Title Twenty-five years of variation in acorn mast production on Allegheny woodrat populations in western Maryland

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Abstract The Allegheny woodrat (*Neotoma magister*) is a small mammal that inhabits rocky outcrops within deep caves and crevices of the Appalachian Mountains currently listed as near threatened globally (International Union for Conservation of Nature RedList) and endangered in Maryland (Maryland Department of Natural Resources). The reason for its current decline is attributed to a variety of factors, including loss or decline of mast species such as the American chestnut (*Castanea dentata* (Marsh.) Borkh.), butternut (*Juglans cinerea* L.), and oaks (*Quercus spp.*). Possible correlations between woodrat populations and oak mast production in western Maryland were analyzed from 27 years of data of woodrat populations and 16-22 years of proximate mast surveys. The Fishing Creek Allegheny woodrat population was significantly positively correlated (r =0.800, p = 0.001) with mast production collected at a site within 1.1 km. Three other woodrat sites were not significantly correlated with mast production, which may be attributed to a greater distance between survey sites or other factors. Sites were analyzed for presence and abundance of all mast producing species as well as other possible woodrat food sources. An important mast source, white oaks (*Quercus alba* L.) were not present at a single site. Gypsy moth (*Lymantria dispar*) infestations may also account for a lack of significant correlations since defoliations may be responsible for decreased acorn production in localized areas. We assessed proportions of earlywood from tree rings at woodrat sites to determine possible years with a higher proportion of earlywood that may correspond with gypsy moth defoliations and a reduction in mast production. White oak and blight-resistant American chestnut supplemental plantings may provide additional hard mast for woodrats in years between abundant mast production from northern red oaks (*Quercus rubra* L.), which were present at all of the woodrat sites.

Keywords Allegheny woodrat, dendrochronology, earlywood, mast production, *Neotoma magister*, oaks, *Quercus*.

Introduction

Declines of wildlife species are sometimes attributed to one factor, but the case of the Allegheny woodrat's (*Neotoma magister*) decline in the eastern United States has remained puzzling and is now considered by many to be the result of a complex interplay of variables. LoGuidice (2006) suggests a multi-faceted approach to understanding the decline of the Allegheny woodrat, which includes habitat fragmentation, food decline, parasite mortality, and fluctuations in competitor and predator communities.

One of the main components of the Allegheny woodrat's diet is hard mast, particularly acorns that provide high energy during winter (Poole 1940; Castleberry et al. 2002; Ford et al. 2006; Manjerovic 2009). Oak masting events occur periodically, cycling every 2-4 years depending on the species (Sork et al. 1993) and therefore, do not provide a consistent source of overwintering food for the Allegheny woodrat. Several populations of mammalian and avian species that rely on oak mast have been shown to fluctuate with cyclical mast years including red-headed woodpeckers and blue jays (Smith 1986), white footed mice (Ostfeld 1996; Wolff 1996; McShea 2000), and white tailed deer (McShea 1993).

Populations of Allegheny woodrats in the north have declined drastically, extirpated in Connecticut and New York, while Maryland is continuing to see a sharp decline (Peles & Wright 2008). The Allegheny woodrat is currently listed on the IUCN red list as near threatened, and is an S1 species in Maryland, Ohio, New Jersey, and New York. The cause of woodrat decline remains unknown and currently several culprits are potentially responsible, including habitat fragmentation, food decline or change, a parasite, *Baylisascaris procyonis* (raccoon roundworm), or a continuation of a long-term trend (Peles & Wright 2008). The food decline hypothesis refers to American chestnut (*Castanea dentata*, (Marsh.) Borkh.), the major food source for Allegheny woodrats, was decimated by the introduced chestnut blight *(Cryphonectria parasitica* (Murr.) Barr) around the mid-20th century (Wright 2000). Prior to its decimation, the most common forest community in the Allegheny region was American chestnut-oak (Braun 1950). The Allegheny woodrat could have relied on the consistent annual hard mast produced by the American chestnut. Oaks (*Quercus* L.) have since replaced the American chestnut as the dominant overstory species (Keever 1953) and have become the Allegheny woodrat's preferred food source with highly energetic and nutritive acorn nuts (Poole 1940).

Oak trees in the northeast are currently experiencing a threat due to the exotic gypsy moth *(Lymantria dispar*) that is spreading throughout the Northeastern and Mid-Atlantic United States after its arrival in the United States in 1869. The gypsy moth is currently one of the most environmentally damaging forest pest in the eastern United States (Kauffman et al. 2017). Gypsy moth defoliation of oak leaves can prevent the tree from producing acorns for several years (Hall 1988) and can lead to oak mortality. Recent Forest Inventory and Analysis data from the US Forest Service has shown a shift in some historically oak dominated forests to an influx in red maple (*Acer rubrum*) dominated forests, a tree species that does not produce a nutritive form of mast (McShea 2007).

Mengak and Castleberry (2008) observed a positive correlation between woodrats and oak mast production at 2 of 4 study sites in western Virginia as part of a 12 year study. One of the sites in their study was not oak-dominated and was used as a negative control. In West Virginia, Manjerovic et al. (2009) found a decline in overall woodrat populations and a positive correlation between adult female woodrat capture index and mast production. Few further studies have focused directly on the relationship between woodrats and hard mast, especially in Maryland. In this study we looked not only at mast fluctuations, but dominance of hard mast producers and diversity within the woodrats' home ranges.

We investigate the food-decline hypothesis in an attempt to explain the continuing woodrat decline and we hypothesize that the Allegheny woodrat's decline is in part due to reduction in quality hard mast. The objective of this study was to analyze the relationship between 27 years of acorn counts and Allegheny woodrat population estimates as well as dominant tree species and diversity across western Maryland to determine the relationship between mast production and woodrat numbers.

Methods

Study site description

The entire study area is contained in western Maryland and consists of a total of 6 regularly monitored Allegheny woodrat sites as well as 16 separate sites of mast survey data collection. The Department of Natural Resources (DNR) in Maryland collected woodrat and mast data from 1990 through 2017. The Department of Natural Resources in Maryland conducted Allegheny woodrat trapping from 1991 to 2017 at 4 sites annually and 2 sites annually then bienially in western Maryland. Most active woodrat sites, where woodrats are consistently trapped, occurred in the Blue Ridge, Valley and Ridge, and Appalachian Plateau physiographic provinces in the four westernmost counties of Maryland and long-term monitoring occurred within these provinces (Bailey 1980). Allegheny woodrat trap sites are located along rocky outcrops and sandstone ridge lines at generally steeper slopes and higher elevations, which is consistent with previously observed woodrat habitat preferences (Poole 1940; Rossell et al. 2009; Lombardi et al. 2017). For this study, we analyzed 4 active woodrat sites and the most proximal mast survey site with a similar elevation (Fig. 1).

Allegheny woodrat trapping and population estimates

Personnel with the Department of Natural Resources (DNR) Natural Heritage Program conducted long-term population monitoring of Allegheny woodrats at 6 sites; 4 monitored annually and 2 monitored biennially beginning in 1990 and continuing through 2017 (Fig. 2). At least one long-term site still occupied by woodrats is represented in each of the four westernmost counties. Trapping at each site was conducted over the course of two nights in July through September using 10 – 35 Tomahawk live traps baited with peanut butter (Model 202 [15.24 cm x 15.24 cm x 48.26 cm] Tomahawk Live Trap, Tomahawk, Wisconsin, USA). Traps were set in crevices and beneath rock overhangs, close to latrines or middens, and were set in the same marked locations for consistency each year of the monitoring period. Trapping was conducted at the end of summer to correspond with the weaning of the young of the year and before nighttime temperatures became too cold. DNR personnel checked traps before 1100h the following morning and recorded the captured woodrat’s sex, reproductive status, weight, age, recapture status, and if unmarked, each woodrat was given a unique ear tattoo. The second night of trapping consisted of the same methods, recording recapture status, demographic information, and marking new individuals.

Capture histories were analyzed using a Lincoln-Petersen estimate and 4 woodrat populations were used for analysis. Each of the woodrat sites used for this study were in different physiographic regions, the High Rock and Dans Rock sites are in the Appalachian Plateau province, the Abe Mills site is in the Ridge and Valley province, and the Fishing Creek site is in the Blue Ridge province (Fig. 1). The elevation at the High Rock site was 907 m and the dominant overstory vegetative species were northern red oak (*Quercus rubra* L.*)*, black birch (*Betula lenta* L.), red maple (*Acer rubrum* L.), and mountain ash (*Sorbus americana* L.). The elevation at Dans Rock was 862m and the dominant overstory vegetative species were black birch, northern red oak, red maple, and sassafras (*Sassafras albidum* Nutt. Nees).The elevation at Abe Mills site was 365 m and the dominant overstory vegetative species were northern red oak, black birch, tree of heaven (*Ailanthus altissima* (Mill.) Swingle), red maple, mockernut hickory (*Carya tomentosa* (Lam. ex Poir.) Nutt.), and chestnut oak (*Quercus montana* Willd.). The elevation at the Fishing Creek site was 355 m and the dominant overstory vegetative species were chestnut oak, northern red oak, eastern hemlock (*Tsuga canadensis* (L.) Carrière), and black birch.

Mast surveys and abundance

The Maryland DNR conducted mast surveys in August-September annually at 4 locations in the 4 western counties of Maryland, Garrett, Allegany, Washington, and Frederick Counties (Fig. 2). Mast survey locations were chosen at 3 different elevation gradients, 1 low (202 – 516 m), 2 medium (254 – 841 m), and 1 high (298 – 894 m). The ranges in elevations at each gradient represent the differences in average elevation throughout the physiographic provinces. DNR conducted the surveys on the same 20 trees, 10 from the white oak group and 10 from the red oak group throughout each year of the survey. Trees within the red oak group included northern

red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), and scarlet oak (*Q. coccinea* Münchh) and trees within the white oak group included white oak (*Q. alba* L.) and chestnut oak (*Q. montana* Willd.). Trees were chosen based on maturity (i.e. only trees producing acorns) and were replaced if they were severely damaged or experienced mortality. The replacement tree was one of the same section of subgenera in the most proximate location to the damaged tree.
Surveys were conducted based on the Sharp (1958) method, which consists of a count of the total number of acorns on the last 61cm (24 inches) of 10 randomly chosen upper canopy branches on each of the selected trees. Acorn counts using the Sharp method have been shown to be as or more effective than mast traps (Perry & Thill 1999) and average count numbers for each tree species was used in our analysis.

Species richness and importance values

We conducted tree surveys to determine the occurrence and abundance of hard mast species within the Allegheny woodrat's foraging range. At least 4 quadrats of 0.02 ha per Allegheny woodrat site were surveyed. We delineated plots randomly within the Allegheny woodrats' foraging zones, which are within 200 m of the trap sites, or the activity centers (Wright & Hall 1996). Within each plot, we identified all woody tree species greater than 4.9 cm DBH (diameter at breast height) to species, and recorded DBH. We calculated importance values as a summation of each species' relative density, relative frequency, and relative dominance as derived from Curtis and McIntosh (1951). We analyzed two sites with SILVAH, or Silviculture of Allegheny Hardwoods, a computer tool used to assist foresters in forestry management decisions. We collected over- and understory data, including tree species, DBH, and saplings present and entered data into the SILVAH computer software (Marquis et al. 1992). The resulting prescription gives a quantifiable result on the quality of the stand and regeneration. We looked at the SILVAH results in this study to determine if competitive regeneration of oaks is adequate at the woodrat sites, which will also help us determine if a site could benefit from supplemental planting.

Mast survey trees as a surrogate for oaks within Allegheny woodrat habitat

We used modified correlogram results from Fearer et al. (2008) that determined strong synchrony in acorn production across sites in western Maryland. The spatial synchrony they described was based on the same acorn surveys conducted by Maryland DNR and shows a strong autocorrelation in sites up to 164 km for the red oak group and 269 km for the white oak group. The woodrat sites fall well within the ranges of autocorrelation, the Dans Rock site is 23 km from the nearest mast site in Garrett County, the High Rock site is 9 km from the nearest mast survey site also in Garrett County. The Abe Mills site is 2.8 km away from the mast site in Washington County, while the Fishing Creek site is 1.1 km from the nearest mast survey site in Frederick County. Because these sites are within the range of synchrony we allowed mast surveys to be used as a surrogate for mast production at woodrat sites. Acorn counts were corrected for actual species present at woodrat sites. At all of the four woodrat sites only red oak and chestnut oak made up a large proportion of the canopy, and therefore, only mast data from those tree species were used in the analysis. We chose mast sites to compare to woodrat sites based on whether they were in the same physiographic province, their proximity, and similar elevation and species present.

Dendrochronology

We took increment cores from at least ten large, dominant oak trees at each woodrat sites between 2016 and 2017. Increment cores were also collected from every tree used in the mast surveys. Two cores were taken per each tree at approximately 180˚ from each other and parallel with the contour to avoid reaction wood. Cores were mounted and sanded following protocols from Stokes and Smiley (1968). Annual increments were measured to the nearest 0.001 mm from 1970-2016 on a Velmex measuring system and cross-dated in COFECHA. Interseries correlation and mean sensitivity were calculated and raw tree ring series were standardized to remove age related growth. We measured earlywood and latewood on the standardized indices and calculated the percentage of earlywood. We noted the years in which earlywood percentage was higher than average, an indicator of gypsy moth defoliation and compared gypsy moth defoliation using aerial data from MD DNR at the woodrat sites and mast survey sites.

Statistical analysis

Spearman correlations were conducted using Lincoln-Petersen population estimates of woodrats and the average total acorn numbers. The acorn numbers were separated by the tree species dominant at the woodrat sites, the average number of acorns calculated, and species averages were summed. We used the Spearman correlation to determine if the amount of mast produced during the fall would affect the overwinter survival and reproductive rates in the form of captured woodrats the following summer. We conducted all statistical analyses in R v. 3.4.0 (R Development Core Team, Vienna, Austria).

Results

Woodrat density

A total of 3,478 trap nights resulted in 637 captures of 304 woodrats at the 6 long-term sites between 1990 - 2016. Lincoln-Petersen population estimates show an overall decline of Allegheny woodrats at each of the monitored sites. The highest population estimate is 36 and each woodrat site has had at least one year with a population estimate of 20 or more woodrats. After 2004, population estimates did not exceed 6 and each site had at least one year with no woodrat captures, except at Dans Rock, which includes a population estimate of 14 woodrats in 2014. The lack of capture may not denote an absence of woodrats at the metapopulation level though was likely indicative of local site extirpation.   Monitioring sites were likely recolonized from nearby unmonitored sites following extirpation.because following a year or two of no detection, at least one woodrat was trapped, this included a capture at Abe Mills in 2017 (Dan Feller, personal obs.).

Stand Structure

Oak species make up a relatively high proportion of the canopy overstory at all 4 of the woodrat sites. The importance value (IV) is a measure of the most dominant species within a general area, in this case ca. 150 m from the woodrat trap location. Northern red oak is the most dominant species, has the highest IV at High Rock and Abe Mills, and is the second most dominant species at Dans Rock and Fishing Creek. Northern red oak has the greatest IV among all sites at Dans Rock at 90.8 followed by High Rock at 85.6 (Table 2). Fishing Creek is the only site where chestnut oak is in the top 5 most dominant species (Table 2). Although, not in the data, chestnut oaks were present at the High Rock site, but were located above the rock outcrop.

Oak regeneration from SILVAH results was most abundant at the Fishing Creek site with two thirds of the plots containing oak saplings compared with one third of plots containing oak saplings at the Abe Mills site (Table 3.). SILVAH data was not collected for the High Rock and Dans Rock sites.

Acorn Abundance

According to Sharp (1958), a good or bumper mast crop equates to greater than 13 acorns per terminal 24 inches of canopy tree branch for white oaks and greater than 16 acorns per terminal 24 inches of canopy tree branch for red oaks. The total number of good/bumper mast years for northern red oaks and chestnut oaks was 9 for Garrett Co. (7 red oak, 2 chestnut oak), 15 for Washington Co.(12 red oak, 3 chestnut oak), and 8 for Frederick Co. (6 red oak, 2 chestnut oak). Good mMast years occurred much less frequentlyoften for chestnut oaks than for red oaks and were generally followed by a period of 1-13 years with little to no mast production. Red oaks exhibited a pattern of 2 or 3 consecutive mast years, followed by several years of little to no mast, which happened 8 times across the 3 counties.

Effects of Acorns on Woodrats

The Spearman correlation between woodrat populations and acorn counts were not significant at any of the sites except for the Fishing Creek and only with the previous year mast production (r = 0.800 p = 0.001, Table 1.). No site was significantly correlated ($p < 0.05$) with the current year or two-year previous mast production. The High Rock woodrat population was negatively correlated to current year, previous year, and two-year previous mast production (r = -0.347, -0.069, and -0.029), while Abe Mills woodrat population was negatively correlated except for with the current year mast production (r = 0.178). The Fishing Creek correlation coefficient (r = 0.800) was a much higher value than the Abe Mills (r = -0.291), High Rock (r = -0.069) or Dans Rock (r = 0.085) values. The Fishing Creek woodrat population was also positively correlated with the current year mast production (r = 0.219, p = 0.433) and the two-year previous mast production (r = 0.324, p = 0.281) even though they were not significant (Table 1).

Dendrochronology

Early wood percentage has been shown to be affected by gypsy moth defoliation in oaks (Muzika & Liebhold 1999). Muzika and Liebhold (1999) observed a significantly higher earlywood percentage in oaks during years of gypsy moth defoliation because earlywood is produced prior to the onset of leaves and thus, gypsy moth defoliation. Because mast survey sites do not overlap directly with woodrat sites, a gypsy moth defoliation may have occurred across a woodrat site and not at a mast survey site and may have affected the mast production of that year or the following year. We looked at years of higher than average earlywood percentage to determine marker years to investigate further (Fig. 5). Fishing Creek had the highest number years in which earlywood ring with was above average, 12 years, compared with High Rock, at 8 years, Dans Rock 9 years, and Abe Mills 8 years (Table 3).

Discussion

Population densities of small mammals can fluctuate with mast production (Ostfeld 1996; Wolff 1996; McShea 2000). Because woodrats are k-selected and not r-selected like white-footed mice, the effect of a mast year on woodrat population change may not be as immediate as with species like the white-footed mouse or the effects may not be distinguishable in direct capture numbers. Mengak and Castleberry (2008) noted a positive correlation between mast and woodrats at 2 of 4 sites, but concluded that mast production is only a piece of the puzzle of the woodrat's survival. In 5 years of data, Manjerovic et al. (2009) found a positive relationship between adult female capture rates and mast, but again, concluded that mast is not the sole determinant of the Allegheny woodrat decline.

Oaks make up a dominant part of the canopy within woodrat foraging zones, but no site has more than 2 dominant oak species in the canopy. The presence of oaks at these extant woodrat sites may be the final factor that is allowing these populations to hold on while other confounding factors including size of rock outcrop, aspect, canopy cover, habitat fragmentation and disease are responsible for the woodrat's overall decline. These were not included as covariates in the current study, but should be included in future work. The diversity of other mast producing or edible species may also be a factor in the survival of these extant populations. Balcom and

Yahner (1996) found a significantly higher percentage of coniferous and mixed forest cover types at extant compared with extirpated woodrat sites, meaning either an increase in protective cover or a higher diversity and abundance of food species. Allegheny woodrats are opportunist feeders, which may explain the lack of extreme fluctuations at the Dans Rock site. Because oaks are not the dominant species, populations of woodrats at that site may not rely as heavily on mast crops and cache and eat more of other species such as black birch, which are available every year. Both northern red oak and black birch have very similar IV indices at Dans Rock, 93.2 and 90.8, respectively (Fig. 4). In addition, the IV index for northern red oak is the highest at Dans Rock compared to the IV index for northern red oak at the other woodrat sites. The high IV of both a heavy mast producer and a non-mast producer, but edible tree species other than oak may account for the lack of extreme fluctuations in the woodrat populations at Dans Rock.

High Rock also has a relatively high red oak importance value index compared with the other sites, which may be why the woodrat population was able to bounce back after a decline in the years 2002 – 2003 (Fig. 3). Subsequently, the woodrat populations were not able to return to high numbers after bumper years in 2005 and 2007, but those years plus a bumper crop in 2011 may have prevented the population from blinking out again. Abe Mills is the only site where exotic species, tree of heaven, are present in the canopy (Table 2). Tree of heaven makes up a relatively large proportion of the canopy with an importance value index of 46.6 and may represent a more highly disturbed site especially in the understory where invasive species may dominate other herbaceous food sources for the woodrat. Despite several good bumper crops in 1996 – 1997, 2000 – 2002, 2006 – 2007, 2011 – 2013, and 2015, woodrat populations continue to decline. During the study period Fishing Creek experienced an invasion of both woody tree

(tree of heaven in spots– missed in plots?) and herbaceous exotic species that significantly diminished available native forage. In fact this site was an old growth forest stand and many of the large overstory oaks succumbed to gypsy moth defoliation opening the canopy and paving the way for invasive plants.

The Spearman correlation between woodrat population and mast production was significant at Fishing Creek, but not High Rock, Dans Rock or Abe Mills. The lack of significance at the 3 sites may be attributed to the greater distances between woodrat and mast survey sites at High Rock, Dans Rock, and Abe Mills. Although, Fearer et al. (1993) showed mast production to be significantly strongly autocorrelated up to 269 km, small nuances such as microclimate or gypsy moth defoliation may account for a different average acorn production at the woodrat sites themselves. The woodrat population at Abe Mills and High Rock were both negatively correlated with the previous year's mast production (Table 1) and the correlation coefficient of woodrat population to mast production at Dans Rock was almost negligible ($r = 0.0846$). The negative and low correlation coefficients may also be the result of variation in mast production at the woodrat site compared with the mast survey sites that were used in the correlation. The rocky thin poor soils and overall lower site index at woodrat sites when compared to the mast sites could have contributed to susceptibility to gypsy moth and just overall lower seed productivity.

White oak and red oak groups generally produce heavy mast crops in alternating years (Sork et al. 1993). Because the chestnut oak mast years were so few, only producing 2 or 3 heavy crops over the course of 27 years, a supplemental planting of white oak or reintroduction of blight-resistant American chestnut, *Castanea dentata,* may allow for acorn production to fill in the gaps during the interim years of red oak mast production. Our results from SILVAH show low competitive regeneration for oaks at the woodrat sites (Table 4). One third of the plots at the Abe Mills site and two thirds of the plots at the Fishing Creek site contain oak saplings. Although neither meet the adequate requirement of oak regeneration for SILVAH, the Fishing Creek site is just under the 70% requirement for adequate oak regeneration. The low oak regeneration prediction suggests that supplementary oak planting would benefit the woodrat sites, especially Abe Mills, to ensure oak remains a consistent component of the overstory into the future.

Our dendrochronology preliminary analysis provided a list of years at each woodrat site where earlywood was a higher proportion of the total ring width. The years with higher proportions of earlywood will be further analyzed to correlate earlywood proportions to gypsy moth defoliations after Muzika and Liebhold (1999). Years with high earlywood percentage do not always correspond with low acorn production during the same year or following year, which may account for differences in acorn production directly at the woodrat sites compared with the mast survey sites.

The decline of the Allegheny woodrat is complex and is likely multi-faceted. The variability in oak masting, gypsy moth defoliation, and diversity of oaks providing hard mast may have an effect on the population fluctuations of the Allegheny woodrat. A strong correlation between mast production and woodrat population at Fishing Creek indicates that acorns are a potentially important factor in woodrat survival. The loss of large overstory oaks and invasion of non-edible exotic herbaceous plants may make the importance value of food high at this site. The lack of a significant correlation between mast production and woodrat population at the other 3 sites in this study may be the result of spatial differences of the data or a more complex combination of factors.

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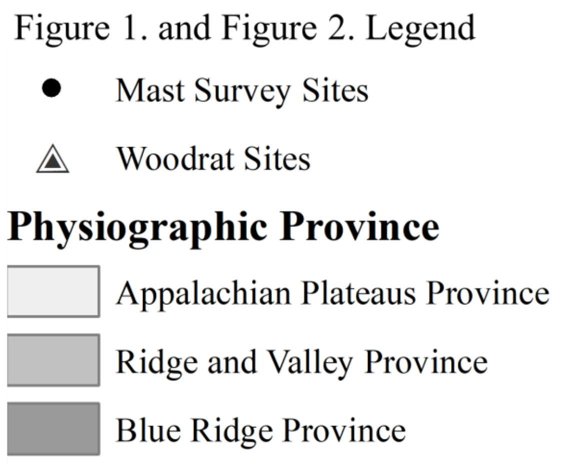
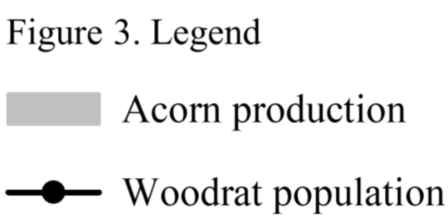
Tables and Figures

Legends





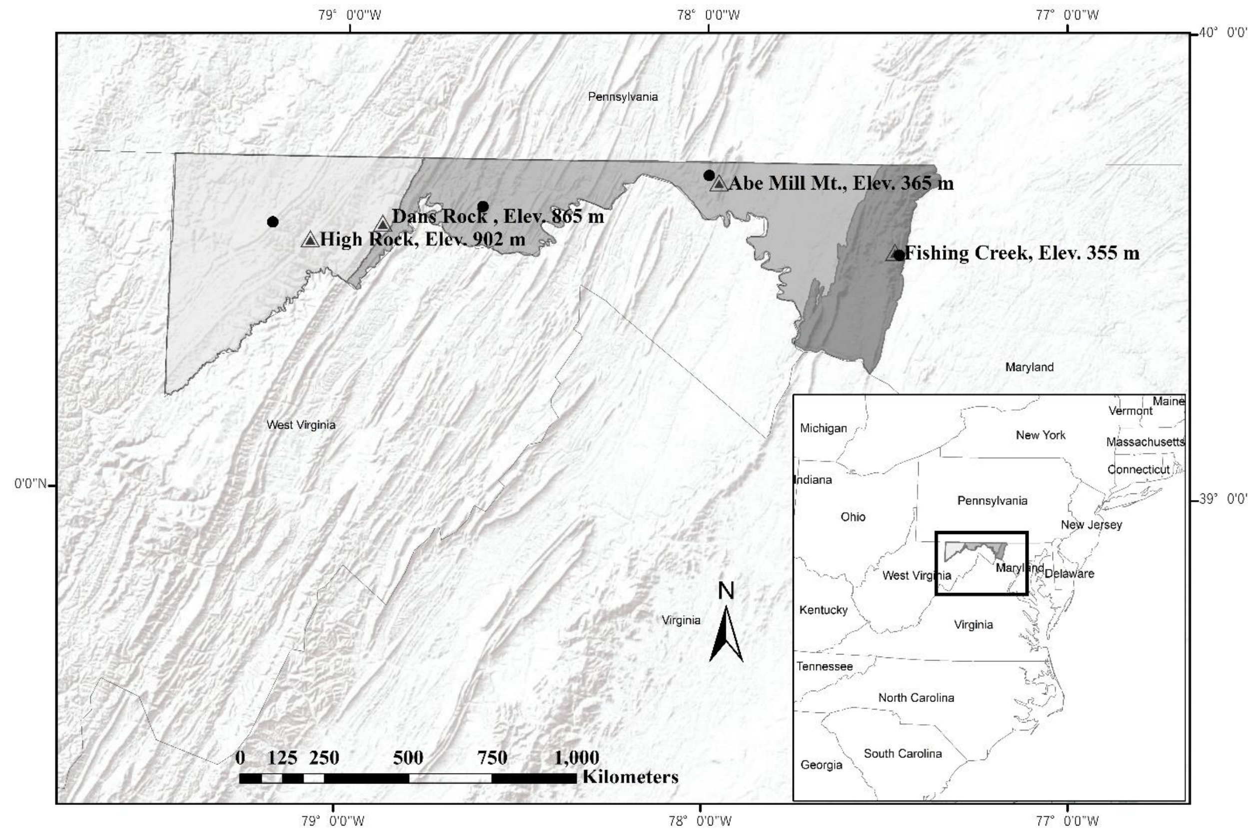


Figure 1. Study location in western Maryland depicting four Allegheny woodrat live-trapping sites and nearest mast survey sites within the Appalachian Plateau, Ridge and Valley, and Blue Ridge physiographic provinces.

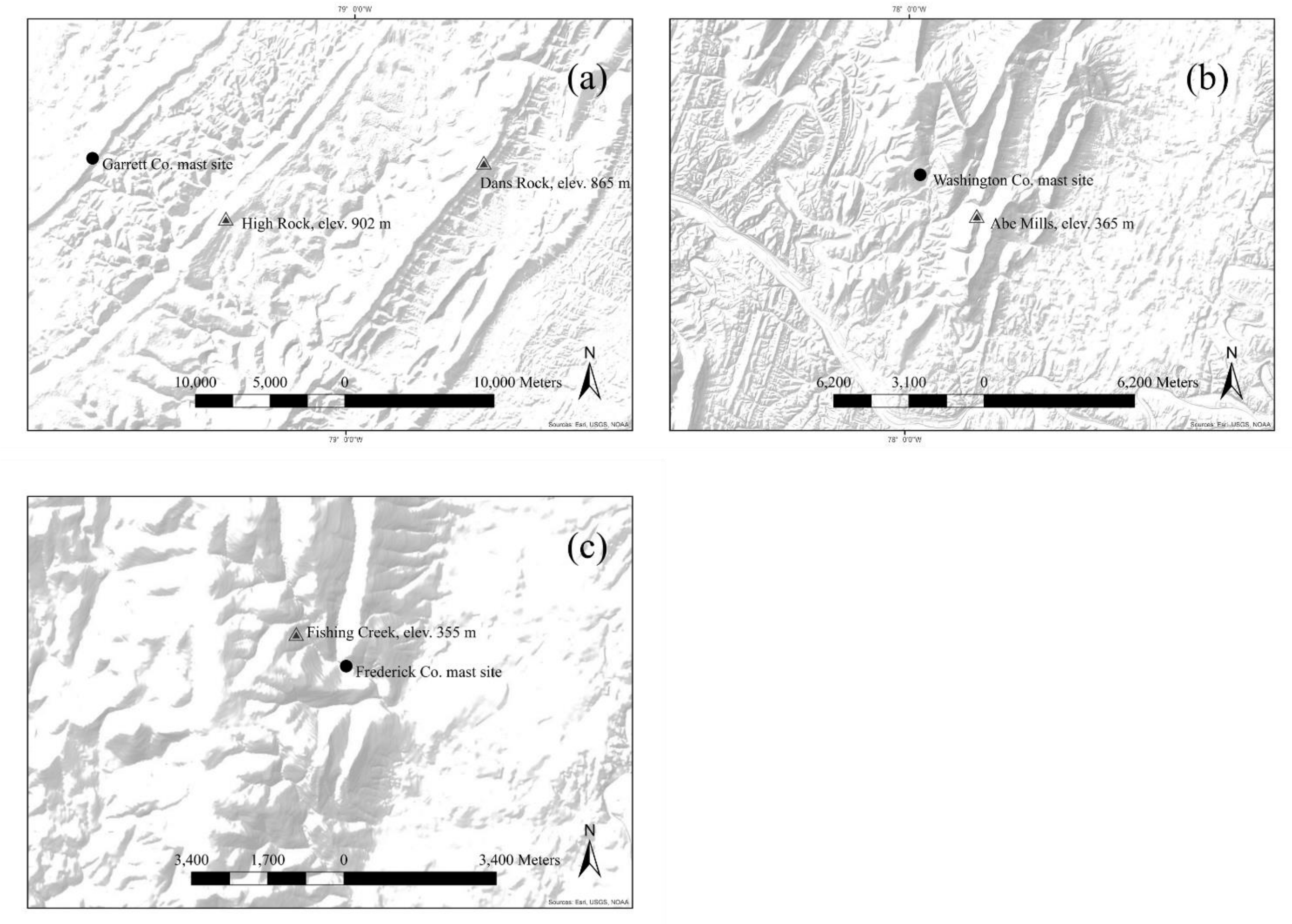


Figure 2. Locations of mast survey sites and Allegheny woodrat live-trapping sites in four counties in western Maryland, High Rock and Dans Rock woodrat sites with Garrett Co. mast site (a), Abe Mills woodrat site and Washington mast site (b), and Fishing Creek woodrat site with the Frederick mast site (c).

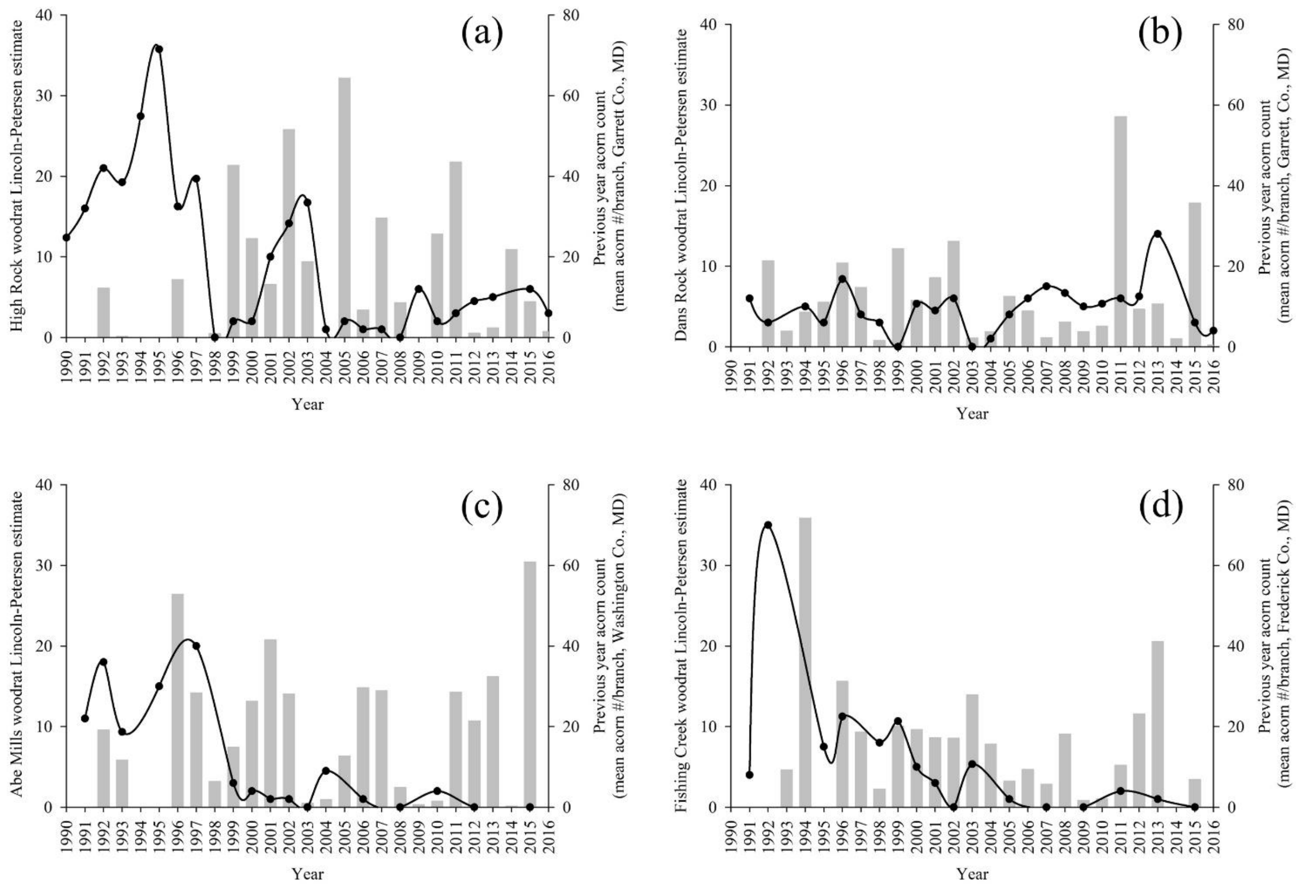


Figure 3. Allegheny woodrat population Lincoln-Petersen estimates in western Maryland (1991-2016) with previous year oak mast abundance from white and red oak tree species present at woodrat sites (1992-2016). Woodrat population estimates from High Rock with acorn production in Garrett Co. (a), woodrat populations from Dans Rock with acorn production in Garrett Co. (b), woodrat populations from Abe Mills with acorn production in Washington Co. (c), and woodrat populations from Fishing Creek with acorn production from Frederick Co. (d). Note: missing mast data for Garrett Co. years 1994, & 1995; Allegany Co. year 1991; Washington Co. 1994 & 1995; Frederick Co. 1995. Missing woodrat data from 2014 at High Rock; 1993 & 2014, at Dans Rock; data collected biennially at Abe Mills and Fishing Creek.

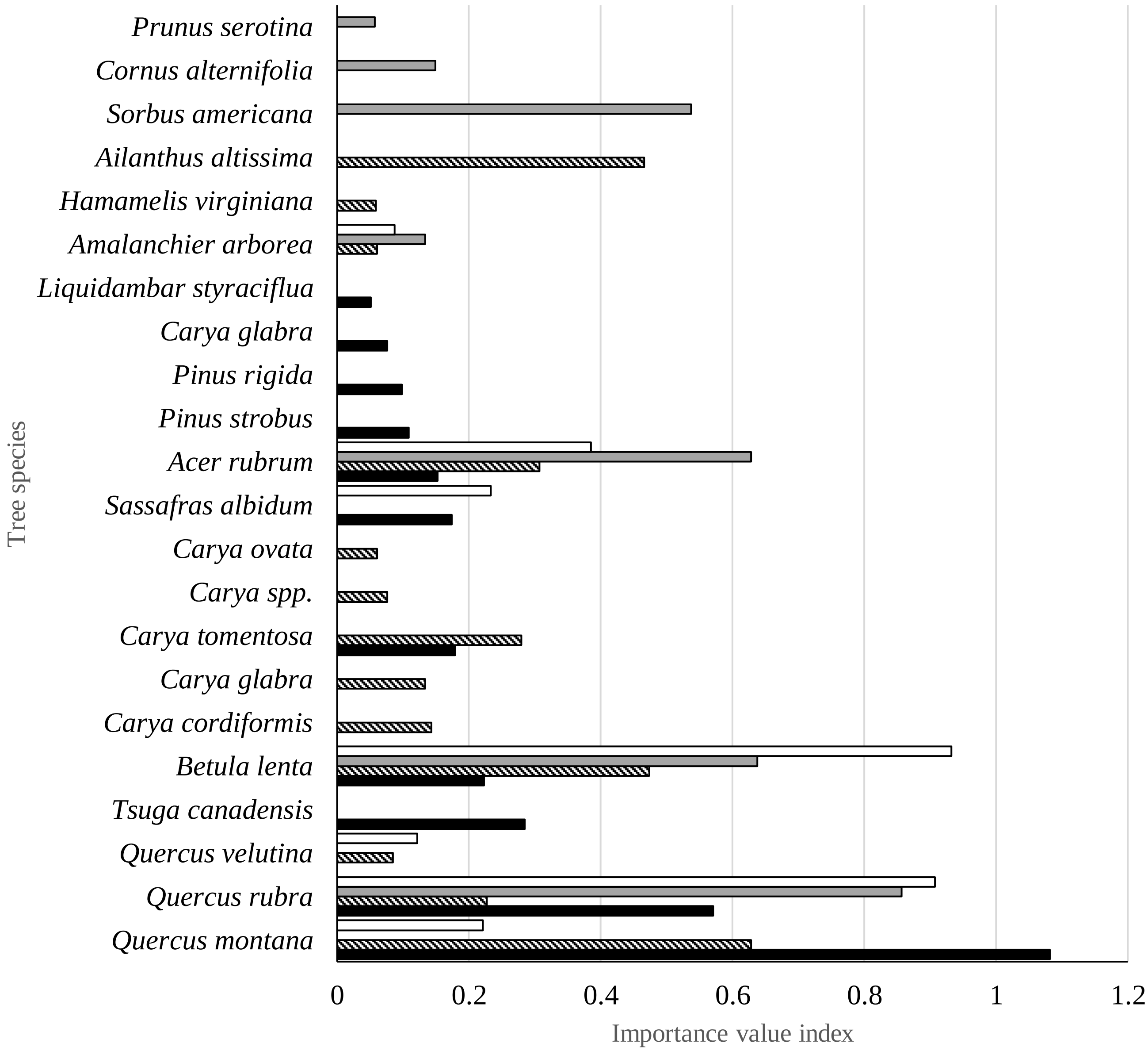


Figure 4. Importance values (relative frequency, dominance, and density) of tree species within random plots (0.02 ha, n = 4-6) at 4 active woodrat sites in western Maryland, High Rock, Dans Rock, Abe Mills, and Fishing Creek. Importance values at each site is a proportion of 3.

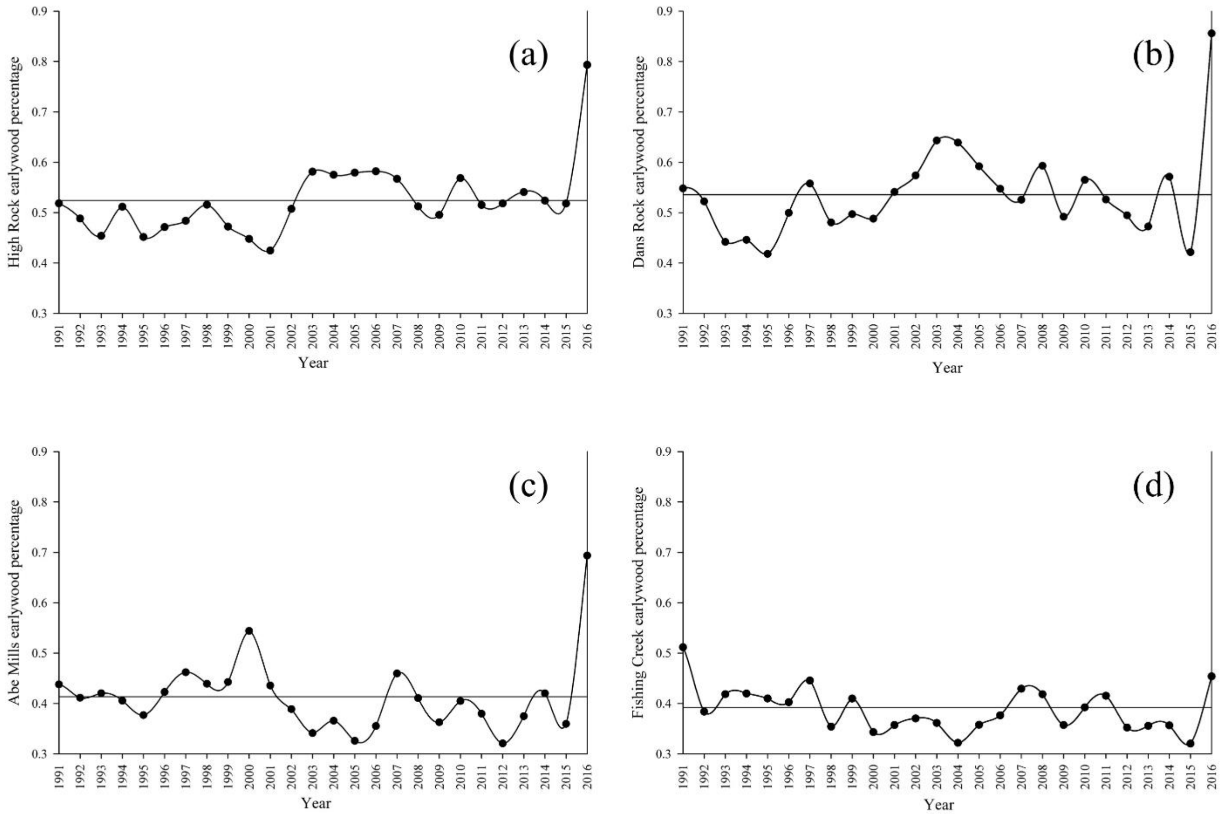


Figure 5. Dendrochronology analysis of percent earlywood from oak ring widths from 1991-2016 from tree cores collected at Allegheny woodrat sites in western Maryland, High Rock (a), Dans Rock (b), Abe Mills (c), and Fishing Creek (d). Horizontal line represents mean percent earlywood.

Table 1. Spearman correlation coefficients (*r*) and sample size (*n*) of woodrat population Lincoln-Petersen estimates and mean acorn counts from survey sites nearest woodrat sites in western Maryland. Data was collected annually or biennially from 1990-2016.

Site	Current Year Mast	Previous year mast	2 year previous mast
High Rock *n = 22*	-0.3466	-0.0697	-0.0287
Dans Rock *n = 22*	0.0573	0.0846	-0.1359
Abe Mills *n = 13*	0.1784	-0.2905	-0.2369
Fishing Creek *n = 16*	0.2189	0.8001*	0.3235

* p-value < 0.05

Table 2. Importance values (IV = relative frequency, dominance, and density) of tree species within random plots (0.02 ha, n = 4-6) at four active woodrat sites in western Maryland. Species ordered from highest to lowest importance value. Importance values at each site is a proportion of 300.

High Rock		Abe Mills		Fishing Creek		Dans Rock	
Species	IV	Species	IV	Species	IV	Species	IV
Quercus rubra	85.6	*Quercus rubra*	62.8	*Quercus montana*	108.1	*Betula lenta*	93.2
Betula lenta	63.7	*Betula lenta*	47.3	*Quercus rubra*	57.1	*Quercus rubra*	90.8
Acer rubrum	62.8	*Ailanthus altissima*	46.6	*Tsuga canadensis*	28.5	*Acer rubrum*	38.5
Sorbus americana	53.7	*Acer rubrum*	30.7	*Betula lenta*	22.3	*Sassafras albidum*	23.4
Cornus alternifolia	14.9	*Carya tomentosa*	27.9	*Carya tomentosa*	17.9	*Quercus montana*	22.1
Amalanchier arborea	13.3	*Quercus montana*	22.7	*Sassafras albidum*	17.4	*Quercus velutina*	13.2
Prunus serotina	5.7	*Carya cordiformis*	14.3	*Acer rubrum*	15.3	*Malus sylverstris*	10.3
		Carya glabra	13.3	*Pinus strobus*	10.9	*Amelanchier arborea*	8.6
		Quercus velutina	8.4	*Pinus rigida*	9.8		
		Carya spp.	7.6	*Carya glabra*	7.6		
		Carya ovata	6.0	*Liquidambar styraciflua*	5.1		
		Amalanchier arborea	6.0				
		Hamamelis virginiana	5.9				

Table 3. Years in which earlywood of tree rings collected at 4 woodrat sites in western Maryland are above average width. Woodrat sites are High Rock, Dans Rock, Abe Mills, and Fishing Creek.

Years with greater than average earlywood

High Rock	Dans Rock	Abe Mills	Fishing Creek
2003	1997	1991	1990
2004	2002	1997	1991
2005	2003	1998	1993
2006	2004	1999	1994
2007	2005	2000	1995
2010	2008	2001	1996
2013	2010	2007	1997
2016	2014	2016	1999
	2016		2007
			2008
			2011
			2016

Table 4. Data from SILVAH computer software depicting prescription results of whether Allegheny woodrat sites in western Maryland have adequate regeneration of competitive oak species based on the percentage of plots with oak saplings.

	Abe Mills	Fishing Creek	
Competitive Regeneration Adequate	No (33.3% of plots)	No (66.7% of plots)	* 70% is adequate for regen.

Table 5. Interseries correlations and mean sensitivities of mast survey tree ring widths in Garrett Co. and Washington Co. Maryland. Spearman's rho (*r*) of relationship between ring widths from mast survey trees and trees from nearest Allegheny woodrat sites.

Site		Interseries correlation	Mean sensitivity	*r*
Garrett Co. mast site	red oaks	0.563	0.198	0.5583*
	white oaks	0.572	0.223	0.4906*
Washington Co. mast site	red oaks	0.611	0.237	0.4168*
	white oaks	0.595	0.243	0.0879

* p-value <0.05