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Estimating Waterfowl Densities in a Flooded Forest: A Comparison of Methods

R. Montague Whiting, Jr.[1,*] and J. Paul Cornes[1,2]

Abstract - During winter, aerial surveys are used to estimate densities of ducks that occupy open-water habitats. However, such surveys are ineffective for sampling forest-dwelling species, especially *Aix sponsa* (Wood Ducks), *Anas platyrhynchos* (Mallards), and *Lophodytes cucullatus* (Hooded Mergansers). We evaluated fixed-radius plot (FRP) and Reynolds and Goodrum variable-radius plot (VRP) methods for estimating waterfowl densities in a flooded hardwood bottomland. We constructed 15 elevated blinds on the Angelina River flood plain in eastern Texas and established a 1-ha FRP around each blind; color-coded markers were placed at fixed intervals from each blind. Observers surveyed waterfowl from blinds for 21 mornings during January–March, 1990. For FRPs, species, sex, and time a bird entered and exited the plot were recorded. For VRPs, similar data and estimated observer-to-bird distance were recorded. Data were arranged in a randomized block design and tested using 1-way analyses of variances. Wood Ducks, Mallards, and Hooded Mergansers comprised 68, 18, and 10% of the birds recorded, respectively. Wood Duck density estimates (per ha) for FRP, Reynolds VRP, and Goodrum VRP methods were 0.65, 0.49, and 1.00 ($P < 0.001$), respectively; for Mallards, estimates were 0.27, 0.20, and 0.33 ($P < 0.001$), respectively; and estimates were 0.09, 0.13, and 0.15 ($P = 0.003$) for Hooded Mergansers, respectively. Based on ease of implementation, complexity of data analyses, and precision of density estimates, the FRP and Goodrum VRP methods are recommended for sampling waterfowl in flooded forests.

Introduction

Biologists have used aerial surveys to estimate waterfowl population sizes since the early 1940s (Henny et al. 1972). Currently, aerial surveys are used to estimate numbers of breeding pairs and breeding habitat conditions in May. Until recently, such surveys were used to estimate waterfowl production in July (United States Fish and Wildlife Service 2006). State wildlife organizations also use aerial surveys to track trends in wintering waterfowl numbers (Mason 2002). Collectively, these data are important in setting annual regulations for waterfowl hunting. Such surveys, however, are of little use in closed-canopy habitats, especially forested wetlands (Conroy et al. 1988, Kirby 1980). As a result, numerous methods have been used in attempts to survey forest-dwelling waterfowl, especially *Aix sponsa* L. (Wood Ducks), but also *Anas platyrhynchos* L. (Mallards) and *Lophodytes cucullatus* A.O.U. (Hooded Mergansers), hereafter collectively referred to as "ducks."

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Biologists have floated streams and rivers counting Wood Duck broods and brood sizes in attempts to estimate annual production (Cottrell and Prince 1990, Minser and Dabney 1973). Most studies suggest that such counts have low potential for predicting production indices (Kirby 1980, Moser and Graber 1990). Such counts are less precise and have higher variation than nesting-season evening roost flight counts (Hein 1966). However, during fall and winter, roost flight counts may yield information on local population abundances (Hester and Quay 1961), but do not provide reliable indices to overall Wood Duck populations or population trends (Hein and Haugen 1966, Parr and Scott 1978).

Densities of wintering Wood Ducks and Mallards have been estimated using plot (Heitmeyer and Fredrickson 1990) and strip-transect methods (Bacon 1990, Sherman et al. 1995). Researchers walked boundaries of 2.02-ha plots and recorded all ducks detected (Heitmeyer and Fredrickson 1990) or walked/waded strip center lines and recorded data appropriate for using the estimator TRANSECT II (Sherman et al. 1995). Although both methods may have potential for estimating waterfowl densities, both are restricted to water depths that can be waded. In fact, there is no satisfactory universal method for estimating densities of Wood Ducks (Bellrose and Holm 1994, Brakhage 1990) and other forest-dwelling ducks (Conroy et al. 1988).

Densities of terrestrial species in forested habitats have been estimated using a variety of methods. Goodrum (1940) developed a variable-radius plot (VRP) method to estimate *Sciurus carolinensis* Gmelin (Gray Squirrel) numbers whereby an observer sits still for a given period of time and notes the location of each squirrel seen. After the specified time, the observer-to-squirrel distances are measured, and the mean of these values is used as a radius to calculate mean uncorrected plot size. The uncorrected plot size is reduced by 25% to compensate for the area that the observer cannot see without moving (Goodrum 1940).

Songbird densities have been estimated using fixed-width (Conner and Dickson 1980) and variable-width (Emlen 1971) transect and fixed-radius plot (FRP) (Fowler and McGinnes 1973, Whiting and Baggett 1988) and VRP methods (Reynolds et al. 1980). The Reynolds method was developed for estimating bird numbers in tall, structurally complex vegetation. Density of a species at a particular blind is determined by constructing a histogram of the number of individuals per unit area in concentric 10.00-m bands around the blind, then determining the radius where density begins to decline. The number of individuals within the circle of that radius is then divided by the area of the circle. Several studies have indicated that this method produces reasonably good density estimates of terrestrial birds in forested habitats (Anderson and Ohmart 1981, DeSante 1981, Edwards et al. 1981).

To date, no known study has used either FRP or VRP methods to estimate densities of Wood Ducks, Mallards, or Hooded Mergansers in flooded forests. Therefore, our objectives were to evaluate FRP and Goodrum and Reynolds VRP sampling methods to estimate densities of these species in such a forest. We also examined changes in estimated densities and sex ratios by species throughout the winter season.

Study Area Description

This study was conducted in the Stephen F. Austin Experimental Forest (SFAEF) in Nacogdoches County, TX. The study area was a 135-ha portion of the 728-ha mature bottomland hardwood forest along the Angelina River within the SFAEF. In the study area, major community types and primary plant species were the *Quercus phellos* L. (Willow Oak) - *Q. nigra* L. (Water Oak) - *Liquidambar styraciflua* L. (American Sweetgum) type on higher flats and lower ridges and the *Q. lyrata* Walt (Overcup Oak) - *Carya aquatica* (Michx. f.) Nutt. (Water Hickory) - *Planera aquatica* J.F. Gmel. (Water Elm) type on lower flats and back swamps (US Fish and Wildlife Service 1985, 1989). A detailed description of the bottomland hardwood forest at the SFAEF can be found in Jones (1987). Soils in the study area are fluvaquents dominated by frequently flooded Mantachie clay loams (fine-loamy, siliceous, acid, thermic fluveric endoaquepts) (Dolezel 1980). A high growth potential for numerous mast-producing hardwood species in combination with seasonal flooding of these soils provides excellent conditions for wintering Mallards and wintering and resident Wood Ducks and Hooded Mergansers.

Methods

We constructed 3 blinds along each of 5 systematically located transects in the study area. The parallel transects were 300 m apart and traversed the study area from north to south; blinds were established at 300-m intervals. Transects were marked with florescent plastic flagging and reflectant tacks for ease of location during predawn hours. Each blind was 2.0 m above the ground in order to be above the normal winter water level. Color-coded markers were placed above the high water line at 30.00-m, 56.42-m, and 90.00-m intervals from each blind; 8 such markers were placed at each interval around each blind. The markers were used to indicate the boundary of the FRP and to aid in estimating observer-to-duck distances (O-D-D) for the VRPs. For the FRP method, each blind was the center of a circular plot with a fixed-radius of 56.42 m and a nominal sampling area of 1.00 ha. For the VRP methods, each blind was the center of 2 variable-size sampling areas.

Sampling waterfowl

Fifty-three observers participated in the study. Before the study began, 38 individuals received training on sampling procedures and bird identification. The 15 individuals that did not receive training prior to the study were given training before conducting sample counts. Five experienced waterfowl observers who agreed to be available for all sample days were appointed as team leaders. On each sample day, 2 observers were assigned to each team leader. During the first 3 sample days, members of each team rotated through the 3 blinds on a line. Thereafter, teams were systematically rotated through all 5 lines such that individuals that participated every sample day conducted counts in every blind once and 6 blinds twice. Counts were conducted under a variety of weather conditions and water levels. Weather conditions ranged from clear and calm to overcast with light rain; counts were not conducted when thunderstorms or heavy rain was predicted. Water levels ranged from flood stage to 1.5 m above flood stage. Usually observers were able to wade to the blinds. When this was not possible, canoes were used and were sunk at or near the blinds. Exposed portions of canoes were covered with camouflage burlap.

Each observation period was 1.5 hours long. The period began 30 minutes before sunrise and ended 1 hour thereafter. Observers remained seated throughout the observation period, but turned to face a different cardinal direction every 12–15 minutes. Data for the FRP and VRP methods were collected simultaneously and recorded on a standardized data sheet (Cornes 1991). Detailed instructions regarding sampling procedures were printed on the back of each data sheet. On each data sheet, the observer's name, observation day (1–21), blind number (1–15), Julian date, and official time of sunrise were recorded. Only ducks on water, on land, or perched in trees were recorded. For each duck, species, sex, and group size were recorded. Binoculars were not used to search for birds; they were used to determine species, numbers, and sex.

For the FRP method, data recorded were time-in and time-out. The time at which a duck was first seen in the fixed sampling area was recorded as time-in, and the time when the duck left the sampling area, could no longer be seen, or the observation period ended was time-out. When there was more than 1 duck in a group, time-in was when the first duck was seen in the fixed sampling area, and time-out was when the last bird of the group left the sampling area, could no longer be seen, or the observation period ended.

For the VRP methods, data recorded were the estimated O-D-Ds (in 5-m increments), direction of the duck from the observation blind, the time the duck was first observed (time-in), and the time the duck was last observed (time-out). Distance and direction were estimated from the blind to the point where the duck was first seen. When there was more than 1 duck in a group, time-in was when the first bird was seen, and the time-out when the last bird of the group could no longer be seen, or the observation period ended. Due to screening vegetation, it was not uncommon for time-in and/or time-out for a duck to be the same for the FRP and VRP sampling methods.

If an individual or group became concealed from view for a brief period (<2 minutes) and then reappeared, time-out was not recorded. However, if the individual or group became concealed for an extended period (>2 minutes) or moved out of the area, then time-out was recorded. Thereafter, ducks that may have re-entered the field of view were treated as a new sighting. Additionally, if several ducks entered a plot as an apparent group and separated while in view, a separate time-out was recorded for each duck or subgroup. If the observation period ended while birds were in view, time-out was recorded as the scheduled ending time of the observation period. Finally, at the end of the observation period, each observer estimated the percent of the FRP effectively seen and the percent of the visible VRP area that was covered by water.

Data analyses

The numbers of ducks recorded on the FRPs and the borderless VRPs were summarized by species and sex within a species for each blind and each sample day. These data were used to contrast and compare the numbers of birds recorded using the FRP and VRP sampling methods. Throughout these analyses, data were analyzed separately for Wood Ducks, Mallards, and Hooded Mergansers.

In order to estimate density, it was necessary to first determine an effective plot size for each method. For the FRP method, the estimated visibility percentages were averaged across all sample days for each blind. The value for each blind then became the proportion of the nominal 1-ha FRP that was the effective sampling area around that blind (Cornes 1991). Values for the 15 blinds were averaged to attain an overall effective sampling area; this value did not differ among species.

For the Reynolds method, the O-D-Ds were used to construct histograms of ducks per ha in 10-m concentric bands around each blind for each species. The outer radius (basal radius) of the band where density began to decline (i.e., inflection point) was then used to calculate the effective circular sampling area around each blind for each species (Cornes 1991); the overall effective sampling area for each species was attained by averaging across blinds. Finally, a weighted effective sampling area was determined for all species combine.

For the Goodrum method, the O-D-Ds for each species were averaged by blind across sample days. The values for each blind were then used as the radii for calculating the effective circular sampling areas around that blind (Cornes 1991). As with the Reynolds method, overall effective sampling areas were calculated by averaging among blinds. Also, as with that method, a weighted effective sampling area was determined with all species combined. Goodrum (1940) recommended a correction factor for unseen portions of the sampling area behind the observer. In this study, observers were well hidden and were able to turn freely in any direction, therefore no correction factor was applied.

In surveying birds using plots, various authors (Bollinger et al. 1988, DeSante 1981, Edwards et al. 1981, Reynolds et al. 1980) used different methods to develop standardized time intervals during which to estimate density. In this study, the standardized time interval was based on the average length of time ducks were in view. For each duck, the difference between time-in and time-out on the FRP and/or the VRP was calculated; values for the 2 VRP methods were identical. For each species and method, the values were averaged by sample day, and then across the entire study period.

The number of time intervals during which to estimate density was determined by dividing the length of the interval into the length of the observation period. Then, using sunrise as a starting point, density estimates were made for each complete time interval prior to and after sunrise. Incomplete time intervals at the beginning and end of the observation period and individuals recorded during those intervals were excluded from analyses.

For each species and method, the mean density for each time interval during each sample day was determined by dividing the number of birds recorded at all blinds during the interval by the product of the overall effective sampling area and the number of blinds occupied. Mean time-interval densities per sample day were determined by averaging time intervals. Finally, mean time-interval densities for the entire study period were determined by averaging across sample days. Coefficients of variation and standard errors were computed for each density estimate. Community density estimates were also determined for each method by combining overall mean density estimates among species.

Nine of the 53 observers participated in 13 or more sample-counts. Data collected by those 9 observers were used to evaluate observer differences in mean: 1) numbers of ducks recorded per day using each method; 2) estimated O-D-Ds on the VRPs; and, 3) estimated visibility percentages on the FRPs. For the first 2 comparisons, the data were pooled for the 3 species. Additionally, mean estimated O-D-Ds were compared among species using data collected by all 53 observers. Likewise, mean FRP visibility estimates were compared among all observers. Finally, changes in average visibility across sample days were evaluated using data from all blinds.

Statistical analyses

For each method, data were tested to determine if differences in numbers of ducks, effective sampling areas, lengths of times ducks were in view, and densities existed among species. Within a species, the same differences were evaluated among methods. Data were also tested to determine if differences existed in densities among time intervals, numbers of ducks recorded among selected observers, sex ratios among 10-m concentric bands around the blinds, and sex ratios and densities among sample days.

For comparisons among methods, species, and time intervals, data were arranged in a randomized block design and examined using 1-way analysis of variance tests (SAS Institute, Cary, NC 1982). Sample days were blocks, and methods, species, observers, and time intervals were treatments in these analyses. For comparisons among sample days and selected observers, data were arranged in a completely randomized design and tested using analysis of variance techniques. For comparisons among sample days, sample day was the grouping variable and sex ratios, densities, and FRP visibility percentages were dependent variables. For comparisons among observers, observer was the grouping variable and duck numbers, FRP visibility percentages, and O-D-Ds were the dependent variables. For comparisons of sex ratios among 10-m bands, data were evaluated using the chi-square test of homogeneity with Pearson's likelihood ratio. Finally, simple linear regression was used to determine if FRP visibility percentages exhibited a linear trend across sample days.

For all comparisons, the null hypothesis was that no differences existed among treatments or grouping variables ($\alpha = 0.05$). When the null hypothesis was rejected, the Tukey W-procedure was used to determine which treatment means were different.

Results

Sample counts

During the 27 January–22 March 1990 study period, 295 sample counts (i.e., observers in blinds) were conducted on 21 sample days. Twenty scheduled counts were not conducted due to observer absence. Blinds not occupied because of observer absence usually were those in close proximity to water edge. Two counts were not used because of observer error, thus the 293 valid counts averaged slightly less than 14 sample counts per sample day.

During the sample counts, 1127 ducks comprising 6 species were recorded within the borders of the FRP (Cornes 1991). Wood Ducks were the most common species, comprising over 68% of the individuals recorded. Mallards (18%) and Hooded Merganser (10%) ranked second and third, respectively. The remaining 4% was made up of individuals classified as unknown or other (4 *Mergus merganser* L. [Common Mergansers]; 2 *Anas acuta* L. [Northern Pintails]; 2 *A. crecca* L. [Green-winged Teal]). For Wood Ducks, Mallards, and Hooded Mergansers, males exceeded females by 47% (478:252, $P <$ 0.001), 64% (127:46, $P = 0.001$), and 27% (63:46, $P = 0.003$), respectively (Cornes 1991). However, there were no differences in the proportions of males to females among sample days (Wood Ducks, $P = 0.673$; Mallards, $P = 0.539$; Hooded Mergansers, $P = 0.416$).

Within the borderless VRPs, 1375 individuals of the same 6 species were recorded. Higher numbers of Wood Ducks ($P < 0.001$), Mallards ($P <$ 0.001), and Hooded Mergansers ($P = 0.009$) were recorded on the VRPs (Wood Ducks: mean ± SE = 43.52/day ± 4.91; Mallards: 12.95/day ± 1.30; Hooded Mergansers: 6.28/day ± 1.21) than on the FRPs (Wood Ducks: 36.43/day ± 3.88; Mallards: 9.86/day ± 1.08; Hooded Mergansers: 5.28/day ± 1.15). Again, Wood Ducks were most common (66%), followed by Mallards (20%) and Hooded Mergansers (10%); the remaining 4% were classified as other or unknown. As with the FRPs, male Wood Ducks exceeded females by 47% (563:298; $P < 0.001$); however, male Mallards exceeded females by only 43% (168:98, $P < 0.001$) whereas male Hooded Merganser exceeded females by 33% (78:52, $P = 0.001$). As with the FRPs, the proportions of males to females among sample days were not different (Wood Ducks, $P = 0.100$; Mallards, $P = 0.183$; Hooded Mergansers, $P =$ 0.604). Likewise, there were no differences in sex ratios among 10-m concentric bands around blinds (Wood Ducks, $P = 0.541$; Mallards, $P = 0.641$; Hooded Mergansers, $P = 0.719$).

Density

For the FRP method, visibility values ranged from 20–100% among observers and from 42–87% among blinds. Among blinds, the mean was 60.0%, thus, the overall effective sampling area used to estimate density for each species was 0.60 ha. For the Reynolds method, basal radii for Wood Ducks, Mallards, and Hooded Mergansers ranged from 20–85 m (mean = 56.3 m), 30–90 m (mean = 58.2 m), and 15–60 m (mean = 40.7 m), respectively, among blinds (Cornes 1991). The resulting effective sampling areas of Wood Ducks and Mallards were larger than that of Hooded Mergansers (Table 1). Mean O-D-Ds by blind for the Goodrum method ranged from 28–55 m (mean = 40.8 m) for Wood Ducks, 35–77 m (mean = 45.4 m) for Mallards, and 10–53 m (mean = 38.2 m) for Hooded Mergansers; effective sampling areas did not differ among species (Table 1). The Reynolds method provided larger sampling areas than the FRP and Goodrum methods for Wood Ducks and Mallards, but not Hooded Mergansers. With species pooled, weighted means for the Reynolds and Goodrum methods were 0.93 ha and 0.57 ha; differences in these values were not examined.

Average lengths of times that Wood Ducks, Mallards, and Hooded Mergansers were visible on the FRPs were shorter than those on the VRPs by 20, 5, and 7%, respectively. Within a species, the greatest difference between the FRP and VRP methods was slightly over 1.50 minutes (i.e., Wood Ducks), while the smallest difference was slightly over 0.50 minutes (i.e., Hooded Mergansers). Mean visible times did not differ between methods for any species.

Mallards were visible for longer periods of time than were the other 2 species. Visible times for Mallards on FRPs and VRPs exceeded those of Wood Ducks and Hooded Mergansers by 83% and 93%, respectively, and by 55% and 89%, respectively. Although Wood Ducks were visible 5% and 22% longer than Hooded Mergansers on the FRPs and the VRPs, respectively, visible times did not differ. After rounding, 3 of the 6 mean times

Table 1. The effective sampling areas (ha) for Wood Ducks, Mallards, and Hooded Mergansers as estimated using the fixed radius plot (FRP) and the Reynolds et al. (1980) and the Goodrum (1940) variable radius plot (VRP) methods. Also included are the mean time that each species was visible (minutes) on the plots. Within rows, means followed by different superscript letter are significantly different at $\alpha = 0.05$. Within columns, means followed by a different superscript numeral are significantly different at $\alpha = 0.05$.

		Area				Time		
Species		Fixed	Reynolds	Goodrum	*P* - value	FRP	VRP	*P* - value
Wood Duck	Mean	0.60^{A}	1.09^{B1}	0.53^{A}	<0.001	7.27^{1}	9.09^{1}	0.05
	SD	0.19	0.61	0.81		7.06	10.31	
Mallard	Mean	0.60^{A}	1.14^{B1}	0.69^{A}	0.001	13.34^{2}	14.09^{2}	0.72
	SD	0.19	0.32	0.40		16.35	16.34	
Hooded Merganser	Mean	0.60	0.57^{2}	0.50	0.46	6.90^{1}	7.43^{1}	0.16
	SD	0.19	0.32	0.27		6.88	6.96	
Weighted mean		0.60	0.93	0.57				
P - value			0.002	0.177		0.01	0.01	

were 7 minutes, thus, 7 minutes was used as the standardized time interval. This standardization provided 12 complete time intervals per sample-day, 4 before sunrise and 8 after sunrise.

For the FRP, Reynolds, and Goodrum methods, 1039, 1023, and 1251 individuals were used in density estimates, respectively. Excluded from each method were 44 ducks classified as other or unknown and 44 individuals recorded during incomplete time intervals. Additionally, for the VRP methods, 13 unknown ducks and 23 with incomplete time intervals were excluded. For the Reynolds method, 228 individuals outside the designated basal radii were excluded. Wood Duck, Mallard, and Hooded Merganser species compositions were 736, 195, and 108, respectively, for the FRP method, 703, 213, and 107, respectively, for the Reynolds method, and 860, 261, and 130, respectively, for the Goodrum method.

For Wood Ducks and Mallards, density estimates differed among methods, with the Goodrum method providing the highest values and the Reynolds method the lowest (range: Wood Ducks, 0.49–1.00 birds/ha; Mallards, 0.20–0.33 birds/ha; Table 2). For Hooded Merganser, density estimates ranged from 0.09–0.15 birds per ha. In contrast to Wood Ducks and Mallards, the Goodrum estimate for Hooded Mergansers was similar to that of the Reynolds method, and both estimates were higher than that of the FRP method. For all 3 sampling methods, estimated densities of Wood Ducks

Table 2. Mean densities (per ha), sampling errors (SE), coefficient of variation percentages (CV%), and sampling error percentages (SE%) of Wood Ducks, Mallards, and Hooded Mergansers as estimated using fixed radius plot (FRP) and Reynolds et al. (1980) and Goodrum (1940) variable radius plot (VRP) methods, Nacogdoches County, TX, winter 1990. Within rows, means followed by a different superscript letter were significantly different at $\alpha = 0.05$. Within columns, means followed by a different superscript numeral are significantly different at $\alpha = 0.05$

		VRP		
Variable	FRP	Reynolds	Goodrum	*P* - value
Wood Ducks				
Density	0.65^{A1}	0.49^{B1}	1.00^{C1}	<0.001
SE	0.13	0.10	0.20	-
CV %	73.23	72.32	70.34	-
SE %	20.00	21.74	20.00	-
Mallards				
Density	0.27^{A2}	0.20^{B2}	0.33^{C2}	<0.001
SE	0.14	0.04	0.07	-
CV %	98.03	81.29	82.76	-
SE %	51.85	30.77	21.21	-
Hooded Mergansers				
Density	0.09^{A2}	0.13^{B2}	0.15^{B2}	0.003
SE	0.03	0.05	0.05	-
CV %	112.63	103.64	102.16	-
SE %	33.33	30.77	33.33	-
All Species				
Density	1.01	0.79	1.48	-
P - value	<0.001	<0.001	<0.001	-

were higher than those of Mallards or Hooded Mergansers. Although Mallards density estimates were >50% higher than those of Hooded Mergansers, they were not significantly different.

Mean time-interval densities were generally lower for intervals prior to sunrise than thereafter, and were significantly lower for the first interval in every case (Cornes 1991). Likewise, mean time-interval densities differed among sample-days, and ranged from 0.14–2.00, 0.00–0.66, and 0.00–0.49 for Wood Ducks, Mallards, and Hooded Mergansers, respectively. Sample-days in March consistently ranked in the lower 1/3 of the density estimates (Cornes 1991).

Average numbers of ducks recorded on FRPs by the 9 selected observers ranged from 2.65–8.00 per day ($P = 0.021$; Cornes 1991). On VRPs, average numbers ranged from 2.52–8.29 ducks per day ($P = 0.076$; Cornes 1991). For the selected observers, mean O-D-Ds on the VRPs were similar ($P = 0.166$, range = 34.1–47.7 m). For all observers, mean O-D-Ds were 42.7 m, 46.3 m, and 41.6 m for Wood Ducks, Mallards, and Hooded Mergansers, respectively ($P = 0.108$). On FRPs, average estimated visibilities by selected observers did not differ significantly ($P = 0.055$), and ranged from 47.8–67.1% (Cornes 1991). For all observers, mean visibility estimates ranged from 53.0–70.0% ($P = 0.364$). Finally, regression of percent visible estimates across sample-days indicated that estimates decreased as the study progressed ($P < 0.001$, $R = 0.882$; Cornes 1991).

Discussion

Assumptions

Validity of our density estimates was based on 5 assumptions (Reynolds et al. 1980, Roeder et al. 1987). First, all ducks had an equal likelihood of occurring anywhere in the habitat. Due to interspecific differences in habitat selection and variation in the extent and duration of overbank flooding in the 728-ha SFAEF bottomland, this assumption may not have been met and our density estimates may not be applicable for the entire area. However, in our 135-ha study area, blinds were located systematically across topography in order to provide a representative sample of areas of varying vegetative densities and water depths, and we are confident that the assumption was met.

Second, length of sample-count interval was long enough to record all visible ducks and short enough that duck locations were essentially fixed. This assumption could have been violated if ducks were counted at 2 blinds or more than once from the same blind during the same time interval. Our blinds were spaced sufficiently far enough apart (300 m) and time intervals were short enough (7 minutes) that the probability of recording a duck at more than 1 blind during a time interval was minimal. Although large numbers of ducks in the vicinity of the blinds could have resulted in the same duck being counted more than once, the average number of ducks per observer per sample-day was low (<8.3). A duck that exited a plot and later reappeared had to be out of sight for at least 2 minutes to be considered a new sighting. Thus, the window for counting such a duck twice was less than 5 minutes. For these reasons, it is unlikely that this assumption was violated and that multiple counting occurred.

Third, all observers were equal in their ability to see and identify birds, and fourth no distance estimation errors were made. Our data suggest that these assumptions may not have been met. For them to be valid, physical factors (e.g., visual acuity, peripheral vision, color sensitivity), psychological factors (e.g., concentration, motivation, alertness), and ability must be equal among observers (Kepler and Scott 1981). Due to unforeseen circumstances, we had to use many more observers than originally planned. While the original 38 observers were trained in duck identification and distance estimation, the other 15 received only cursory training. More importantly, some observers were dedicated waterfowl hunters whereas others had spent little time in wetland habitats. Undoubtedly, observers differed in their ability as well as their physical and psychological characteristics. Violations of these assumptions probably resulted in density estimates that were lower than the true values. These problems could be minimized if observers were well trained and experienced in the methodology (Kepler and Scott 1981).

Fifth, there were no observer effects (Bollinger et al. 1988). Observers entered blinds 15–30 minutes prior to the beginning of the observation period, and most ducks roosted elsewhere and flew into the study area after daylight. Likewise, there was no evidence that observers in blinds or sunken canoes disturbed the ducks. Numerous ducks of each species were recorded within 10 m of a blind, and on several occasions, ducks swam under an occupied blind or across a sunken canoe. Therefore, bias due to observer effects should have been minimal.

Density

The Goodrum method resulted in the smallest plot sizes and the highest numbers of ducks, thus the highest density estimates. Goodrum mean O-D-Ds were shorter than either the FRP effective radius or the Reynolds basal radii, thus Goodrum sampling areas were smallest. Likewise, with that method, all identified ducks were used in density calculations whereas ducks outside the FRPs and the basal radii of the Reynolds VRPs were excluded.

For Wood Ducks and Mallards, Reynolds density estimates were lower than FRP or Goodrum estimates. Reynolds et al. (1980) established basal radii around each blind for each species; we did likewise. However, we recorded so few ducks around some blinds on some sample days (range: Wood Ducks 0–25, mean = 2.90; Mallards 0–10, mean = 0.86; Hooded Mergansers 0–8, mean = 0.42; Cornes 1991) that determining the inflection point was difficult at best. In retrospect, we should have pooled among blinds and used a single basal radius for each species.

Studies of songbirds in forested habitats have suggested that the FRP method may fail to account for detectability differences among species (Reynolds et al. 1980), and VRP methods may produce underestimates of density (Conner et al. 1983, DeSante 1981) due to bird inconspicuousness

(Bollinger 1998). In our study, proportions of Wood Ducks, Mallards, and Hooded Mergansers recorded using the FRP method were similar to those recorded using VRP methods. Likewise, although females of each species are less colorful than males, sex ratios of Wood Ducks and Hooded Mergansers were similar between plot types, and higher proportions of female than male Mallards were recorded on the borderless VRPs than on the FRPs. These results suggest that adjusting the sampling areas of the FRPs based on the percentages of the plots visible compensated for detectability differences among species and that population characteristics of the 3 species can be satisfactorily determined using either FRP or VRP methods.

Disregarding the percent of dry land on the FRPs and VRPs may have led to density underestimates using all 3 methods. The mean percent of dry land in the visible sampling area of the VRPs averaged 18%. Since no ducks were recorded on dry land, it is likely that the effective sampling areas were overestimated, thus density was underestimated. To improve density estimates, dry land area should be excluded when calculating effective sampling areas.

Variation in densities among sample-days was probably a result of waterfowl emigration and immigration and vegetation changes (i.e., increased foliage). After sample-day 16 (2 March 1990), densities of Wood Ducks and Hooded Mergansers were dramatically reduced; Mallard densities remained relatively high throughout the study period, however (Cornes 1991). Although changes in vegetation associated with spring leaf-out reduced visibility, factors such as breeding activity, migration, and increased proportions of dry land area may have also contributed to lower densities of Wood Ducks and Hooded Mergansers during the late winter.

Our coefficients of variation and sampling errors were much higher than those of other authors. As suggested by Conroy et al. (1988), Heitmeyer and Fredrickson (1990) used a coefficient of variation of ≤ 0.13 as a desirable level of precision. In our study, the lowest coefficient of variation was 0.70, considerably higher than the suggested level. Sampling errors that were considered acceptable in the Heitmeyer and Fredrickson (1990) study ranged from 3 to 15%. Again, the lowest estimate in our study (20%) was higher than their suggested level. Reasons for our high coefficients of variation and sampling errors are probably related to a number of factors, including differences in observer ability and water depth in the study area, which fluctuated by as much as 1.5 m during the study, and the extended sampling period. Also, total numbers of ducks recorded per blind varied widely (range: 7–184, mean = 91.7) as did numbers per sample day (range: 15–107, mean = 53.6). The coefficients of variation and sampling errors could probably be greatly reduced by using well-trained observers, a sampling period much shorter than ours, and sample days without rain or fog.

Sex ratios

Bellrose (1976) reported that the male to female ratios of wintering Wood Ducks and Mallards were relatively balanced with 12–15% more males. Heitmeyer and Fredrickson (1990) reported similar proportions for Wood

Ducks. In our study, the proportions of males to females for both species were considerably higher. Some researchers attribute such differences to weather factors. Alford and Bolen (1977) found that the percentage of male Northern Pintails increased as ambient temperature decreased. They stated that similar trends may be true for other waterfowl species that lack life-long pair bonds. It is possible that extreme cold prior to this study may have driven females further south.

Better visibility during fair weather could have increased the detectability of males, thus increasing the proportion of males counted. However, since there was no difference in the proportions of males across sample-days, weather-related visibility was probably not a problem. The drab plumage of females could have decreased their detectability, resulting in undercounting of this segment of the population. The higher proportion of female Mallards recorded on the VRPs than on the FRPs (Table 1) and the fact that we found no differences in sex ratios among bands on the VRPs suggests that the detectability of females was not a problem. In fact, the proportions of male and female Wood Ducks and Mallards could be characteristic of wintering populations in eastern Texas. This study and a subsequent time-budget study that utilized the same blinds the following year had similar proportions (Clark and Whiting 1994). Variation between sexes may be characteristic of the region and not a result of the above-mentioned factors.

Bellrose (1976) reported that Hooded Mergansers have 30% more males than females. In this study, the proportions of male Hooded Mergansers recorded on the FRPs and the VRPs (Table 1) were similar to that of Bellrose (1976). This result suggests that the gender differences we recorded are characteristic for this species.

Recommendations

Our results indicate that the FRP and VRP methods can be used to sample waterfowl in flooded bottomland hardwood forests. Observation blinds are required for all 3 sampling methods. In relatively small areas, blinds should be placed systematically across topography to provide a representative sample of areas of varying vegetation density and water depth. In large areas, it may be necessary to place blinds at random locations. Blinds should be far enough apart and the time intervals short enough that it is unlikely that ducks would be recorded at more than 1 blind during an interval. Blinds could be placed at intervals greater than 300 m, but probably no closer. Our 7-minute time interval seemed to work well for estimation of densities using all 3 methods. Even with a relatively large number of ducks within the visible sampling area, keeping track of which duck had been counted was not a problem. Increasing the length of the interval would increase the probability of counting individuals more than once at a blind during an interval. Shortening the interval may result in undercounting of visible ducks. Counts should be restricted to the winter season prior to spring leaf-out and during periods of suitable weather and water conditions.

For both the FRP and VRP methods, establishing distance markers are essential. However, VRP methods require more markers and markers farther from the blind than the FRP method; markers may be difficult to place in areas of dense vegetation. For the FRP method, data collection does not require estimating O-D-Ds, and thus is easier (Reynolds et al. 1980). Calculating density estimates for the FRP and Goodrum methods are both relatively simple procedures. Conversely, calculating such estimates for the Reynolds method is relatively complex. Also, to be appropriate for surveying ducks in flooded forests, basal radii calculations would need to be modified. For these reasons, we believe that the FRP and Goodrum VRP methods are best suited for estimating duck numbers in flooded forests.

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