Restoration of the wild turkey in east Texas: simulation of alternative restocking strategies

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Abstract

Models that simulate population dynamics of relocated populations should prove useful during the restoration of extirpated species. One fundamental question facing restoration ecologists attempting to restore wild turkey (Meleagris gallopavo) populations is the number of birds to release per restoration site. We describe the development of a simulation model capable of evaluating a variety of stocking strategies for eastern wild turkeys (Meleagris gallopavo silvestris). Simulation results suggest that in the coniferous and deciduous forests of east Texas, supplemental (multiple) stockings do not use difficult-to-procure broodstock as effectively as initially stocking new sites. We also found that using juvenile females or a combination of 50% adult and 50% juvenile females significantly \[^{*}\] increased turkey survival. Based upon these data, it appears that biologists attempting to restore wild turkeys in east Texas should use the higher stocking rates we evaluated and \( \geq 50\% \) juvenile females during releases. Models that simulate the dynamics of relocated populations benefit restoration efforts by allowing restoration ecologists to evaluate various stocking strategies quickly and inexpensively prior to initiating costly restoration programs. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Eastern wild turkey; Meleagris gallopavo silvestris; Restoration; Stocking rates; Simulation model

1. Introduction

Models that simulate the dynamics of relocated populations should prove useful during the restoration of many species. For example, an important concern of restoration ecologists is determining which factors most constrain relocated populations. With many species, few ecological studies exist, making it difficult to know where research and management efforts might be applied most effectively. A priori evaluation of proposed management strategies often is necessary during restoration efforts due to time constraints associated with implementing management strategies, learning from their failure, and trying new

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ones. Simulation models are useful tools for such explorations (Peterson et al., 1991). In the case of wild turkey restoration efforts in Texas, simulation models that explicitly represent population parameters of relocated wild turkey populations should improve the overall success of turkey restoration programs.

A fundamental question facing those attempting to restore wild turkey populations is determining the optimal number of birds to release (Kennamer et al., 1992). Important factors include numbers of each sex and age-class as well as frequency of releases (e.g., single versus multiple stockings). Although literature documenting differences in mortality and natality for wild turkeys among sex, age-class, and bird origin is available (Hopkins, 1981; Little and Varland, 1981; Campo, 1983; Vangilder et al., 1987; Miller, 1990), the relative importance and interactions among these variables during wild turkey restoration attempts has received little attention. Similarly, information on the importance of frequency of release during wild turkey restoration efforts is limited.

In this paper, we describe the development of a model capable of simulating the dynamics of a wild turkey population and a variety of restoration strategies. We then evaluate various stocking strategies that might prove beneficial for wild turkey restoration efforts in east Texas. These a priori evaluations allow restoration ecologists to make better-informed decisions regarding stocking strategies designed to maximize effectiveness of wild turkey releases.

2. Eastern wild turkey restoration

2.1. Brief life history

The eastern wild turkey is a large gallinaceous bird (7.7–9.5 and 3.6–5.0 kg for adult males and females, respectively (Pelham and Dickson, 1992)) found in southeastern United States (Fig. 1). Although turkey chicks require large quantities of insects in their diets, adults are primarily herbivorous (Hurst, 1992). The breeding season for eastern wild turkeys begins in early February and extends through early June (Blankenship, 1992). In early April, wild turkey hens typically lay one egg per day in nests on the ground until their clutch is completed (10–12 eggs) and incubation lasts approximately 28 days. Wild turkey hens produce no more than one brood per year.

2.2. East Texas restoration

By 1900, eastern wild turkey numbers were sparse throughout the southeastern United States. Habitat loss and unregulated hunting contributed to the decline in wild turkey abundance (Kennamer et al., 1992). Initial restoration efforts (1930s) using wild-trapped Rio Grande (Meleagris gallopavo intermedia) and pen-raised eastern turkeys were unsuccessful (Newman, 1945; Mosby, 1975). In the early 1950s, development of the cannon-net allowed the efficient capture and relocation of the eastern sub-species. As a result, many southeastern states successfully used wild-trapped eastern wild turkey broodstock for restoration (Kennamer and Kennamer, 1990).

In 1942, wild turkey numbers were estimated to be less than 100 birds in the Pineywoods and Post Oak Savannah regions of eastern Texas (Fig. 1; Newman, 1945; Gould, 1975). In 1979 and 1980, wild-trapped eastern turkeys from Louisiana and Mississippi were released successfully on two sites in the Pineywoods (Campo, 1983). This demonstrated the importance of using wild-trapped eastern wild turkeys for the east Texas restoration program. Recently, Texas Parks and Wildlife Department (TPWD) has obtained increasing numbers of wild-trapped eastern wild turkeys. Initial restoration efforts were in the Pineywoods region (Newman, 1945; Campo et al., 1984). Recently, these efforts have expanded into the Post Oak Savannah. Since 1987, wild-trapped eastern wild turkeys were released into east Texas with variable success (M.J. Peterson, TPWD, unpublished data).

2.3. Stocking rates

Stocking rates used in the southeastern US during restoration programs have varied markedly from state to state. Kennamer (1986)
reported that numbers of eastern wild turkeys released varied from nine to 56 birds per site. For example, Iowa stocked ten hens and three gobblers per site, resulting in populations capable of withstanding hunting pressure within 5 years (Little, 1980). Gilpin (1959) used a stocking rate of four hens and two gobblers to restock portions of West Virginia. In the Pineywoods Region of eastern Texas, Hopkins (1981) and Campo (1983) used a stocking rate of 12 hens and three gobblers. In the Post Oak Savannah of Texas, this rate appeared inadequate (Feuerbacher, 1997; Lopez et al., 1998).

In east Texas, at least, survival decreased with the age class of hens released. For example, Lopez et al. (1998) found that approximately 48% of post-release adult hen mortality occurred during the nesting season in contrast to 0% for juvenile.

Fig. 1. Historic range (grey area) of eastern wild turkey in east Texas. Ecological regions outlined by dashed lines.
Fig. 2. First-year survival of eastern wild turkeys relocated into eastern Texas by age-class.

hens (Fig. 2). A combination of factors might explain this comparatively high loss of adult hens. For example, increased movements by adults during the pre-nesting season might increase energy loss and susceptibility to predation (Miller, 1990). Similarly, habitat unfamiliarity might magnify susceptibility to predation (Miller et al., 1985; McGuiness et al., 1990; Miller, 1990). Because hens are most vulnerable to predation during incubation and 2-weeks post-hatch (Speake et al., 1969), it is not surprising a higher proportion of adult hens attempting to nest the year of release leads to higher mortality as compared to juveniles. In the past, TPWD biologists have avoided using juvenile turkeys during restoration efforts (J. Burk, TPWD, unpublished data) because it was assumed that adults would have higher survival and reproductive success. Lopez et al. (1998) hypothesized that using juvenile hens for restoration might increase the effectiveness of turkey releases by increasing the proportion of birds surviving 1 year post-release. These hens then would be better adapted to the new habitat and have higher survival during their first nesting attempt. The utility of this stocking strategy, however, has yet to be evaluated.

It also appears that survival increases with supplemental stocking attempts in east Texas. For example, Lopez et al. (1998) and Feuerbacher (1997) found lower survival for initially stocked males as compared to supplementally stocked males. We define initially stocked birds as birds released into areas the first year with no birds present. We define supplementally stocked birds as birds released into areas a year after birds had been initially stocked. Lopez et al. (1998) and Feuerbacher (1997) suggested supplemental releases might increase the number of birds surviving 1 year post-release, thus maximizing the efficiency of wild turkey restoration efforts. If short-term survival increases with supplemental stockings (i.e. more birds surviving to the second- and third-year) and greater reproductive success is observed with these resident birds ( > 1 year post-release), then reproductive output would be maximized (i.e. higher recruitment per bird released). Information on the effectiveness of supplemental releases for wild turkeys is limited (Campo, 1983; Backs and Eisfelder, 1990; Feuerbacher, 1997), so the utility of this stocking strategy warrants further investigation.

We developed a systems simulation model to identify and evaluate stocking strategies that should maximize wild turkey restoration efforts in Texas. Specifically, we examined two questions: (1) what stocking rates (i.e. number per release, frequency) are most effective?; and (2) which age-class should be preferred broodstock for initial and supplemental stocking attempts?

3. Model description

3.1. Conceptual model overview

The model represents the dynamics of a sex- and age-structured population of wild turkeys (Fig. 3). Both female and male birds can enter the population as pouls hatched from eggs laid by resident females or as artificially stocked juveniles or adults. All pouls and surviving artificially stocked juveniles and adults enter the resident population 365 days after hatching or stocking. Mortality rates are sex- and age-specific and artificially stocked adults suffer higher mortality than resident adults during the first year after introduction. The model is formulated as a compartment model based on difference equations with a 1-day
time step, and is programmed in STELLA® Version 3.05 (High Performance Systems, Inc. 1994) on a personal computer.

3.2. Model quantification

Daily changes in the number of birds in each sex- \( i \), 1 = females and 2 = males), age- \( j \), days after entry into the population), and condition-class (poults, stocked juvenile, stocked adult, resident) are represented by the state variable equations:

\[
Poults_{i,j}(t+1) = (\text{Reproduction}_{i,j}) \Delta t \quad \text{for } j = 1, \text{ and} \]

**Females**

![Female turkey model diagram]

**Males**

![Male turkey model diagram]

Fig. 3. Diagram of wild turkey restoration model representing population dynamics for relocated wild turkeys.
Poults_{i,j} (t + 1) = Poults_{i,j - 1} (t)
for 1 < j < 366
(1)

Juveniles_{i,j} (t + 1) = (Juveniles Stocked,) \Delta t
for j = 1 and
(2)

Juveniles_{i,j} (t + 1) = Juveniles_{i,j - 1} (t) - (Juvenile Mortality_{i,j - 1}) \Delta t
for 1 < j < 366
(3)

Adults_{i,j} (t + 1) = (Adults Stocked,) \Delta t
for j = 1 and
(4)

Adults_{i,j} (t + 1) = Adults_{i,j - 1} (t) - (Adult Mortality_{i,j - 1}) \Delta t
for 1 < j < 366
(5)

Residents_{i,j} (t + 1) = Residents_{i} (t)
+ (Poulter Recruitment_{i,365})
+ Juvenile Recruitment_{i,365}
+ Adult Recruitment_{i,365}
- Resident Mortality, \Delta t
(6)

Thus the identity of each cohort of females and males is maintained for the first 365 days after entering the population, either via natural reproduction or stocking, after which time all birds are considered resident adults.

3.2.1. Reproduction

Based on data obtained from studies in the Pineywoods (Hopkins, 1981; Campo, 1983) and Post Oak Savannah regions (Feuerbacher, 1997; Lopez et al., 1998) of Texas, we assumed first-year reproduction of stocked adult females (0.0–0.05 poults per hen) was lower than second-year reproduction of resident females (0.0–0.20 poults per hen). Each \Delta t during simulations, natality rates were selected randomly from uniform distributions within these ranges. We assumed a 50:50 sex ratio and that all poults enter the population on day-of-year (DOY) 150. Thus

If DOY = 150:

Reproduction_{i} = \sum_{j} \left( x \times \text{Adults}_{i,j} + \beta \times \text{Residents}_{i,j} \right) / 2
otherwise

Reproduction_{i} = 0

where \( x \) is a uniform random variate on the interval 0.00–0.05 and \( \beta \) is a uniform random variate on the interval 0.00–0.20. Reproductive parameters \( (x, \beta) \) represent known values from radio-marked birds (Lopez et al., 1998).

3.2.2. Mortality

Lopez et al. (1998) reported first-year annual mortality \( (M) \) for relocated adult males \( (M = 0.714, \text{ S.E.} = 0.121, N = 14) \), adult females \( (M = 0.625, \text{ S.E.} = 0.086, N = 32) \), and juvenile females \( (M = 0.375, \text{ S.E.} = 0.121, N = 16) \), and noted that second-year mortality for males \( (M = 0.069, \text{ S.E.} = 0.058, N = 16) \) and females \( (M = 0.087, \text{ S.E.} = 0.058, N = 16) \) was lower than during the year they were released. Furthermore, Lopez et al. (1998) and Feuerbacher (1997) observed lower mortality for supplementally stocked males \( (M = 0.286, \text{ S.E.} = 0.121, N = 14) \) as compared to initially stocked males \( (M = 0.714, \text{ S.E.} = 0.121, N = 14) \), thus suggesting that supplemental releases might increase survival of relocated birds. Because of insufficient data, we assumed that supplementally stocked females had similar decreases in mortality. Each \( \Delta t \) during simulations, survival rates were selected randomly from normal distributions with the above means and standard errors (S.E.), with the distributions truncated at \( \pm 2 \) S.E. Thus

for \( i = 1 \) (females):

Juvenile Mortality_{i,j} = \alpha \times \text{Juveniles}_{i,j} (t)
(6)

Adult Mortality_{i,j} = \beta \times \text{Adults}_{i,j} (t)
(7)

Resident Mortality_{i} = \delta \times \text{Residents}_{i} (t)
(8)

and for \( i = 2 \) (males):

Juvenile Mortality_{i,j} = \phi \times \text{Juveniles}_{i,j} (t)
(9)

Adult Mortality_{i,j} = \gamma \times \text{Adults}_{i,j} (t)
(10)

Resident Mortality_{i} = \eta \times \text{Residents}_{i} (t)
(11)
Table 1
Truncated (at ± 2 S.E.) normal distributions (annual mortality rates) from which daily mortality rates are drawn for initially- and supplementally-stocked juvenile, stocked adult, and resident females and males

<table>
<thead>
<tr>
<th></th>
<th>Initially stocked (mean, S.E.)</th>
<th>Supplementally stocked (mean, S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocked juveniles</td>
<td>0.375, 0.121</td>
<td>0.286, 0.121</td>
</tr>
<tr>
<td>(x)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocked adults</td>
<td>0.625, 0.086</td>
<td>0.286, 0.121</td>
</tr>
<tr>
<td>(β)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residents (δ)</td>
<td>0.087, 0.058</td>
<td></td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocked juveniles</td>
<td>0.714, 0.121</td>
<td>0.286, 0.121</td>
</tr>
<tr>
<td>(φ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocked adults</td>
<td>0.714, 0.121</td>
<td>0.286, 0.121</td>
</tr>
<tr>
<td>(γ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residents (η)</td>
<td>0.069, 0.058</td>
<td></td>
</tr>
</tbody>
</table>

where $x$, $β$, $δ$, $φ$, $γ$, and $η$ are normal random variates drawn from the distributions indicated in Table 1. Mortality parameters ($x$, $β$, $δ$, $φ$, $γ$, $η$) represent known values from radio-marked birds (Lopez et al., 1998).

3.3. Artificial stocking simulations

Fifteen stocking strategies (i.e. five stocking rates within each of three age-class scenarios) were simulated (Table 2). Stocking rates ranged from the original rate used by TPWD (stocking rate 1) to supplemental stockings (stocking rate 5). Age-class scenarios for released females varied as follows: (1) all adults; (2) 50% adults and 50% juveniles; and (3) all juveniles. Because TPWD releases primarily adult males, we simulated releases of only adult males. For example, for stocking rate 1 (three gobblers and 12 hens), simulated age-classes were: (1) three adult males, 12 adult females; (2) six adult males, six juvenile females, and six adult females; and (3) three adult males, 12 juvenile females. All 15 stocking strategies were simulated for the following three survival scenarios: (1) best-case scenario (high survival); (2) average-case scenario (average survival); and (3) worst-case scenario (low survival). For the best-case and worst-case scenarios, we increased and decreased, respectively, the mean survival estimate used in our model by 1 S.E. The average-case survival scenario represents the mean survival estimates reported by Lopez et al. (1998) and Feuerbacher (1997) as summarized above. Thirty replicate simulations were run for each survival scenario associated with each stocking strategy for a duration of 4 years.

The effectiveness of each stocking strategy was measured by the percentage population increase ($R$) determined by the total number of birds remaining at the end of 4 years divided by the total number of birds released. The mean $R$ per 30 replications was determined for all 45 combinations of stocking strategy and survival scenario. We used an ANOVA to detect differences ($P < 0.05$) among stocking strategies and a Tukey’s mean separation test to identify differences among specific strategies (SAS Institute, 1985).

Table 2
Fifteen stocking strategies (five stocking rates within each of three age-class scenarios (ACSb)) simulated using the wild turkey restoration model

<table>
<thead>
<tr>
<th>Stocking rate</th>
<th>ACS1b</th>
<th>ACS2b</th>
<th>ACS3b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>5/5/5</td>
<td>15/15/15</td>
<td>5/5/5</td>
</tr>
<tr>
<td>5</td>
<td>10/10/10</td>
<td>30/30/30</td>
<td>10/10/10</td>
</tr>
</tbody>
</table>

* Numbers separated with a slash (/) represent bird numbers released during the first-, second- and third-year, respectively.

ACS1 = all males and females released were adults; ACS2 = all males released were adults, a half of females released were adults, and a half of females released were juveniles; and ACS3 = all males released were adults and all females released were juveniles.
Table 3
Stocking strategy effectiveness (measured by the percentage population increase (\(R^a\)) by stocking rate, age-class, and survival

<table>
<thead>
<tr>
<th>Stocking rate</th>
<th>Best-case(^b) (high survival)</th>
<th>Average-case(^b) (average survival)</th>
<th>Worst-case(^b) (low survival)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.691A</td>
<td>1.282A</td>
<td>0.930A</td>
</tr>
<tr>
<td>2</td>
<td>1.589A</td>
<td>1.380A</td>
<td>1.183B</td>
</tr>
<tr>
<td>3</td>
<td>1.609A</td>
<td>1.399A</td>
<td>1.180B</td>
</tr>
<tr>
<td>4</td>
<td>0.833B</td>
<td>0.720B</td>
<td>0.620C</td>
</tr>
<tr>
<td>5</td>
<td>0.835B</td>
<td>0.708B</td>
<td>0.624C</td>
</tr>
<tr>
<td>Juvenile</td>
<td>1.656A</td>
<td>1.362A</td>
<td>1.147A</td>
</tr>
<tr>
<td>Juvenile/adult</td>
<td>1.589A</td>
<td>1.333A</td>
<td>1.103A</td>
</tr>
<tr>
<td>Adult</td>
<td>0.988B</td>
<td>0.897B</td>
<td>0.772B</td>
</tr>
</tbody>
</table>

\(^a\) \(R\) = total number of birds remaining at the end of 4 years/total number of birds released. Means with the same letter are not significantly different.

\(^b\) Fifteen scenarios simulated under three different survival curves: (1) best-case, (2) average, and (3) worst-case scenarios.

\(^c\) Mean \(R\) determined from all stocking strategies.

Fig. 4. Mean trajectory of stocking strategy effectiveness as measured by the percentage population increase (\(R\); total number of birds remaining at the end of 4 years divided by the total number of birds released) for five simulated stocking rates using only adult turkeys (Table 2).

4. Simulation results and discussion

4.1. Stocking rates

Simulation results demonstrated several patterns of model behavior important to understanding wild turkey restoration in east Texas. In general, supplemental stockings were not an effective use of broodstock as initial stockings (Table 3, Fig. 4). Our model predicted stocking strategies 4 and 5 (supplemental stockings) used broodstock least efficiently, with \(R < 1\) for all three survival scenarios. Currently, supplemental stocking is being considered by TPWD biologists as an alternative stocking strategy for the wild turkey restoration program. It appears, however, that releasing turkeys on suitable sites without current populations might be the most efficient use of limited and expensive broodstock.

The original TPWD stocking rate (stocking rate 1) was found to be of adequate size for both the best- and average-case scenarios (high and average survival) (Table 3, Fig. 5). It appeared inadequate, however, for the worst-case (low survival)
scenario simulations. Between 1979 and 1994, this stocking strategy was used by TPWD biologists in attempting to restore wild turkey populations. Although most releases in the Pineywoods and northern Post Oak Savannah were successful, the majority of sites in the central and southern Post Oak Savannah failed (M. J. Peterson, TPWD, unpublished data). This variable success was mirrored by model predictions. Stocking rates 2 (current TPWD stocking strategy) and 3 (‘super-stocking’) were not only suitable for best- and average-case scenarios, but also appeared adequate for the worst-case (low survival) scenario (Table 3). Although super-stocking has been proposed as a restoration strategy in east Texas, this scenario has yet to be evaluated in the field.

4.2. Age class

We found the age of birds released was an important factor in the success of simulated wild turkey releases (Table 3, Fig. 6). The use of juvenile females, or a combination of 50% adult and 50% juvenile females, significantly increased turkey survival whether best-, average-, or worst-case scenarios were simulated. As discussed earlier, TPWD biologists assumed that adult females would have higher survival and attempted to use predominately adult females during restoration efforts. Increasing the proportion of juvenile females in releases not only should increase restoration success, but also should simplify procurement of female birds.

5. Implications for restoration ecology

This paper illustrates that models simulating the dynamics of relocated populations can prove useful to restoration ecologists by evaluating stocking strategies quickly and inexpensively prior to initiating costly restoration programs. In the case of wild turkey restoration efforts in east Texas, the cost of trapping and transporting wild turkeys is greater than $525 per bird. Therefore, evaluating potential stocking strategies with variables known or assumed to be important a priori should decrease the time period required to estab-

![Fig. 5. Mean trajectory of stocking effectiveness (R; total number of birds remaining at the end of 4 years divided by the total number of birds released) for the original TPWD stocking rate (three male adults, 12 female adults) simulated by survival scenario (best, average, and worst case; mean ± 1 S.E.).]
lish turkey populations and costs associated with those efforts. For example, insight into usefulness of restoration strategies in east Texas, such as supplemental stocking or use of juvenile birds, is clearly demonstrated by our analyses. The use of simulation models such as this also quickly identifies areas where further research is needed. We suggest that simulation models of this type should prove useful not only to those attempting to restore galliforme populations, but also to restoration ecologists working with other avian species, mammals, or endangered species.

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