A COMPARISON OF WHITE-TAILED DEER RECRUITMENT RATES TO RELATIVE PREDATOR ABUNDANCE IN MARYLAND

by

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ABSTRACT

In the late 1990s, Maryland's deer management plan aimed to reduce and stabilize the state's white-tailed deer (*Odocoileus virginianus*) population. While attempting to achieve this goal through liberalized seasons and bag limits, managers estimated a decreasing fawn recruitment rate and sought to better understand causes for these declines, particularly in the western portion of the state. Fawn recruitment may be impacted by several factors: predation, disease, starvation, malnutrition, parasite-load, and collisions with vehicles and farm machinery. My study's goal was to better understand the predator-prey relationship within western Maryland. One hypothesis is the predator community reducing the fawn recruitment. In western Maryland, black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and coyote (*Canis latrans*) are established, but the variation in abundance of these populations has not been well documented. I established 3 study areas focused on 3 publicly hunted state forests (Potomac-Garrett, Savage River, and Green Ridge State Forests). The first objective was to estimate the deer density and fawn recruitment at each study area. I used road-based distance sampling using a forward-looking infrared (FLIR) device to scan the landscape from August-October, 2015 and 2016. I replicated the FLIR survey 6 times on each study area in 2015 and 2016. Once collected, the data were analyzed using a uniform-key function within program DISTANCE. Neither deer density (Potomac-Garrett = 16 deer/km^2, Savage River = 6 deer/km^2, Green Ridge = 12 deer/km^2) nor fawn recruitment (Potomac-

Garrett = 0.56 fawn/doe, Savage River = 0.54 fawn/doe, Green Ridge = 0.52 fawn/doe) changed between years.

My second objective was to estimate a relative predator (black bear, bobcat, and coyote) density among study areas. Each study area contained a systematic grid of 20 cameras spaced 3.2-km apart. This grid created an 8-km^2 buffer around each camera to maintain site independence based on the average home range size of my target species. Cameras were deployed from June-August for a 60-day survey period in 2015 and 2016. Throughout the study, I logged 6,300 camera trap nights during the summer months. To compare predator densities using optimal sampling protocol, I performed an additional 60-day camera survey from December 2016-February 2017, logging 3,300 camera trap nights. I analyzed all data using Royal and Nichols (2004) N-Mixture Model within package *unmarked* for R 3.0.3 software. Predator densities shared 95% confidence intervals among sites and years. The average yearly mean and standard error of black bear density for each state forest were: Potomac-Garrett: M = 0.35, SE =0.10 bear/km^2, Savage River: M = 0.51, SE = 0.12 bear/km^2, and Green Ridge: M = 0.28, SE = 0.07 bear/km^2. The average yearly mean and standard error of bobcat density for each state forest were: Potomac-Garrett: M = 0.10, SE =0.11 bobcat/km^2, Savage River: M = 0.13, SE = 0.14 bobcat/km^2, and Green Ridge: M = 0.09, SE = 0.11 bobcat/km^2. The average yearly mean and standard error of coyote density for each state forest were: Potomac-Garett: M = 1.84, SE = 1.10 coyote/km^2, Savage River: M = 0.88, SE = 0.55 coyote/km^2, and Green Ridge: M = 0.19, SE = 0.16 coyote/km^2. Finally, I compared fawn recruitment to the predator densities at each of the 3 study areas. The results of our study indicated a stable, albeit on the low side of fawn recruitment but variable predator density across the landscape, suggesting that the predator community is not lowering the fawn recruitment.

Chapter 1

A COMPARISON OF WHITE-TAILED DEER RECRUITMENT RATES TO RELATIVE PREDATOR ABUNDANCE IN MARYLAND

1.1 Introduction

The Maryland Department of Natural Resources (MDNR) established its first deer management plan in 1998. The MDNR had 4 main goals in this plan, one of which was to "maintain deer populations at levels necessary to ensure compatibility with human land uses and natural communities" (MDNR 2009). Throughout the 1990's, Maryland's white-tailed deer (*Odocoileus virginianus*) population was increasing but still under the biological carrying capacity; however, a cultural carrying capacity was likely exceeded based on increased complaints of ornamental plant damage, deer crossing major commuter corridors, and concern of Lyme disease prevalence (MDNR 2009). These complaints combined with reduced hunting opportunities due to development of suburban areas amplified the issues the state was facing. To achieve the goal of the management plan, the state enacted liberal seasons and bag limits for antlerless deer harvest. The MDNR successfully lowered the deer population through these actions, but it remains too high in many parts of the state. However, in the years after the population was lowered within western Maryland (Region A), the hunting community became concerned by the reduced number of deer observations. The state of Maryland currently manages its white-tailed deer population in 2 regions (Figure 1.1). Region A consists of Garrett, Allegany, and western Washington Counties. Region B consists of the remaining 21 counties. More restrictive season and bag limits were enacted in Region A to address the concerns of the hunters and increase the population within Region A. However, the deer population within Region A was slow to respond to the reduced harvest pressure. The MDNR estimated a low fawn recruitment compared to historical data. In the case of this study, I define fawn recruitment as the number of fawns that survive their first 60-days of life per adult doe (1.5+ years). In the last 20 years, region A's fawn recruitment has averaged 0.50 (0.31-0.80) whereas region B's fawn recruitment has averaged 0.68 (0.44-0.90). Fawn recruitment may be impacted by predation, disease, starvation, malnutrition, parasites, and collisions with vehicles and farm machinery (Nelson et al. 1987, Vreeland et al. 2004), but predation is often implicated as the main source. Three mammalian predators of neonatal fawns occur in western Maryland: black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and coyote (*Canis latrans*), all of which have experienced an increase in population abundance over the last 30 years (Eyler and Timko 2014).

Historically, black bears were found statewide in Maryland (Mansueti 1950), but deforestation and unregulated hunting resulted in a severe decline of black bear abundance throughout the state. The distribution of bears was reduced to areas within Garrett and Allegany Counties, and from 1937–1951, the population decreased from 150 to 20 individuals (Paradiso 1969). In response to this decline, the Maryland Department of Natural Resources (MDNR) closed the bear hunting season in 1953 and then in 1972 changed the status of the black bear from forest game animal to an endangered species. Through reforestation and harvest protection, the bear population recovered and was delisted in 1980. By 1985, the black bear was reclassified as a forest game animal with a closed hunting season. In 2000, Maryland biologists using a hair snare survey estimated 700 adult and subadult bears with a density of 10.5 bear/100km^2 in Garrett and Allegany Counties (Bittner et al. 2002). In 2004, Maryland opened the first hunting season for black bear in 51 years. Currently, the MDNR targets an 8-12% harvest rate with a goal of 20-25% overall mortality annually (Spiker 2013, MDNR 2015). Another hair-snare survey was performed in 2005, estimating 15.2 bear/100km^2. The most recent density estimate was conducted in 2011 and estimated the bear population in western Maryland to be 513-889 (density of 25 bear/100km^2) with an annual growth rate of 11.7% from 2005-2011 (Jones 2015, MDNR 2015). Surrounding states have observed similar levels of black bear population growth; both Pennsylvania and West Virginia bear harvest rate and vehicle collisions have increased exponentially in the past 20 years (Ternent 2006, Carpenter 2016).

Similar to the black bear, Maryland's bobcat population was drastically reduced in the late 1800's, and was subsequently able to recover due to forest regeneration and a closed hunting season. Currently, bobcats are seen regularly throughout Garrett and Allegany Counties and are becoming more common in counties to the east. The MDNR lists bobcats as a fur-bearing mammal with a closed season, but the population size has not been estimated (MDNR 2014a). West Virginia has a bobcat harvest season running from November-February; the average harvest from 2011-2015 was 1,852 bobcats/year (WVDNR 2016). Pennsylvania established a bobcat season in 2008, running from December-February. Based on annual harvest reports, vehicle collisions, and accidental captures by trappers, the bobcat population is estimated to be stable within Pennsylvania (Lovallo and Hardisky 2012).

Historically, the coyote was found in the western U.S., but has been moving eastward for the past 100 years. The species reached Maryland in 1972 and is thought to have immigrated from both the north and south. Since then coyotes have spread throughout the state; however, the population size is unknown. Currently, coyotes are considered a fur-bearing mammal and have an open hunting season that lasts year-round in Maryland. Coyotes have a trapping season from October 31 to February 1 west of the Chesapeake Bay and Susquehanna River, and from November 14 to February 13 to the east (MDNR 2014b). Surrounding states have similar harvest season and bag limits. West Virginia has harvested an average 2,268 coyote/year from 2011-2015 (WVDNR 2016). Pennsylvania has been experiencing an increase in number of coyotes harvested annually for the last 20 years; the coyote population is estimated to be stable within the state (Lovallo and Hardisky 2012).

Errington (1956) presented the concept of a "doomed surplus" within a population that predator communities may utilize without a negative consequence on the population. The population loss due to the predator communities would be described as a compensatory form of mortality (Gasaway et al. 1992), with predators causing limitations to population growth with additive mortality. White-tailed deer fawn mortality due to predation has ranged from 0-100% throughout the United States. Black bear, bobcat, and coyote are previously reported as being a significant form of mortality to neonatal fawns (Ballard et al. 1999, Decker et al. 1992, Long et al. 1998, Vreeland et al. 2004, Duquette et al. 2014a, Nelson et al. 2015).

To aid the understanding of deer demographic characteristics within Region A, my first objective was to use forward looking infrared (FLIR)-based road transects with distance sampling to estimate deer demographic rates across 3 state forests in region A and compare results to deer population reconstruction (PR) estimates calculated using harvest data. Predation has been previously cited as a major cause of reduced fawn recruitment. The second objective of my study was to estimate abundance for black bear, bobcat, and coyote on 3 state forests in western Maryland and to compare these estimates among areas. The final objective of my study was to compare fawn recruitment to a relative density of predators among 3 state forests in western Maryland.

1.2 Study Area

I conducted this research on Potomac-Garrett State Forest, Savage River State Forest, and Green Ridge State Forest in western Maryland (Figure 1.2). Potomac-Garrett (72.8 km^2) and Savage River State Forests (218.5 km^2) are located in Garrett County, Maryland. Potomac-Garrett hunters harvested an average 3.4 deer/km^2/year and Savage River hunters harvested an average 1.7 deer/km^2/year, whereas Garrett County reported an average of 1.4 deer harvested/km^2/year from 2007-2016 (MDNR 2017). Green Ridge State Forest (192.5 km^2) lies on the eastern edge of Allegany County, Maryland. Green Ridge hunters harvested an average 2.4 deer/km^2/year and Allegany County hunters averaged 1.8 deer harvested/km^2/year from 2007-2016 (MDNR 2017). Garrett County has 2.6 times more agricultural landcover than Allegany County.

These state forests each were >90% second-growth mature forest. Dominant overstory species included hickories (*Carya spp*.), oaks (*Quercus spp.*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), interspersed with white pine (*Pinus strobus*), Virginia pine (*Pinus virginiana*), red pine (*Pinus resinosa*), red spruce (*Picea rubens*) and black cherry (*Prunus serotina*). Common midstory and understory species included Japanese knotweed (*Polygonum cuspidatum*), northern highbush blueberry (*Vaccinium corymbosum*), mayapple (*Podophyllum spp.*), greenbriar (*Smilax spp*.), eastern redbud (*Cercis canadensis*), and sassafras (*Sassafras albidum*) (Perdue 2011).

1.3 Methods

1.3.1 Deer FLIR Survey

I conducted 6 replicates of FLIR surveys at the 3 state forests (SF) used as study areas from mid-August to mid-October 2015 and 2016. I used the 45km survey route established in Green Ridge SF by Haus (2013) and established a new 45km survey route on Savage River SF and Potomac-Garrett SF. The Green Ridge SF survey route consisted of: Green Ridge, Mertens, Kirk, Malcolm, Old Town Orleans, and Fifteen Mile Creek roads. Savage River SF survey route consisted of: West Shale, Big Run, and Dry Run roads. Potomac Garrett SF survey route consisted of: Sang Run, Oakland Sang Run, Shingle Camp, Swallow Falls, Herrington Manor, Snaggy Mountain, and Cranesville roads. All routes I surveyed were comprised of similar habitat (>96% mature forest, <2% single field, <2% maintained interspersed lawns). To reduce weather related biases, I restricted sampling periods to similar weather conditions (precipitation<0.05 cm/hour, visibility>70m from road, wind<4.0 km/h). To ensure independence of survey nights, I surveyed each route no more than once every 3 nights.

I surveyed each route using a Thermal–Eye 250D Digital FLIR device (L–3 Communications Infrared Products, Dallas, TX) using the protocol utilized by Haus (2013). I began surveys no earlier than 1 hour after sunset with start and stop locations constant across surveys. I used a 2-person team that traveled the survey route at a speed no greater than 20km/hour surveying only the right side of the road. To reduce bias, I was the only observer throughout the study. When a cluster (single deer or multiple deer) was observed, I used a 12–volt spotlight (Cyclops Solutions LLC, Grand Prairie, TX) to determine the sex and age (adult/fawn) of each individual. I recorded perpendicular distance to the cluster or original position if deer were observed moving in response to the approaching vehicle. I obtained distance estimates using a laser rangefinder (Leica Camera AG, Solms, Germany; ± 1 m accuracy).

I used Program DISTANCE 6.0, version 2 to estimate density and fawn recruitment (Thomas et al. 2010). Due to my sampling protocol requiring similar weather and habitat conditions, I did not include covariates. I used a uniform key function with cosine adjustment based on the standard distribution of deer detected from the road transects and used a 0.5 sampling factor because we only surveyed one side of the road. I analyzed the data using a right-truncation at 70m throughout the study due to inaccuracies estimating age class beyond 70m. I compared estimates between study areas using point estimates (number of deer/km^2), standard error (SE), 95% confidence interval (CI) overlap, and percent coefficient of variation (CV). I considered distance results generated as different estimates if there was no overlap in 95% CIs, and only estimates with CV <25% were used (Skalski et al 2005).

1.3.2 Predator Camera Survey

Camera surveys have been used to estimate mammal population abundance (Bull et al. 1992, Mace et al. 1994, Bowman et al. 1996, Fuller et al. 2001, Watts et al. 2008, Haus 2013), distribution (Kucera and Barrett 1993, Brooks 1996), and structure (Ikeda et al. 2013). Recent studies have shown remote camera trapping utilizing package *unmarked* (Fiske and Chandler 2011) for R 3.0.3 software (R Core Team 2013) to be an effective method to estimate abundance (Duquette et al. 2014b, Rovero et al. 2014, Hallam et al. 2015, Olson et al. 2017).

I conducted a 60-day remote camera survey from June to August in 2015-2016. I placed 12-20 Reconyx HC-600 infrared cameras (Reconyx Inc., Holmen, WI) at each of the 3 study areas. I placed each camera 3.2km apart, providing an 8.0km^2 buffer around each camera (Figure 2.1). This buffer was established to provide camera site-independence for the sampling period and was based on the average female home range size of the 3-target species in similar habitat during the summer months (Alt et al. 1980, Litvaitis 1986, Holzman 1992, Moyer et al. 2007, Jones 2012). I adjusted camera placement within 500m of assigned point to increase likelihood of visitation by all predators (i.e. presence of game trail, optimal camera and bait tree, surrounding cover type, etc.)

At each site, I established a scent station with a camera to record visitation. Fine scale site selection prioritized finding a tree with dbh > 150cm to be used as the scent tree and a camera tree 3-5m away with dbh > 80cm (Figure 2.2). I placed 3-6 ml of Caven's gusto and 8-12 ml of annis oil directly on the trunk of the scent tree roughly 2 meters high and directly facing the camera. Using 30mm fishing line, I hung a turkey feather 2-3 meters off the ground using a tree limb and >30 cm away from the trunk of the scent tree (Figure 2.2). I oriented the feather between the tree and camera. I disturbed the leaf litter, moss, or top soil at the base of the scent tree in a 30x30 cm area. Finally, I dug a 7.5-10 cm deep and 2.5 cm wide hole at the base of the scent tree's trunk facing the camera and applied Carman's Coyote Pro Mix to the hole. I placed one Reconyx HC-600 infrared camera on the camera tree directly facing the scent tree. I placed the camera 0.6-1.0m up the trunk of the camera tree, with exact height and angle of camera being adjusted to achieve the best field of view of the scent station (Figure 2.2). I revisited camera stations every 7-10 days to reapply scents, download images, and camera maintenance.

Previous literature indicates that certain mammal species have an increased chance of detection during the winter months. As a comparison of detection rate and estimated predator densities, I performed a supplementary 60-day survey from December 2016-February 2017. The target species of this survey were bobcats and coyotes. I placed cameras in the same locations used during summer surveys and followed all previous methods for camera placement, scent application, site visits, data manipulation, and analysis. Additionally, during the winter survey, I attached 1-1.5 kg of either store-bought chicken breast or road-killed deer to the scent tree using 0.81mm wire. I did not estimate bear density in the winter survey due to decreased activity during the winter months.

I compiled all photographs by camera site at the end of each 60-day survey period. Camera data were analyzed with each sampling period consisting of 24 hours, from 1800-1799. To reduce double sampling, I examined all photos of each individual species within a sampling frame, discarding any photo that could not be identified as a separate individual based on morphological traits. I estimated relative predator density using package *unmarked* (Fiske and Chandler 2011) for R 3.0.3 software (R Core Team 2013) to estimate predator abundance with the *pCount* function, which uses the Royle-Nichols N-mixture model to produce estimates.

I performed a literature review to determine what covariates could be important for each species. I expected black bear abundance to be positively associated with increased forest area and total distance of minor roads (Brody and Pelton 1989, Clark et al. 1993). I expected bears to be negatively associated with major roads (Young and Beecham 1986). I expected bobcats to be positively associated with percent forest and minor roads, and negatively associated with major roads and percent developed land (Conner and Leopold 1993, Lovallo et al. 1996). I expected Julian date to be important during the winter to account for increased activity during the start of the survey coinciding with the end of deer harvest (Koehler and Hornocker 1991). I expected coyotes to be positively associated with agriculture and minor roads, and negatively associated with major roads (Litvaitis and Shaw 1980, Roy and Dorrance 1985, Kamler and Gipson 2000, Crete et al. 2001). I expected coyotes to use the habitat differently as the season progressed so I used a model comparing both Julian date and minor roads (Ozoga and Harger 1966, Koehler and Hornocker 1991, Kays et al. 2008).

I compared all models with observation covariates to a model with no covariates (null) and a model with all covariates used for that species (global). The black bear observation covariates I used were: percent forest land within each camera buffer (forest), total km of minor road within each camera buffer (minor), total km of major road and highways within each camera buffer (major), and the interaction of (forest*minor). The bobcat observation covariates I used were: Julian date, forest, minor road, major road, and percent developed land within each camera buffer (developed). The observation covariates I used for coyote were: Julian date, percent agriculture land within each camera buffer (agriculture), minor roads, major roads, and Julian date plus minor (Julian date+minor).

I performed covariate calculation within ArcGIS 10.2 using the 2014 topologically integrated geographic encoding and reference system (TIGER) shapefile for minor and major roads, and the 2011 USGS national landcover dataset for percentage of forest, agriculture, and developed land within camera buffers. I classified highway using master address file (MAF) and TIGER feature class code (MTFCC) S1100, major road as code S1200, and minor road as code S1400, S1500, S1630, S1640, S1710, S1730, S1740, S1750, S1780, and S1820. I classified developed as any land with code 21-31, forest as any land with code 41-71, 90, and 95, and agriculture with any code 81 and 82. There were no highways present within any camera buffers of Potomac-Garrett or Savage River, and within Green Ridge the total km of highway ranged from 0-14km. Covariate ranges were similar between state forests (Table 1.1).

I estimated black bear density using zero-inflated Poisson distribution. I estimated bobcat and coyote density using negative binomial distribution. I chose the distribution for each species based on the distribution type best fitting the data-points (Royle 2004, Kery et al 2005). I chose the top observation covariate using Akaike Information Criterion corrected for small sample size (AICc; Hurvich and Tsai 1989; Table 1.2, 1.3). I chose the model with the lowest AICc value for each species and all models with ΔiAICc ≥ 2 (Burnham and Anderson 2002, Posada and Buckley 2004) were considered to have support (Table 1.2, 1.3).

1.3.3 Predator-Prey Relationship

To determine the predator-prey relationship present on the landscape, I compared fawn recruitment estimates based on the FLIR surveys to the density estimates of predators at each site in both 2015 and 2016 via graphical comparisons. I formulated three hypotheses as the most likely predator-prey relationship present on the landscape. I describe hypothesis *a* as: recruitment was less in areas of increased predator density; the predator species may be reducing the recruitment in that area (Figure 1.5a). I describe hypothesis *b* as: fawn recruitment was greater in areas of low predator density, the lack of predator species in that area would allow the recruitment to achieve greater levels (Figure 1.5b). Finally, I describe hypothesis *c* as: recruitment did not change between regions, and predator densities differed, the recruitment was not affected by predator densities (Figure 1.5c).

1.4 Results

1.4.1 Deer FLIR Survey

During the 2015 survey period, I observed 106, 65, and 82 clusters of deer along the Potomac-Garrett, Savage River, and Green Ridge routes, respectively. During the 2016 survey period, I observed 152, 62, and 80 clusters of deer along the Potomac-Garrett, Savage River, and Green Ridge routes, respectively. All estimates of deer density and fawn recruitment achieved <25% CV in 2015 and 2016 (Table 1.4).

Deer density estimates across all state forests ranged from 5-13 deer/km^2 and 7-19 deer/km^2 in 2015 and 2016, respectively. Fawn recruitment across the 3 state forests ranged from 0.57-0.60 fawn/doe and 0.48-0.52 fawn/doe in 2015 and 2016, respectively. Due to 95% confidence interval overlap, estimated deer density and fawn recruitment did not change among state forests or years (Table 1.4).

In 2015, the population reconstruction (PR) model estimated 17 deer/km^2 within Garrett and Allegany Counties. Potomac-Garrett's FLIR estimated similar density and 95% confidence interval overlaps the PR's point estimate. Savage River and Green Ridge FLIR 95% confidence interval estimates do not overlap the point estimate from the PR model in 2015. The PR model estimated 15 deer/km^2 in 2016 for Garrett and Allegany Counties. Potomac-Garrett and Green Ridge's 95% confidence intervals for deer density from the FLIR surveys overlapped the point estimate of the PR model in 2016. Savage River's 95% confidence interval of deer density based on the FLIR survey did not overlap the PR point estimate in 2016. Based on the PR model, recruitment within Allegany County in 2015 was 0.44 and Garrett County estimated 0.40, FLIR estimates of recruitment did not overlap in 95% confidence interval (Table 1.4). In 2016, Allegany County was estimated to have 0.55 recruitment from the PR model, overlapping the 95% confidence interval from the FLIR survey for Green Ridge (Table 1.4). In 2016, neither Potomac-Garrett nor Savage River FLIR survey estimates of fawn recruitment shared 95% confidence interval overlap with Garrett County's estimate of 0.37 from the PR model (Table 1.4).

1.4.2 Predator Camera Survey

I collected 17,216 images over 3,000 camera trap nights and 24,364 images over 3,300 camera trap nights in 2015 and 2016, respectively. Bears were detected at 44, bobcats at 11, and coyotes at 15 of 50 camera stations in 2015. In 2016 bears were detected at 47, bobcats at 6, and coyotes at 19 of 60 camera stations. During the 2016 winter survey, I collected 27,893 total images over 3,240 camera trap nights. One camera was stolen within Green Ridge SF, dropping the entire camera station from the winter analysis. Over the 60-day survey bobcats were detected at 16 camera stations and coyotes at 44 of 59 camera stations. Detections of species per 100 camera trap nights varied among sites (Table 1.5)

The top models based on AIC for black bear were the global model and the interaction of percent forest within camera buffers and total km of minor roads within camera buffers (Table 1.2). The top model for bobcat during the summer surveys was percent forest within camera buffers (Table 1.2). The coyote top observation covariate during the summer was Julian date; however, aside from null and global, all models performed with a ΔAICc ≤ 2 and no model held a high proportion of weight suggesting little descriptive strength (Table 1.2). During winter months, the top bobcat observation covariate was Julian date, however due to several models performing under ≤2 AIC_c and no model carrying a high proportion of the weight, a null model was used to estimate density (Table 1.3). The coyote top model during the winter survey was the global model using total km of minor, major, and highway roads, Julian date, and percent agriculture land within camera buffers (Table 1.3). At each of the 3 state forests, estimated density and detection probability of each species did not change during the summer surveys in 2015 and 2016 (Table 1.6, 1.7).

1.4.3 Predator-Prey Relationship

The fawn recruitment confidence intervals overlapped for the 3 state forests in 2015. Density estimate confidence intervals of bear, bobcat, and coyote also did not change between state forests in 2015; however, point estimates of coyote density increased from east to west (Figure 1.6). Although the point estimates were greater in Potomac-Garrett compared to Green Ridge, the fawn recruitment rates were similar. Based on the 2016 estimates, fawn recruitment confidence intervals overlapped among state forests. Again, density estimate confidence intervals of bear, bobcat, and coyote overlapped; however, point estimates of coyote density increased from east to west (Figure 1.7). Both 2015 and 2016 estimates of fawn recruitment and predator densities support hypothesis *c* that varying predator densities are not impacting fawn recruitment. When results of fawn recruitment and predator density were averaged between 2015 and 2016, predator density estimates decreased in state forests from west to east while fawn recruitment remains stable (Figure 1.8). These estimates support a predator-prey relationship similar to hypothesis *c* in which varying predator densities are not impacting the fawn recruitment in the region.

1.5 Discussion

1.5.1 Deer Density and Fawn Recruitment

Several survey methods have been used for density and recruitment estimates, including: pellet counts (Eberhardt and Van Etten 1956, Neff 1968), spotlight surveys (Progulske and Duerre 1964, McCullough 1982), aerial counts (Caughley 1976, Potvin et al. 2002), mark–recapture studies (McCullough and Hirth 1988), and motion–triggered camera surveys (Jacobson et al. 1997, Koerth and Kroll 2000, Dougherty and Bowman 2012). However, some of these methods were not viable for our study due to: the limitations of pellet counts (Van Etten and Bennett 1965, Neff 1968, Fuller 1991), the inability to perform aerial counts due to a closed canopy, and mark-recapture being cost-prohibitive. A study performed within western Maryland which compared camera, spotlight, and FLIR surveys, found the most efficient method to estimate deer density and fawn recruitment to be forward-looking infrared-based road transect surveys (Haus 2013).

I compared the 95% confidence interval of fawn recruitment estimates based on distance sampling for each study area to point estimates of fawn recruitment based on a population reconstruction (PR) model utilizing state harvest data at the county level. Within Garrett and Allegany County, FLIR data estimated the deer density to be less than the PR estimate in 2015 and equal to the PR estimate in 2016. The variability in the FLIR and PR estimates may best be explained by the change in mast crop in 2015 and 2016 (Table 1.8, MDNR 2016). Deer may be able to spend more time within the state forests in 2016 due to an increased availability of mast in 2016 compared to 2015

(Carlock et al. 1993, McShea and Schwede 1993, Norton et al. 2012). FLIR deer density estimates within Savage River during both 2015 and 2016, and Green Ridge 2015 did not share 95% confidence interval overlap with the PR model estimates. A possible explanation for the differences in densities between the state forests and county averages are that the state forests are public land with lower quality deer habitat compared to the remainder of the county habitat. The overall increase in mean density estimates from 2015 to 2016 was also observed in the archery hunter surveys (MDNR 2016b). The archery survey reported an increase of 8% in Potomac-Garrett, 27% in Savage River, and 5% in Green Ridge of deer observed throughout the archery season.

Overall, density estimates from the long-term PR data match what I found through FLIR surveys; in addition, my estimates of fawn recruitment demonstrated a lower recruitment rate compared to previous studies. The fawn recruitment within the region may be impacted by several sources including: predation, reduced age structure, legal and illegal harvest, disease, starvation, malnutrition, parasites, accidents, and collisions with vehicles and farm machinery (Ozoga and Verme 1986, Nelson et al. 1987, Vreeland et al. 2004). The estimated fawn recruitment did not change across the 3 state forests in either 2015 or 2016. FLIR estimates of recruitment had minimal overlap of the PR estimate of recruitment. This minimal overlap may be explained by variability in fawn harvest selection and the PR model increasing accuracy of recruitment estimates with increased years of data (Downing 1980, Davis et al. 2007).

1.5.2 Predator Density Estimation

The top model for bears is the global model involving minor roads, major roads, and percent forest within each camera buffer. A model involving an interactive term between the percent forest and total km of minor roads within each camera buffer as well as a model of just minor roads all performed with ΔAICc ≥ 2. Previous literature has shown that minor roads provide a travel corridor for black bear movement and that bears are positively associated with larger forest patches (Brody and Pelton 1989, Clark et al. 1993, Trombulak and Frissell 2000). Relative predator densities between the 3 state forests match what is known of the mammal community in western Maryland, based on knowledge of regional biologists and harvest records. Historically, bear harvest in Maryland was greatest within Garrett County, and bears have been expanding their range from the Appalachian Plateau eastward (Spiker 2013). This matches our data estimating greater bear density within Garrett County compared to Allegany. My estimated bear density within western Maryland was greater than what was estimated in 2011 (Spiker 2011). The Maryland DNR performed DNA-based mark-recapture surveys in 2000, 2005, and 2011 to estimate the black bear population within western Maryland. From 2000-2011 the study estimated an 11.7% annual increase of black bear abundance. From 2005 to 2011, the black bear population was estimated to have increased 94%. The 2011 survey estimated 0.25 bear/km^2, while our average density for the region from the 2015 and 2016 surveys was 0.38 bear/km2; representing a 52% increase.

Unlike the black bear observation covariates, model selection revealed a strong covariate for bobcat detections. The top model for bobcats during the summer surveys was the percent of forest land within each camera buffer, and no other model performed within ΔiAICc ≤ 2. In addition, the forest covariate model held 61% of the model weight, the strongest of any covariate for all models. Our data supports previous literature indicating bobcats prefer unfragmented forest stands (Crooks 2002, Donovan 2011).

The detection rate for bobcat did not change between summer and winter survey designs. This lack of change may have several underlying processes but without any quantifiable evidence I can do little more than speculate on the reasoning. The top model based on the winter survey data were Julian date, percent developed land, and percent forest land. Both Julian date and percent developed may be described by the hunting and trapping activity occurring during the first half of the survey. Percent forest performed well in both summer and winter surveys most likely due to bobcats preferring unfragmented forest stands year-round. The variability in bobcat density estimates between years may be due to the scarcity in data. The bobcat density estimate describes an even distribution of bobcats throughout Garrett and Allegany County. This distribution may be due to bobcats having been without any harvest pressure within Maryland since their population decline in the late 1800's.

Similar to black bear model results, coyote detections were difficult to describe. Julian date was the strongest observational covariate for coyotes during the summer surveys; however, all models aside from the global and null had little support and carried minimal amounts of weight. The lack of a clear top model may be due to the sparse levels of data during the summer surveys. Coyote detections increased as the season progressed. I speculate that this may be due to adult coyotes being cautious while the current year's pups are being cared for, coyotes becoming more comfortable with the game cameras over time, at the end of the summer the pups and juveniles have become more independent and are detected as individuals, reduced movement away from den sites, or any combination of these factors.

Unlike bobcats, the detection rate of coyotes increased during the winter survey compared to the summer. Camera trapping during the winter months presented optimal conditions for detecting coyote due to minimal vegetation blocking fields of view, bait present at stations, and increased activity levels of coyotes during the breeding and gestation periods (Andelt and Gipson 1979, O'Connor and Rittenhouse 2017). With winter survey data, the only model to perform with support was the global model. With the global model being the only model with ΔiAICc ≥ 2, the data could not be explained through covariates. Across all years of camera surveys, coyotes have the greatest density within Potomac-Garrett and a decreasing density in state forests to the east. Coyote density estimates from my camera surveys align with coyote detections reported in the MDNR archery hunter surveys. The archery survey reports hunters in the Appalachian Plateau detected coyotes 2.2 times more often than in the ridge and valley region of the state in 2016 (MDNR 2016b**).** The estimated distribution from my camera data matches previous data that coyotes established in Maryland within the Appalachian Plateau habitat and spread east (MDNR 2014b).

Overall, the mean density estimates for black bear, bobcat, and coyote using package unmarked and the *pcount* function provided a density value that are similar to other values in surrounding states. That being said, these surveys took place over 2 years, a relatively small timeframe to monitor several secretive species in a region. However, the detections per 100 camera trap nights for each species followed a similar trend to the predicted density at each state forest and year; the predicted densities failed to be improved upon with strong covariates. Bobcat model performance ranked the percent forest area within each camera buffer as a very strong covariate (ΔiAICc ≥ 2 and 61% of the weight). Predicting the density using this strong covariate (forest) and no covariates (null), the results changed minimally (<0.01 change in mean). A more robust method could be a DNA-based survey which can identify individuals, such as a hair snare survey.

1.5.3 Predator-Prey Relationship

Total predator densities were greatest within Potomac-Garrett and less in the state forests to the east (Figure 1.8). This result is most apparent with coyotes, having the greatest densities within Garrett County. Throughout the United States, coyotes are considered the main source of predation for neonatal fawns (Nelson and Woolf 1987, Vreeland et al. 2004, Crimmin et al. 2012, Petroelje et al. 2013, Kilgo et al. 2014). If predators were impacting fawn recruitment, I would predict a lower fawn recruitment within the state forests of Garrett County compared to those of Allegany County, Maryland. However, the recruitment from the FLIR surveys does not estimate a difference in fawn recruitment across region A of Maryland. I did not observe a correlation between total predator or coyote densities and fawn recruitment. The trend of black bear and bobcat densities and fawn recruitment were similar; however, estimated black bear and bobcat densities were low. Historic data at the county level estimates low fawn recruitment levels within region A of western Maryland. My results estimate similar and slightly greater levels of recruitment. Although the predator community within the region does not appear to be affecting the recruitment rate, there does appear to be another factor or factors limiting recruitment rates.

1.6 Management Implications

Based on my findings, the coyote population of western Maryland does not appear to be reducing the fawn recruitment rate. Although there were similarities between the black bear and bobcat densities and fawn recruitment between the state forests, these species were estimated to have a low density and have minimal evidence of being a substantial source of fawn mortality. Overall, it does not appear the predators are the cause of the low recruitment rates. I hypothesize two alternative causes of the reduced fawn recruitment within western Maryland; a reduced maternal age across the region (Ozoga and Verme 1986) and low habitat quality (Tollefson et al. 2011) are the most likely causes and should be investigated further.

TABLES

Table 1.1 Mean and standard error (SE) of covariates within each camera buffer across 3 state forests within western Maryland, 2015-2016. All calculations were made using ArcGIS 10.2 using the 2014 TIGER shapefile (*a, b, c)*, or the 2011 USGS national landcover dataset (*d, e, f)*.

State Forest	Agriculture[a]	Developed[b]	Forested[c]
Potomac-Garrett	7 % (2.0)	7% (1.0)	84% (2.3)
Savage River	5% (1.5)	5% (0.5)	84% (1.8)
Green Ridge	10% (1.6)	5% (0.7)	89% (2.0)

	Highway[d]	Major[e]	Minor[f]
Potomac-Garrett	0	0.87 km (0.4)	18.0 km (2.9)
Savage River	0	1.1 km (0.5)	10.2 km (1.0)
Green Ridge	1.7 km (1.1)	1.1 km (0.5)	13.8 km (0.8)

a. The percentage of agriculture land within each camera buffer
b. The percentage of forested land within each camera buffer
c. The percentage of developed land within each camera buffer
d. Total kilometer of highway roads (MTFCC S1100) within each camera buffer
e. Total kilometer of major roads (MTFCC S1200) within each camera buffer
f. Total kilometer of minor roads (MTFCC S1400, S1500, S1630, S1640, S1710, S1730, S1740, S1750, S1780, and S1820) within each camera buffer

Table 1.2 Summer survey top N-mixture models for each of the 3 species to estimate density of each species on 3 state forests within western Maryland, 2015-2016. Covariates are listed by model performance based on Akaike's information criterion adjusted for small n (AIC_c).

Model	ΔAIC_c	Akaike weight
Black Bear		
Global	0.000	0.34
Forest*Minor	0.37	0.28
Minor Road	1.04	0.20
Forest	2.51	0.10
Highway	2.87	0.08
Null	9.01	0.00
Bobcat		
Forest	0.00	0.61
Global	3.19	0.13
Minor Road	3.22	0.12
Major Road	4.12	0.08
Developed	4.54	0.06
Julian Date	7.70	0.01
Null	15.02	0.00
Coyote		
Julian Date	0.00	0.25
Highway	0.64	0.18
Minor Road	0.95	0.15
Agriculture	1.16	0.14
Major Road	1.18	0.14
Julian Date+Minor Road	1.75	0.11
Global	7.19	0.00
Null	12.89	0.00

Table 1.3 Winter survey top N-mixture models for each of the 3 species to estimate density of each species on 3 state forests within western Maryland, 2015-2016. Covariates are listed by model performance based on Akaike's information criterion adjusted for small n (AIC_c).

Model	ΔAIC_c	Akaike weight
Bobcat		
Julian Date	0	0.29
Developed	0.55	0.23
Forest	1.37	0.15
Minor Road	2.04	0.12
Major Road	2.50	0.09
Null	3.43	0.07
Global	7.35	0.02
Coyote		
Global	0.00	0.57
Null	3.08	0.12
Julian Date	3.91	0.08
Major Road	4.44	0.06
Highway	4.72	0.06
Minor Road	4.73	0.06
Agriculture	4.90	0.04
Julian Date + Minor Road	6.05	0.01

Table 1.4 Density and fawn recruitment estimates of white-tailed deer obtained using road-based conventional distance sampling surveys using a FLIR device (FLIR) on 3 state forests within deer management region A, Maryland, USA.

	Year					
	2015			2016		
	Density					
State Forest	Deer/km^2 (SE)	95%CI	CV	Deer/km^2 (SE)	95%CI	CV
Potomac-Garrett	13 (6.6)	8-19	7.5	19 (8.3)	13-28	6.3
Savage River	5 (2.3)	3-7	7.2	7 (3.0)	5-10	6.6
Green Ridge	7 (1.7)	5-10	3.8	17 (7.7)	9-25	6.6
	Recruitment					
State Forest	Fawn/Doe (SE)	95%CI	CV	Fawn/Doe (SE)	95%CI	CV
Potomac-Garrett	0.60 (0.08)	0.51-0.67	7.6	0.52 (0.07)	0.43-0.60	5.4
Savage River	0.59 (0.13)	0.47-0.72	14.8	0.50 (0.14)	0.38-0.65	13.3
Green Ridge	0.57 (0.02)	0.56-0.58	4.1	0.48 (0.10)	0.38-0.59	8.7

Table 1.5 Camera survey detections of target species (black bear, bobcat, and coyote) per 100 camera trap nights at 3 state forests within western Maryland. 2015 and 2016 60-day survey from June-August. Winter 60-day survey from December, 2016-February, 2017. Black bear were excluded from the winter survey due to reduced activity.

	2015	2016	Winter
State Forest	Detections per 100 camera trap nights		
		Black bear	
Potomac-Garrett	7.1	4.6	N/A
Savage River	7.1	8.1	N/A
Green Ridge	3.3	3.6	N/A
		Bobcat	
Potomac-Garrett	0.7	0.1	0.2
Savage River	0.8	1.7	1.8
Green Ridge	0.4	0.1	0.6
		Coyote	
Potomac-Garrett	2.6	2.4	5.6
Savage River	1.7	0.6	5
Green Ridge	0.2	0.3	1.8

Table 1.6 Estimated predator density (individuals/km^2), standard error (SE), 95% confidence interval (95%CI), and detection probability on 3 state forests in western Maryland obtained via camera survey data analyzed using package *unmarked* in R (3.0.2) June-August, 2015 and 2016.

	2015			2016		
State Forest	Density (SE)	95%CI	Det. Prob	Density (SE)	95%CI	Det. Prob
			Black bear			
Potomac-Garrett	0.45 (0.12)	0.27-0.75	1.7%	0.24 (0.07)	0.14-0.42	1.7%
Savage River	0.52 (0.12)	0.33-0.84	1.7%	0.49 (0.12)	0.31-0.79	1.7%
Green Ridge	0.27 (0.07)	0.16-0.44	1.5%	0.28 (0.07)	0.17-0.45	1.5%
			Bobcat			
Potomac-Garrett	0.17 (0.18)	0.02-1.41	1.7%	0.03 (0.03)	0.01-0.33	1.7%
Savage River	0.11 (0.13)	0.01-1.06	1.7%	0.14 (0.15)	0.02-1.14	1.7%
Green Ridge	0.16 (0.17)	0.02-1.29	1.7%	0.03 (0.05)	0.01-0.51	1.7%
			Coyote			
Potomac-Garrett	1.95 (1.12)	0.63-5.99	1.4%	1.73 (1.07)	0.52-5.79	1.4%
Savage River	1.28 (0.79)	3.8-4.31	1.4%	0.47 (0.31)	0.13-1.72	1.4%
Green Ridge	0.13 (0.12)	0.02-0.77	1.4%	0.25 (0.19)	0.05-1.51	1.4%

Table 1.7 Estimated predator density (individuals/km^2), standard error (SE), 95% confidence interval (95%CI), and detection probability on 3 state forests in western Maryland obtained via camera survey data analyzed using package *unmarked* in R (3.0.2) December, 2015-February, 2016.

		Winter		
State Forest	Density	SE	95%CI	Det. Prob
		Bobcat		
Potomac-Garrett	0.05	0.09	0.01-1.88	1.6%
Savage River	0.29	0.63	0.01-21.40	1.6%
Green Ridge	0.10	0.23	0.01-8.23	1.6%
		Coyote		
Potomac-Garrett	2.48	1.35	0.85-7.22	1.7%
Savage River	2.22	1.19	0.78-6.34	1.7%
Green Ridge	0.78	0.45	0.25-2.45	1.7%

Table 1.8 Results of western Maryland mast survey performed by the Maryland Department of Natural Resources. Acorn abundance is expressed as an average number of acorns per branch from 2012-2016 (MDNR 2016)

	2012	2013	2014	2015	2016
GARRETT					
Black Oak	2.25	19.28	6.72	1.25	40.27
White Oak	0.15	0.4	9.47	1.63	13.7
Unit Average	1.2	9.84	8.1	1.44	27.06
ALLEGANY					
Black Oak	5.27	2.15	37.6	0.625	10.02
White Oak	6.25	0.75	3.37	0	2.15
Unit Average	5.76	1.45	20.5	0.31	6.09
WASHINGTON					
Black Oak	19.3	0.42	47.98	2.32	14.34
White Oak	18.85	1.75	10.2	0.6	6.65
Unit Average	19.1	1.1	29.05	1.46	10.5
FREDERICK					
Black Oak	37.7	0	4.4	0	17.25
White Oak	0.65	0	1.4	0	0.4
Unit Average	19.1	0	2.9	0	8.8

FIGURES

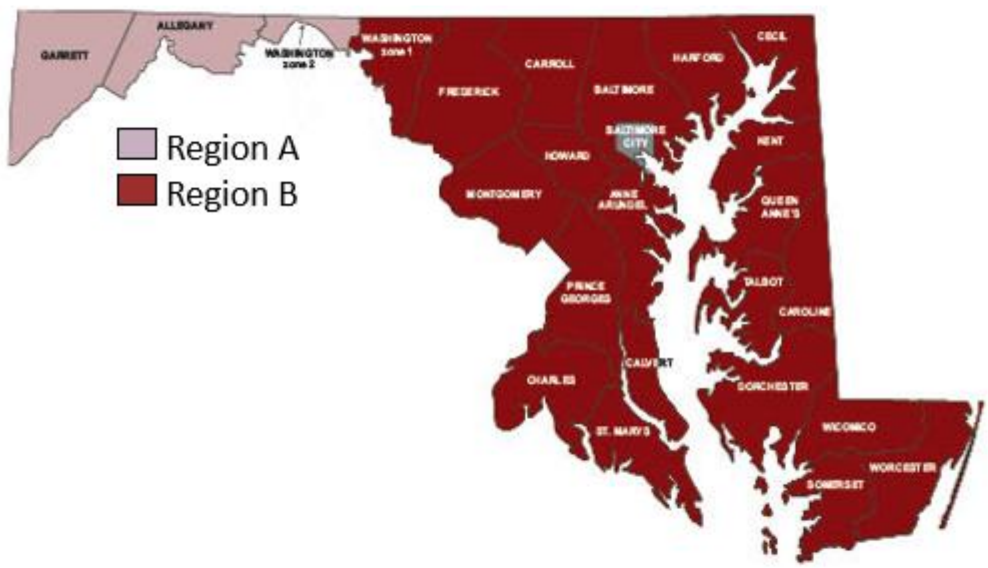

Figure 1.1 Deer management regions in Maryland, 2015-2016. Region A consisted of Garrett, Allegany, and western Washington Counties. Region B consisted of the remainder of the state.

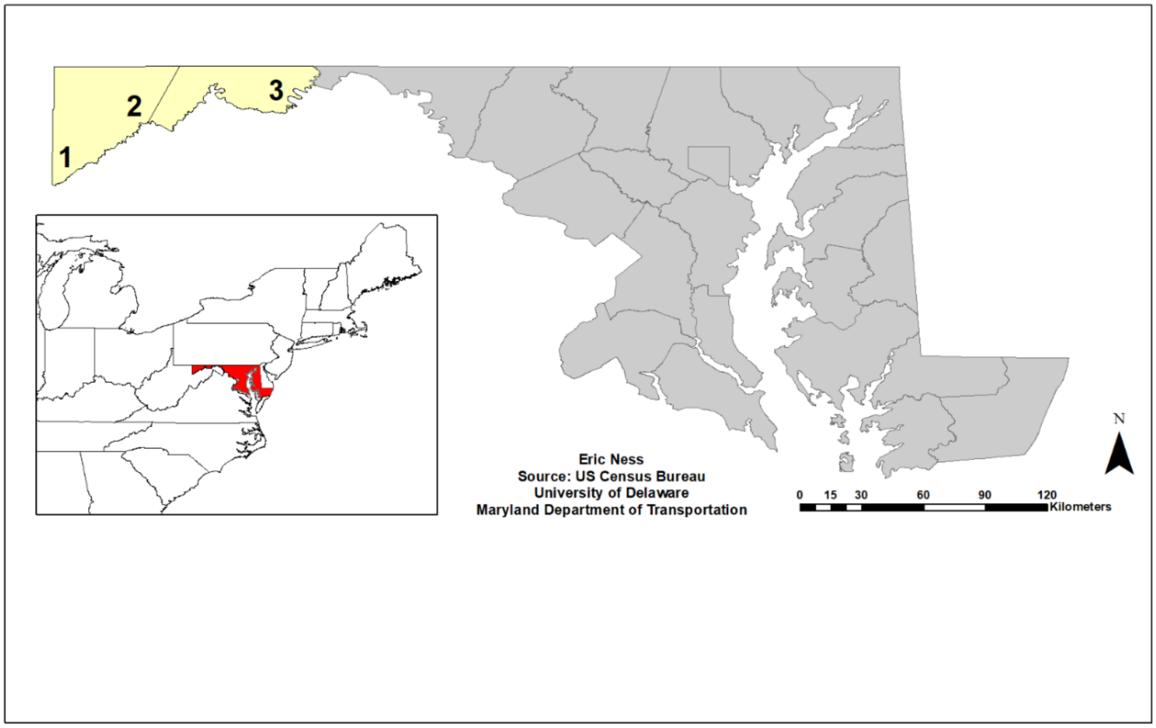

Figure 1.2 Study sites (from west to east: Potomac-Garret (1), Savage River (2), and Green Ridge (3) State Forests) locations used for FLIR surveys in 2015-2016.

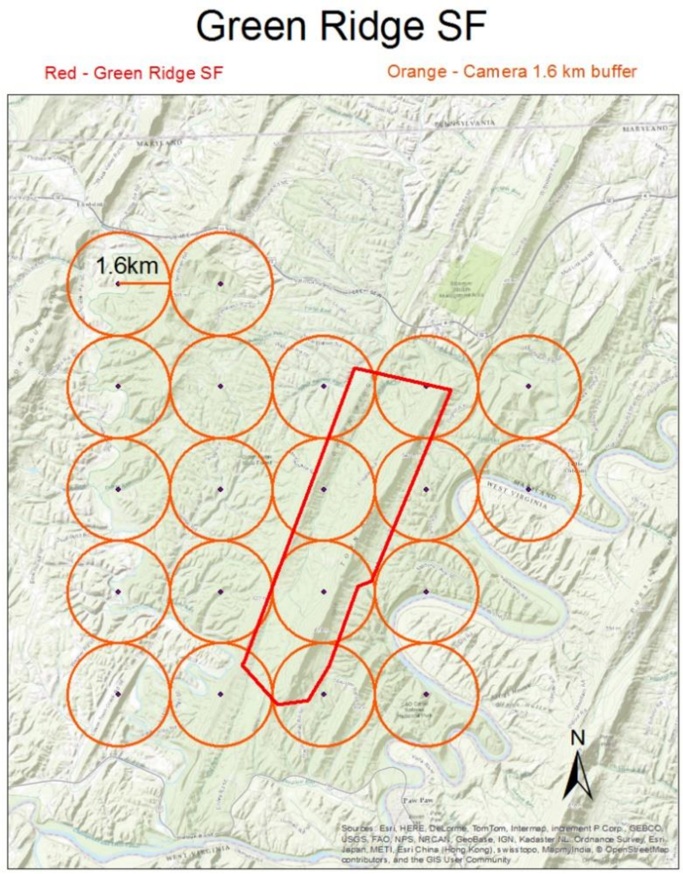

Figure 1.3 Camera grid within the Green Ridge State Forest study area 2015-2016. Each point represents a camera station and the circles around each represent the 8.04 km^2 the cameras cover.

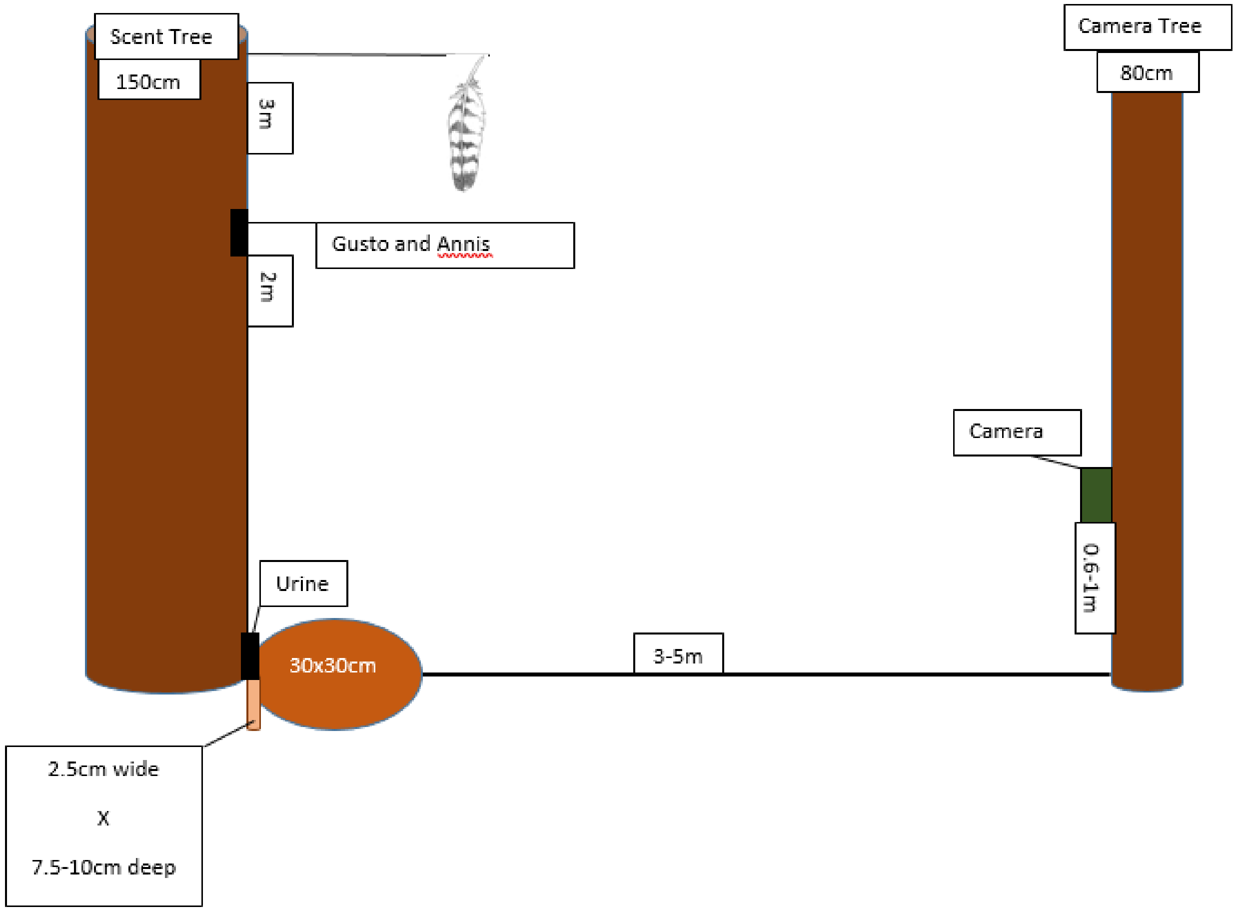

Figure 1.4 Illustration of camera site construction for optimal detections of target species (black bear, bobcat, and coyote) using a scent tree and camera tree in Maryland, 2015-2016.

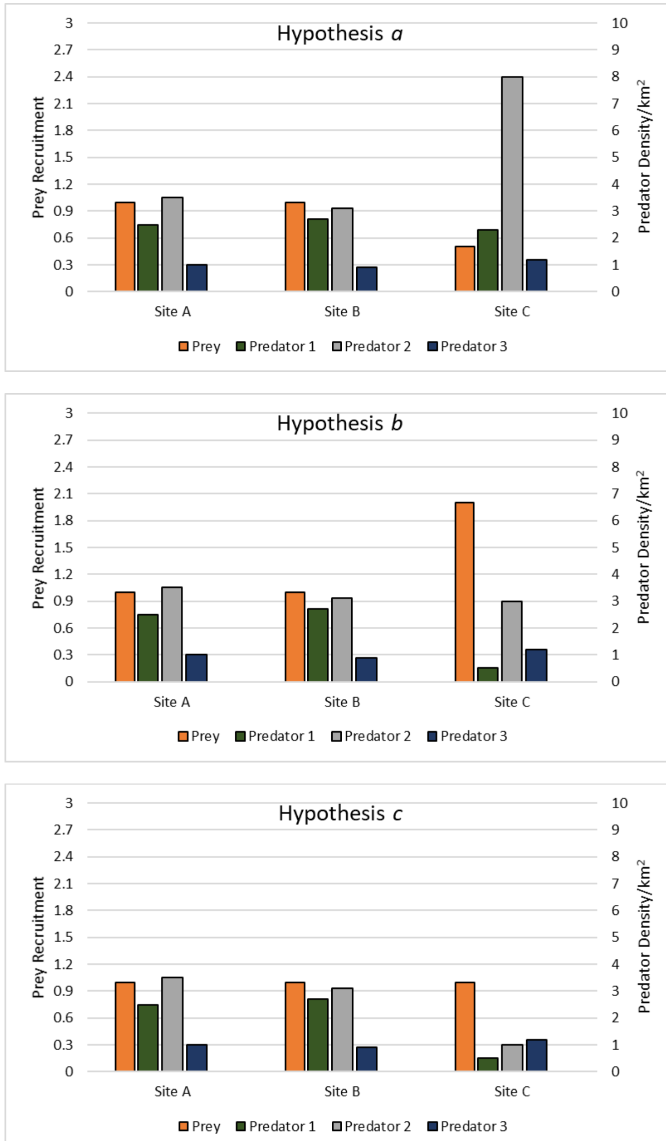

Figure 1.5 Example of three most likely predator-prey relationships present.

Hypothesis *a:* predator 2 density is higher in site C, and the prey recruitment is also lower in site C. From this example, with an increased predator 2 density, prey recruitment is lower.

Hypothesis *b:* predator 1 density is lower in site C, and the prey recruitment is higher in site C. From this example, with a lower predator 1 density, prey recruitment has been able to increase.

Hypothesis *c:* predator 1 and predator 2 density is lower in site C, and the prey recruitment is similar in all sites. From this example, with a lower predator 1 and predator 2 density, prey recruitment remains the same.

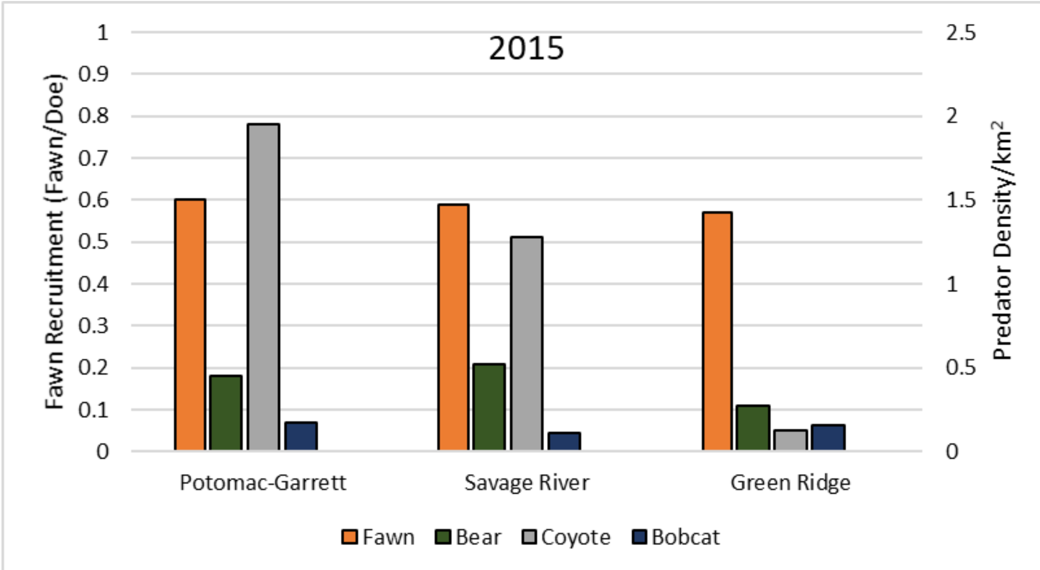

Figure 1.6 Predator-prey relationship based on estimates of fawn recruitment and predator density from 2015 surveys in western Maryland.

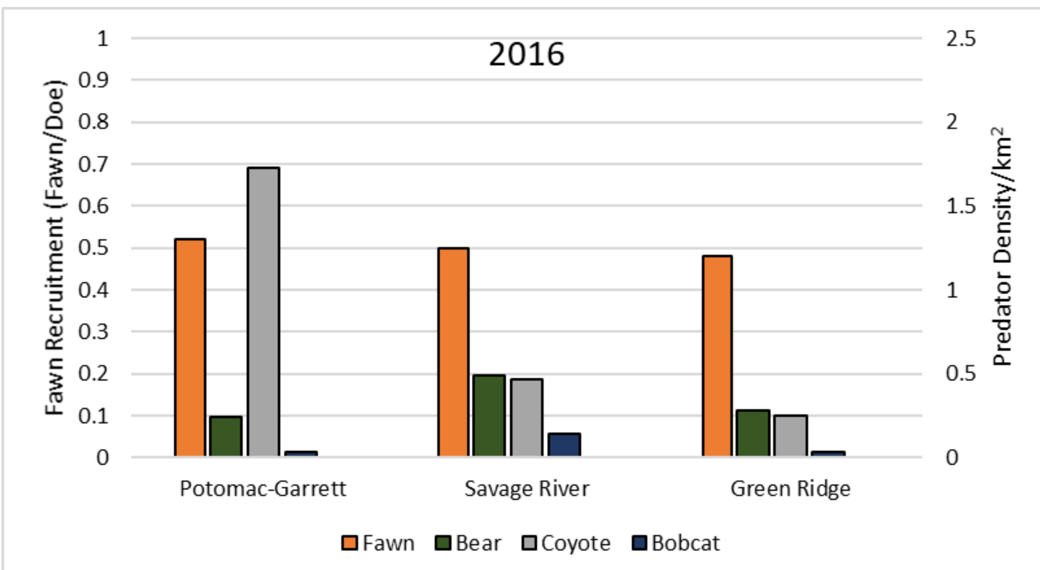

Figure 1.7 Predator-prey relationship based on estimates of fawn recruitment and predator density from 2016 surveys in western Maryland.

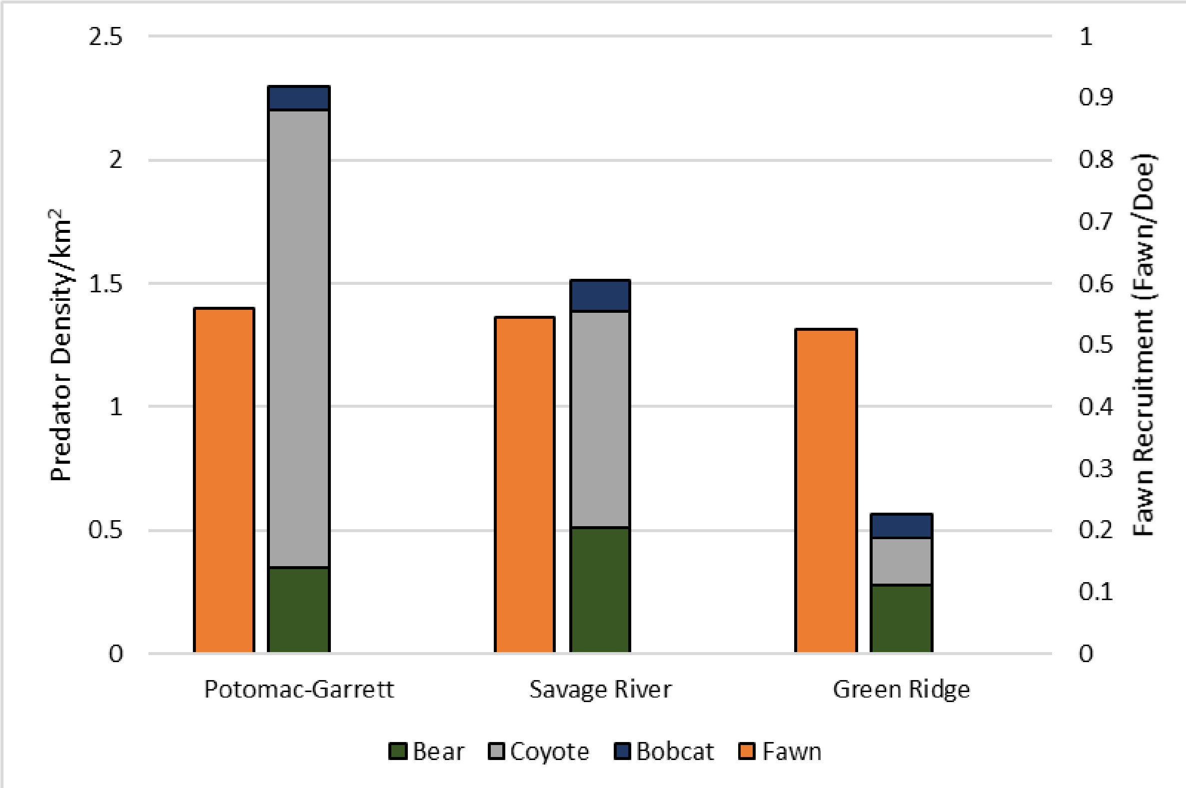

Figure 1.8 Averaged results of FLIR (right axis) and camera surveys (left axis) for 2015 and 2016 surveys. Estimated recruitment (fawn) does not change between sites; however, estimated total predator density of black bear, bobcat, and coyote decreases from west to east in western Maryland.

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