25 Mar 2025

RH: Cars et al. • Deer Antler Characteristics

# Environmental and temporal factors affecting record white-tailed deer antler characteristics in Ontario, Canada

Brooklyn S. Cars, Environmental and Life Sciences Graduate Program, Trent University, 2140 East Bank Drive, Peterborough, ON K9J 7B8, Canada

Joseph M. Northrup, Environmental and Life Sciences Graduate Program, Trent University, 2140 East Bank Drive, Peterborough, ON K9J 7B8, Canada and Wildlife Research and Monitoring Section, Ontario Ministry of Natural Resources, Peterborough, Ontario, Canada

Keith Beasley, The Foundation for the Recognition of Ontario Wildlife, Ontario, Canada

Paul Beasley, The Foundation for the Recognition of Ontario Wildlife, Ontario, Canada

Kevin Beasley, The Foundation for the Recognition of Ontario Wildlife, Ontario, Canada

Aaron B.A Shafer, Environmental and Life Sciences Graduate Program, Trent University, 2140 East Bank Drive, Peterborough, ON K9J 7B8, Canada

**Correspondence:** Brooklyn S. Cars, Trent University, 2140 East Bank Drive, Peterborough, ON K9J 7B8, Canada. Email: brooklyncars@trentu.ca

**ABSTRACT**

White-tailed deer (*Odocoileus virginianus*) are an ecologically and economically important species in North America. Their antlers, one of their most recognizable features, are used for dominance displays, mate attraction, and defense, with size and morphology being key determinants of success. Antler characteristics are influenced by a combination of genetic and environmental factors, including habitat quality and resource availability. In this study, we explored how diverse environmental factors, including climate and land cover composition, impact antler size, morphology, and the distribution of record scoring white-tailed deer across Ontario, Canada, using data from long-term antler scoring records. We used conditional autoregressive (CAR) models to examine these relationships and found that warmer temperatures the year of harvest were positively associated with larger antlers and more record deer in a given county, while winter precipitation the year of harvest was negatively associated with these characteristics, likely due to reduced forage availability or increased energy expenditure during more severe winters. Rangeland and forest land cover types were positively associated with increased antler size and tine number. We observed no temporal changes in antler size in Ontario, contrasting with broader trends observed in North America. These results show how local environmental conditions and land cover composition influence antler traits and the distribution of record white-tailed deer, highlighting the complexity of environmental influences on trait variation.

**KEYWORDS** white-tailed deer, *Odocoileus virginianus*, antler size, antler morphology, environmental factors, Ontario, hunters, harvest, climate effects, land cover

The Cervidae (deer) family emerged during the late Miocene where they developed the secondary sex characteristics that we associate with modern deer (Gilbert et al. 2006). One such secondary sex characteristic, antlers, are bony extensions of the skull that generally shed every year, and apart from caribou (*Rangifer tarandus*) are only found on males (Rue, 1989; Hewitt, 2011). Antlers have multiple purposes including, dominance displays and interactions, use as weapons against predators and other male Cervidae, and as indicators to females that they are of good genetic quality (Clutton-Brock, 1982; Goss, 2012). In white-tailed deer, males are the dominant sex where social dominance is largely dictated by age and body mass, both of which are closely tied to antler size (Townsend and Bailey 1981). Fully matured males tend to have larger antlers due to the lower energy demands for body growth and thus their ability to allocate resources to antlers (Goss, 1983). Likewise, in red deer, larger antlers are associated with increased reproductive success (Kruuk et al. 2002). That being said, younger or smaller-antlered males can achieve mating success if they are more dominant and in good overall health, particularly in populations with a female-skewed sex ratio or a younger male age structure, or by avoiding direct competition with larger males and opportunistic mating (Townsend and Bailey 1981, Turner et al. 2016, Partridge 2017).

Antler characteristics are influenced by both genetic and environmental factors. Jamieson et al. (2020) found that the number of antler tines and antler beam length in white-tailed deer (*Odocoileus virginianus*) were approximately 32% and 45% heritable, respectively. Cain et al. (2019) showed that larger-antlered deer in the Midwest United States were associated with areas that had more fragmented land cover and edge habitats, suggesting that habitat composition can shape resource availability and, in turn, antler growth. Strickland and Demarais (2008) also observed a positive association between agriculture and mean antler size in the Southern United States. Intergenerational maternal effects have also been seen to influence antler and other physical traits (Freeman et al. 2013), with for example

maternal nutrition influencing offspring body mass and antler size in white-tailed deer (Monteith et al. 2009). Similarly, Peterson et al. (2019) found that extreme environmental conditions, such as drought, had lasting effects on antler development in white-tailed deer: deer born during an extreme environmental year had smaller antlers in later years, suggesting that early-life environmental stress can have persistent effects on antler growth. Collectively, these studies highlight the need to consider multi-year and spatial environment covariates when modelling trait variation.

In recent years, hunters in Ontario (Canada) can purchase a white-tailed deer licence and an antlered deer (i.e. Buck) tag valid for any open deer season, while antlerless deer (female/fawn buck) tags are awarded via random draw for a specific Wildlife Management Unit (WMU) (Ontario Ministry of Natural Resources and Forestry 2019). This system allows wildlife managers to regulate the population through antlerless tag quotas as females are critical for population growth (Ontario Ministry of Natural Resources and Forestry 2019). Hunters that target male white-tailed deer are often seeking trophy bucks with higher scoring antlers, which are evaluated based on characteristics such as tine length and number, beam length and circumference, and antler spread (D'Angelo and Grund 2015, Boone and Crockett Club 2025). As a result of high-scoring bucks often experiencing heavier harvests, there has been a broad negative trend in the mean antler size of trophy white-tailed deer over the last century (Monteith et al. 2013). This decline is not only significant for hunters who might experience reduced opportunities for harvesting large, trophy bucks, but the removal of larger males could also disrupt the populations mating structure, potentially resulting in smaller less dominant males becoming more prevalent (Langvatn and Loison 1999, Pigeon et al. 2016). This shift could also weaken so-called indicators of overall genetic quality and potentially lead to reduced reproductive success and a population that is less adaptable to environmental changes (Ditchkoff et al. 2001, Malo et al. 2005).

This study aims to determine which environmental factors influence antler size and morphology

in white-tailed deer across Ontario, Canada. Long-term antler scoring records provided us with a unique opportunity to examine white-tailed deer antler characteristics and temporal patterns over time and space in the province. We used conditional autoregressive (CAR) and generalized linear models to examine the influence of environmental factors on the spatial distribution, tine number, antler symmetry, and overall antler score of record white-tailed deer across Ontario. We predicted that there is a relationship between antler size and environmental factors, such as climate and habitat composition, with larger antlers expected in counties with cover types that allow for a balance of forage and cover (Cain et al., 2019) and agriculture (Strickland and Demarais 2008). Additionally, we predicted that a selective harvest pressure on record deer would have led to a decline in antler size across the province over time (Monteith et al., 2013).

## STUDY AREA

White-tailed deer in Ontario, Canada, occupy a diverse landscape with varying anthropogenic influences. The climate across Ontario is highly variable with short summer growing seasons followed by long winters where food is limited, often causing a decline in body condition (Ontario Ministry of Natural Resources and Forestry 2019, Government of Ontario 2024). Deer in Ontario inhabit coniferous and mixed woods forests, and agricultural landscapes. Coniferous forests offer shelter from excessive snowfall and deciduous forest offer winter browse (Hewitt 2011). While browse is lower in nutritional quality, it is abundant during Ontario’s colder, making up 74-91% of the deer’s diet seasons when other vegetation is scarce (Mautz et al. 1976, Hewitt 2011). Further, Ontario's expanding infrastructure and growing population, which has tripled in the last 50 years, have confined deer to smaller areas, leading to an increase in deer density and a decline in the availability of deer habitat and food (Armstrong et al. 1983, Government of Canada 2016, 2022). However, the proliferation of agricultural landscapes might increase food availability in some regions (Hewitt 2011).

## METHODS

### Data collection

We obtained Ontario antler data from The Foundation for the Recognition of Ontario Wildlife (FROW) for the years 1941 to 2022. FROW is a non-profit organization that manages the records of big game animals in Ontario. Antler measurements were submitted by hunters to FROW from every county in Ontario, except for Temiskaming. The antler dataset included date of kill (DOK), antler type (typical or atypical), tine numbers and multiple scores following FROW's scoring system, which assigns scores based on additive measurements of the antler including tine length, beam circumference, and spread. FROW has a minimum requirement that must be met in order for a deer to be entered into the record (Foundation for the Recognition of Ontario Wildlife 2015), so we refer to these deer as "record deer" hereafter. Because we were interested in assessing the influence of spatial and temporal variables on records, we removed entries that did not contain a county or DOK. Lack of landcover data dating back pre--1999 resulted in all deer entries prior to 1997 being removed only in the spatial models. We then assessed the influence of a series of environmental and temporal variables on tine number, gross score, net score, symmetry and the number of record deer per county.

Predictor variables in our model included temperature ($^{o}$C), precipitation (mm), and number of growing degree days for each county corresponding to the year a record deer was harvested (Table S1, available in Supporting Information). These variables were obtained from Natural Resources Canada (Hutchinson et al., 2009; Hopkinson et al., 2011; McKenney et al., 2011). We extracted temperature and precipitation data from the months March to August as these are the months when antler growth occurs (Hewitt 2011). For precipitation we also extracted the months January to March to gauge winter severity through snow fall. Precipitation data were averaged. For temperature, we followed Siegert *et al.* (2013) and calculated the yearly temperature difference by subtracting each county's average temperature over

the time series from the temperature for each individual year. The temperature and precipitation data for 1 year prior to the DOK and 2 years prior to the DOK also extracted.

ArcGIS pro (version 3.1.3; Johnston and Environmental Systems Research Institute, 2004), was used to extract landcover data. We used 2 land cover layers: the Ontario Land Cover Compilation v.2.0 (Land Information Ontario, 2023a) which captured the years 1999-2011 and Ontario Land Cover Version 1.0 (Ontario Land Cover Version 1.0 - Overview n.d.) which captured the years 2015 to 2020. Depending on their DOK the record deer were assigned to a landcover dataset (Table S1). For the years not captured by the landcover databases (2012-2014), whichever layer encompassed the year closest to the DOK was used. Reclassification of the land cover categories within these databases was completed to ensure consistency between land cover types: reclassified categories were; agriculture, infrastructure, deciduous forest, coniferous forest, mixed forest, other forest, rangeland, water, wetlands, and other landcover types (Fig. 1). The proportion of each landcover type per county was then calculated, and "other landcover" was dropped in order to interpret the relationship between the response variable and the proportion covariates (see Valle *et al.*, 2024).

The final 3 predictor variables used were average county elevation (m), county size ($km^2$) and deer abundance (Table S1). Average county elevation and county size are fixed variables, with a single value used over the study period. A relative index of white-tailed deer abundance per county was generated using the deer seen per day dataset collected by the province of Ontario and was averaged across all available years (2008-2023) to provide a single estimate per county.

**Statistical analysis**

All variables were standardized, and we assessed pairwise correlations among them, removing those with a correlation greater than 0.70 or less than -0.70. We then fit a series of models to each response variable. All spatial models were fitted using the S.CARmultilevel function from the

CARBayes package (Table S2, available in Supporting Information; Lee, 2013). To assess the number of record deer harvested in each county we used a Poisson regression with a county area offset to ensure that the number of record deer was not an artifact of county size. All record deer despite year were included in the frequency count, so DOK was not considered when assigning temperature, precipitation, or land cover in this model. Instead, average values for each county over the specified time span were used. This allowed us to observe relationships between environment and the all-time spatial distribution of record deer harvests across Ontario counties.

To evaluate antler characteristics, we used DOK when assigning temperature, precipitation and landcover values which will allow us to observe spatial-temporal relationships at the individual level. A Poisson regression model was used to assess the number of antler tines, a binomial regression model was used to assess antler symmetry (symmetrical = 0, asymmetrical = 1) and gaussian regression models were used to assess antler score (Net and Gross). Finally, a standard generalized linear model from the base r package (R Core Team 2023) was used to assess temporal trends in antler score and tine number, with year as the predictor variable. Harvest data was sparse pre 1980 and so we used only entries from 1980 onward. Additionally, minimum scoring requirements were increased in 2006, so all records from 1980 to 2006 below this adjusted score were excluded (Atypical = 130 and Typical = 120; Foundation for the Recognition of Ontario Wildlife, 2015).

## RESULTS

The final dataset after cleaning consisted of 2,413 entries between 1997 and 2020. Number of growing days was removed due to its high correlation with temperature. Temperature was kept as it directly reflects seasonal climate variation and is easier to interpret. Abundance was also removed due to its high correlation with multiple landcover variables. In this analysis, we used 2 different confidence intervals (CI) to assess the significance of each parameter. A 95% CI was used to identify parameters

that had a high level of certainty in their effect, as the CI not overlapping zero indicates strong evidence of influence. For parameters with an 80% CI, we interpreted the effect as moderate, meaning the evidence was less definitive but still suggested a potential influence

Average temperature had a positive effect on the number of record deer per county (Fig. 2; $\beta$ = 1.24, 95% CI = 0.53 □ 1.95). Elevation also showed a positive but less certain effect (Fig. 2;$\beta$ = 0.31, 80% CI = -0.07 □ 0.72). This model had strong spatial variance ($\tau^2$; 0.98) and moderate spatial autocorrelation ($\rho$; 0.46). For tine number, the temperature 1 year prior to the year of harvest had a positive effect (Fig 2; $\beta$ = 0.02, 95% CI = 0.003 □ 0.032). The temperature of the year of harvest and the % of Rangeland per county also showed positive but less certain effects (Fig 2 & 3; $\beta$ = 0.01, 80% CI = -0.005 □ 0.028 and $\beta$ = 0.94, 80% CI = -0.40 □ 2.26, respectfully). This model had a low $\tau^2$ (0.003) and moderate $\rho$ (0.63). For antler symmetry, precipitation during antler growth 2 years prior to the year of harvest had a negative effect (Fig 2; $\beta$ = -0.12, 95% CI = -0.23 □ -0.01), while the temperature of the year of harvest had a positive but less certain effect (Fig 2; $\beta$ = 0.10, 80% CI = -0.02 □ 0.21. This model had a low $\tau^2$ (0.03) and moderate $\rho$ (0.38).

For Gross Score, we found the temperature the year of harvest had a positive effect (Fig 2; $\beta$ = 0.01, 95% CI = 0.004 □ 0.02), while precipitation during the winter the year of harvest had a negative effect (Fig 2; $\beta$ = -0.01, 95% CI = -0.01 □ -0.0001). Further, precipitation during antler growth the year of harvest, precipitation during the winter 1 year prior to the year of harvest, temperature 2 years prior to harvest and the % of Deciduous Forest per county all showed positive but less certain effects (Fig 2 & 3; $\beta$ = 0.01, 80% CI = -0.0003 □ 0.01, $\beta$ = 0.01, 80% CI = -0.001 □ 0.01, $\beta$ = 0.003, 80% CI = -0.001 □ 0.01 and $\beta$ = 0.22, 80% CI = -0.07 □ 0.50, respectfully). This model had $\tau^2$ and residual variance ($v^2$), both of which were relatively low (0.001 and 0.01 respectively), and $\rho$ was moderately high (0.70).

For Net Score, temperature the year of harvest, temperature 2 years prior to the year of harvest

and the % of Rangeland per county had positive effects (Fig 2 & 3; $\beta = 0.01$, 95% CI = 0.003 □ 0.02, $\beta = 0.01$, 95% CI = 0.001 □ 0.01 and $\beta = 0.58$, 95% CI = 0.07 □ 1.09 respectively). Further, precipitation during antler growth the year of harvest, the % of Deciduous Forest per county and the % of Coniferous Forest per county showed positive but less certain effects (Fig 2 & 3; $\beta = 0.004$, 80% CI = -0.001 □ 0.01, $\beta = 0.27$, 80% CI = -0.04 □ 0.57 and $\beta = 0.28$, 80% CI = -0.05 □ 0.61, respectfully), while the precipitation during the winter the year of harvest had a less certain negative effect (Fig 2; $\beta = -0.004$ and a CI of -0.01 □ 0.002. $\tau^2$ and $v^2$ were relatively low (0.002 and 0.01 respectively), and $\rho$ was moderately high ($\beta$ =0.74). Finally, there was no temporal trend in size and tine number over time (Table S3, available in Supporting Information).

## DISCUSSION

The recreational hunting of white-tailed deer brings in millions of dollars to the Canadian economy annually (Fish and Wildlife Ontario 2016). To the Indigenous peoples of North America, white-tailed deer are a food source but their antlers and hides provide material for clothing, tools, and shelter, while also playing an important role in spiritual ceremonies (Brown 2011). Despite their economic and cultural importance, the size of trophy antlers appears to be declining across North America (Monteith et al. 2013). This decline showcases the need to better understand the factors influencing antler growth on a regional level, with for example studies suggesting that edge habitats containing forest cover could increase antler size (Cain et al. 2019). Accordingly, we investigated spatial drivers and temporal patterns of harvested record deer in Ontario, Canada. We observed that increases in temperature during the month's antler growth is occurring (March-August) positively influenced all antler characteristics (Fig 2), and that rangeland and forest makeup are key landscape components correlated to overall increase in antler size. No change in antler size was detected over time in Ontario (Fig. 4).

This data set is representative of adult antlered white-tailed deer within Ontario and although not a random sample, the data captures a large range of variation in antler size across the population (Fig S1, available in Supporting Information) and temporal, spatial and environmental influences will be reflected in this large sample of male white-tailed deer (see also Strickland and Demarais, 2008; Monteith *et al.*, 2013; Cain *et al.*, 2019). All models exhibited moderate to high spatial autocorrelation ($\rho$) suggesting that nearby counties tend to have similar conditions (i.e., temperature). However, a moderate value indicates that some unaccounted-for spatial covariates are still present but not explicitly modeled. Possible missing covariates such as land productivity, landcover structure, or distribution of certain minerals like phosphorus and calcium could be factors worth further exploration (Grasman and Hellgren 1993, Cain et al. 2019), though the appropriate GIS layers currently do not exist for Ontario. We observed low $\tau^2$ in models assessing antler characteristics indicating that, although the predictors often have similar conditions in neighboring counties, antler size does not exhibit strong spatial structure. However, a strong $\tau^2$ when assessing the count of record deer per county does suggest that counties with higher numbers of record deer are more likely to have neighboring counties with similarly high counts, likely reflective of variation regional hunting interest and behaviour. Notably, hunter behaviour and success which will vary by roads, dwellings, and accessibility (Kilgo et al. 1998, Bonnot et al. 2013).

**Environmental drivers of record antlers**

Temperature was the most consistent environmental driver of antler traits: higher temperature was related to an increase in antler size metrics in all models (Fig 2). During the year of harvest a 1°C increase in temperature was associated with a ~1% increase in tine number, a ~10% increase in symmetry, and a ~1% increase in score. Warmer temperatures have been linked to larger antlers and greater reproductive success in white-tailed deer and other Cervidae (Clements et al. 2010, Simard et al.

2010). Increased plant growth from warmer conditions means more forage availability for the deer and therefore more energy is able to be allocated to antler growth (French et al. 1956, Hatfield and Prueger 2015). Here, the unique annual regrowth of antlers makes them strongly affected by yearly temperature changes (Foley et al. 2012). When looking at tine number and score, the temperature one year prior to harvest and 2 years prior to harvest respectively, also had positive effects on antler size and morphology (Fig. 2). Antler growth depends on the accumulation of resources stored in the animal's body, warmer environments, and in turn higher nutritional gain, in prior years can enhance fat reserves which are then used in subsequent antler cycles when that energy is needed (Hewitt 2011).

Similar inference can be made from the influence of precipitation during antler growth the year of harvest on antler size. Wetter conditions can lead to increased plant growth which could again affect the annual regrowth of antlers (Foley et al. 2012, Scharwies and Dinneny 2019). A 1mm increase in precipitation was associated with a ~1% increase in net score. Similarly, we saw negative effects from precipitation during the winter the year of harvest on antler size (Fig 2). More snow in winter can make it more difficult for the deer to move around and find forage, which causes them to congregate in deer yards (Government of Ontario 2019). Deer yards are an area made up of coniferous trees that have a large canopy for blocking excessive snowfall (Government of Ontario 2019). With deer being confined to these yards deer density and the availability of forage for each individual animal decreases (Patterson and Power 2002). This could then put individuals with poor body conditions at a disadvantage and minimal fat reserves when antler regrowth commences (Lesage et al. 2001).

Rangeland and Forest landcover had positive effects on antler characteristics, meaning that as the percentages of these types of landcover in each county rose so too did antler score and tine number (Fig 5). Rangeland and Forest together have been found to increase the probability of harvesting a record deer and are ideal prime edge habitats (Cain et al. 2019). Forests will

block excessive snowfall and contain large amounts of northern deer's primary food source, browse (Hewitt 2011). Further, rangeland allows for greater visibility of large antlered bucks from further away, potentially increasing hunter success or improving the effectiveness of dominance displays and mate attraction, while also providing food such as grasses (Gilbert et al. 2006, Hewitt 2011, Houde et al. 2020). Collectively, these combined edge habitats are preferred by white-tailed deer as it allows them to have a larger variety of food sources and provides both more space for movement (rangeland) while still having adequate cover (forest) (Halls 1984, Alverson et al. 1988).

**Number of harvested deer and antler symmetry**

We observed that increased average temperatures were associated with more record white-tailed deer being harvested in a given Ontario county with a 1°C increase in temperature during the year of harvest being associated with an increase in the number of record-sized deer by 1.24 deer in a given county. Similar to antler size, warmer temperatures allow for more forage availability assuming deer densities are not overwhelming the landscape. With more food available, more energy is able to be allocated to individual deer in a county, presumably allowing more to reach record deer status. The number of record deer harvested were not significantly affected by any landcover covariates (Fig 3); so, while landcover type positively impacts antler size, the overall effect is minor such that it does not increase the net number of large animals harvested in a given year. Curiously, record deer numbers were positively affected by elevation (Fig. 2). It is tempting to suggest this being reflective of mature deer finding refuge from human activity via fewer roadways at these elevations. Less trafficked zones allow deer to move more freely and access critical resources with minimal human interference (Hamilton et al. 2024) and behaviourally deer learn to avoid humans (Kilgo et al. 1998, Marantz et al. 2016). However, the elevational range is small in the province (0 m – 700 m) and obfuscated when averaged across the

county as done here (66 m – 415 m), and thus finer scale analysis is warranted to better understand this effect.

The symmetry of antlers appears to be impacted by precipitation, with higher precipitation levels 2 years prior to antler growth resulting in less symmetrical antlers. Under uniform environmental conditions, white-tailed deer exhibit a genetic predisposition for antlers to grow symmetrically (Ditchkoff et al. 2001). White-tailed deer can develop antler asymmetry when exposed to environmental stressors affecting their energy allocation before and during antler growth (Goss 2012). The mechanism by which precipitation 2 years prior impacts asymmetry is not clear. Maternal effects on antler size are documented in cervids (Freeman et al. 2013), so early-in-life conditions can impact adult traits, with the impact to antlers seemingly long-lasting (Freeman et al. 2013). Asymmetry has also been seen to increase as trait size increases (De Coster et al. 2013), which we observed in our data set (Fig S2, available in Supporting Information); however, we see no strong relationship between precipitation and antler size, making this explanation unlikely. It is thus conceivable that high environmental stressors might have long-term impacts on symmetry, even for antlers that are shed annually.

**Temporal patterns of record deer**

Over the last 40 years, there has been no significant change in antler size (or score) and the tine number of harvested record white-tailed deer in Ontario (Table S3). This contrasts the findings of Monteith et al. (2013) who reported a negative trend across North America in antler size in white-tailed deer from 1950 to 2008. These negative trends were hypothesized to be a combination of harvest-induced reduction in age structure, sociological effects and density dependence (Monteith et al. 2013). Our finding suggests that antler trends in white-tailed deer are region specific and might change depending on the environment and pressures present.

In Ontario, the number of active hunters has stayed relatively consistent since 2008 while the

number of records submitted to FROW has declined (Fig 6). This could be indicative of a possible shift in hunting priorities (Monteith et al. 2013), but multiple tough winters in 07/08 and 10/11, have coincided with apparent population declines (Ontario Outdoors Magazine Game Forecast 2009, 2011) which would explain a decrease in entries. Still, the number of white-tailed deer in Ontario are relatively low especially compared to other regions of North America where population numbers are substantially higher. For example, Michigan with similar environmental conditions to Ontario and an area of ~ 250,493 $km^2$ has a population of ~2 million white-tailed deer, compared to Ontario with an area of over 1 million $km^2$ and a white-tailed deer population of ~400 thousand (Mason 2016, Conner 2021). In much of North America, warmer climates lead to longer growing seasons and an abundance of high-quality food, which allows white-tailed deer to reach their maximum physical size during antler growth (Sontheimer et al. 2024). In contrast, Ontario's colder winters limit access to nutritious food, which could be preventing deer from achieving their full antler growth potential; this limitation could mean there is still room for growth. Our models indicate that warming temperatures in Ontario are positively influencing antler development, as milder winters and longer growing seasons improve food availability. With ongoing climate changes, we would predict a positive trend in overall antler size if environmental conditions became more favourable for deer and harvest pressures remain like those during our time series.

## MANAGEMENT IMPLICATIONS

Our findings highlight how variation in habitat conditions across Ontario counties are related to differences in antler size and morphology as well as record white-tailed deer distributions. Understanding these patterns and relationships can help identify conditions more likely to produce larger antlered deer, and by communicating these findings, hunters can better manage their expectations and recognize aspects that could cause certain regions to have higher large-antlered white-tailed deer

concentrations, leading to greater satisfaction (D'Angelo and Grund 2015). An increase in hunter satisfaction should, in turn, generate revenue that supports the funding of conservation efforts, wildlife management programs, and local economies. With no significant temporal trend in antler size, the current harvest practices are likely effective, but we note increased harvest pressure on males in other regions has led to a reduction in age structure (Langvatn and Loison 1999, Mysterud 2011). Density dependence also disproportionately affects large males, as they often enter the winter months with low fat reserves from energy expenditure during the mating season (Lesage et al. 2001, Keyser et al. 2005), which could have implications for survival and future antler growth. This reinforces the need to continue to monitor harvest practices to ensure that population dynamics and habitat limitations do not negatively impact the long-term sustainability of Ontario's deer population.

**ACKNOWLEDGMENTS**

This work was supported by NSERC Discovery Grant (ABAS; 410 SDC); Canadian Foundation for Innovation (ABAS): John R. Evans Leaders Fund (ABAS) and the Ontario Early Researcher Award (ABAS). Trent University is located on the traditional territory of the Michi Saagiig Anishnaabeg.

**ETHICS STATEMENT**

No approval of research ethics committees was required to accomplish the goals of this study.

**DATA AVAILABILITY**

The antler data that support the findings of this study are available from The Foundation for the Recognition of Ontario Wildlife, Ontario, Canada and were acquired under research agreements for this study. All other model covariates are provided.

**CONFLICT OF INTEREST**

Authors declare no competing interests.

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## FIGURES

Figure 1. Approximate Ontario land cover distribution (Left) and elevation (Right) divided by county.

Figure 2. Parameter estimates of 80% and 95% confidence intervals (CI) for all models, predicting the effect of elevation, temperature, and precipitation on the response variables.

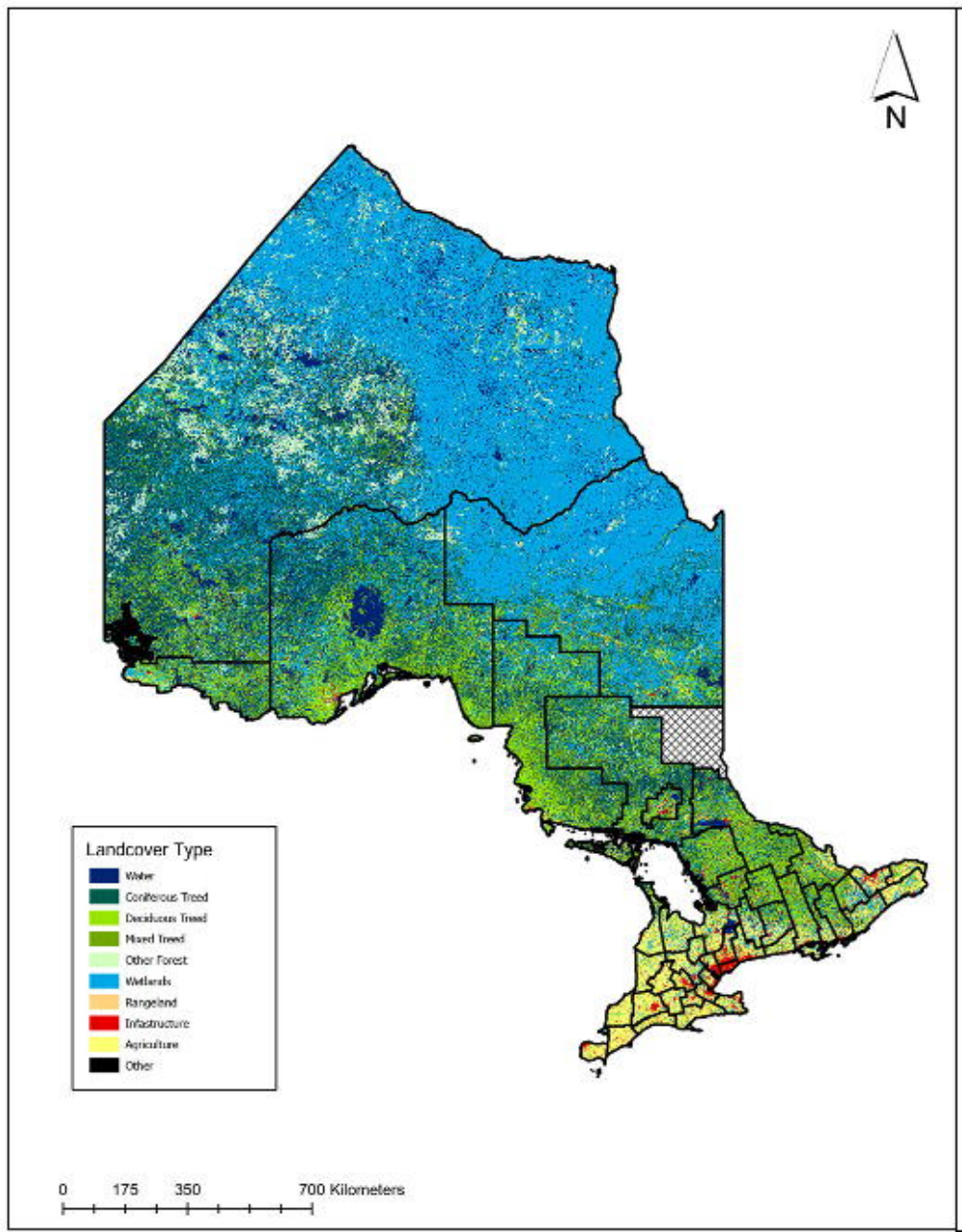
Figure 3. Parameter estimates of 80% and 95% confidence intervals (CI) for all models, predicting the effect of landcover proportion on the response variables.

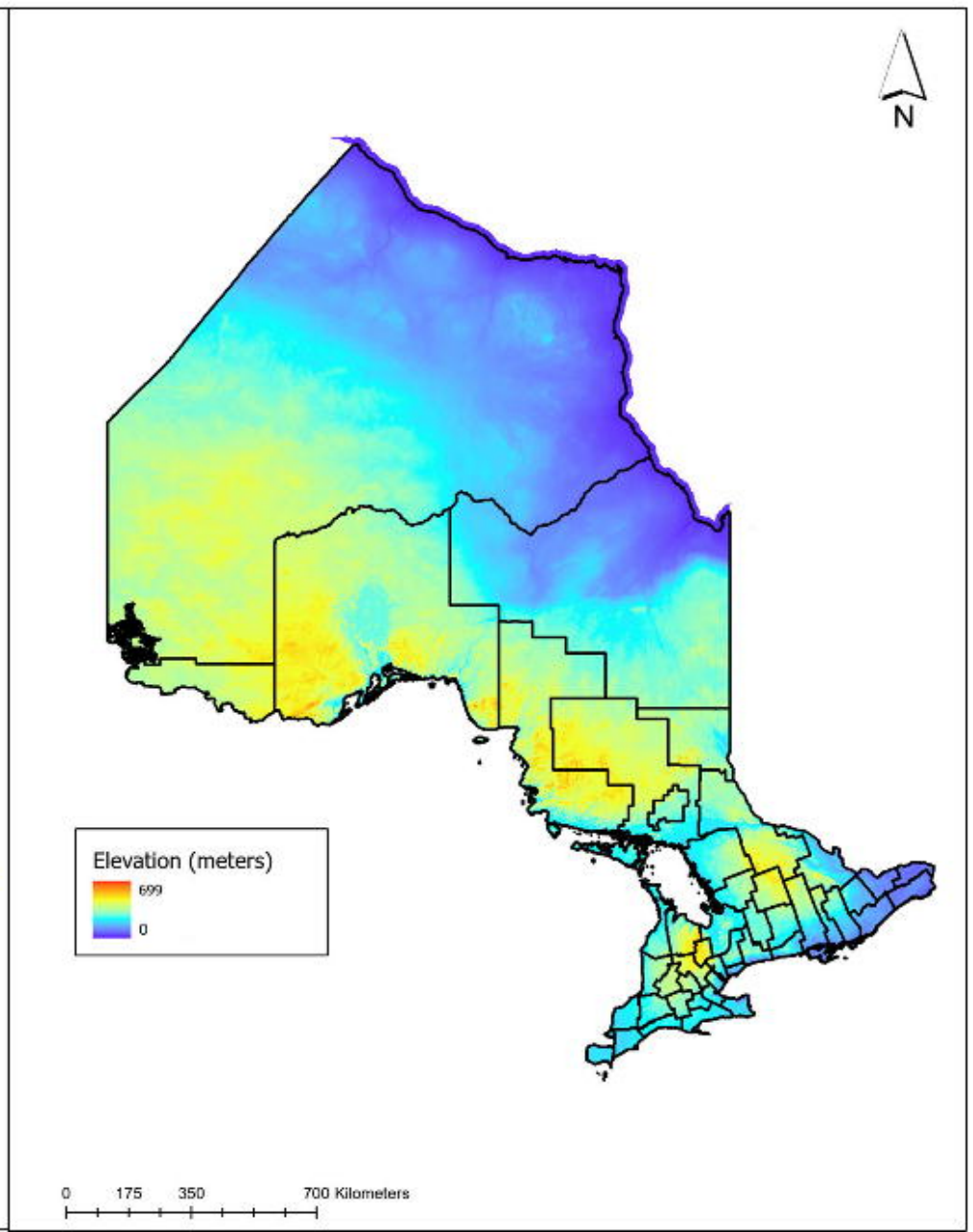
Figure 4. Change in antler score and tine number over time. Cutoffs are representative of Boone and Crockett data, depicting the higher cutoff size for record antlers in other parts of North America.

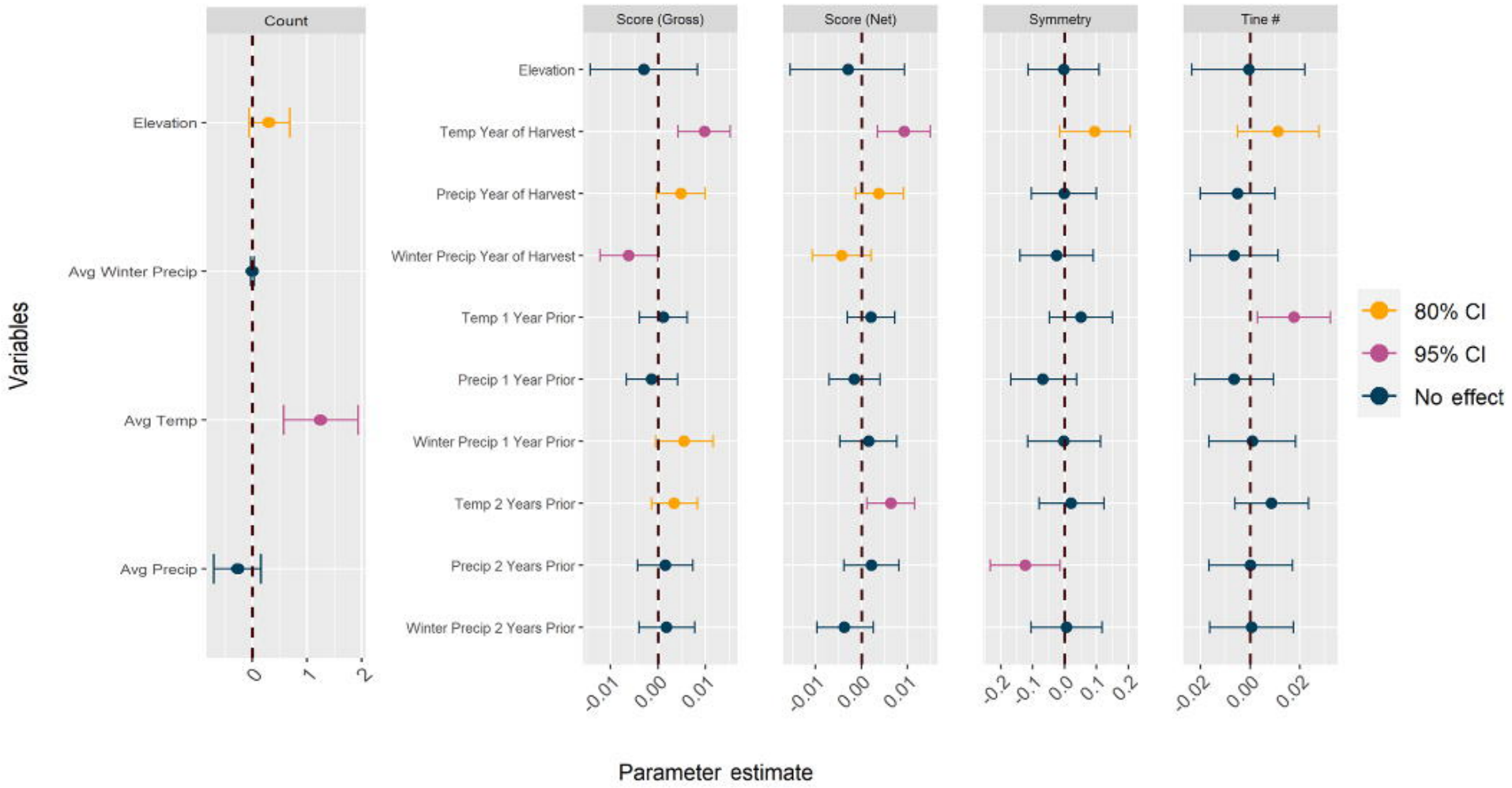
Figure 5. Percent of significant landcover per predicted antler score and tine number

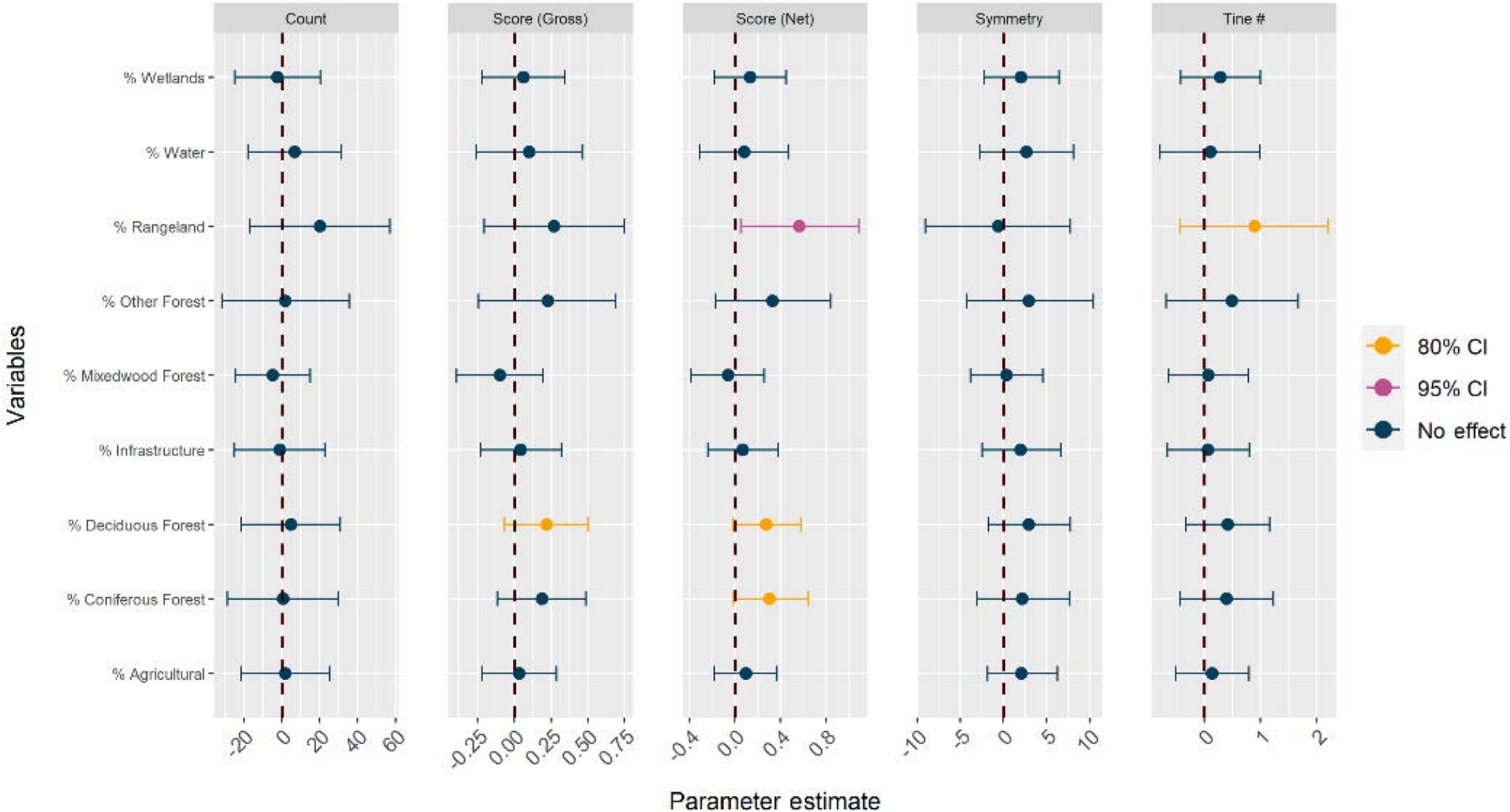
Figure 6. Number of records submitted to the Foundation for the Recognition of Ontario Wildlife (FROW) from 1997 to 2020 (blue) and Number of active hunters from 2008 to 2022 (pink)

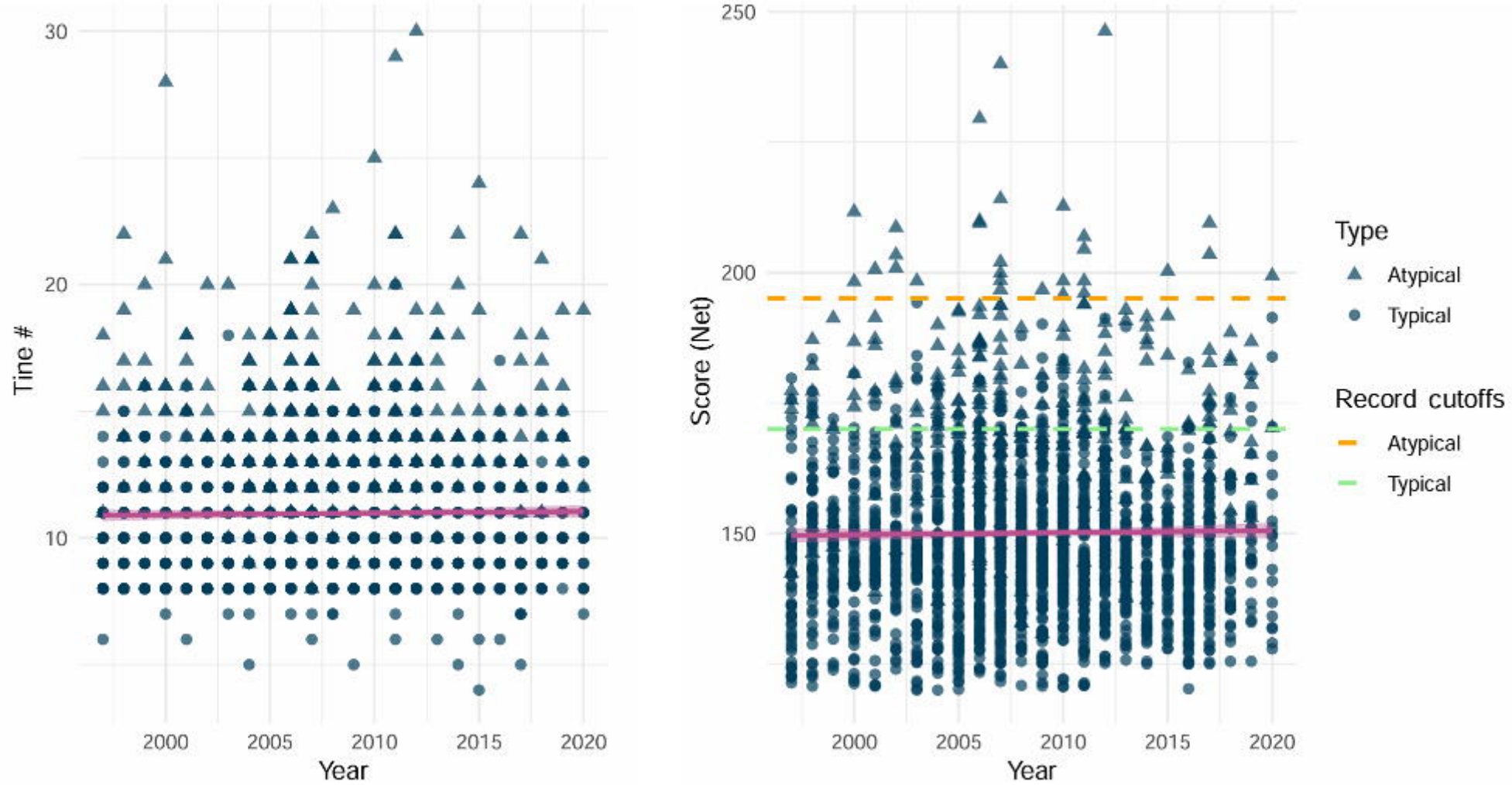
## APPENDIX A. SUPPLEMENTAL

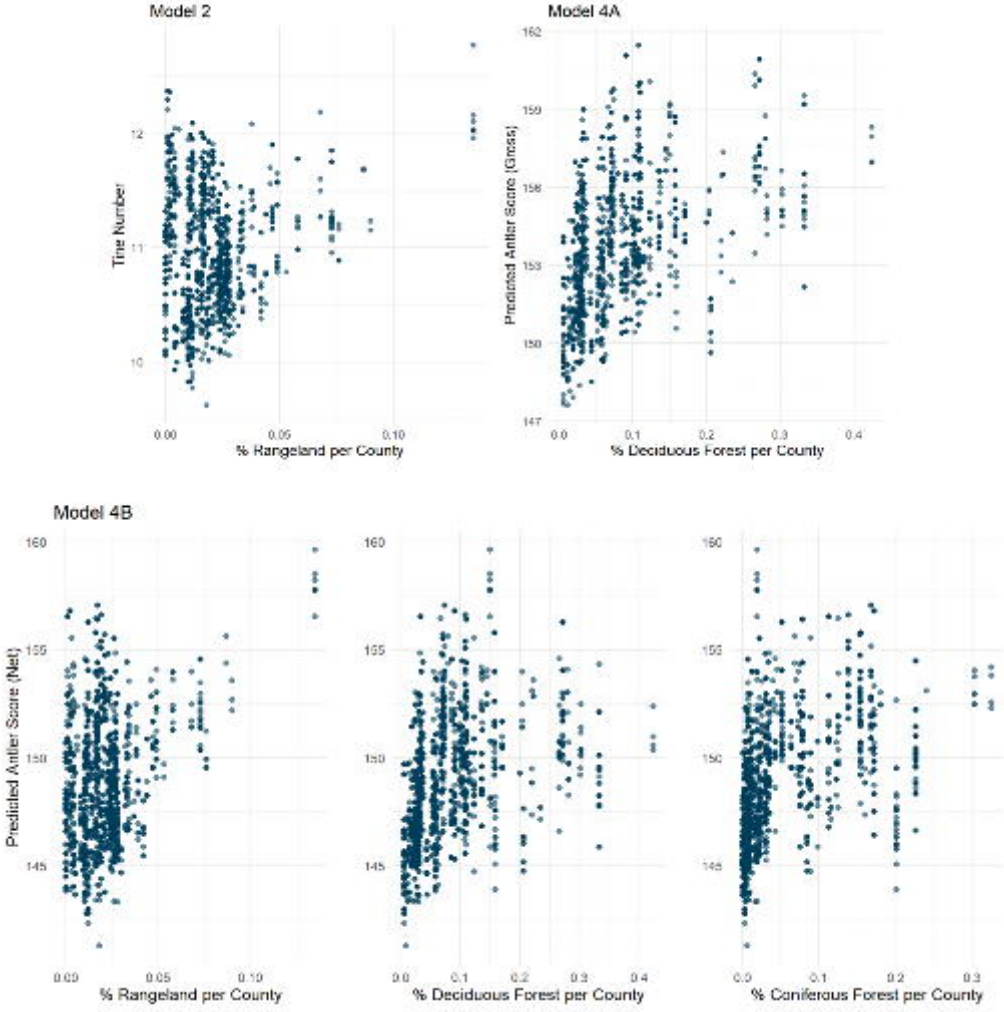

N
Landcover Type
Water
Coniferous Treed
Deciduous Treed
Mixed Treed
Other Forest
Wetlands
Rangeland
Infastructure
Agriculture
Other
0 175 350 700 Kilometers

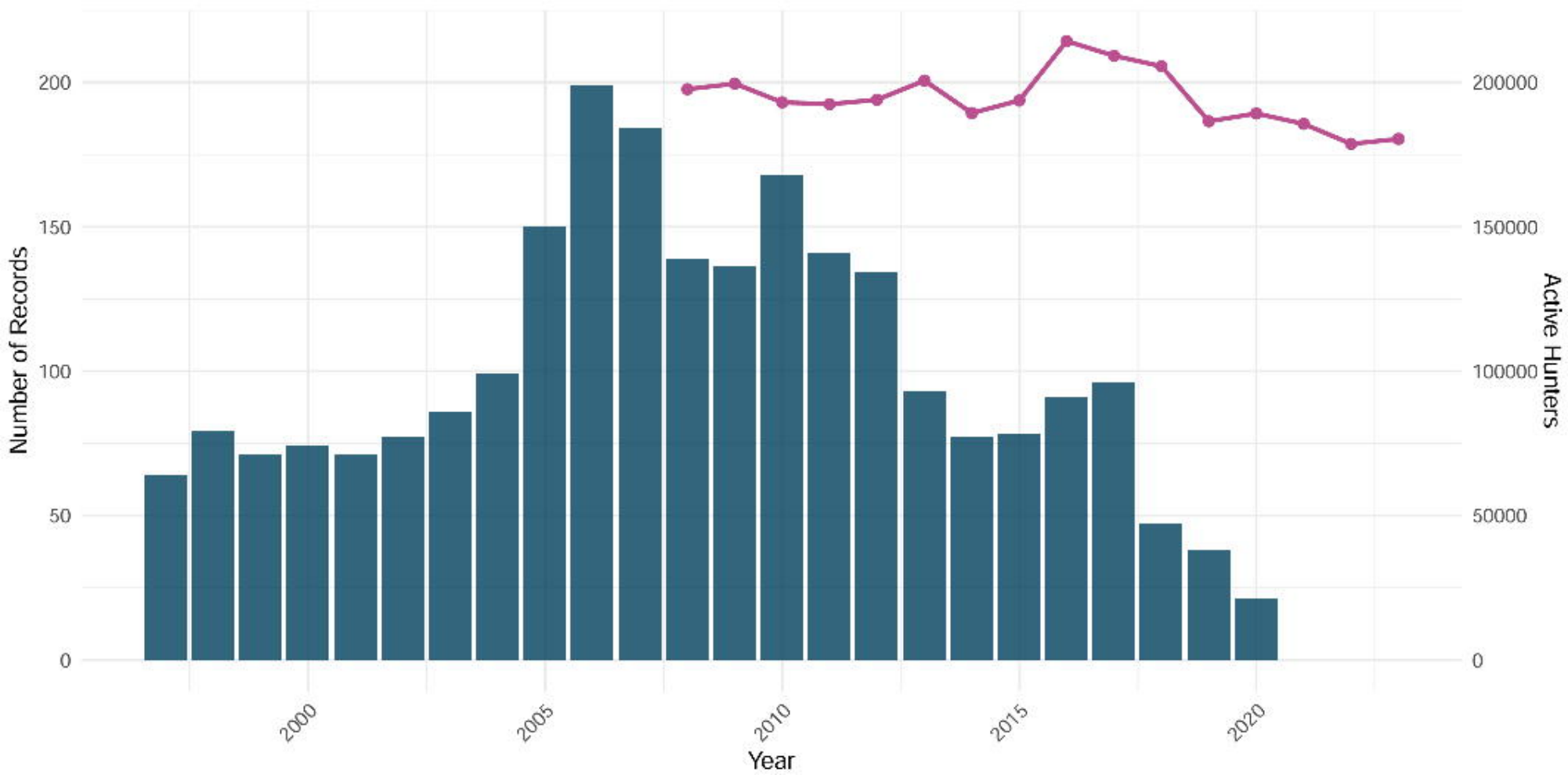

N
Elevation (meters)
699
0
0 175 350 700 Kilometers


Count
Score (Gross)
Score (Net)
Symmetry
Tine #
Variables
Elevation
Avg Winter Precip
Avg Temp
Avg Precip
Temp Year of Harvest
Precip Year of Harvest
Winter Precip Year of Harvest
Temp 1 Year Prior
Precip 1 Year Prior
Winter Precip 1 Year Prior
Temp 2 Years Prior
Precip 2 Years Prior
Winter Precip 2 Years Prior
0
1
2
-0.01
0.00
0.01
-0.2
-0.1
0.0
0.1
0.2
-0.02
0.02
80% CI
95% CI
No effect
Parameter estimate


Count
Score (Gross)
Score (Net)
Symmetry
Tine #
% Wetlands
% Water
% Rangeland
% Other Forest
% Mixedwood Forest
% Infrastructure
% Deciduous Forest
% Coniferous Forest
% Agricultural
Variables
-20
0
20
40
60
-0.25
0.00
0.25
0.50
0.75
-0.4
0.0
0.4
0.8
-10
-5
0
5
10
0
1
2
Parameter estimate
80% CI
95% CI
No effect


30
20
10
Tine #
2000
2005
2010
2015
2020
Year
250
200
150
Score (Net)
2000
2005
2010
2015
2020
Year
Type
Atypical
Typical
Record cutoffs
Atypical
Typical


Model 2
Time Number
12
11
10
0.00
0.05
0.10
% Rangeland per County
Model 4A
Predicted Antler Score (Gross)
162
159
156
153
150
147
0.0
0.1
0.2
0.3
0.4
% Deciduous Forest per County
Model 4B
Predicted Antler Score (Net)
160
155
150
145
0.00
0.05
0.10
% Rangeland per County
0.0
0.1
0.2
0.3
0.4
% Deciduous Forest per County
0.0
0.1
0.2
0.3
% Coniferous Forest per County


Number of Records
Active Hunters
Year
0
50
100
150
200
0
50000
100000
150000
200000
2000
2005
2010
2015
2020