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A Rapid Hard-Mast Index From Acorn Presence–Absence Tallies

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ABSTRACT We used 21 years of acorn data from visual surveys of oak (*Quercus* spp.) trees ($n = 20{,}113$) conducted in western North Carolina, USA, to develop predictive equations for hard-mast indices (HMIs) based on the proportion of trees bearing acorns (PBA). We calculated PBA using visual estimates of the percentage of oak crown with acorns (PCA), assigning acorn presence if PCA $\geq 33.5\%$. The proportion of trees bearing acorns and average PCA were highly correlated, and PBA alone was a successful predictor of HMIs. Precise estimates of PBA (therefore HMIs) at a 95% confidence level required 139–385 sample trees for each oak subgroup or spatial scale of interest, and the sample size required varied with the true PBA. Substituting this faster, simpler visual survey method for others involving labor-intensive counts of twigs and acorns means that more trees can be sampled (if needed) with less time and effort for improved PBA (therefore HMI) precision. We offer a reliable method for predicting HMIs that are comparable to past HMI estimates for states using the Whitehead (1969) method, thus providing continuity in tracking long-term acorn production patterns. We also developed categories for subjectively ranking acorn crop sizes based on the range of PBA observed during 21 years. We recommend that PBA be adopted by resource management agencies as a standard, stand-alone index of acorn production to ensure comparable data among years and across the eastern United States. A standardized protocol for assigning acorn presence or absence must be used for consistent, comparable regional use of PBA in predicting HMIs or by itself as an index of acorn production. (JOURNAL OF WILDLIFE MANAGEMENT 71(5):1654–1661; 2007)

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KEY WORDS acorn crop, acorn crop prediction, hard-mast index, hard-mast survey, visual survey.

Acorn crop size varies considerably among oak (*Quercus* spp.) species, years, and places (Greenberg and Parresol 2002) and directly affects oak regeneration (Loftis and McGee 1993) and wildlife species that depend on acorns for food (Martin et al. 1951). Reproduction, survival, harvest rates (Ryan et al. 2004), movements, and body condition of many game species, including white-tailed deer (*Odocoileus virginianus*; Wentworth et al. 1992, Feldhamer 2002), black bear (*Ursus americanus*; Vaughn 2002, Clark et al. 2005), and wild turkey (*Meleagris gallopavo*; Steffen et al. 2002), are influenced by acorn availability. Wolff (1996) suggests that acorns are a keystone forest resource because they influence small mammal populations. Because acorn availability strongly influences wildlife and forest ecology, land managers and researchers devote a lot of effort to estimating the size of acorn crops.

Researchers have developed many methods for estimating the size of acorn crops. Acorn traps have been used by several researchers (see Greenberg and Parresol 2002) for quantitative estimates of acorn yield at an individual tree or stand-level. Hard-mast indices (HMIs) rate acorn crops on a relative scale. In qualitative visual survey methods workers subjectively rank acorn crops into categories from none to bumper (Sharp 1958, Graves 1980, Christisen and Kearby 1984). Quantitative hard-mast indices include visual surveys, such as time-constrained acorn counts (Koenig et al. 1994), and scored estimates of the percentage of crown with acorns (PCA) and counts of twigs and acorns on a subsample of oak limbs (Whitehead 1969). Clearly the time and labor required for twig and acorn counts are much higher than requirements for subjective ranking or rapid estimates of the percentage of crown with acorns.

Perry and Thill (1999) found that 5 commonly used HMIs based on visual estimates were highly correlated with acorn density estimates from acorn traps. However, in some cases, index values may not accurately reflect crop size, as indices are scaled to an unrealistic potential for acorn production (Pozzanghera 1990).

Greenberg and Parresol (2002) found that acorn density per fruiting tree was positively correlated with the proportion of trees bearing acorns (PBA). Thus, good crop years were the result of more trees producing acorns and more acorns per tree. Conversely, poor crop years were the result of fewer trees producing, each with fewer acorns. Because of the strong association between PBA and acorn density per tree, PBA alone was a significant predictor of yearly acorn crop size (Greenberg and Parresol 2002). However, the relationship Greenberg and Parresol (2002) described was based on acorn trapping data rather than visual surveys, and it predicted numbers of acorns per square meter basal area of oaks rather than HMIs. Until our study, the use of visual surveys to calculate PBA had not been tested and PBA had not been used to predict HMIs.

Hard-mast indices do not measure acorn production, but they are useful for comparing relative crop sizes among years and areas and for tracking long-term patterns of acorn production (some states have conducted surveys for >20 yr; Clark et al. 2005). Using PBA to predict HMIs that are equivalent and comparable to past HMI estimates would maintain continuous tracking of long-term acorn production patterns and save time. However, estimation of PBA could vary depending on differences in acorn detectability (Perry and Thill 1999), observer differences (Graves 1980), the

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number of trees sampled, and how acorn presence is assigned. Hence, a simple, consistent protocol for assigning acorn presence or absence in calculating PBA must be used, regardless of whether PBA is used by itself as an index of hard-mast production or is used to predict HMIs (Whitehead 1969). Further, an adequate number of trees (sample size) must be surveyed for each oak subgroup (species or subgenus) or spatial scale of interest to achieve precise estimates of the true PBA (Greenberg and Parresol 2002).

The use of various visual survey methods by state and federal agencies makes HMI comparisons among states difficult (Pozzanghera 1990). Recent efforts by the Northeast Fish and Wildlife Association and the Northeast Wild Turkey Technical Committee, to coordinate a standard HMI method in the northeast region of the United States have resulted in cooperation by states including Virginia, West Virginia, Maryland, Ohio, New Hampshire, Connecticut, and Rhode Island, USA since 2004 (G. Norman, Virginia Department of Game and Inland Fisheries, personal communication). The new northeast HMI method uses 30-second visual scans of oak tree crowns (Koenig et al. 1994) to assign presence or absence of acorns, which is used to calculate the proportion of trees bearing acorns as an index of acorn production (Greenberg and Parresol 2002). In contrast, a modified Whitehead (1969) HMI has been used for >20 years by several southeastern states, including South Carolina, North Carolina, Georgia, and Tennessee, USA. Clearly, there is a need to simplify and coordinate HMI methods among all eastern states, while maintaining continuity in tracking long-term acorn production patterns.

We used 21 years of hard-mast data from visual surveys (Whitehead 1969) conducted in the southern Appalachian mountains of western North Carolina to determine if the time- and labor-intensive field methods currently used to determine HMIs could be simplified by using PBA to predict HMIs (Whitehead 1969) or as a stand-alone index of acorn production. Our objectives were to: 1) determine if PCA is correlated with PBA using visual survey data, 2) develop and evaluate equations for predicting HMI (Whitehead 1969) based on PBA, 3) determine whether PBA alone is an adequate index of acorn production, 4) determine minimum sample sizes required to achieve specified levels of precision when estimating PBA, and 5) develop categories for ranking acorn crop sizes based on the range of PBA observed during 21 years.

STUDY AREA

Our study was conducted within the mountainous Blue Ridge Physiographic Province of Western North Carolina. Average annual rainfall in the region ranged from approximately 135 cm to 229 cm and was evenly distributed throughout the year. Soils were predominantly Dystrochrepts and Hapludults (Pittillo et al. 1998). Mature forest ranged 80 years to 100 years in age. Cove hardwood forests were dominated by yellow-poplar (*Liriodendron tulipifera*) and northern red oak (*Quercus rubra*), and also include magnolia (*Magnolia* spp.), white ash (*Fraxinus americana*), beech (*Fagus grandifolia*), hemlock (*Tsuga canadensis*), and silverbell (*Halesia carolina*). Upland hardwood forests were dominated by scarlet oak (*Q. coccinea*), chestnut oak (*Q. prinus*), and black oak (*Q. velutina*), and blackgum (*Nyssa sylvatica*) and sourwood (*Oxydendrum arboreum*) were common mid-story trees. Northern red oak was the predominant oak at high elevations (>1,200 m). Red maple (*Acer rubrum*), hickories (*Carya* spp.), flowering dogwood (*Cornus florida*), and white oak (*Q. alba*) occurred throughout the hardwood forests (Pittillo et al. 1998).

METHODS

Hard-Mast Surveys and Index Calculation

We surveyed oak trees for acorns annually from late August to early September, 1985–2005 on 10 different routes (11 in 2001, 2002, 2003, and 2005) in 10 western North Carolina counties. Species included northern red, black, scarlet, and southern red (*Q. falcata*) oaks in the red oak (*Erythrobalanus*) subgenus and white and chestnut oaks in the white oak (*Leucobalanus*) subgenus. Routes ranged from about 16 km to 32 km in length, and we spaced survey stops ($\bar{x} = 23.2 \pm 6.3$ SD stops/route) at elevation intervals of about 30.5 m. Elevation ranged from approximately 488 m to 1,676 m but varied among routes.

At each stop, we surveyed approximately 5 nut-producing trees (mostly oaks) $\geq$23 cm diameter at breast height, in dominant or co-dominant canopy positions and adjacent to roads. We did not tag sample trees, but we sampled many of the same individuals in multiple years. We surveyed trees using the Whitehead (1969) method. First, we scanned the tree crown with binoculars for about 2 minutes, and we estimated and recorded PCA. Next, for the terminal 0.9 m of each of 5 tree limbs, we estimated the total number of twigs, the number of twigs with acorns, and the number of acorns per acorn-bearing twig. We summed counts of each variable over the 5 limbs, and we used totals to calculate the percentage of twigs with acorns (PTA) and average number of acorns per fruiting twig (NAT; Whitehead 1969, Perry and Thill 1999).

We assigned the PCA, PTA, and NAT score based on percentage class (for PCA and PTA) or count (NAT) categories (Table 1). We used cutoffs for percentage classes and count categories (Table 1) that differed slightly from those we employed in the original Whitehead (1969) method (J. Wentworth, United States Forest Service, personal communication). We summed the 3 scores (PCA, PTA, and NAT) for the final HMI for that tree. For example, a tree with acorns on 35% of its crown (PCA score = 2), acorns on 25% of its twigs (PTA score = 1), and an average of 3 acorns per acorn-bearing twig (NAT = 2) would have an HMI value of 5 on a scale of 0 (crop failure) to 10 (bumper crop; Whitehead 1969). For each survey route and for the western North Carolina region, we calculated the HMIs for the 5 dominant species (northern red, black, scarlet, white, and chestnut oaks), the red and white oak subgenera, and all oak species combined by averaging the HMIs of individual trees within those subgroups.

Table 1. Percentage classes and corresponding scores of the 3 variables used to determine hard-mast indices (HMI) using a modified Whitehead (1969) method. Scores are assigned for each variable, and summed to derive a hard-mast index (0–10 scale) for individual trees. Indices for individual trees can be averaged across species, subgenera, or genera at different scales to derive local or regional HMIs.

% crown with acorns		% of twigs with acorns		No. acorns/ fruiting twig	
% class	Score	% class	Score	$\bar{x}$ no.	Score
<5.5	0	<5.5	0	<0.5	0
5.5–33.4	1	5.5–33.4	1	0.5–2.4	1
33.5–66.4	2	33.5–66.4	2	2.5–4.4	2
≥66.5	3	≥66.5	3	4.5–6.4	3
				≥6.5	4

Statistical Analyses

In regression analysis, when several predictor variables provide the same information, a single predictor variable may be used (Judge et al. 1988). We used Pearson's product moment correlations of regional average PCA and PBA (one data point = 1 yr for each species, subgenus, and all oaks) to determine whether both factors acted synchronously to affect yearly size of acorn crops and to determine whether PCA and PBA were collinear.

We tested 3 different criteria for assigning presence or absence of acorns on trees, and to generate 3 estimates of PBA. We assigned absence of acorns if 1) PCA <5.5% (PCA score = 0), 2) PCA <33.5% (PCA score = 1), or 3) HMI = 0. To assess which PBA estimate was most strongly correlated with HMI, we ran Pearson's product moment correlations with each of the 3 PBA estimates using data from all survey routes pooled for each species, for subgenera, and for all oaks.

We used reduced major axis regression (Sokal and Rohlf 1981) with regional (all survey routes pooled) data to develop predictive equations for HMI using PBA as the predictor variable for each species, for both subgenera, and for all oaks. Reduced major axis regression was appropriate because our independent variable (PBA) was a sample-based estimate; thus, our independent variable was considered a random variable subject to error. In contrast, ordinary least-squares regression analysis assumes that X is a fixed variable with no error (see Greenberg and Parresol 2002 for further explanation). For our regressions we report the correlation coefficient, rather than the coefficient of determination, because in reduced major-axis regression the slope is significantly different from zero if the correlation coefficient is significant (Ricker 1984). We also correlated PBA with HMI by species, subgenera, and all oaks using data from individual survey routes. However, in most cases the sample sizes used to estimate PBA were too small to permit us to develop predictive equations with acceptably high confidence levels.

Prediction of an accurate HMI requires a precise estimate of its predictor variable, in this case PBA. This is obtained by surveying an adequate number of representative sample trees for each oak subgroup or spatial scale of interest. We used a hypothetical range (0–95% at 10% intervals) of PBA to calculate sample sizes (n) required to estimate PBA at a 5% level of precision (d), with both a 90% ($\alpha = 0.1$, therefore $Z = 1.645$) and a 95% ($\alpha = 0.05$, therefore $Z = 1.96$) confidence level using the equation:

$$n = \frac{Z^2_{\alpha/2}\tilde{p}\tilde{q}}{d^2} \qquad (1)$$

(Zar 1984), where Z is a standard normal variate, α = Type I error rate, $\tilde{p}$ is the hypothetical PBA, and $\tilde{q} = 1 - \tilde{p}$ (Greenberg and Parresol 2002).

We used data for all oaks in the western North Carolina region as an example, to categorically rank acorn crop sizes based on the range of PBA observed during 21 years. We first standardized the actual PBAs to a 0–100% scale based on the maximum PBA observed during the 21 years (in this case, 59.2%), using the equation:

$$(\mathrm{PBA}_{\mathrm{standardized}} = \mathrm{PBA}_{\mathrm{year}}/\mathrm{PBA}_{\mathrm{max}}) \times 100 \qquad (2)$$

where $\mathrm{PBA}_{\mathrm{standardized}}$ is a standardized PBA based on actual field PBA values, $\mathrm{PBA}_{\mathrm{year}}$ is the PBA value for any given year, and $\mathrm{PBA}_{\mathrm{max}}$ is the maximum PBA value observed during the 21 measurement years. We then assigned a subjective ranking of mast crops based on field observation of mast crops and corresponding HMIs over the last 21 years.

RESULTS

We conducted 20,113 visual surveys of oaks in western North Carolina during 1985–2005. The number of trees we surveyed each year ranged from 816 to 1,019. Sample sizes were smaller when we split the sample into oak subgroups (n = 22–408/yr/species for the region) and survey routes (n = 1–85/yr/species/survey route).

Average PCA and PBA were correlated (collinear) every year for each species, subgenera, and all oaks combined ($r \geq 0.993$; $P < 0.001$; Fig. 1), indicating that only 1 of the 2 measures was necessary in our regression analyses. Although both variables were potentially good predictors of HMI, we focused only on PBA in developing predictive equations for HMI.

Each of the 3 estimates of PBA (based on the 3 criteria used to define absence of acorns on a tree) was significantly ($P < 0.001$) and strongly ($r \geq 0.945$) correlated with HMI for each species, subgenera, and all oaks combined (Table 2). Because all 3 criteria were potentially good predictors of HMI, we used absence defined as PCA < 33.5% to develop predictive equations for HMI because this was the most conservative definition of acorn presence and required the least crown-search time for acorns during visual surveys.

For all species (Fig. 2; Table 3), both subgenera, and all oaks combined on a regional level (Table 3), PBA was a significant and strong predictor of HMI. Using PBA, we estimated the regional HMI for any given year as:

$$\hat{y} = b_0 + b_1\hat{x} \qquad (3)$$

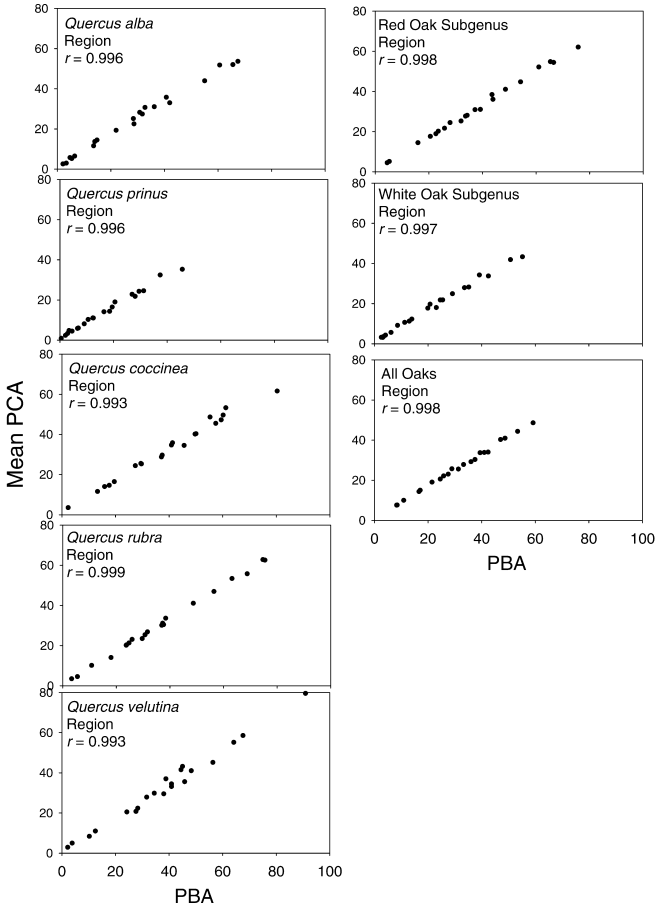

Figure 1. Correlation of mean percentage of crown with acorns (PCA) with proportion of trees bearing acorns (PBA) for 5 oak species, the red and white oak subgenera, and all oaks combined in western North Carolina, USA, 1985–2005 ($n = 21$ yr). All correlations were significant ($P < 0.001$).

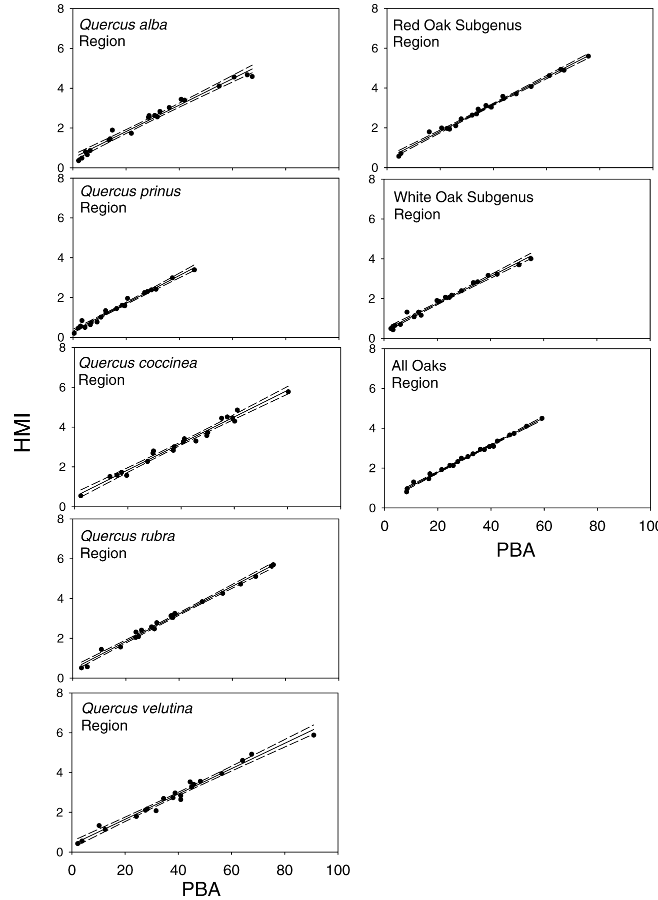

Figure 2. Regression of the mean hard-mast index (HMI) with the proportion of trees bearing acorns (PBA) for 5 oak species, the red and white oak subgenera, and all oaks combined in western North Carolina, USA, 1985–2005 ($n = 21$ yr). Dashed lines represent the 95% mean confidence band.

where $\hat{y}$ is the predicted HMI, *b*s are equation coefficients (from Table 3), and $\hat{x}$ is the proportion of trees bearing acorns (PBA; for each species, subgenus, and all oaks respectively). A significant ($P < 0.001$) correlation existed between PBA and HMI at the level of individual survey routes for all 5 species ($r \geq 0.898$), both subgenera ($r \geq 0.964$), and all oaks combined ($r = 0.964$; Fig. 3). However, variance was greater at the level of survey routes (Fig. 3) than at the regional level (Fig. 2) as a consequence of sampling fewer trees (n = 1–85/yr/species/survey route) and using an inadequate sample size to estimate the annual PBA and HMI.

Table 2. Pearson's product moment correlations[a] of the hard-mast index (HMI; modified from Whitehead [1969]) on the proportion of trees bearing acorns, using 3 definitions of acorn absence based on the percentage of crown with acorns (PCA) for 5 species of oak, the red oak subgenus, the white oak subgenus, and all oaks combined in western North Carolina, USA, 1985–2005 ($n = 21$ yr).

		Acorns absent if:		
		PCA < 5.5%	**PCA < 33.5%**	**HMI = 0**
Species	**Trees sampled[b]**	***r***	***r***	***r***
Red oak group	491–618	0.986	0.996	0.962
Black oak	22–92	0.976	0.991	0.952
Northern red oak	310–408	0.986	0.996	0.945
Scarlet oak	113–180	0.972	0.991	0.971
White oak group	325–424	0.993	0.993	0.975
Chestnut oak	177–225	0.988	0.991	0.972
White oak	148–200	0.986	0.991	0.959
All oaks	816–1,019	0.985	0.997	0.966

[a] All correlations were significant ($P < 0.001$).
[b] Yearly range in no. of trees sampled.

Sample sizes required to obtain precise estimates of PBA varied with desired confidence level and with the true population PBA. Fewer sample trees were required during poor (few mast-trees producing) or good (most mast-trees producing) mast years; greatest sample sizes were needed when 50% of trees bore acorns (moderate or average mast yr; Table 4). Required sample sizes were from 60–165 trees (80% CL), 98–271 trees (90% CL), and 139–385 trees (95% CL; Table 4).

For the 21 years of data used, PBA never exceeded 90.9% (black oak) for any species, 75.7% for either subgenus, or 59.2% for all oaks at the regional level. Similarly, HMI never exceeded 5.9 (black oak) for any species, 5.6 for either subgenus, or 4.5 for all oaks at the regional level (Fig. 2). Maximum PBAs (up to 100% among species, 100% for subgenera, and 87.4% for all oaks) and HMIs (up to 9.0 among species, 7.7 for subgenera, and 6.7 for all oaks) were

Table 3. Reduced major axis regression[a,b] of hard-mast index (HMI; modified from Whitehead [1969]) on the proportion of trees bearing acorns for 5 oak species, the red oak subgenus, the white oak subgenus, and all oaks combined surveyed in western North Carolina, USA, 1985–2005 ($n = 21$ yr).

Species	*n* trees[c]	b_0	b_1	r	$\bar{x}$	S_{xx}	$\hat{\sigma}_\varepsilon^2$
Red oak subgenus	491–618	0.444	0.068	0.996	37.2	7,708.65	0.014
Black oak	22–92	0.348	0.064	0.991	37.9	9,286.43	0.036
Northern red oak	310–408	0.446	0.069	0.996	36.4	9,021.62	0.016
Scarlet oak	113–180	0.471	0.068	0.991	39.6	7,634.63	0.034
White oak subgenus	325–424	0.383	0.068	0.993	22.2	5,122.64	0.018
Chestnut oak	177–225	0.291	0.071	0.991	16.4	3,223.38	0.015
White oak	148–200	0.485	0.067	0.991	28.9	8,603.23	0.036
All oaks	816–1,019	0.403	0.069	0.997	31.4	4,244.86	0.007

[a] All regressions were significant ($P < 0.001$).
[b] b_0 = model intercept; b_1 = eq coeff.; $\bar{x}$ = mean proportion of trees bearing acorns; S_{xx} = variance of X (X = PBA in the population); $\hat{\sigma}_\varepsilon^2$ = residual error. The variables $\bar{x}$, S_{xx}, and $\hat{\sigma}_\varepsilon^2$ are used for constructing CIs about the prediction values (Greenberg and Parresol 2002).
[c] Yearly range in no. of trees sampled.

higher for individual survey routes (Fig. 3). Our subjective crop size rating was standardized based on the observed range of annual regional PBAs, with cutoffs at 20% intervals for 5 categories ranging from failure to bumper (Table 5).

DISCUSSION

We found a strong positive relationship between average PCA and PBA, indicating that PBA and acorn density per acorn-bearing tree act synchronously to affect acorn crop size in any given year (Greenberg and Parresol 2002). The close association between PBA and average PCA enabled us to use PBA by itself to successfully predict HMIs (Whitehead 1969) for all oaks and oak subgroups tested. The proportion of trees bearing acorns, calculated from visual surveys of acorn presence or absence, can be used to calculate HMIs using equation 3 with the equation coefficients (Table 3). Additionally, PBA is itself an indicator of crop size, without the use of HMI formulas or predictive models. However, large numbers of trees must be sampled for each oak subgroup (species, subgenera) or spatial scale of interest to obtain precise estimates of PBA and, therefore, accurate predictions of HMI. By substituting a fast, simple acorn presence–absence tally for the labor-intensive counting of twigs and acorns, the number of trees sampled can be increased if needed, and the time and effort dedicated to annual hard-mast surveys can be greatly reduced.

If PBA (alone or as a predictor for HMI) is to be a useful tool for land managers, a standardized protocol is needed for defining acorn presence or absence for PBA estimation. Standardization of criteria for defining acorn presence or absence in estimating PBA would ensure that this measure of acorn production data is comparable among geographic locations and years.

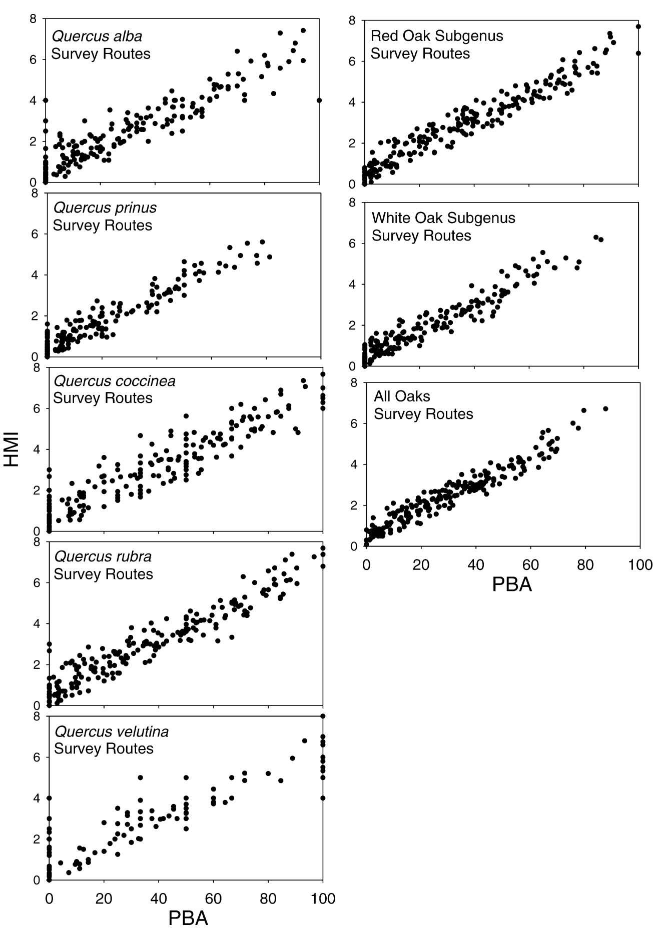

Figure 3. Correlation of the mean hard-mast index (HMI) with the proportion of trees bearing acorns (PBA) for 5 oak species, the red and white oak subgenera, and all oaks combined for each of 10 survey routes (11 in 2001, 2002, 2003, and 2005; $n \geq 10$ survey routes for 21 yr = 213 data points) in western North Carolina, USA, 1985–2005.

Table 4. Sample size (using eq [1] from Zar [1984]) required for estimating the proportion of trees bearing acorns (PBA) at 10% increments of PBA and at 3 levels of precision (d), with an 80%, 90%, and a 95% confidence level.[a]

	CL		
PBA	**80%**	**90%**	**95%**
10%	60	98	139
20%	106	174	246
30%	139	228	323
40%	158	260	369
50%	165	271	385
60%	158	260	369
70%	139	228	323
80%	106	174	246
90%	60	98	139

[a] 80% CL: $\alpha = 0.2$, therefore Z = 1.282; 90% CL: $\alpha = 0.1$, therefore Z = 1.645; 95% CL: $\alpha = 0.05$, therefore Z = 1.96.

Table 5. Subjective rating of mast crops for all oaks based on the proportion of trees bearing acorns (PBA) that is standardized by adjusting to the actual long-term range of PBA, using data from visual surveys conducted in Western North Carolina, USA, 1985–2005. Ratings use 5 categories with 20% standardized PBA intervals as cutoffs and include failure (0–19%), poor (20–39%), average (40–59%), good (60–79%), and bumper (80–100%) acorn crops.

Yr	*N*	HMI[a]	PBA[b]	Standardized PBA[c]	Rating[d]
1987	943	0.8	8.3	14	Failure
2003	1,015	1.0	8.5	14	Failure
1997	998	1.3	10.9	18	Failure
2000	981	1.5	16.6	28	Poor
1986	816	1.7	17.0	29	Poor
1992	936	1.9	21.5	36	Poor
1991	883	2.1	25.8	44	Average
2005	990	2.1	24.5	41	Average
1990	930	2.3	27.5	47	Average
1993	976	2.5	28.9	49	Average
2002	1,019	2.6	31.3	53	Average
1996	950	2.7	33.3	56	Average
1999	973	2.9	37.5	63	Good
1994	963	2.9	36.0	61	Good
1985	906	3.1	39.4	67	Good
1989	949	3.1	41.0	69	Good
2004	964	3.4	42.4	72	Good
1998	971	3.7	47.1	80	Bumper
1988	973	3.7	48.7	82	Bumper
2001	1,007	4.1	53.4	90	Bumper
1995	970	4.5	59.2	100	Bumper

[a] Hard-mast index (modified Whitehead 1969 method).
[b] % of trees bearing acorns, with acorn presence assigned (for calculating PBA) if % crown with acorns (PCA) is >33.5%.
[c] Standardized PBA = $(PBA/PBA_{max}) \times 100$; here PBA_{max} is 59.2.
[d] Subjective rating based on standardized PBA.

Our data indicate that any of the 3 tested criteria for defining the presence or absence of acorns could potentially be used to estimate PBA for HMI prediction models. In all likelihood other reasonable criteria used to define acorn presence or absence, such as the time-constrained crown searches (Koenig et al. 1994) that are used in many northeastern states (G. Norman, personal communication), could be used to estimate PBA and, if desired, to develop HMI prediction models. However, our predictive equations are based on a specific criterion (absence defined as PCA < 33.5% for calculating PBA) and, thus, cannot be used for HMI predictions based on other definitions of acorn presence or absence.

Greenberg and Parresol (2002), using acorn trap data, described a tool for using PBA to estimate crop size per square meter basal area of oak. Clearly, any relationship between PBA and estimates of real numbers of acorns is contingent on how acorn presence or absence is assigned to trees for PBA calculations. To translate visual survey data into real numbers of acorns produced, the relationship between visually determined (rather than acorn trap data) PBA and real numbers of acorns produced must be established. To establish this relationship, and to ensure that it is consistent among geographic locations and years, a standard protocol for assigning the presence or absence of acorns must be used. We recommend assigning acorn presence (for PBA estimation) if PCA ≥ 33.5%. This cutoff is arbitrary but conservative, and it provides a tested basis for calculating PBA to use for HMI prediction. Further, it provides a standard to ensure consistent, comparable estimates of PBA (and HMIs) among all agencies that conduct hard-mast surveys.

Estimations of PCA can be done rapidly and provide a tested basis for calculating PBA to predict HMIs. Further, continuous PCA data provide more potentially useful information than other methods for assessing acorn presence or absence such as time-constrained acorn counts (Koenig et al. 1994) or a simple designation of acorn presence or absence. We also found that PCA alone, on a continuous (0–100%) scale, was a significant predictor of HMI (although we did not elaborate on it in this manuscript), indicating that PCA is a potentially valuable tool for assessing acorn crops. Further, continuous PCA data may prove useful in the future in establishing relationships between PCA, PBA, and acorn densities on acorn-bearing trees.

Clearly, even if relationships were established between PCA, PBA, and acorn densities on acorn-bearing trees, neither PBAs, HMIs, nor Greenberg and Parresol's (2002) crop size estimates could be used to estimate real acorn production on the landscape, unless the number (or basal area [m^2]) of oak trees on a given land area were known. This is because total acorn production per unit land area will vary with density of oaks and overstory conditions (Perry and Thill 2003). However, future research that establishes a relationship between visual surveys of PBA or HMI, and average number of acorns per acorn-bearing tree, could give land managers with oak inventory data a tool for calculating approximate acorn production for their own management areas.

Categorical cutoffs for designating crop sizes are subjective, and HMI values may not always reflect crop size relative to the actual range of acorn production, or the potential crop size for a species, subgroup, or all oaks within a region. Further, categories or index values for crop size may have little biological meaning. For example, moderate and good acorn crops may not differ in their effect on wildlife populations or oak regeneration. However, if crop-size rankings are desired, they should be scaled to the observed long-term range of PBA or HMIs for individual species, subgenera, or all oaks, rather than to a theoretical (and often unrealistic) maximum (e.g., a 0–100% scale for PBA or a 0–10 scale for HMI; Pozzanghera 1990). For example, PBA for all oaks in western North Carolina never exceeded 60% during 1985–2005. Therefore, evaluating its performance on a scale of 0–100% would not accurately reflect relative crop size, unless the scale was adjusted to its actual, long-term range of PBA. We provided guidelines for ranking acorn crops by first standardizing the actual long-term range of PBA to a 0–100% scale using an example (in our case, all oaks for the region) with equation 2, and then assigning a subjective ranking of mast crops based on field observation of mast crops and corresponding HMIs over the last 21 years. Managers can use this method for evaluating crop size of individual species, subgroups, or all oaks based on long-term performance records in their own region.

We found that numbers of trees required to get precise (within 5% of the true proportion) estimates of PBA (and accurate predictions of HMIs) ranged from 60 to 165 at an 80% confidence level, and from 139 to 385 at a 95% confidence level. Required sample sizes may vary among years or locations according to the true proportion of trees bearing acorns, with the highest number of sample trees required during moderate crop years (when about 50% of trees bear acorns). However, because PBA cannot be known a priori, we suggest that managers sample a constant and sufficient number of trees for each oak subgroup (species, subgenera) or spatial scale of interest, rather than varying sample sizes among years or locations. Permanently tagged, identified, and measured survey trees, although not critical for estimating PBA or predicting HMI, would ensure greater consistency in hard-mast surveys among years and generate more information on acorn production patterns by individual trees.

Sample sizes can be small, and HMI predictions, therefore, potentially inaccurate, when the population of sampled oaks (e.g., all oaks for all survey routes combined) is split into oak subgroups such as subgenera or species or into smaller areas such as survey routes. We found a good fit between PBA and HMI even when the number of sample trees used to generate both variables was small (e.g., individual species on survey routes), but variance was high. However, both HMI estimates and the HMI predictions that are based on small sample sizes have a high likelihood of being inaccurate (low CL). Higher maximum estimates of PBA and HMI for individual survey routes than for regional (pooled) data could be due to greater consistency in acorn production at smaller spatial scales, or a reflection of smaller sample sizes and inaccurate estimates. By reducing the time required for visual surveys, our method provides an opportunity for land managers to increase sample sizes for oak subgroups or local areas as needed, if accurate HMI predictions are desired.

HMIs do not gauge actual crop size but can be a valuable management tool for comparing relative crop sizes among years and areas (Clark et al. 2005). Our method provides land managers with a fast, simple, and reliable method to predict HMIs (using PBA) that are equivalent and comparable to past HMI estimates used in southeastern states, thus providing continuity in tracking long-term acorn production patterns. The PBA can also be used as a stand-alone index of acorn production, if it is estimated based on sufficient a sample size and using standard protocols for designating acorn presence or absence. We recommend that resource management agencies in the eastern United States region use this standardized PBA method as an index of acorn production to ensure that acorn production data are comparable among geographic locations and years.

MANAGEMENT IMPLICATIONS

We offer a fast, and reliable method for using PBA to predict HMIs that are comparable to past HMI estimates for states using the Whitehead (1969) method, thus providing continuity in tracking long-term acorn production patterns. The PBA can also be used as a stand-alone index of acorn production. However, for PBA to be a useful and meaningful tool to land managers, either for predicting HMIs or as a stand-alone index, PBA estimations must be based on sufficient a sample size and using standard protocols for designating acorn presence or absence. We recommend using PCA estimated on a continuous scale (0–100%), and assigning acorn presence if PCA $\geq$ 33.5%. This cutoff is arbitrary, but provides a tested standard for calculating PBA to predict HMIs. Further, continuous PCA data may prove useful in the future in establishing relationships between PCA, PBA, and acorn densities, and developing a tool for land managers to estimate acorn production for their own management areas. To obtain precise estimates of PBA and, therefore, accurate predictions of HMI we suggest that managers sample a constant and sufficient number (165 for an 80% CL, and 384 for a 95% CL) of trees for each oak subgroup (species, subgenus) or spatial scale of interest. Permanently tagged, identified, and measured survey trees, while not critical for estimating PBA or predicting HMI, would ensure greater consistency in hard-mast surveys among years and generate more information on acorn production patterns by individual trees. Substituting a fast, simple estimate of PCA (used for calculating PBA) for labor-intensive counting of twigs and acorns means that the number of trees sampled can be increased for oak subgroups or local areas if needed, and the time and effort dedicated to hard-mast surveys can be reduced greatly each year. We recommend that PBA, with standardized protocols for its estimation, be used by resource management agencies as a standard, stand-alone index of acorn production to ensure comparable data among years and across the eastern United States.

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