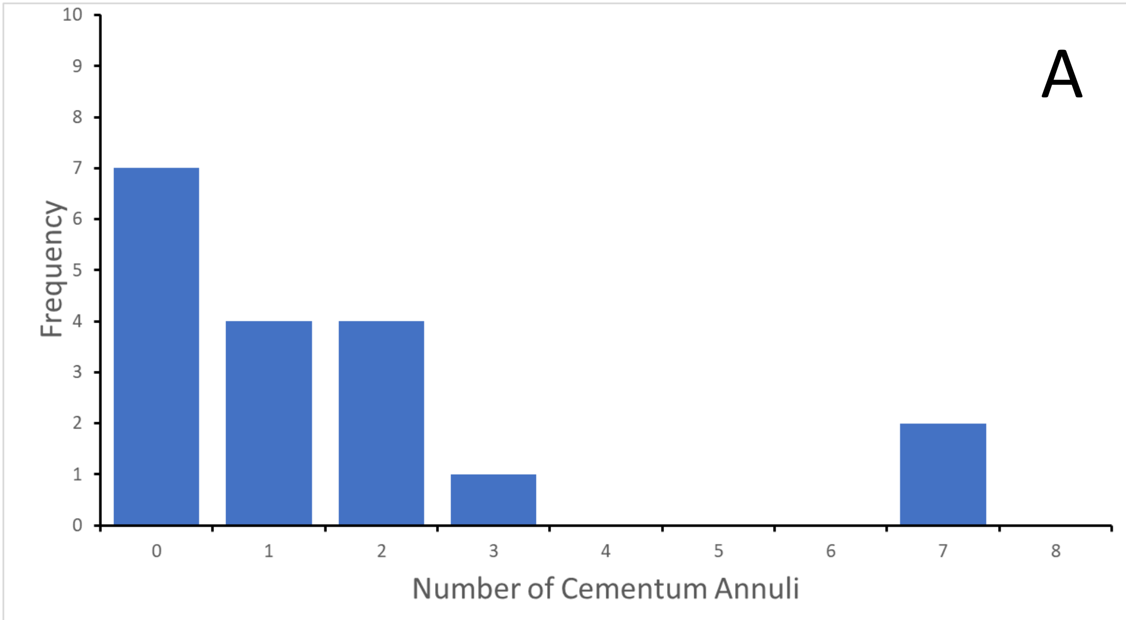


Figure II.10. Age distribution of all gray foxes from the Trans Pecos (A) and age-structured regression (B) derived from cementum annuli analysis (n = 46), western Texas, 2016-2017.



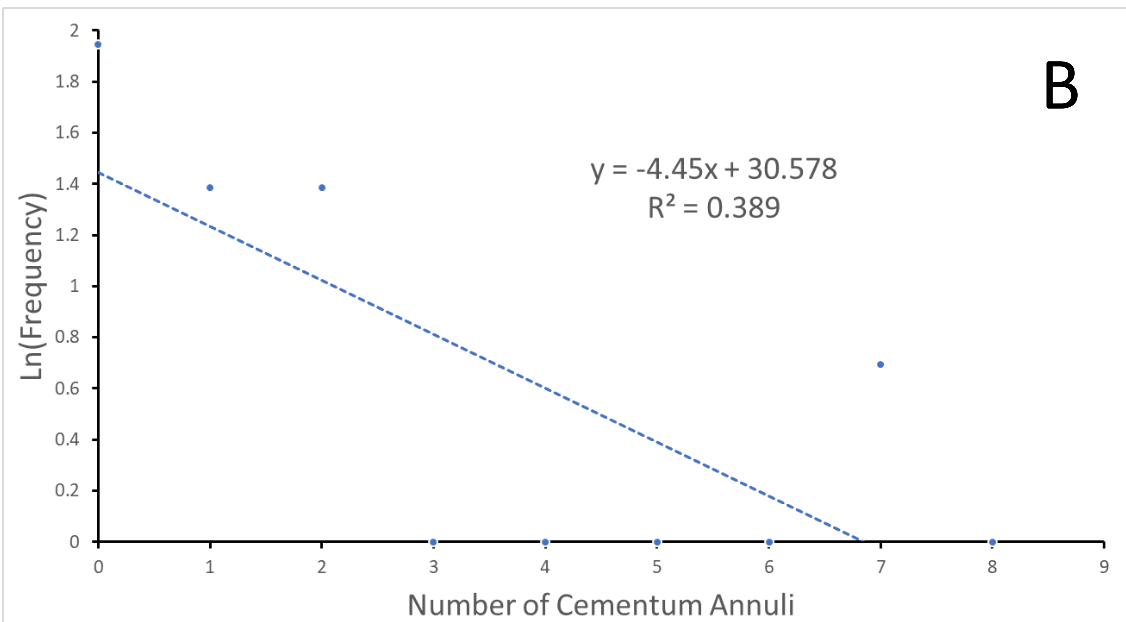


Figure II.11. Age distribution of female gray foxes from the Trans Pecos (A) and age-structured regression (B) derived from cementum annuli analysis (n = 18), western Texas, 2016-2017.

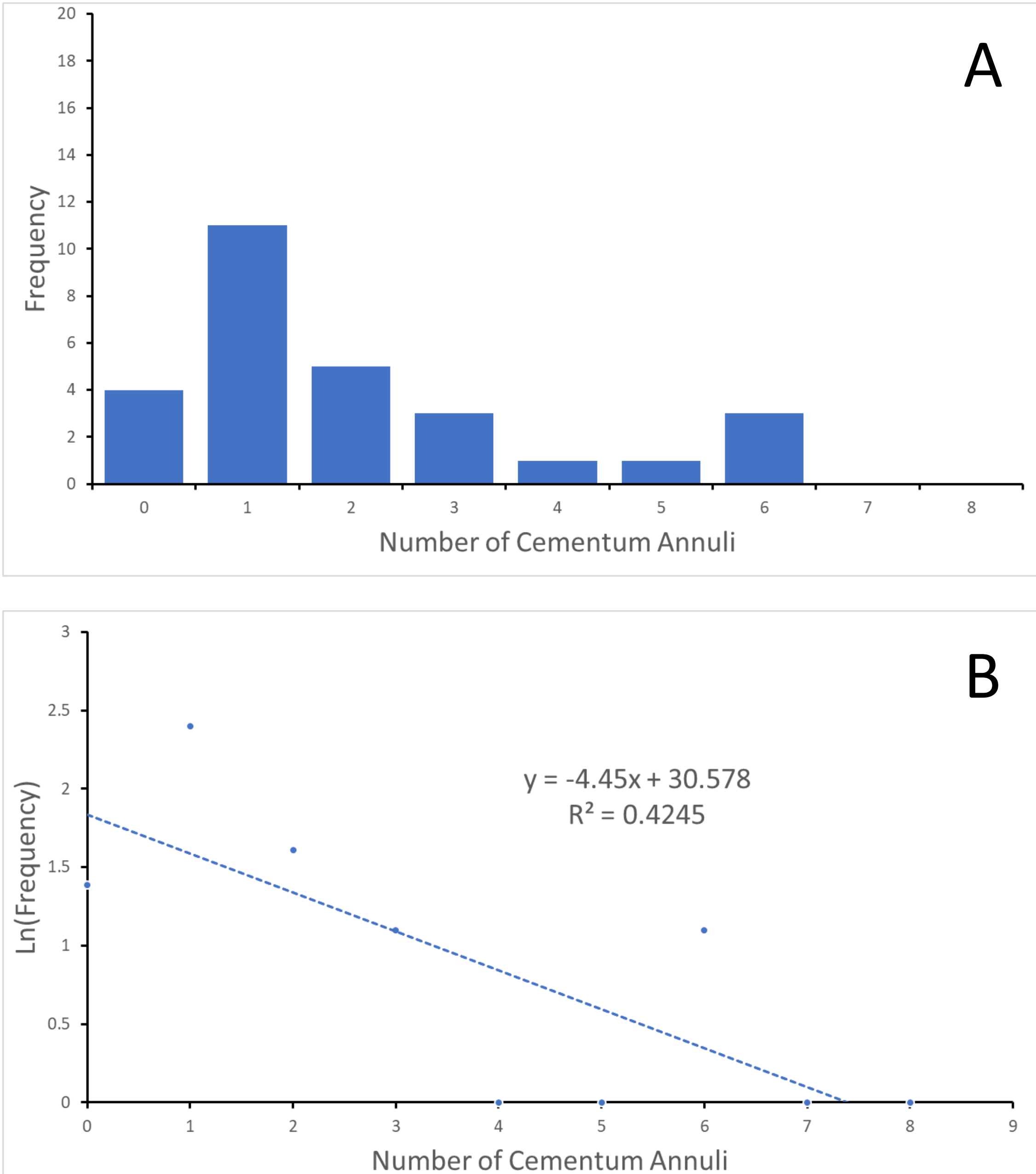


Figure II.12. Age distribution of male gray foxes from the Trans Pecos (A) and age-structured regression (B) derived from cementum annuli analysis (n = 28), western Texas, 2016-2017.