

EFFECTS OF BAG LIMITS ON BOBWHITE HUNTERS AND HARVEST

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Abstract: Scientific management of quail harvest at the state level must be based on a clear understanding of the effects of hunting regulations on hunters and populations. Therefore, we assessed how reduction in bag limits would affect hunter opportunity and harvest rates of northern bobwhites (*Colinus virginianus*) in Oklahoma, USA, using harvest data from questionnaire surveys. Reductions in bag limits were regressive because reductions had relatively less effect on hunting opportunity and harvest rate at low populations than at high populations. Based on data primarily from Oklahoma and Missouri, we found that the negative binomial distribution described the probability of an integer bag (0, 1, 2, 3, ... birds) if the mean and variance of daily bag were known. The negative binomial distribution provides a general method of assessing the effects of bag-limit reduction on hunting opportunity and harvest rates. The skill of the average hunter apparently declined as the statewide bobwhite population increased. Although hunting was self-regulatory in that the number of hunters declined as the bobwhite population declined, it was not self-regulatory when adjusted for the relative skill of hunters at low and high populations. We argue that fixed, relatively low bag limits established as a risk-averse strategy for low populations of bobwhites may not necessarily have large impact on hunting opportunity with high populations.

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Management of quail harvest at the state level has long operated under the assumption that hunting mortality is compensatory (Roseberry 1982), at least in the sense that a sustained yield is extractable from a state population. Empirical findings indicate that daily bag limits ≥ 8 –10 birds have little effect on hunting opportunity and harvest rates (Peterson 2001). Also, the population of hunters tends to wax and wane with quail abundance, thus suggesting a self-regulatory component in state harvest (Peterson and Perez 2000). The sustained yield assumption, bag-limit effect, and self-regulatory nature of hunting effort generally have resulted in the promulgation of liberal harvest regulations (daily bag, season length). Moreover, liberal regulations were socially justified on the basis that they provide maximum recreational opportunity to hunters.

Two factors have caused management biologists to reassess the traditional justifications for statewide harvest management. First, the general decline of northern bobwhites (Brennan 1991, Church et al. 1993, Brady et al. 1998, Peterson et al. 2002) indicates that harvest is occurring in declining populations in a large portion of the United States. Moreover, harvest is occurring in landscapes that have undergone habitat loss and fragmenta-

tion, thus possibly rendering local populations more sensitive to recreational harvest (Roseberry and Klimstra 1984:147–148, Guthery et al. 2000). Ellison (1991) suggested that harvest of tetraonids existing in small metapopulations might have to be banned for population persistence. Population decline and habitat degradation raise questions as to whether the traditional assumption of sustained-yield management holds on modern landscapes.

The second factor is the finding that harvest mortality tends to be more additive than compensatory for bobwhites during the fall–spring period (Roseberry and Klimstra 1984:142, Robinette and Doerr 1993, Dixon et al. 1996). The additivity of fall–spring harvest also becomes evident when early research (Baumgartner 1944, Glading and Saarni 1944) is reanalyzed (Guthery 2002:101).

Declining populations and associated habitat problems, plus new understanding of the nature of fall–spring mortality, suggest a need to clearly understand the effects of statewide harvest regulations on quail populations. To our knowledge, the major previous assessments of such regulations are in Peterson and Perez (2000), Peterson (2001), and Bristow and Ockenfels (2000). Our objectives were to test the findings of Peterson and Perez (2000) and Peterson (2001) with an independent dataset and to refine understanding of certain harvest management processes. Following Peterson (2001) and Bristow and Ockenfels

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(2000), we assessed the effects of bag-limit reduction on the percent of hunters affected (hunting opportunity). We also derived a method to estimate how reduction in bag limits affects percent harvest of quail at the state level. Because these assessments are derivable from the cumulative proportion of hunters taking a specified number of birds, we delved into the underlying probability structure of the cumulative proportion function. We tested Peterson's (2001) hypothesis that bag limit reductions are regressive because they have relatively more effect on high than on low populations (opposite of the desired effect). Finally, we tested an implicit assumption of Peterson and Perez's (2000) finding that hunting tends to be self-regulatory. They did not test whether the efficiency of hunters remains constant as quail abundance varies—an assumption that must hold for a linear, self-regulatory effect to be accepted without amendment. One expects a priori that the average hunter during population lows is more dedicated and efficient than the average hunter during population highs.

METHODS

We used roadside surveys to index the abundance of bobwhites in Oklahoma. Bobwhites were counted on 32-km routes by Oklahoma Department of Wildlife Conservation biologists starting at sunrise or 1 hr before sunset in habitat typical of the county in 75 of 77 Oklahoma counties (2 urbanized counties excluded). Two routes were established in 8 larger counties. Routes were driven at 32 km/hr, and singles, pairs, and coveys were counted and recorded separately. The counts were repeated in August and October. The index we analyzed ($I = \text{mean}/\text{route}$) represents an average over the 2 months ($n = 164$ or 166, depending on year) for the state. We assumed that the index was a linear, zero-intercept function of statewide bobwhite abundance.

We obtained data on harvest from a random sample survey of 2,008 license holders in 1992, 2,154 in 1998, and 2,125 in 2001 (not all respondents hunted bobwhites). Prior to telephone contact, a postcard (1992) or a letter (1998, 2001) notified each license holder that he or she was selected to participate in the study and described the importance of the survey. In 1998 and 2001, each respondent received a paper version of the questionnaire shortly after the end of hunting season with a self-addressed envelope for those who preferred to participate in the survey through the mail rather than over the telephone.

We did not provide return postage because the survey design was predominantly telephone-based, and license holders who did not respond through the mail were contacted by telephone. Response rates were relatively high (approx 80%). Further, a comparison of respondents who were difficult to reach with those who were contacted early revealed no systematic bias in responses. Therefore, we do not suspect that nonresponse bias significantly affected our results.

The data obtained through the questionnaire survey related to daily bag limits of 10 birds for each hunting season (20 Nov 1992–15 Feb 1993, 1 Nov 1998–31 Jan 1999, and 1 Nov 2001–31 Jan 2002). For each respondent, we obtained mean daily bag for hunters who hunted ≥ 1 day. We defined this value as a random variable ($b = \text{total bag}/\text{total days hunted}$) for an individual. We developed cumulative proportion functions with these data for each hunting season (cumulative proportion of hunters that attained a specified daily bag). Because this function is asymptotic at 1.0, we modeled the data with logistic and Gompertz functions following Banks (1994). The Gompertz function is similar to the logistic function but has added flexibility because the point of inflection is not constrained relative to the asymptote. Because both functions were equally parameterized (parsimonious), we report whichever function achieved the highest r^2 value. Following Peterson (2001), we modeled separately the cumulative proportion when relative abundance ($I \pm \text{SE}$) of bobwhites in Oklahoma was low (2001; $2.2 \pm 0.44/\text{route}$), medium (1998; $6.2 \pm 0.89/\text{route}$), and high (1992; $12.3 \pm 1.36/\text{route}$). After deriving cumulative proportion functions ($C(b)$), we estimated the proportion of hunters affected by a reduction in bag limit as $1 - C(b_l)$, where b_l is some bag limit of interest that falls below the legal daily bag (b) or below the daily bag associated with the asymptotic limit (1.0). The latter daily bag may be less than the legal daily bag.

We estimated the proportional reduction in harvest (R) associated with a reduced bag limit by differentiating $C(b)$ to obtain the density function $c(b)$. We then calculated

$$R = \frac{\int_{b_l}^{\infty} bc(b)db}{\bar{b}}, \quad (1)$$

where \bar{b} = the mean of the mean daily bags for a given year. The lower limit of integration is b_l (the reduced daily bag of interest) and the upper limit

is the legal daily bag. The term represented by the integral is the total bag, relative to the mean, represented by daily bags $> b_t$.

The cumulative proportion of hunters as a function of mean daily bag is not a pure reflection of reality because daily bags are integer values (0, 1, 2, 3, ...), whereas mean daily bags need not be integer values. The cumulative proportion function, therefore, is a discrete function whose nature is of applied and theoretical interest. The mean daily bag may be viewed as a Poisson rate and the discrete function modeled accordingly. As a Poisson rate, the mean daily bag of a particular hunter is independent of the bags of other hunters in the sample. However, under the Poisson model one must assume a constant rate (mean daily bag) in time and space, which clearly does not hold for daily bags of quail (abundance varies with area and time during a hunting season). A form of the negative binomial distribution permits variable rates in time and space (Rice 1988:254). We tested the negative binomial distribution to model probabilities of daily bags given the estimated mean and variance of daily bag for selected data where we had frequencies for integer-valued daily bags. These data included 1-day hunters in the questionnaire survey for 1992, 1998, and 2001 (yield integer bags); Hood (1956); and data from the White River Trace Conservation Area in Dent County, Missouri, USA, 1991–2002. Hunting on the latter area took place during 1–30 November from daylight until 1300 hr; the bag limit was 8 birds and all hunters checked into and out of the area.

The probability of harvesting b birds ($b = 0, 1, 2, 3 \dots$) on a given hunting trip, or $f(b)$, was estimated as

$$f(b) = \left(1 + \frac{m}{k}\right)^{-k} \left(\frac{\Gamma(b+k)}{b! \Gamma(k)}\right) \left(\frac{m}{m+k}\right)^b,$$

where $m \cong \bar{b}$ and $k \cong \bar{b}^2 / (s^2 \bar{b})$ (Rice 1988:255). See Hilborn and Mangel (1997:76–83) for explanation of the gamma (Γ) function and derivation of the formula.

To assess whether the efficiency of hunters changed with bobwhite abundance in Oklahoma, we used data from 12 years (1990–2001) when both questionnaire and roadside surveys were conducted. The daily bag limit was 10 birds, and season length was about 3 months. We defined hunter efficiency (skill) as $y = \text{harvest}/\text{hunter-day}/\text{index bird } I$, where the number of hunter-days statewide was estimated from the questionnaire survey (hunters \times mean days/hunter). We

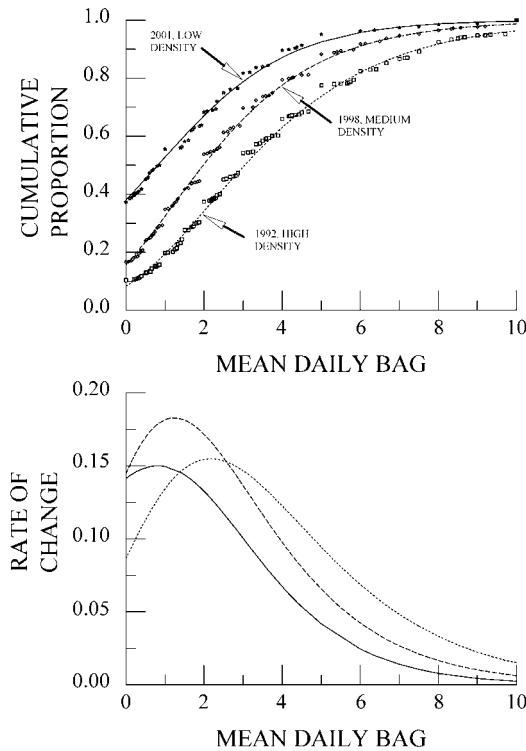


Fig. 1. Trends in the cumulative proportion of hunters attaining mean daily bags as associated with variation in relative density of northern bobwhites in Oklahoma, USA. The bottom figure shows the rate of change in the cumulative proportion curves. Data from 1992 and 1998 were fit to the Gompertz function whereas data from 2001 were fit to the logistic function.

then assessed y as a negative exponential function of the population index (I). We used an exponential model because it is (1) equally parsimonious with linear models (2 parameters), (2) more general (takes different shapes) than linear models, and (3) more appropriate (asymptotic lower bound) in certain situations than a linear model with a negative slope. We also assessed the mean of the mean daily bags (\bar{b}) as an exponential function of the abundance index.

RESULTS

Cumulative Proportion Functions

The Gompertz and logistic functions provided excellent fits to the cumulative proportion of hunters (C) as a function of mean daily bag (b ; Fig. 1). The functions, subscripted to year, were

$$\begin{aligned} C_{1992} &= \exp(-2.49 \exp(-0.42b)), \\ C_{1998} &= \exp(-1.85 \exp(-0.50b)), \text{ and} \\ C_{2001} &= 1 / (1 + \exp(0.50 - 0.60b)). \end{aligned}$$

Table 1. Estimated effects of daily bag-limit reductions on hunters affected (%) and reduction in harvest (%)^a at different relative densities of northern bobwhites in Oklahoma, USA, 2001 (low density), 1998 (medium density), and 1992 (high density).

Bag reduced from 10 to	Low		Medium		High	
	Hunters affected	Reduction in harvest	Hunters affected	Reduction in harvest	Hunters affected	Reduction in harvest
8	1.3	6.9	3.3	9.2	8.3	14.4
6	4.3	20.0	8.8	25.0	18.2	35.6
4	13.0	45.6	22.2	52.1	37.1	64.7
2	33.2	81.9	49.4	85.0	65.9	91.3

^a The absolute reduction in harvest (no. of birds) is estimable based on total estimated harvests of 3,328,404 in 1992, 1,048,878 in 1998, and 366,289 in 2001.

These curves, which changed with the index of abundance for bobwhites in Oklahoma, were associated with mean daily bags of 3.4 ± 0.26 (SE, $n = 100$) in 1992, 3.0 ± 0.29 ($n = 81$) in 1998, and 2.6 ± 0.33 ($n = 53$) in 2001. Based on derivatives of these cumulative functions (Fig. 1), the rate of increase accelerated up to bags of about 2 birds in 2001 (low density) and bags of 2–3 birds in 1998 (medium density) and 1992 (high density); then the rate of increase decelerated, reaching zero at a mean daily bag ≥ 10 birds.

Derivations from the models (Fig. 1) indicated reductions in daily bag limits from 10 to 8, 6, 4, or 2 birds would have higher effects on hunters when the population was high than when the population was low (Table 1). For example, the percent of hunters affected by a 10-to-8 reduction was

6.4 times higher in 1992 (high populations) than in 2001 (low populations). As theoretical bag reduction became more severe, the percentage of hunters affected converged to similar values. For example, using the same comparison just given, the percent of hunters affected by a 10-to-2 reduction was 2.0 times higher in 1992 than in 2001.

The percent reduction in harvest associated with bag-limit restriction followed patterns similar to the percent of hunters affected (Table 1). That is, percent reduction in harvest was greater at high than at low population levels, but the comparative values converged as reduction in bag limit became more severe. However, the absolute values changed. Without exception, the estimated percent reduction in harvest exceeded the percent of hunters affected. For example, at a 10-to-8 reduction, the percent reduction in harvest was 1.7–5.3 times the percent of hunters affected. Note that these findings hold in relative terms but not necessarily in absolute terms (percent harvest, not total harvest).

Table 2. Data used to estimate parameters for negative binomial predictions of the frequencies of daily hunting bags for northern bobwhites and assessment of the fit of the negative binomial model to observed frequencies in Oklahoma and Missouri, USA.

Data source	Daily bag			Negative binomial fit	
	<i>n</i>	\bar{x}	<i>s</i> ²	df	χ^2
1-day hunters, Oklahoma					
1992	88	3.1	10.72	9	11.3
1998	65	2.8	8.85	8	10.4
2001	48	1.4	5.80	3	9.8 ^a
Hood (1956)	345	1.6	3.99	8	5.4
White River Trace, Missouri					
1991	275	1.4	3.20	6	21.0 ^a
1992	187	1.5	3.74	6	10.9
1993	198	1.2	2.98	6	13.7 ^a
1994	270	1.6	4.41	6	4.8
1995	204	0.7	1.67	6	7.8
1996	210	0.9	2.13	6	4.1
1997	189	0.6	1.24	6	3.4
1998	198	1.2	2.52	6	7.9
1999	169	0.6	1.55	6	6.3
2000	207	1.1	2.77	6	8.8
2001	187	0.8	1.94	6	4.0
2002	148	1.2	3.55	6	9.5

^a Exceeds critical χ^2 value at $P < 0.05$.

Negative Binomial Predictions

The data used to derive the parameters *m* and *k* for the negative binomial distribution revealed considerable variability in daily bag relative to the mean (Table 2). Frequencies of integer-valued daily bags fit the negative binomial model in 13 of 16 tests. The negative binomial tended to underestimate the proportion of hunters obtaining bags of zero and overestimate the proportion obtaining bags of 1 when the model failed to fit the observed frequencies. When frequencies of these classes (0 and 1) were pooled, the model provided adequate fits in all 16 tests.

Given apparent adequacy of the negative binomial model, we modeled the effects of mean daily bag and variance in the daily bag on the cumulative proportion of hunters achieving a given integer bag. Arbitrarily holding relative variation constant at 1.09 to illustrate the effects of mean daily bag, we found performance of the negative

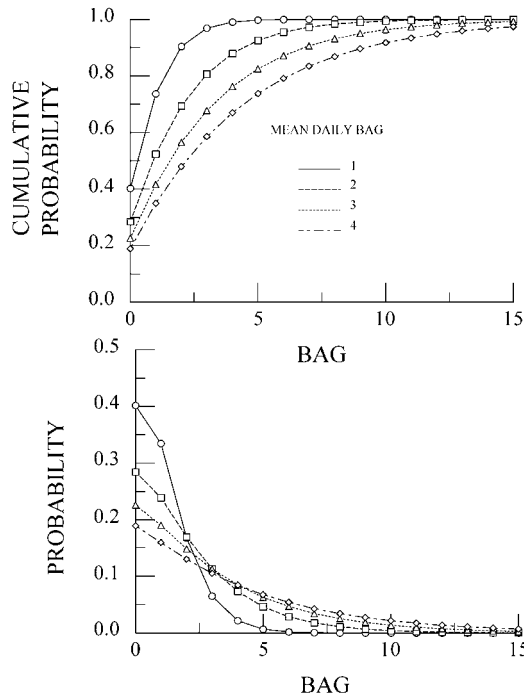


Fig. 2. Trends in cumulative and raw probabilities of integer-valued daily bags for northern bobwhites in Oklahoma, USA, as modeled with the negative binomial distribution, as the mean daily bag varies with the variance held at 1.09 times the mean.

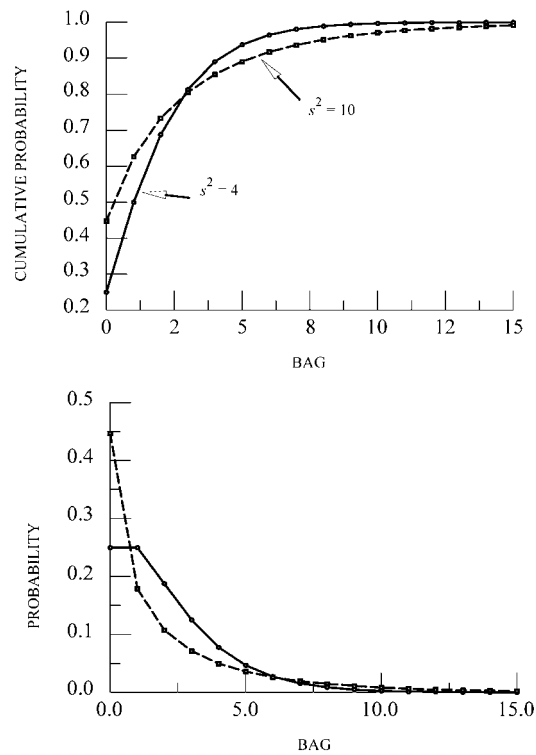


Fig. 3. Trends in cumulative and raw probabilities of integer-valued daily bags for northern bobwhites in Oklahoma, USA, as modeled with the negative binomial distribution, with the mean held constant at 2.0 and the variance ranging between 4 and 10.

binomial model (Fig. 2) mimicked our findings with empirical data (Fig. 1). That is, at lower mean daily bags, the cumulative function increased at higher rates and reached an asymptote faster in comparison with higher mean daily bags. Arbitrarily holding the mean daily bag constant at 2.0 and modeling with variances of 4.0 and 10.0 to illustrate the effects of variance, we found a higher variance increased the probability of zero bags and reduced the probability of achieving bags of 1 through 6 (Fig. 3). For bags of 7–12, the higher variance was associated with a slightly higher probability of a given bag than the lower variance. At bags >12, predicted probabilities converged.

Hunter Skill and Relative Abundance

Within the range of the data we obtained, skill of the average hunter declined as the population index increased (Fig. 4) in Oklahoma. The model suggested a roughly constant fractional reduction in hunter skill for each unit increase in the population index ($\exp[-0.098] = 0.907$). That is, $y = 0.85(0.907)^I$ expresses the same relationship as the exponential equation (Fig. 4), which indicates a 100% increase (doubling) in the popula-

tion was associated with about a 10% decrease in the hunter efficiency. At the highest population index recorded (12.3), skill was modeled at $y = 0.25$ birds/hunter-day/index bird. At the lowest index (2.2) skill was $y = 0.69$ birds/hunter-day/index bird. Thus, hunter efficiency was about 2.8 times higher at the lower population level, subject to uncertainty.

With the above results, we can estimate what the total harvest might have been if the predicted hunter skill had occurred at different values for the population index and total hunter-days. Skill of $y = 0.25$ bird/hunter-day/index bird is the same as $y = [0.25 (\text{index bird})]/\text{hunter-day}$. Thus, the total harvest (H) is estimated as

$$H = (y) (I) (\text{total hunter-days}).$$

If the 1992 skill rate had held for the 2001 population-index value and hunter effort, the estimated harvest would have been $0.25(2.2)(250,894) = 137,992$ birds. The actual harvest for 2001 was

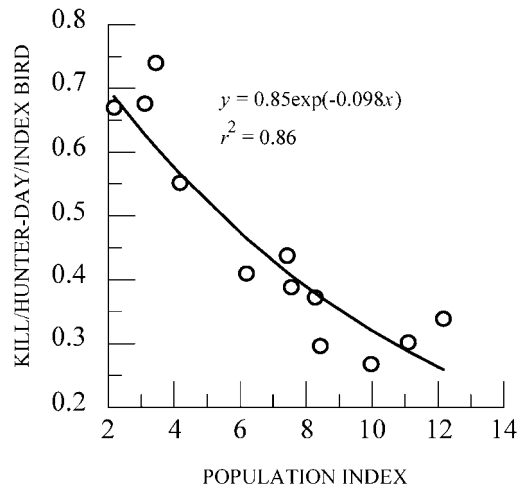


Fig. 4. Harvest rate as a function of the statewide population index of northern bobwhite abundance in Oklahoma, USA, 1990–2001.

250,893 birds, a difference of 112,901 birds. Conversely, if the 2001 skill rate had held for the 1992 population index and hunter effort, the estimated harvest would have been 0.69(12.3)(807,193) = 6,850,647 birds. The actual harvest for 1992 was 3,238,404 birds, a difference of 3,612,243 birds. These numbers, which are subject to uncertainty, give an idea of the magnitude of the effect on total harvest associated with population-dependent hunter efficiency and population variability.

To further illustrate the effects of systematic variation in hunter skill, we adjusted the predicted number of hunters, given the population index, by relative hunter efficiency (Fig. 5). We first estimated hunter efficiency at the highest population-index value (the lowest hunter efficiency) and then determined the ratio: (hunter efficiency at population indices below maximum)/(hunter efficiency at maximum). We multiplied this ratio times the predicted number of hunters at a given population index to obtain a curve of the effective number of hunters (Fig. 5). This effective num-

ber of hunters increased as the population declined, which would further draw into question the self-regulatory nature of hunting.

Mean Daily Bag and Relative Abundance

The mean daily bag increased at a modestly accelerating rate as the population index increased (Fig. 6). The exponential equation can be expressed as $\bar{b} = 1.77(1.06)^I$. This result indicated that a doubling (100% increase) of the population was associated with a 6% increase in the mean daily bag. At an index population of 12.3, the mean daily bag was modeled at 3.6 birds; whereas at an index population of 2.2, the modeled bag was 2.0.

DISCUSSION

The reliability of our findings was contingent on the assumption that the index of abundance (no. of bobwhite/32-km route) was an approximately linear, zero-intercept function of bobwhite abundance (N) in Oklahoma. The lack of intercept seems reasonable because in the absence of bobwhites none would be seen during counts (the point $y = 0$ when $N = 0$ must be real). Hunting success tends to be linearly correlated with bobwhite density on local areas (Guthery 1986:149, Palmer et al. 2002). Also, data from roadside counts were linearly correlated with total annual harvests in Texas (Peterson and Perez 2000, DeMaso et al. 2002), which held for our data ($r = 0.85$, $P < 0.001$, $n = 10$). These 2 linear correlations (success with absolute density,

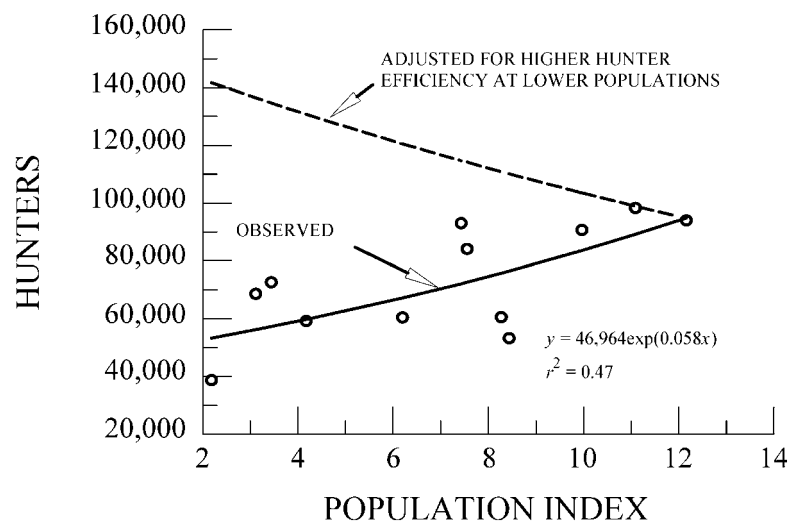


Fig. 5. Number of licensed hunters and number adjusted for relative skill as a function of the statewide population index of northern bobwhite abundance in Oklahoma, USA, 1990–2001.

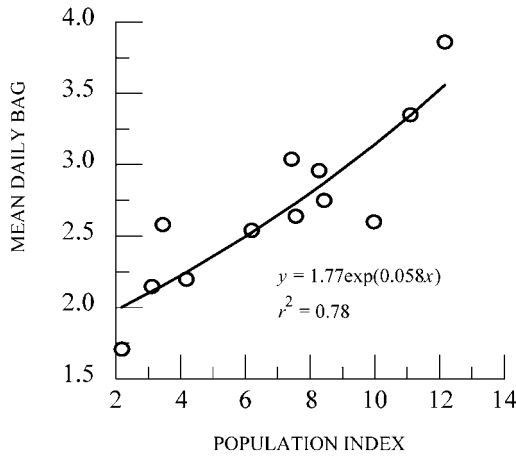


Fig. 6. Mean daily bag as a function of the statewide population index of northern bobwhite abundance in Oklahoma, USA, 1990–2001.

harvest with indexed density) imply algebraically that the index is linearly correlated with bobwhite abundance. Thus, evidence indicates that our assumption was tenable, although we recognize considerable variability and potential bias in the roadside index. For example, the index may be biased high during hot summers in Texas (Lusk et al. 2002).

With respect to the hypotheses we set out to test, our empirical (Fig. 1) and theoretical findings (Table 2) supported Peterson’s (2001) discovery of the regressive nature of bag-limit reductions on hunting opportunity defined as the percentage of hunters affected by bag limits (i.e., stronger relative effects at low than at high bobwhite populations). We also found that bag-limit reductions were regressive with respect to percent harvest of the population, resulting in greater percent reductions at higher than at lower populations (Table 1).

Our results did not support the assumption that the efficiency of hunters remains constant as bobwhite populations vary because skill of the average hunter seemed to increase as bobwhite abundance declined (Fig. 4). These results suggest that the self-regulation process (hunter abundance tracks quail abundance) is incomplete and, perhaps, misleading if the skill of hunters relative to bobwhite abundance is considered (Fig. 5). We surmise that the self-regulation hypothesis breaks down because the average hunter during population lows is more dedicated and experienced, and perhaps hunts in better habitat than the average hunter during popula-

tion highs. Hurst and Warren (1982) reported that avid hunters had much higher harvest rates and put greater effort into hunting than did the average quail hunter in Mississippi, USA. This conjecture, which should be tested, implies a need for data on hunter characteristics in variable bobwhite populations.

The apparent applicability of the negative binomial distribution (Table 2) for predicting probability and cumulative probability of integer-valued daily bags might be a useful finding. The negative binomial model is quite general because it permits variability in Poisson rates (no./time) in time and space and treats the variability under the gamma distribution (Hilborn and Mangel 1997). The negative binomial models permit quantitative assessment of cumulative proportion functions if a mean daily bag and associated variance are known. Thus, any agency that has data on mean daily bags can assess how bag limits might affect hunters and harvest under variable populations. This analysis would entail, for example, selecting the lowest and highest mean daily bags on record and calculating and plotting negative binomial probabilities for each. The resulting plots should approximately bracket the range of possible outcomes for variable populations in a given state.

The discrete homologue of equation (1) for estimating proportional reduction in harvest (R) with a reduced daily bag limit is

$$R = \frac{\sum_{i>b} p_i i}{b}$$

where B = the daily bag limit, b_l = the reduced integer bag limit of interest, and $p_i = f(b_i)$, the negative binomial probability of an integer bag of size b , $b = 2, 3, 4, \dots, B$. For ex post facto analysis, the estimated absolute reduction in harvest is the product $R(\text{total harvest})$.

The application of growth models (Fig. 1) or the negative binomial distribution (Fig. 2) to assess the effects of bag-limit reductions on hunting opportunity and harvest reveals that there are as many cumulative proportion-of-hunters functions as there are mean daily bags with associated variance. Thus, managers should not extrapolate findings from 1 analysis to other situations because the effect of bag-limit reductions depends on population abundance and variables that influence mean daily bag and associated variance.

An assumption underlying our analysis and that of Peterson (2001) is that the cumulative propor-

tion-of-hunters function does not change as the bag limit changes. We intuit the assumption probably is false but nugatory when a bag limit is reduced from high to slightly lower levels (e.g., from 10 to 8 birds). However, when a bag limit is reduced from high to low levels (e.g., from 10 to 2 birds), certain relations should change. For example, under a bag limit of 2 birds in comparison with 10 birds, we might expect the proportion of hunters obtaining zero birds to decline because more birds would be available to them. Robertson and Rosenberg (1988:196) observed that harvest restrictions could result in a more even spread of game amongst hunters. Similarly, Allen (1954:128) found that daily bag limits distributed early season harvest amongst more hunters. Moreover, the cumulative proportion-of-hunters function should reach the asymptote (2 in this example) more rapidly. Effects such as these could possibly bias estimates of percent reduction in harvest (low or high populations) as derived from the formulas we presented. The magnitude of such effects is unknown but in need of theoretical and empirical analyses.

Finally, we offer some observations on management of the quail harvest at the state level based on our results and those of Peterson (2001). First, the social justification for high bags (more opportunity for recreation) appears somewhat quixotic if a daily bag exceeds 10 birds because hunters rarely attain higher bags. High bags for hunters are especially rare given low populations. Moreover, reduced bag limits do not automatically reduce total recreation (hunter-days). Hunters attaining a low bag on any day, and thus reducing time afield, could take more hunting trips such that their total recreation remains constant or increases. However, hunters may perceive a decline in hunting opportunity (or the possibility of a decline) with reduced bag limits even when no actual decrease in opportunity exists. This perception is a sociological phenomenon that is not easily altered through bag-limit manipulations.

Second, suppose that reduced harvest of low populations resulted in more rapid recovery of low populations because of an increased number of breeders after the harvest season. We recognize this supposition is controversial and provisional. However, Roseberry (1979) observed a slight retardation in recovery rates associated with harvest of low populations, although he did not view this as serious over the long term. If daily bag limits were fixed over time for simplicity and set low for sensitivity to low populations, the low

bag limit obviously would be compatible with high populations. In 1 sense, the low limit would affect only those hunters who chose not to hunt at a low bag limit. We suspect, though, that the decision to hunt is independent of bag limit, within limits, and is dependent on perceptions of quail abundance in a given hunting season (Peterson and Perez 2000). Based on Oklahoma data, a bag reduction from 10 to 4 would lower the daily harvest of an estimated 13.0% of hunters given low populations and 37.1% of hunters given high quail populations (Table 1). This implies the bag reduction would be irrelevant to $\geq 62.9\%$ of hunters.

Quail harvest management should be as scientific as current knowledge permits, especially in the face of declining populations of some species in some areas. Like Roseberry (1982), we advocate the concept of sustained-yield as opposed to annual-surplus management. Understanding how alterations of bag limits influence the total harvest in a state is a necessary part of sustained-yield management.

MANAGEMENT IMPLICATIONS

We raise issues regarding quail harvest in hopes that doing so might stimulate thought leading to deeper understanding of harvest management at the state level. However, we agree with Peterson (2001) that harvest management in most cases manages hunting rather than harvest. Therefore, bag-limit changes contain a sociological dimension that should be considered when setting hunting regulations.

The results of our analyses have the following implications related to the management of bobwhite harvest at the state level. First, managers should expect reductions in bag limits to be regressive (Peterson 2001) because such reductions had relatively more effect on hunter opportunity and percent harvest at high than at low population levels. Second, the negative binomial distribution for predicting the probability of attaining integer-valued daily bags appears to provide a general framework for modeling the effects of bag limit changes on hunting opportunity and harvest. Third, because the skill of the average hunter increased as the statewide bobwhite population declined, at least in Oklahoma, managers should question the hunter self-regulation hypothesis as a principle of state-level harvest management. Finally, fixed, low bag limits established to protect low populations might not necessarily have a large impact on hunting opportunity with high populations.

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