Applied Geography 98 (2018) 1–8

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Longleaf pine masting, northern bobwhite quail, and tick-borne diseases in the southeastern United States

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ARTICLE INFO

Keywords:
Longleaf pine
Masting
Tick-borne disease
Northern bobwhite quail
Southeast

ABSTRACT

Although the relationship between oak mast and Lyme disease incidence in humans is established in the Northeastern U.S., mast-disease relationships have not been explored for longleaf pine in the southeastern U.S. Here, we examine if relationships exist between longleaf pine mast and tick-borne disease incidence in humans using climate, wildfire, and northern bobwhite quail (*Colinus virginianus*) data as possible influential variables. We examined the relationship between longleaf pine mast data and tick-borne disease incidence for Lyme, Spotted Fever Group Rickettsia (SFGR), and *Ehrlichia chaffeensis* (ehrlichiosis) using one-sided Pearson's product-moment correlations at ten individual masting locations and for the entire masting region in the southeastern U.S. Region-wide mast from the previous year were positively correlated with northern bobwhite quail and negatively correlated with Lyme disease. Additionally, northern bobwhite quail were negatively correlated with SFGR and ehrlichiosis, and both drought severity and fire were not correlated with the other variables. We posit the nutrient-rich pine seeds that are a major food source for northern bobwhite quail promote above-average quail populations the following year. As quail diet transitions from seeds in cool months to ground-dwelling insects the following spring and summer, we hypothesize the ability of northern bobwhite quail to consume ticks reduces tick populations and significantly reduces disease incidence in humans.

1. Introduction

Longleaf pine (*Pinus palustris.*) is native to the southeastern U.S. and exists primarily within the Coastal Plain and Piedmont physiographic regions with outlier populations dispersed in the Ridge and Valley region of Northern Alabama and Georgia (Peet, 2006) and the Uwharrie Mountains of central North Carolina (Patterson & Knapp, 2016). Once considered the dominant coastal-plain pine tree prior to European settlement (Ware, Frost, & Doerr, 1993), only a fraction of its range remains intact due to centuries of land-use changes including deforestation, fire suppression, conversion of forest savanna to agriculture, and the naval stores industry (Frost, 1993). Recent analysis (Oswalt et al., 2012) documenting the extent of longleaf pine forests in the southeastern U.S. estimates that approximately three percent of the original forests remain, with a range reduction from 38 million hectares to just over one million hectares. The extant stands of longleaf pine support a suite of rare and endemic species (e.g. red cockaded woodpecker (*Leuconotopicus borealis*); eastern indigo snake (*Drymarchon corais couperi*); gopher tortoise (*Gopherus polyphemus*) Means, 2006)), with remnant longleaf savannas harboring exceptionally high plant diversity for the Western Hemisphere (Noss et al., 2015; Peet & Allard, 1993). Longleaf pine savannas are embedded within the newest global biodiversity hotspot, The Coastal Plain Floristic Provenance, with over 1600 endemic plant species found nowhere else on Earth (Noss et al., 2015). Thus, the rarity and importance of longleaf pine forests has promoted research devoted to better understanding longleaf pine forest reforestation and how interannual mast (i.e., cone crop) variability affects regeneration success.

Annual cone production for longleaf pine is variable due to episodic cone masting cycles (Boyer & Peterson, 1983). Above-average cone crops occur throughout the species' range every 5–7 years (Wahlenberg, 1946), with large "bumper" crops occurring every 8–10 years (Maki, 1952). To better understand masting cycles of longleaf pine, annual cone-count inventories were initiated by W.D. Boyer of the United States Forest Service (USFS) in Escambia County, Alabama in 1958 and have been expanded to over 11 locations throughout the southeastern US (Brockway, 2015; Connor, Brockway, & Boyer, 2014, p. 24). Spatiotemporal variability of cone mast has been observed throughout the species' range that is attributable to either changes in forest management or climate conditions leading to improved pollination efficiency

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https://doi.org/10.1016/j.apgeog.2018.06.010
Received 13 June 2017; Received in revised form 27 April 2018; Accepted 22 June 2018
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and conelet survival (Croker & Boyer, 1975, Boyer, 1987, 1997, 1998). Additionally, others (Chen, Guo, & Brockway, 2016; Guo, Zarnoch, Chen, & Brockway, 2016; Leduc et al., 2016; Pederson, Kush, Meldahl, & Boyer, 1999; Shoulders, 1967) have fond a suite of monthly climate conditions that correlate with longleaf pine mast during its 3-year development. Bumper mast years are critical for successful longleaf pine regeneration (Brockway, Outcalt, & Boyer, 2006) and for providing food resources for several species native to longleaf pine forests (Means, 2006). Studies using the USFS mast data either have principally observed environmental factors that influence mast including thinning (Boyer, 1979), climate (Pederson et al., 1999, Guo et al., 2016, Leduc et al., 2016), or the inherently complex and sporadic nature of mast variability (Chen et al., 2016). To our knowledge, these data have not been used to address potential interactions between mast abundance and bird populations and how these relationships may indirectly affect the incidence of tick-borne disease prevalence in humans.

Over two decades of research has linked masting cycles of hardwood trees (*Quercus* spp.) to mast predator populations (deer, mice, chipmunk), which serve as hosts for a variety of ticks that can transmit tick-borne diseases to humans. Most of the mast-tick-disease research has focused on the northeastern U.S. due to the density of reported cases of Lyme disease and the geographic dispersal of *Ixodes scapularis*, the blacklegged (deer) tick that can spread *Borrelia burgdorferi*, the spirochete bacteria causing Lyme disease in humans (Kugeler, Farley, Forrester, & Mead, 2015). Ostfeld, Cepeda, Hazler, and Miller (1995) observed an unusual increase in larval ticks in oak forests the year following a bumper acorn mast positing that white-tailed deer (*Odocoileus virginianus*) feeding on the bumper mast harbored adult ticks that would drop off and lay their eggs the following spring. Subsequent studies tested the hypothesis of an "acorn connection" (Ostfeld, 1997) to explain how mast variability of hardwood trees modulates host populations that in turn affect tick populations and alter the propensity to spread Lyme disease to humans (Jones, Ostfeld, Richard, Schauber, & Wolff, 1998; Ostfeld, Canham, Oggenfuss, Winchcombe, & Keesing, 2006, 2001; Schauber, Ostfeld, & Evans, 2005).

These mast/disease studies from the northeastern U.S. have shown that acorn abundance of year X positively influences mast-consumer populations, which in turn positively influences infected tick nymph abundance in year X + 1 and Lyme disease incidence in year X + 2. Here, we address if a similar relationship (i.e. a "cone connection") exists between longleaf pine mast, the mast-consuming northern bobwhite quail (*Colinus virginianus*), and tick-borne diseases in the southeastern U.S.. Based on data from five locations in the longleaf pine range, Reid and Goodrum (1979) found longleaf pine seeds comprised 85% of northern bobwhite quail diet during peak seed availability in November and 22–46% of the total winter diet, suggesting they are a major longleaf pine mast consumer. The consumption of ticks (and thus tick populations) by the northern bobwhite quail, a specialist to longleaf pine forests (Means, 2006), is not well documented. While most of the adult bobwhite quail diet is comprised of seeds and leaves, between 5% (male) to 20% (female) of their diet are arthropods (Cornell, 2018). Conversely, bobwhite chicks are principally fed insects during their first 6–8 weeks (Cornell, 2018), which likely includes ticks.[1]

In the southeastern U.S., several tick species carry bacteria associated with a variety of tick-borne diseases (Stromdahl & Hickling, 2012). The Gulf Coast tick (*Amblyomma maculatum*) shares a range coincident with longleaf pine and is the principal carrier of *Rickettsia parkeri* rickettsiosis (Paddock & Goddard, 2015; Parola et al., 2013). Other southeastern U.S. tick species include the Lonestar (*Amblyomma americanum*), American Dog (*Dermacentor variabilis*), Brown Dog (*Rhipicephalus sanguineus*), and Blacklegged (*Ixodes scapularis*) ticks. These species can transmit bacteria to humans and include multiple species of Rickettsia attributed to spotted-fever group rickettsiosis (SFGR), *Ehrlichia chaffeensis* (ehrlichiosis), and *Borrelia burgdorferi* (Lyme disease) (Childs & Paddock, 2003; Nadolny, Wright, Sonenshine, Hynes, & Gaff, 2014; Stromdahl & Hickling, 2012). Both SFGR and ehrlichiosis have not been studied for mast–disease relationships yet are of growing human-health concern in the southeastern U.S. (Parola et al., 2013), and pathogens such as *Rickettsia parkeri* that comprise SFGR can be found in > 50% of gulf coast ticks (Nadolny et al., 2014). Similarly, ehrlichiosis, whose primary vector is the Lonestar tick (Goddard & Varela-Stokes, 2009; Varela-Stokes, 2007), is most prevalent in the southeastern and south-central U.S. (CDC, 2016).

An efficient method for reducing tick populations in longleaf pine forests occurs through prescribed burning (Gleim et al., 2014; Hoch, Semtner, Barker, & Hair, 1972; Mather, Duffy, & Campbell, 1993). Gleim et al. (2014) found a significant reduction in four species of ticks associated with long-term prescribed burning at the J.W. Jones Ecological Research Center (and USFS mast-count site) that they deemed consistent with previous research regarding the influence of fire in pine and mixed-pine forests (Cully, 1999; Jacobson & Hurst, 1979). Similarly, biological control using fungicides (Ostfeld, Price, Hornbostel, Benjamin, & Keesing, 2006) or bird species (Ostfeld & Lewis, 1999) has provided mixed results. Likewise, longleaf pine literature does not include discussion on the effects of masting cycles on tick-borne disease prevalence in the southeastern U.S. In this study we examine the relationship between longleaf pine mast, tick-borne disease incidence and a specialist bird species of longleaf pine forests using a multidecadal longleaf pine mast dataset. Specifically, we hypothesize a positive relationship will exist between northern bobwhite quail and longleaf pine mast. Additionally, we hypothesize a negative relationship will exist between northern bobwhite quail and tick-borne diseases. We expect at least a one-year lag to be operative for these relationships.

2. Data and methods

2.1. Pine-cone data

Longleaf pine cone mast is counted annually each April at 11 sites in the longleaf pine range from eastern North Carolina to central Louisiana and reported by the USFS (Brockway, 2015, p. 24). Mast counts for each site represent the cones that will ripen and release seeds during October–November following the spring survey. Based on mast-data completeness, we selected 10 locations (Fig. 1, Table 1) excluding one site, Ordway-Swisher Biological Station, as 2015 was its first year of data collection. For each location, we used all available years coinciding with tick-borne disease data availability unless data were otherwise unavailable (Table 1).

2.2. Disease data

Annual, county-level tick-borne disease incidence data were obtained from the US Centers for Disease Control and Prevention (CDC) for Lyme, SFGR, and ehrlichiosis. Lyme data were downloaded from the CDC Lyme webpage whereas a data request was fulfilled through the National Notifiable Disease Surveillance System (NNDSS) for SFGR and ehrlichiosis. SFGR is a composite of three bacteria/tick species including *Rickettsia rickettsia* carried by three tick species including the American dog tick, Rocky Mountain wood tick (*Dermacentor andersoni*), and the Brown dog tick; *Rickettsia parkeri* carried by the Gulf Coast tick; and Rickettsia species 364D carried by Pacific Coast tick (*Dermacentor occidentalis*). Similarly, ehrlichiosis describes three bacterial diseases and we were able to obtain confirmed cases caused by the species

[1] Biologist Eric Powers (https://www.yc2n.com/bobwhite-quail-vs-tick-study.html) has studied the effects of releasing young bobwhite quail on Long Island, NY to reduce tick populations and has found that this is an effective strategy. Additionally, in summer 2016, Patterson contacted Dr. Keith Clay who is who is a Distinguished Professor of Biology at Indiana University focusing on disease and host ecology. Patterson directly asked Dr. Clay about the feasibility of the bobwhite quail and tick connection and Dr. Clay stated that while he knew of no formal studies on this, he thought viability of this linkage was with merit.

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