

**Examining Detection Probabilities in Waterfowl Pair and  
Brood Surveys in Northeastern North Dakota**

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Anthony M. Pagano

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Major Advisor: Todd W. Arnold, Ph.D.

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## Abstract

Recently, there has been extensive criticism of traditional wildlife surveys because they fail to take detection probabilities into account. Current methods for conducting ground-based waterfowl pair and brood surveys follow the assumption that detection probabilities are close to 1 or, at the very least, that they are consistent among observers, environments, and species. To test this assumption, I used an independent double-observer method to examine detection probabilities in ground-based pair surveys and a multiple sampling mark-recapture approach to examine sightability bias in ground-based brood surveys. Sightability in waterfowl pair and brood counts varied considerably among observers and species. A more experienced observer had higher pair sightability (91%) than a novice observer with only 1 week of training (79%). Brood sightability was highest for diving ducks (57%) and lowest for mallards (32%) and blue-winged teal (31%). Pair sightability was also influenced by wetland size, duck density, precipitation, and time of day, but not by survey type (roadside vs. walk-up), whereas brood sightability was also influenced by time of day, duckling density, date, and wind speed, but not by brood age or survey type. Based on these results, I derived brood-to-pair ratios adjusted for sightability-bias as well as estimates similar to traditional uncorrected counts. I found brood-to-pair ratios explained 10 – 60% of the variation in nesting success among 8 study sites, but estimates of productivity were dramatically higher in sightability-adjusted estimates compared to uncorrected counts. My results show that traditional ground-based duck surveys that fail to account for detection probabilities result in dramatic underestimates of population size, especially for broods.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	i
ABSTRACT.....	iii
LIST OF TABLES.....	vii
LIST OF FIGURES.....	ix
 CHAPTER 1: ESTIMATING DETECTION PROBABILITIES IN WATERFOWL PAIR COUNTS USING AN INDEPENDENT DOUBLE-OBSERVER APPROACH...1	
INTRODUCTION.....	1
STUDY AREA.....	5
METHODS.....	6
Assumptions.....	6
Walk-up Surveys.....	6
Roadside Surveys.....	8
Data Analysis.....	9
RESULTS.....	13
DISCUSSION.....	16
Evaluation of Assumptions.....	18
MANAGEMENT IMPLICATIONS.....	20
TABLES.....	22
FIGURES.....	29
 CHAPTER 2: ESTIMATING SIGHTABILITY OF WATERFOWL BROODS USING ROADSIDE AND WALK-UP SURVEYS.....36	

	v
INTRODUCTION.....	36
STUDY AREA.....	39
METHODS.....	39
Assumptions of Closed-population Mark-recapture Models.....	39
Walk-up Surveys.....	40
Roadside Surveys.....	42
Data Analysis.....	42
RESULTS.....	46
DISCUSSION.....	48
Evaluation of Assumptions.....	52
MANAGEMENT IMPLICATIONS.....	54
TABLES.....	56
FIGURES.....	62
 CHAPTER 3: THE USE OF SIGHTABILITY-ADJUSTED BROOD-PAIR RATIOS TO	
ESTIMATE WATERFOWL PRODUCTIVITY.....	68
INTRODUCTION.....	68
STUDY AREA.....	70
METHODS.....	71
Brood-to-Pair Ratios.....	71
Nesting Success.....	73
RESULTS.....	73
DISCUSSION.....	74
MANAGEMENT IMPLICATIONS.....	77

	vi
TABLES.....	78
FIGURES.....	81
LITERATURE CITED.....	85

## LIST OF TABLES

### Chapter 1

Table 1.1. Explanatory variables used in the analysis of indicated breeding pairs (IBP) examining waterfowl sightability in northeastern North Dakota, USA, 2006 .....	22
Table 1.2. Competing sightability models ranked according to $\Delta AIC_c$ values calculated in Program MARK for the analysis of indicated breeding pairs (IBP) and combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) analysis of waterfowl sightability in northeastern North Dakota, USA, 2006 ....	23
Table 1.3. Competing sightability models ranked according to $\Delta AIC_c$ values calculated in Program MARK for the indicated breeding pairs (IBP) analysis of waterfowl sightability in northeastern North Dakota, USA, 2006 .....	24
Table 1.4. Beta estimates calculated in Program MARK based on the best-supported model from the indicated breeding pairs (IBP) analysis examining waterfowl sightability in northeastern North Dakota, USA, 2006 .....	25
Table 1.5. Competing sightability models ranked according to $\Delta AIC_c$ values calculated in Program MARK for the combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) analysis of waterfowl sightability in northeastern North Dakota, USA, 2006 .....	26
Table 1.6. Sightability estimates calculated in Program MARK for each species and each observer based on the best-supported model from the indicated breeding pairs (IBP) analyses of waterfowl sightability in northeastern North Dakota, USA, 2006 .....	27
Table 1.7. Abundance of indicated breeding pairs (IBP) using standard single-observer pair survey methods and sightability-adjusted estimates based on the best-supported model examining waterfowl sightability in northeastern North Dakota, USA, 2006 .....	28

### Chapter 2

Table 2.1. Explanatory variables used in the analyses of waterfowl brood sightability in northeastern North Dakota, USA, 2006 .....	56
Table 2.2. Univariate analyses in which competing sightability models were ranked according to $\Delta AIC_c$ in Program MARK for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006 ..	57

Table 2.3. Multivariate analyses in which competing sightability models were ranked according to $\Delta AIC_c$ values calculated in Program MARK for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006 .....	58
Table 2.4. Competing sightability models ranked according to $\Delta AIC_c$ values calculated in Program MARK for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006 .....	59
Table 2.5. Beta estimates calculated in Program MARK based on the best-supported model for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006 .....	60
Table 2.6. Abundance estimates of waterfowl broods surveyed in northeastern North Dakota, USA, 2006 .....	61
<b>Chapter 3</b>	
Table 3.1. Nesting success and brood-to-pair ratio estimates for upland-nesting waterfowl species combined consisting of mallards, blue-winged teal, northern shovelers, northern pintails, and gadwalls from 8 study sites in northeastern North Dakota, USA, 2006 .....	78
Table 3.2. Nesting success, single-occasion brood-to-pair ratio, and sightability-adjusted brood-to-pair ratio estimates for mallards, blue-winged teal, and gadwalls from 8 study sites in northeastern North Dakota, USA, 2006 .....	79
Table 3.3. Pearson correlations between estimates of Mayfield nesting success and brood-to-pair ratio estimates from single-occasion and sightability-adjusted estimates from 8 study sites in northeastern North Dakota, USA, 2006 .....	80

## LIST OF FIGURES

### Chapter 1

- Fig. 1.1. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of the total number of individual ducks recorded per wetland. Based on results examining waterfowl sightability from ducks surveyed in northeastern North Dakota, USA, 2006 .....29
- Fig. 1.2. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based the best-supported model for each observer over all species illustrating the additive effect of wetland size. Based on results examining waterfowl sightability from ducks surveyed in northeastern North Dakota, USA, 2006 .....30
- Fig. 1.3. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of light rain. Based on results examining waterfowl sightability for ducks surveyed in northeastern North Dakota, USA, 2006 .....31
- Fig. 1.4. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of social grouping. Based on results examining waterfowl sightability for ducks surveyed in northeastern North Dakota, USA, 2006 .....32
- Fig. 1.5. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based the best-supported model for each observer over all species illustrating the additive effect of time of the survey. Based on results examining waterfowl sightability from ducks surveyed in northeastern North Dakota, USA, 2006 .....33
- Fig. 1.6. Sightability estimates from the combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of sex of the individual recorded. Based on results examining waterfowl sightability for ducks surveyed in northeastern North Dakota, USA, 2006 .....34
- Fig. 1.7. Sightability estimates for each observer and species based on the best-supported model from the indicated breeding pairs (IBP) analysis calculated in Program MARK with all other explanatory variables set to their mean, from waterfowl surveyed in northeastern North Dakota, USA, 2006 .....35

## Chapter 2

- Fig. 2.1. Waterfowl brood sightability estimates over all species illustrating the additive effect of the total number of ducklings recorded per wetland based on the best-supported model calculated in Program MARK. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006 .....62
- Fig. 2.2. Waterfowl brood sightability estimates over all species illustrating the additive effect of brood size based on the best-supported model calculated in Program MARK. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006 .....63
- Fig. 2.3. Waterfowl brood sightability estimates over all species illustrating the additive effect of mean wind speed (km/h) over the 3 replicates based on the best-supported model calculated in Program MARK. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006 .....64
- Fig. 2.4. Waterfowl brood sightability estimates over all species illustrating the additive effect of date the survey was conducted based on the best-supported model calculated in Program MARK. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006 .....65
- Fig. 2.5. Waterfowl brood sightability estimates over all species illustrating the additive effect of percent tall emergent vegetation surrounding the wetland perimeter based on the best-supported model calculated in Program MARK. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006 .....66
- Fig. 2.6. Waterfowl brood sightability estimates for each replicate and each species based on the best-supported model calculated in Program MARK. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006 .....67

## Chapter 3

- Fig. 3.1. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for combined mallards, blue-winged teal, northern shovelers, northern pintails, and gadwalls from 8 study sites in northeastern North Dakota, USA, 2006 .....81
- Fig. 3.2. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for mallards from 8 study sites in northeastern North Dakota, USA, 2006 .....82

Fig. 3.3. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for blue-winged teal from 8 study sites in northeastern North Dakota, USA, 2006 .....83

Fig. 3.4. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for gadwall from 8 study sites in northeastern North Dakota, USA, 2006 .....84

## **Chapter 1. Estimating Detection Probabilities in Waterfowl Pair Counts Using an Independent Double-Observer Approach**

### **Introduction**

Wildlife population counts are typically conducted utilizing standardized methods to minimize differences in detection probabilities among surveys. An implicit assumption in this approach is that detection probabilities are consistent and approach unity (Anderson 2001, 2003; White 2005). However, conducting wildlife surveys without taking into account detection probabilities has recently come under intense scrutiny (Nichols et al. 2000; Anderson 2001, 2003; Rosenstock et al. 2002; Thompson 2002; but see Bart et al. 2004). Anderson (2001) described 3 sources of variation in detectability. First, differences among observers in their experience, training, fatigue, attitude, and other factors can affect detectability. Second, environmental factors such as weather, vegetation, and sunlight can affect detectability over different sampling occasions. And finally, behavior, size, conspicuousness, and other characteristics of the surveyed organisms can affect detectability among species or among individuals. Because detection can be affected by such a large number of factors, detectability is unlikely to be consistent among samples (Anderson 2001). In fact, Anderson (2003:288) argued that without a quantitative estimate of detectability, counts of animals are “feckless,” whereas White (2005:211) stated, “These uses of uncorrected counts are some of the most perilous uses of an index in the practice of wildlife management because this assumption of proportionality is seldom verified, and is often false.” At the very least,

the onus of demonstrating that detection rates are consistent would seem to fall on those employing the population index (MacKenzie and Kendall 2002).

A number of statistical methods have been developed for estimating detectability. These include double-sampling (Bart and Earnst 2002), distance-sampling (Rosenstock et al. 2002), removal methods (Farnsworth et al. 2002), the double-observer method (Nichols et al. 2000), and various other mark-recapture approaches. Double-sampling requires an ability to conduct complete counts for comparison with incomplete counts (Bart and Earnst 2002). The North American air-ground breeding population surveys for waterfowl (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1987) are treated as such a survey, with aerial surveys representing incomplete counts and ground-based surveys representing complete counts that are used to estimate visibility correction factors. However, the assumption of complete detectability on ground transects is questionable. Distance sampling requires the ability to measure observed distances from a point or transect line to the objects being surveyed (Rosenstock et al. 2002). Detectability is presumed to be 100% along the point or transect line and to decline monotonically as distance from the point or line increases. Removal methods (Farnsworth et al. 2002) break a long observation period into several smaller intervals and examine the rate at which new individuals are acquired through time, allowing estimation of the proportion of individuals that are never acquired. The double-observer approach utilizes 2 concurrent observers and estimates each observer's probability of detecting an animal, given that the animal is present and conspicuous during the survey (Nichols et al. 2000, Moore et al. 2004, Alldredge et al. 2006). Other closed-population mark-recapture approaches can be utilized with 2 or more independent observers, or 2 or

more sequential observation periods (Moore et al. 2004, Alldredge et al. 2006); the double-observer method is a specialized example of these approaches.

The double-observer approach, developed by Nichols et al. (2000), is a modification of a technique used originally by Cook and Jacobson (1979) to estimate bias in aerial surveys of big game mammals. It uses multiple observers as a means of measuring detectability. Nichols et al. (2000) describe how detectability estimation can help improve abundance estimates:  $\hat{N} = \frac{C}{\hat{p}}$ , where C represents the apparent count,  $\hat{p}$  is the estimated probability of detection, and  $\hat{N}$  is an estimate of true abundance. In specialized cases where  $p = 1$  the survey can be considered a true population estimate or census (Lancia et al. 1994, Nichols et al. 2000).

For the independent double-observer approach, 2 observers independently and simultaneously conduct surveys, allowing for the use of closed-population capture-recapture models (Nichols et al. 2000, Moore et al. 2004, Alldredge et al. 2006). Differences in observations can be determined and a detection probability can be calculated for each observer. Thus, one can adjust counts by quantifying factors that influence detection such as variation among observers, environmental conditions, and attributes of the surveyed organisms (Nichols et al. 2000, Moore et al. 2004). However, a drawback to the double-observer approach is that it estimates only the apparent population, defined as those individuals that vocalize or move out into the open and are therefore available to be detected (Moore et al. 2004, Fletcher and Hutto 2006). It cannot account for inconspicuous individuals or secretive species that have zero probability of being detected by either observer (Moore et al. 2004). Nevertheless, the double-observer

approach has been shown to provide less biased estimates of abundance than single-observer counts, and typically does not require dramatic changes in field methodologies (Nichols et al. 2000, Moore et al. 2004, Fletcher and Hutto 2006).

Concern with the accuracy of waterfowl pair counts is not new. Diem and Lu (1960) and Dzubin (1969) discussed the need for greater repetition, experienced surveyors, and for taking into account environmental biases. In particular, Dzubin (1969:223) stated that the census-takers themselves were influential in the results of the census and, as such, described waterfowl censusing as “highly subjective.” Although Dzubin’s recommendations have led to a standardization of techniques, costs and feasibility have restricted abilities to heed all of his proposals in ensuring the accuracy of waterfowl surveys (Cowardin and Blohm 1992).

Standard waterfowl pair-count methodology involves a single observer who records the number and identity of waterfowl observed within a given sample area (e.g., an entire 64 ha plot or a 200-m-wide belt transect along a roadway; e.g., Dzubin 1969, Hammond 1969). Observations from small-scale sample areas are used to estimate breeding populations on larger scales. Pair-counts are assumed to enumerate close to 100% of the breeding pairs present. Even if this assumption is not met, it is presumed that detectability of pairs does not differ among observers, among duck species, time periods, or across habitat types, so that data at least function as consistent-proportion indices of abundance (Anderson 2001). To help achieve this goal, standardized counting methods are employed (Dzubin 1969). This allows for an assumption that detectability remains consistent throughout counts, even if it is  $<1$ .

I utilized an independent double-observer approach to test the reliability of these assumptions. My main objective was to determine if detection probabilities for ground-based waterfowl pair surveys were essentially 100%. If not, did they vary among observers, habitats, or species? In addition, I examined the efficacy of incorporating an independent double-observer approach into standard ground-based pair count methodologies. If I observed high detection probabilities in my study, it could help validate current methodologies for conducting breeding waterfowl surveys. If not, the methodology developed in my study could help provide a means of obtaining visibility-adjusted counts.

### **Study Area**

I conducted my study in 2006, in the Devils Lake Wetland Management District of northeastern North Dakota within Benson, Cavalier, Nelson, Ramsey, Towner, and Walsh counties. This study was integrated with a number of ongoing studies by the Delta Waterfowl Foundation to investigate the effects of predator management on waterfowl breeding biology and productivity in the Prairie Pothole Region. I conducted my research on 8 93-km<sup>2</sup> (6 x 6 mile) study sites. Five of these sites were part of Delta Waterfowl's predator management research involving the lethal removal of medium-sized mammalian predators, primarily raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and red fox (*Vulpes vulpes*) (Garrettson and Rohwer 2001). The other 3 study sites had no ongoing predator trapping and served as controls for the predator management study. These sites were composed of both private and public lands (primarily federal Waterfowl Production Areas). Sites were selected following similar criteria outlined by Garrettson and Rohwer (2001), meaning they had >10% grassland

cover typically in the form of Conservation Reserve Program (CRP) fields and high wetland densities.

## **Methods**

### *Assumptions*

The assumptions of the independent double-observer method are similar to any closed population mark-recapture study (Otis et al. 1978, Williams et al. 2002). These are: the population is spatially and demographically closed between surveys and there is no undetected movement on or off survey areas, marks are not lost by observers, all animals have equal probability of being recorded, animals are correctly marked, and observers function independently, such that a detection by one observer does not influence a detection by another observer (Otis et al. 1978, Williams et al. 2002).

### *Walk-up surveys*

As early-nesting species (e.g. mallards (*Anas platyrhynchos*)) were the species of primary interest in this study, I conducted a single round of double-observer walk-up surveys from 3-18 May 2006, following methodology similar to the U.S. Fish and Wildlife Service's (USFWS) 4-square-mile breeding waterfowl survey (Cowardin et al. 1995). Two observers conducted surveys on 5 randomly selected 32-ha (800 x 400 m) plots per study site. One observer had conducted numerous pair counts in the previous year, whereas the other observer was a novice and had received only 1 week of training prior to collecting data. All plots were located in areas dominated by perennial cover (e.g., CRP fields) because I planned to revisit the same plots later for brood surveys when growing crops might have prevented me from gaining landowner access. Observers surveyed all wetlands <5 ha; I excluded wetlands  $\geq$  5 ha (about 3% of the wetland area

available to be surveyed) to ensure that both observers could survey the entire area at the same time (Graham and Bell 1989, Nichols et al. 2000, Fletcher and Hutto 2006). Surveys were conducted simultaneously by 2 observers from 0900 to 1630 hours. Surveys commenced as soon as the wetland basin became visible and ceased after both observers announced to each other that they had finished surveying that wetland. To maintain independence of observations, observers remained 3-6 m apart with one observer leading and the second observer following (order alternated between wetlands). In instances where wetlands were small (<0.2 ha) and both observers were confident they could see both sides of the wetland, observers separated and one observer traversed one side of the wetland while the second observer traversed the opposite side. In addition, observers used methods to ensure their actions did not influence the observations of the other, including mock recording, mock or prolonged stopping, delayed recording, and mock or prolonged use of binoculars. Observers marked locations of birds on rough maps for each wetland to ensure differences in detections could be identified later. Observers recorded social groups in the following categories: lone pairs, lone females, lone males, grouped pairs, grouped males  $\leq 5$ , grouped males  $> 5$ , grouped females, and groups of 2 males:1 female (Dzubin 1969). A bird or pair was only considered alone if spaced  $> 5$  m from another bird or pair (Dzubin 1969). To reduce double counts caused by researcher activity, all birds that flew away from ponds while under observation were counted, whereas birds that landed on ponds while under observation were not counted (Hammond 1969). In addition, observers recorded wetland characteristics, including wetland cover type (Stewart and Kantrud 1971), percent inundation (in increments of 20%, compared to printouts from the USFWS National Wetland Inventory), and

percentage of the wetland perimeter surrounded by tall emergent vegetation (in categories of 0, 20, 40, 60, 80, or 100%). Observers also recorded weather conditions at the start of each survey, including air temperature (°C), precipitation and cloud cover (sunny, light rain, cloudy), and wind speed (km/h). I measured air temperature and wind speed using a Skymate wind meter SM-18.

### *Roadside surveys*

I conducted roadside surveys from 4-15 May 2006, on the same study sites used for walk-up surveys, using all passable roads within each study site. I surveyed all wetlands within 150 meters of the roadside and for which 100% of the basin was visible from the roadside. Surveys ran from 0900 to 1630 hours. Observers surveyed wetlands simultaneously using binoculars from the driver or passenger seat of a Ford Explorer sport utility vehicle. An opaque partition was placed between observers to help prevent the actions of one observer from cueing the other, while not impairing observers' ability to see wetlands or the driver's ability to drive. Observers alternated between passenger and driver for each study site. Surveys commenced as soon as both observers could see the wetland. Depending on wetland size, I used 1 to 4 stopping points for each wetland. The survey of each wetland was completed once both observers announced to each other that they had finished (once 1 observer announced they had finished surveying that observer could no longer record birds). Observers used similar methods as in walk-up surveys to ensure their actions did not influence the observations of the other observer (e.g., mock recording, mock use of binoculars). Observers marked locations of birds on rough maps for each wetland to ensure differences in detections later could be identified (i.e., both observers might have recorded a pair of blue-winged teal, but if these

observations were at opposite sides of a 3-ha wetland, I would conclude that they were different detections). I recorded wetland characteristics following the same protocol as used for walk-up surveys. Observers also recorded weather conditions at the start of the survey and at hourly intervals thereafter following the same methodology as used for walk-up surveys. I did not conduct roadside or walk-up surveys under conditions of heavy rain, sleet, snow, fog, or ice cover, and canceled surveys were conducted on the following day.

### *Data Analysis*

I determined the area of each wetland basin by creating and measuring a digital layer using ArcGIS (Version 9.1, ESRI Inc. 2005) based on georeferenced aerial photos taken by the USFWS in late April to early May 2006. I performed 2 analyses of waterfowl sightability. The first analysis included only encounter histories for indicated breeding pairs (IBP), which would provide sightability estimates of most interest to managers evaluating sightability bias in breeding waterfowl population estimates. The second analysis was performed following the same methodology as the first, but included encounter histories for both IBPs and non-IBPs (Full dataset), which might be used by investigators interested in examining changes in waterfowl social groupings throughout the breeding season (e.g., Serie and Cowardin 1990). I used an IBP criterion following Dzubin (1969), such that lone pairs, grouped pairs, lone males, and males in groups of  $\leq 5$  were treated as paired individuals. Waterfowl surveys are timed to occur after approximately half of the females have started nesting, hence males in small groups are presumed to reflect paired males whose mates are on nests, whereas unmated males are presumed to occur in groups  $>5$  (Dzubin 1969, but see Brasher et al. 2002 for

counterexamples). I created an encounter history for each detection event (i.e., each social group detected by at least 1 observer). This produced 3 possible capture histories:  $x_{10}$  in which birds were recorded only by the first observer,  $x_{01}$  in which birds were recorded only by the second observer, and  $x_{11}$  in which birds were recorded by both observers (Williams et al. 2002, Fletcher and Hutto 2006). Maximum-likelihood estimators can then be used to calculate detection probabilities for observers 1 and 2

where  $\hat{p}_{obs1} = \frac{x_{11}}{x_{11} + x_{01}}$  and  $\hat{p}_{obs2} = \frac{x_{11}}{x_{11} + x_{10}}$  (Williams et al. 2002, Fletcher and Hutto

2006). Overall sightability ( $\hat{p}$ ) can be calculated as  $\hat{p} = 1 - (1 - p_{obs1})(1 - p_{obs2})$ , which is the probability at least one observer detected any particular bird (Cook and Jacobson 1979, Nichols et al. 2000, Moore et al. 2004). Variance of overall sightability can be

calculated using the delta method,  $\hat{v}\hat{a}r(\hat{p}) = \frac{x_{01}x_{10}(x_{01} + x_{10})\hat{p}}{(x_{01} + x_{11})^2(x_{10} + x_{11})^2}$  (Graham and Bell

1989).

I calculated IBPs and non-IBPs for all species and those species with large enough sample sizes (>50 detections) were analyzed using the Huggins' closed-capture model in Program MARK (White and Burnham 1999), which allows for testing of observer variability and some forms of heterogeneity among individuals (Williams et al. 2002, Alldredge 2006). The Huggins' model is a linear-logistic multinomial model in which the likelihood is conditioned on the number of animals detected, meaning that only individuals that were encountered at least once are included in analyses (Huggins 1989, 1991; Moore et al. 2004; Fletcher and Hutto 2006). This allows for the incorporation of individual covariates in the closed-population mark-recapture analyses in which

$$p_i = \frac{e^{\beta_0 + \beta_1 x_i}}{1 + e^{\beta_0 + \beta_1 x_i}}$$
 where  $x_i$  represents the covariate value for individual  $i$  (Huggins 1989, 1991; Williams et al. 2002). I considered each observation a separate capture event and capture probabilities were allowed to vary for each observation. Recapture probability (c) was constrained to equal capture probability,  $c_2 = p_2$ , meaning that observations were treated as being independent, such that a detection by one observer does not influence detection by the other observer (Moore et al. 2004, Fletcher and Hutto 2006). I performed all analyses using the logit link function in MARK (White and Burnham 1999), which constrains detection probabilities to fall within the logical parameter space of 0 - 1. I used the small-sample extension of Akaike's Information Criterion (AIC<sub>c</sub>; Burnham and Anderson 2002) to determine the best-supported models. In the Huggins' model, estimates of abundance are a derived parameter, and when individual covariates are included, estimates of abundance are based on the Horvitz-Thompson estimator:

$$\hat{N} = \sum_{i=1}^n \frac{x_i}{\hat{p}_i},$$

meaning that detection probabilities are uniquely calculated for each

individual (Horvitz and Thompson 1952, Williams et al. 2002, Alldredge et al. 2006).

For both analyses, I identified 3 variables as being potential main effects; observer, species, and study site. I assumed *a priori* that detection probabilities would vary between observers (Model  $p_{\text{obs}}$ ), so I included this main effect in all models. I also identified 3 *a priori* main-effect tests, a model with both observer and study site variation (Model  $p_{\text{obs}*\text{site}}$ ), a model with observer and species variation (Model  $p_{\text{obs}*spp}$ ), and a model with observer variation and variation in sightability between dabbling and diving ducks (Model  $p_{\text{obs}*dab \text{ vs } div}$ ). I did not consider *a priori* models incorporating both site- and species-specific variation because such models would have required  $8 \times 8 = 64$

different attribute groups. I treated the best-supported of these 4 models (i.e., the model with the lowest  $AIC_c$  value) as the main-effects model for exploratory testing of the additive effects of individual covariates. For examining sources of variation in detection probabilities of IBPs, I selected 14 individual covariates (Table 1.1), based primarily on previously documented factors identified as potentially influencing waterfowl pair sightability (e.g., Diem and Lu 1960, Dzubin 1969). Two of my initial covariates were highly correlated with other variables (wetland size squared and an interaction between wetland size and percent emergent vegetation surrounding the wetland), so I excluded them from further consideration. I treated all remaining individual covariates as additive, meaning that the influence of the covariate was treated as equal across both observers and all species. I transformed all continuous covariates using Z-transformations ( $\frac{x - \bar{x}}{sd}$ ) so that each covariate would have a mean of 0 and a SD of 1, but I treated the remaining covariates as dummy variables, assigning them values of either 0 or 1.

I used a stepwise forward-selection approach to determine if the best-supported main-effects model could be improved by incorporating a single individual covariate, which was modeled to have a similar effect over all species and observers (i.e., utilizing ‘logit parallelism,’ sensu Lebreton et al. 1992). If a covariate did not lead to a reduction in  $AIC_c$  compared to the main-effects model, I discarded it from further analysis and the model including that covariate was discarded from the model set. If 2 or more single covariates added to the main-effects model led to reduced  $AIC_c$  values, I considered 2-covariate models by adding to the top-supported single-covariate model any other

covariates that had lower  $AIC_c$  values over the main-effects model. I retained any models that led to reductions in  $AIC_c$ , and discarded from further consideration any models (and covariates) that led to increases in  $AIC_c$  over the previous best-supported model. I continued this approach, sequentially adding additional covariates, until none of them led to improvements over the prior model. I followed the same approach for analyzing the Full dataset, using 14 individual covariates in the analysis. These included all covariates used in the IBP analysis, except the covariate entitled social group was replaced by a covariate denoting sex of the observed duck(s) (Table 1.1).

## Results

I recorded a total of 3,186 IBPs during this study, including 8 species that had large enough sample sizes for detailed analysis: 656 mallards, 1,066 blue-winged teal (*Anas discors*), 325 northern shovelers (*Anas clypeata*), 131 northern pintails (*Anas acuta*), 410 gadwalls (*Anas strepera*), 227 redheads (*Aythya americana*), 96 ruddy ducks (*Oxyura jamaicensis*), and 170 lesser scaup (*Aythya affinis*). For the IBP analysis, I conducted 2 initial tests. First, I tested for variation among the 8 study sites by comparing 2 models: 1 with study site and observer effects and the other without a study site effect. The model with no study site effect was better-supported by the data ( $AIC_c$  weight = 0.985 vs. 0.015, Table 1.2), so I excluded study site effects from subsequent models. Second, I treated the 8 species separately and I compared 3 models: 1 with species and observer effects, 1 without species effects, and 1 hybrid model that lumped species into 2 groups (dabblers vs. divers). The model treating each species separately was by far the best-supported ( $AIC_c$  weight = 1.0 vs. 0 and 0 for the other 2 models, Table 1.2).

This model with the factorial effects of 8 species and 2 observers was further evaluated using a stepwise approach to examine the influence of 14 individual covariates. The results from this analysis identified 8 individual covariates that better described the variability in sightability than the main-effects model alone (Table 1.3) with individuals per wetland and wetland size being the best-supported ( $AIC_c$  weight = 0.74 and 0.18 respectively).

Following a forward selection approach, I sequentially added individual covariates starting with these 2 covariates until all 8 covariates had been tested and the addition of another covariate no longer reduced the  $AIC_c$  value. The best-supported model from this analysis was the model including the factorial effects of species and observer along with the additive effects of the total number of individual ducks recorded per wetland, wetland size, precipitation, social grouping, and time of the survey ( $AIC_c$  weight = 0.656, Table 1.3). Based on this best-supported model the total number of individual ducks recorded per wetland, wetland size, and precipitation had negative effects on sightability (Table 1.4, Fig. 1.1-1.3), whereas social grouping and time of the survey had positive effects (Table 1.4, Fig. 1.4-1.5).

I followed the same approach to analyze the Full dataset that included both IBPs and non-IBPs. For this analysis, the best-supported of the main-effect analyses was also the model incorporating variability among all 8 species and both observers (Table 1.2). Of the individual covariates tested, I found 6 covariates that were better-supported than the main-effects model alone (Table 1.5), with the sex of the detected individual having the strongest support ( $AIC_c$  weight = 1.0). As with the IBP dataset, I sequentially added these 6 covariates to the main-effects model until the lowest  $AIC_c$  value had been

obtained and all 6 covariates had been added. The best-supported model included the factorial effects of species and observer with the additive effects of sex of the individual, wetland size, total number of individual ducks recorded per wetland, precipitation, and wind speed ( $AIC_c$  weight = 0.451, Table 1.5). Based on this best-supported model, sex of the individual exhibited a strong positive effect on sightability ( $\beta = 2.09$ , 95% CI = 1.75, 2.42) (Fig. 1.6), whereas wetland size, individual ducks recorded per wetland, precipitation, and wind speed all had negative effects ( $\beta = -0.09$ , 95% CI = -0.19, 0.01;  $\beta = -0.11$ , 95% CI = -0.21, -0.02;  $\beta = -0.26$ , 95% CI = -0.60, 0.07; and  $\beta = -0.06$ , 95% CI = -0.15, 0.02; respectively).

I derived estimates of sightability from the IBP analysis based on the best-supported model (Table 1.6), both the IBP and Full dataset analyses provided similar sightability estimates. For all species, the more-experienced observer (observer 1) had higher sightability rates than the novice observer (observer 2), and this was especially prominent for ruddy ducks (Table 1.6, Fig. 1.7). Using the mean for each species from the best-supported model, observer 1 had an average IBP sightability of 0.911 (95% CI = 0.861, 0.942), whereas observer 2 had an average sightability of 0.789 (95% CI = 0.733, 0.836). Using the mean for each species and both observers, mean IBP sightability over all species and observers was 0.850 (95% CI = 0.797, 0.889).

The probability either observer detected a duck (overall sightability ( $\hat{p}$ )) was 0.976 (SE = 0.003) for mallards, 0.981 (SE = 0.003) for blue-winged teal, 0.988 (SE = 0.004) for northern shovelers, 0.980 (SE = 0.007) for northern pintails, 0.981 (SE = 0.004) for gadwalls, 0.991 (SE = 0.003) for redheads, 0.967 (SE = 0.021) for ruddy ducks, and 0.991 (SE = 0.004) for lesser scaup. Using the mean IBPs from birds

recorded by each observer to represent a standard single-observer pair count, such a count would have under-estimated indicated breeding pairs by 10 – 29%, depending upon species (Table 1.7).

## **Discussion**

In my study sightability rates varied markedly between observers and among species, but not among study sites. Sightability was highest for an experienced observer who had conducted numerous pair counts in a previous year, whereas it was about 10% lower for an inexperienced observer who had received 1 week of training prior to collecting data. Across most species, observers had similar sightability rates, but sightability of ruddy ducks was particularly low for the novice observer, which suggests the importance of incorporating sightability estimates if multiple species of various size and behavior are to be enumerated. Unlike other species that would often swim to the center of the wetland or flush in response to human observers, ruddy ducks often escaped by diving into emergent cover, and it seemed especially important to tally them quickly before they became virtually undetectable.

Females had much lower sightability than males or pairs, which would be expected given the less-conspicuous nature of female plumage and behavior (Diem and Lu 1960). The number of individual ducks per wetland and social grouping also reduced sightability of IBPs, indicating that as bird densities increased, observers' ability to record all birds declined. This effect may have been caused in part by birds flushing during surveys, making it difficult for observers to identify pairs on the wing, particularly in instances where high densities of birds were being surveyed. Wetland size also influenced sightability, with larger wetlands having reduced sightability. In addition, I

found light rain reduced sightability. These results confirm previously documented sources of reduced sightability (Diem and Lu 1960, Dzubin 1969). Lastly, I found time of the survey had some influence on sightability, with surveys later in the day having higher sightability than surveys conducted in the morning (Fig. 1.5). This result differs from some previously cited sources examining the role of time of day on waterfowl pair surveys. Diem and Lu (1960) found time of day and air temperature to have significant effects on surveys of dabbling ducks, whereas Dzubin (1969) recommended surveys take place between 0800-1200 hours, on sunny days, with air temperatures above 4.4 °C, and wind speeds <15 mph (24.1 km/h). However, Barras (1999) found that time of day (morning versus afternoon) did not influence surveys of breeding mallards and Sauder et al. (1971) found wind speeds and cloud cover had no significant effect on pair counts of mallards, blue-winged teal, and gadwalls. In this study, temperature, cloud cover, and wind speed had little effect on sightability, indicating that if these factors are influential, they are influencing the behavior and movement of the birds themselves and not the observers.

There was no discernable difference in sightability estimates between roadside and walk-up surveys, suggesting that both methods are equally reliable, lending credence to the use of roadside surveys, which are logistically simpler, in place of walk-up surveys, provided surveys can be designed to ensure samples are representative of the population of interest (Barras 1999). In this study, roads were typically laid out in a systematic grid, meaning roadside samples were analogous to a systematic sampling scheme (Austin et al. 2000). Systematic samples are generally easier to implement and in

some cases more representative of the study area than other sampling approaches (Garton et al. 2005).

Surprisingly, cover type and percent tall emergent vegetation surrounding the wetland perimeter did not influence sightability, but for walk-up surveys observers attempted to flush any birds hiding in dense vegetation and this could reduce the influence of cover types and vegetation on sightability. In addition, birds surveyed using roadsides may have been virtually undetectable to both observers in wetlands with minimal amounts of open water (e.g., cover types 1 or 2).

#### *Evaluation of Assumptions*

Unlike other methodologies designed to estimate sightability, such as distance sampling or double sampling, the independent double-observer approach does not require dramatic changes in field protocol beyond the inclusion of a second observer, use of a fixed radius, and taking steps to ensure observations are independent. The first 2 assumptions of the independent double-observer method are that the population is closed and marks are not lost by observers. These are satisfied in that observers survey the same areas simultaneously, which necessitates the use of a fixed-radius sample that ensures observers are surveying the same areas at the same time and that there is no undetected movement into or off of the survey area (Graham and Bell 1989, Nichols et al. 2000, Alldredge et al. 2006, Fletcher and Hutto 2006). The use of a fixed-radius could potentially be relaxed if detection distances were incorporated within the independent double-observer approach (e.g., Alldredge et al. 2006). The assumption that all animals have equal probability of being captured is not biologically realistic, but Magnusson et al. (1978) tested this assumption and found that when the assumption failed it did not cause

excessive bias. Furthermore, the use of individual covariates allows for testing of observable heterogeneity in sightability (Alldredge et al. 2006, Fletcher and Hutto 2006).

The assumption that all animals are correctly marked has the greatest potential to bias sightability estimates because it is difficult [particularly in situations where densities are high (Graham and Bell 1989)] to ensure detections by observers are not of different individuals, rather than the same individual (Moore et al. 2004, Fletcher and Hutto 2006). Recording observations on rough maps (as used in this study) aids in identifying unique individuals, but does not eliminate the potential for incorrect identification. In instances where there was some uncertainty as to whether observers had identified the same individual or 2 distinct individuals, I conservatively treated it as the same individual. In cases where it was apparent that a bird had been misidentified, I selected the identification based on the observer with greater pair survey experience (such cases of apparent misidentification occurred for 4% of all detections by observer 2, primarily as cases in which observer 2 misidentified redheads as lesser scaup).

Lastly, the assumption that observers function independently requires additional effort on the part of observers, such as the methods of mock observation and recording used in this study. In addition, for most surveys bird densities were high, which should have further reduced the potential for observers cueing off one another (Alldredge et al. 2006). Nevertheless, if this assumption is not satisfied, sightability estimates still perform better than standard count indices (Nichols et al. 2000). The dependent double-observer approach, in which a secondary observer serves to identify animals missed by a primary observer, does not require independence among observers, but the use of this approach reduces model flexibility (Nichols et al. 2000). Graham and Bell (1989)

compared the Cook and Jacobson (1979) model (dependent double-observer) to the independent double-observer model (Lincoln-Petersen) and found the independent double-observer model had lower variance and was more efficient. Alldredge (2004) also compared the dependent double-observer approach to the independent double-observer approach and reached the same conclusions.

One drawback to double-observer approaches is that they only estimate the apparent population and fail to account for any individuals that are truly undetectable (Graham and Bell 1989, Moore et al. 2004, Fletcher and Hutto 2006). Consequently, in testing for the influence of variables on sightability the double-observer approach only accounts for factors influencing detected birds and not for factors that affect whether or not a bird will be detected at all (Moore et al. 2004).

### **Management Implications**

My results demonstrated that standard single-observer pair counts would have underestimated abundance over all waterfowl species surveyed. In addition, an observer with greater pair survey experience had higher sightability rates over all species, which further elucidates the importance of training and the experience of observers. Sightability did not vary among study sites, but in this study the same observers were used throughout all sites. In studies where observers differ among sites, variation in sightability among observers could bias population estimates and potentially influence conclusions.

Although survey timing was designed primarily to examine sightability of early-nesting species (e.g., mallards), the methods used in this study could be easily applied to pair surveys targeted for late-nesting species (e.g., gadwalls). The independent double-observer approach provides a relatively non-intrusive method to reduce the amount of

bias caused by differences in observers, species, and other sources of heterogeneity.

My results indicate that ground-based surveys could provide more reliable estimates of waterfowl population numbers by incorporating sightability estimates directly into the survey protocol.

Table 1.1. Explanatory variables used in the analysis of indicated breeding pairs (IBP) examining waterfowl sightability in northeastern North Dakota, USA, 2006. Estimates of variables used in the combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) were almost identical, but included the variable entitled sex (listed below) and species and study sites were coded as single detections, rather than IBPs.

Variable	Description	Coding	Mean	Range
Obs 1	Observer 1, Encounter occasion, 0 = undetected, 1 = detected	Binomial	0.92	0 or 1
Obs 2	Observer 2, Encounter occasion, 0 = undetected, 1 = detected	Binomial	0.81	0 or 1
Spp	8 species, coded as IBPs	Categorical		0-5
Site	8 study sites, coded as IBPs	Categorical		0-5
Sex	0 = female only, 1 = males or pairs	Binomial	0.93	0 or 1
Ducks	Total number of ducks observed on wetland	Continuous	15.93	1-60
Group	Social group, where 0 = lone pairs or lone males, 1 = multiple males or pairs	Binomial	0.07	0 or 1
Size	Wetland size in ha	Continuous	2.15	0.01-4.5
Cover	Wetland cover type (Stewart and Kantrud 1971), where 1 = closed and 4 = open	Ordinal	2.93	1-4
WetVeg	Wetland perimeter surrounded by tall emergent vegetation (Intervals of 20%)	Continuous	78.89	0-100
Method	Survey type: 0 = roadside or 1 = walk-up survey	Binomial	0.33	0 or 1
Date	Date of survey (expressed as Julian date)	Continuous	10 May	2–18 May
Time	Time of the survey	Continuous	12:04	9:00-16:33
Clouds	Cloud cover, where 0 = sunny, 1 = cloudy	Binomial	0.36	0 or 1
Rain	Precipitation, where 0 = dry, 1 = light rain	Binomial	0.07	0 or 1
Wind	Wind speed in km/h	Continuous	18.56	0-40.88
Temp	Temperature in °C	Continuous	12.72	2.6-25.2

Table 1.2. Competing sightability models ranked according to  $\Delta AIC_c$  values calculated in Program MARK for the analysis of indicated breeding pairs (IBP) and combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) analysis of waterfowl sightability in northeastern North Dakota, USA, 2006. Models tested the support for observer variation, p(obs) (2 observers), observer and species variation, p(obs\*spp) (8 species), observer and grouped dabber versus diver variation, p(obs\*dab vs div) (2 groups), and observer and study site variation, p(obs\*site) (8 study sites) where \* indicates a factorial effect. The best-supported models had  $AIC_c$  values of 4443.42 (IBP) and 4808.13 (Full).

Model	K <sup>a</sup>	$\Delta AIC_c^b$ (IBP)	$w_i^c$ (IBP)	Dev <sup>d</sup> (IBP)	$\Delta AIC_c$ (Full)	$w_i$ (Full)	Dev (Full)
p(obs*spp)	16	0	1.0	4411.33	0	1.0	4776.05
p(obs)	2	67.72	0	4507.13	87.21	0	4891.35
p(obs*dab vs div)	4	71.20	0	4506.61	90.34	0	4890.46
p(obs*site)	16	71.54	0	4482.87	94.25	0	4870.29

<sup>a</sup> Number of estimable parameters in model.

<sup>b</sup>  $AIC_c$  difference of the current model versus the highest-ranked model.

<sup>c</sup> Relative likelihood of the current model (*i*) based on  $AIC_c$  value.

<sup>d</sup> Model deviance.

Table 1.3. Competing sightability models ranked according to  $\Delta AIC_c$  values calculated in Program MARK for the indicated breeding pairs (IBP) analysis of waterfowl sightability in northeastern North Dakota, USA, 2006. Models tested the support for the factorial effects (\*) of observer and species variation, p(obs\*spp) (8 species), and the additive influence (+) of individual covariates. The best-supported model had an  $AIC_c$  value of 4408.37.

Model <sup>a</sup>	K <sup>b</sup>	$\Delta AIC_c$	$w_i$	Dev
p(obs*spp+ducks+size+rain+group+time)	21	0	0.656	4366.22
p(obs*spp+ducks+size+rain+group)	20	1.31	0.341	4369.54
p(obs*spp+ducks+size+rain)	19	10.97	0.003	4381.21
p(obs*spp+ducks+size)	18	17.03	0	4389.29
p(obs*spp+ducks)	17	18.44	0	4392.71
p(obs*spp+size)	17	21.26	0	4395.53
p(obs*spp+rain)	17	23.74	0	4398.01
p(obs*spp+group)	17	25.51	0	4399.78
p(obs*spp+clouds)	17	30.68	0	4404.95
p(obs*spp+wetveg)	17	34.38	0	4408.65
p(obs*spp+wind)	17	34.39	0	4408.66
p(obs*spp+time)	17	34.80	0	4409.07
p(obs*spp)	16	35.05	0	4411.33

<sup>a</sup> Abbreviations correspond to explanatory variables listed in Table 1.1.

<sup>b</sup> Column descriptions as in Table 1.2.

Table 1.4. Beta estimates calculated in Program MARK based on the best-supported model from the indicated breeding pairs (IBP) analysis examining waterfowl sightability in northeastern North Dakota, USA, 2006.

Parameter <sup>a</sup>	Estimate	SE	95% CI
$\beta_0$	2.111	0.249	1.622 – 2.599
$\beta_{\text{ducks}}$	-0.141	0.050	-0.239 – -0.043
$\beta_{\text{size}}$	-0.056	0.051	-0.156 – 0.043
$\beta_{\text{rain}}$	-0.438	0.156	-0.745 – -0.131
$\beta_{\text{group}}$	0.471	0.139	0.198 – 0.744
$\beta_{\text{time}}$	0.077	0.042	-0.006 – 0.159
$\beta_{\text{MALL}}$	-0.592	0.276	-1.133 – -0.052
$\beta_{\text{BWTE}}$	-0.984	0.259	-1.492 – -0.476
$\beta_{\text{NOSH}}$	-0.769	0.284	-1.326 – -0.211
$\beta_{\text{NOPI}}$	-0.695	0.340	-1.363 – -0.028
$\beta_{\text{GADW}}$	-0.551	0.283	-1.106 – 0.005
$\beta_{\text{REDH}}$	-0.059	0.330	-0.705 – 0.587
$\beta_{\text{RUDU}}$	-1.981	0.324	-2.617 – -1.346
$\beta_{\text{obs1}}$	0.305	0.352	-0.385 – 0.996
$\beta_{\text{MALL*obs1}}$	0.038	0.387	-0.721 – 0.796
$\beta_{\text{BWTE*obs1}}$	1.029	0.379	0.286 – 1.772
$\beta_{\text{NOSH*obs1}}$	1.176	0.454	0.287 – 2.065
$\beta_{\text{NOPI*obs1}}$	0.432	0.508	-0.564 – 1.429
$\beta_{\text{GADW*obs1}}$	0.247	0.407	-0.551 – 1.044
$\beta_{\text{REDH*obs1}}$	0.100	0.478	-0.836 – 1.036
$\beta_{\text{RUDU*obs1}}$	2.137	0.629	0.904 – 3.370

<sup>a</sup> Abbreviations correspond to explanatory variables listed in Table 1.1. MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall, REDH = redhead, and RUDU = ruddy duck.

Table 1.5. Competing sightability models ranked according to  $\Delta AIC_c$  values calculated in Program MARK for the combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) analysis of waterfowl sightability in northeastern North Dakota, USA, 2006. Models tested the support for the factorial effects (\*) of observer and species variation, p(obs\*spp) (8 species), and the additive influence (+) of individual covariates. The best-supported model had an  $AIC_c$  value of 4669.81.

Model <sup>a</sup>	K <sup>b</sup>	$\Delta AIC_c$	$w_i$	Dev
p(obs*spp+sex+size+ducks+rain+wind)	21	0	0.451	4570.80
p(obs*spp+sex+size+ducks+rain)	20	0.16	0.417	4572.97
p(obs*spp+sex+size+ducks)	19	2.84	0.109	4577.66
p(obs*spp+sex+size)	18	5.92	0.023	4582.75
p(obs*spp+sex)	17	21.95	0	4600.80
p(obs*spp+size)	17	180.43	0	4759.28
p(obs*spp+ducks)	17	182.20	0	4761.05
p(obs*spp+rain)	17	188.60	0	4767.45
p(obs*spp+wind)	17	191.92	0	4770.77
p(obs*spp+clouds)	17	193.48	0	4772.32
p(obs*spp)	16	195.19	0	4776.05

<sup>a</sup> Abbreviations correspond to explanatory variables listed in Table 1.1.

<sup>b</sup> Column descriptions as in Table 1.2.

Table 1.6. Sightability estimates calculated in Program MARK for each species and each observer based on the best-supported model from the indicated breeding pairs (IBP) analyses of waterfowl sightability in northeastern North Dakota, USA, 2006.

Species <sup>a</sup> and Observer	Estimate <sup>b</sup>	SE	95% CI
MALL observer 1	0.866	0.016	0.831 – 0.894
MALL observer 2	0.821	0.018	0.784 – 0.853
BWTE observer 1	0.922	0.009	0.901 – 0.938
BWTE observer 2	0.756	0.014	0.728 – 0.782
NOSH observer 1	0.944	0.014	0.909 – 0.966
NOSH observer 2	0.793	0.023	0.745 – 0.835
NOPI observer 1	0.896	0.030	0.822 – 0.942
NOPI observer 2	0.805	0.037	0.723 – 0.867
GADW observer 1	0.892	0.017	0.855 – 0.921
GADW observer 2	0.827	0.020	0.785 – 0.862
REDH observer 1	0.921	0.019	0.875 – 0.951
REDH observer 2	0.886	0.022	0.836 – 0.923
RUDU observer 1	0.929	0.034	0.825 – 0.973
RUDU observer 2	0.533	0.053	0.430 – 0.633
LESC observer 1	0.918	0.021	0.866 – 0.951
LESC observer 2	0.892	0.024	0.836 – 0.931

<sup>a</sup> MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall, REDH = redhead, RUDU = ruddy duck, and LESC = lesser scaup.

<sup>b</sup> Estimates calculated with covariates set at their mean, where ducks = 15.93, size = 2.15, rain = 0.07, group = 0.07, and time = 12:04.

Table 1.7. Abundance of indicated breeding pairs (IBP) using standard single-observer pair survey methods (mean estimates between both observers) and sightability-adjusted estimates ( $\hat{N}$ ) based on the best-supported model examining waterfowl sightability in northeastern North Dakota, USA, 2006.

Species <sup>a</sup>	Single-Observer Estimates	Single-Observer SE	Adjusted Estimate <sup>b</sup> ( $\hat{N}$ )	SE <sup>b</sup> ( $\hat{N}$ )	95% CI <sup>b</sup> ( $\hat{N}$ )
MALL	577	13.5	669.7	4.4	663.4 – 681.2
BWTE	913	89.0	1088.0	5.7	1079.4 – 1102.3
NOSH	285	25.5	329.5	2.5	326.6 – 337.4
NOPI	114	6.0	133.8	2.0	131.8 – 140.9
GADW	358	14.0	418.8	3.5	414.1 – 428.7
REDH	207	4.0	229.3	1.7	227.6 – 235.3
RUDU	71	21.5	100.3	3.1	97.2 – 111.5
LESC	154	2.5	172.2	1.7	170.6 – 178.3

<sup>a</sup> MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall, REDH = redhead, RUDU = ruddy duck, and LESC = lesser scaup.

<sup>b</sup> Calculated in Program MARK using the Horvitz-Thompson estimator (Horvitz and Thompson 1952).

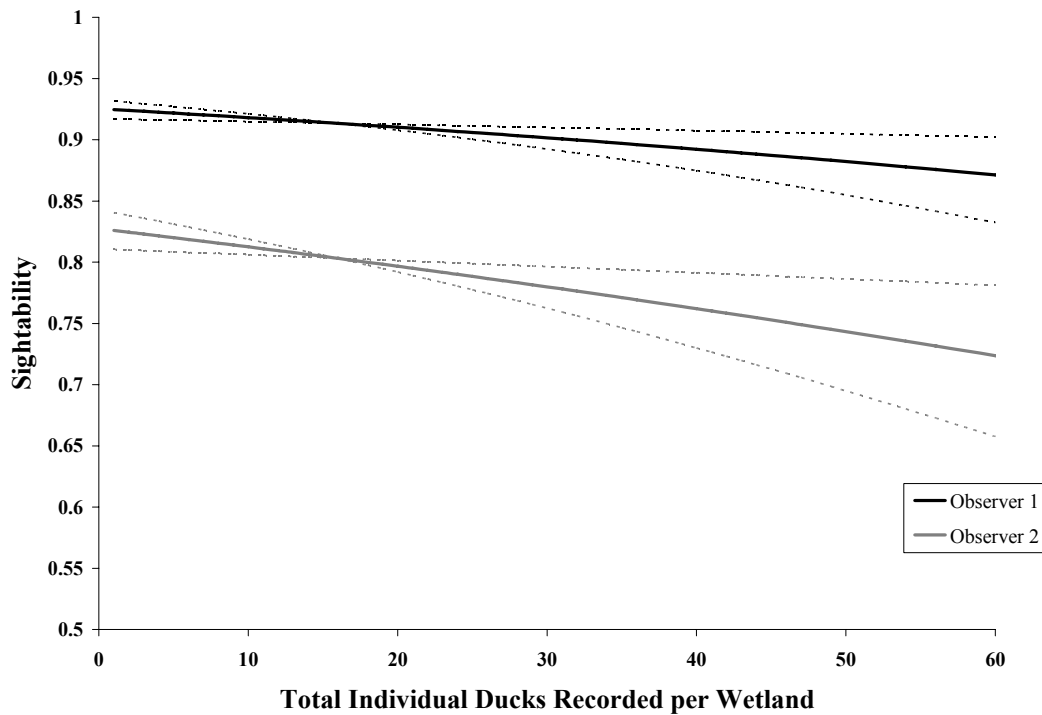


Fig. 1.1. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of the total number of individual ducks recorded per wetland, while setting all other explanatory variables to their mean. Based on results examining waterfowl sightability from ducks surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

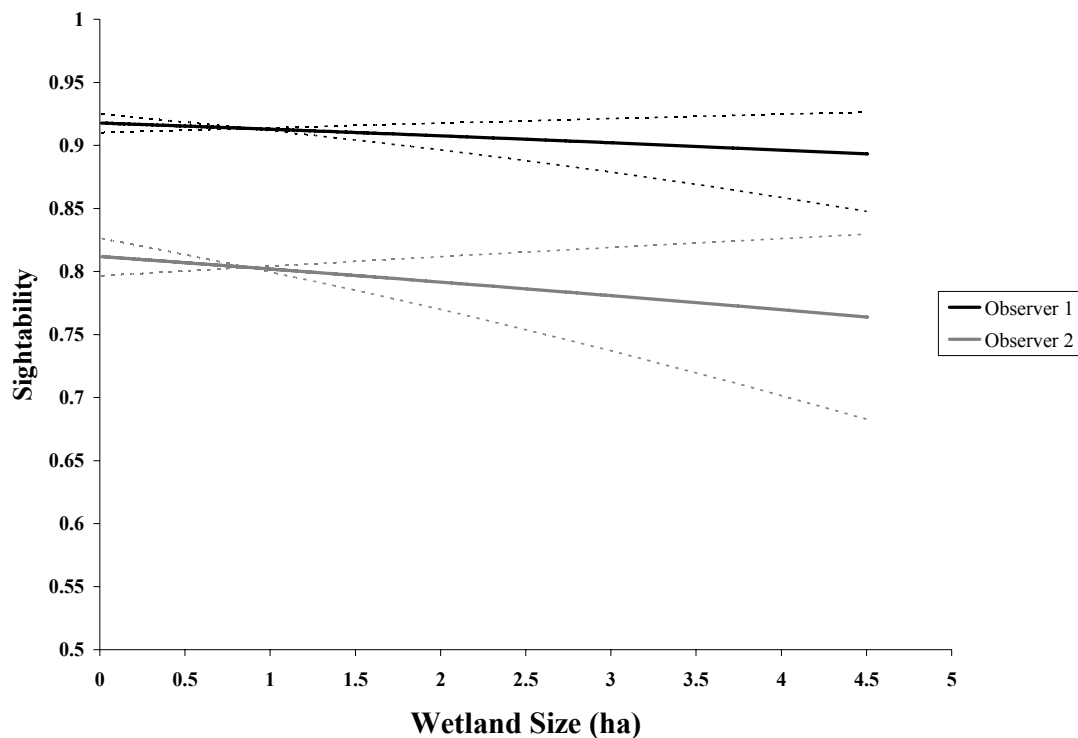


Fig. 1.2. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based the best-supported model for each observer over all species illustrating the additive effect of wetland size, while setting all other explanatory variables to their mean. Based on results examining waterfowl sightability from ducks surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

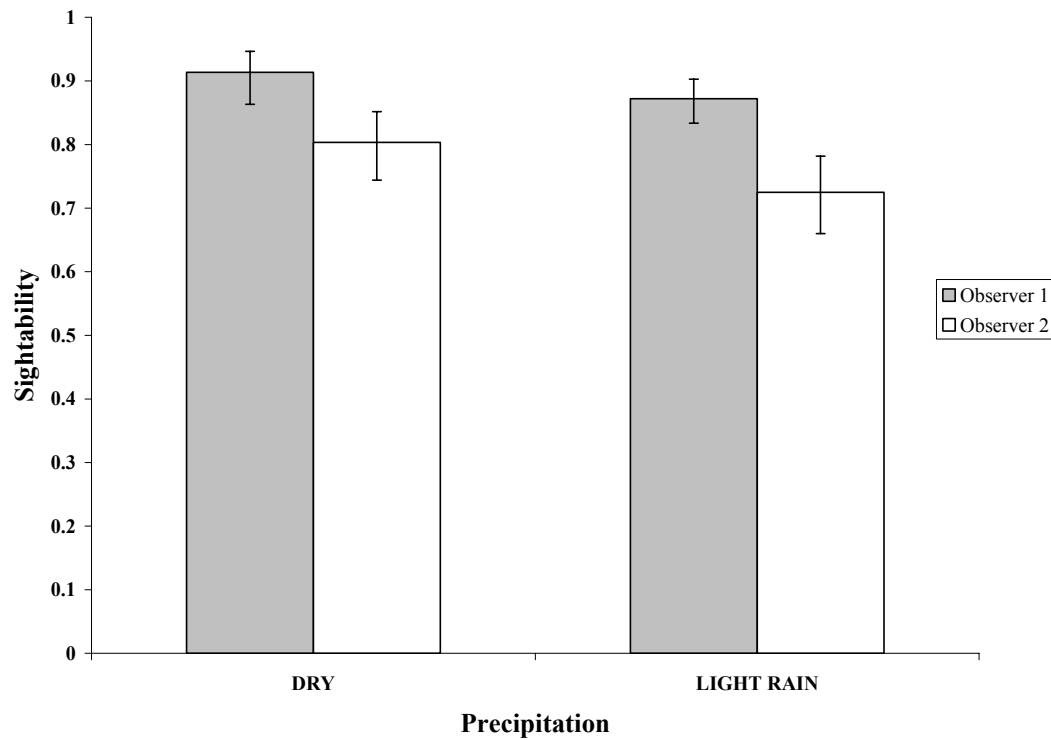


Fig. 1.3. Sighting estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of light rain, while setting all other explanatory variables to their mean. Based on results examining waterfowl sighting for ducks surveyed in northeastern North Dakota, USA, 2006. Error bars represent 95% CI.

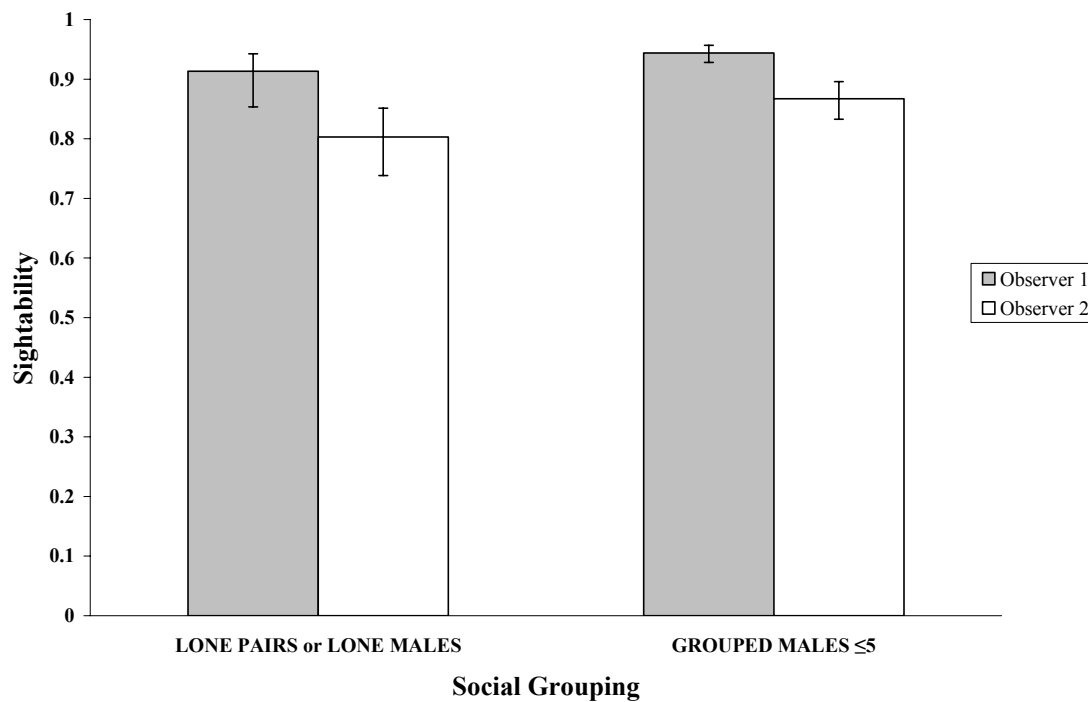


Fig. 1.4. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of social grouping, while setting all other explanatory variables to their mean. Based on results examining waterfowl sightability for ducks surveyed in northeastern North Dakota, USA, 2006. Error bars represent 95% CI.

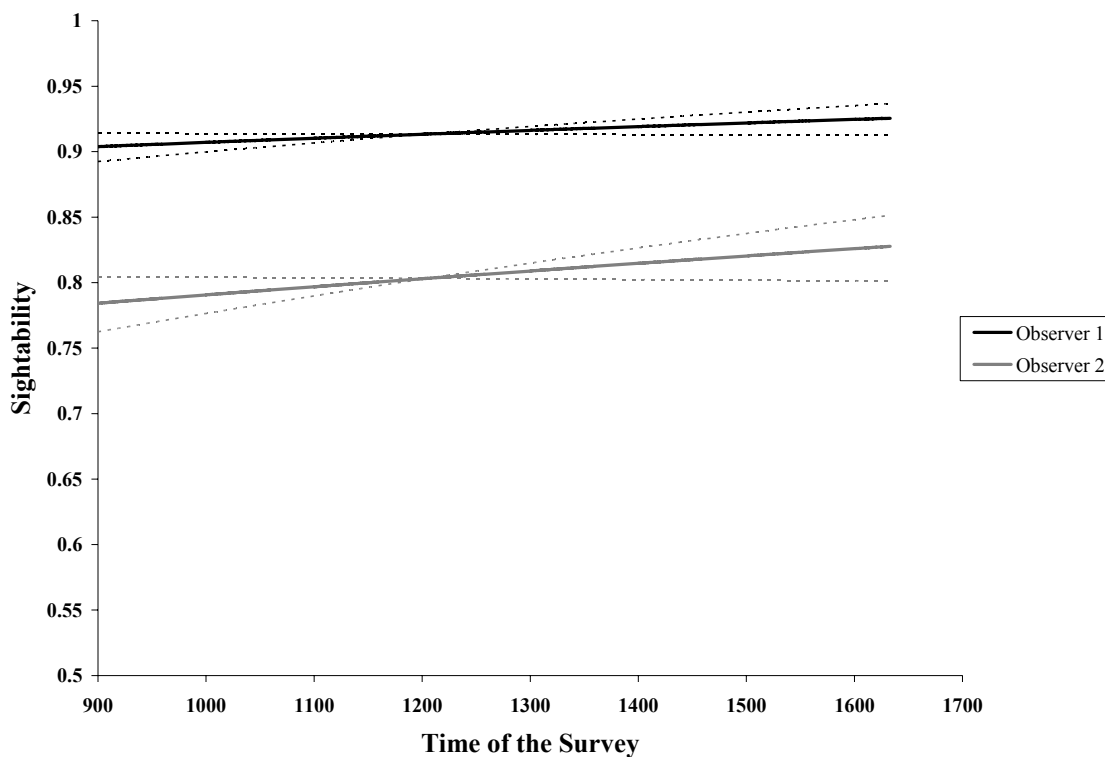


Fig. 1.5. Sightability estimates from the indicated breeding pairs (IBP) analysis calculated in Program MARK based the best-supported model for each observer over all species illustrating the additive effect of time of the survey, while setting all other explanatory variables to their mean. Based on results examining waterfowl sightability from ducks surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

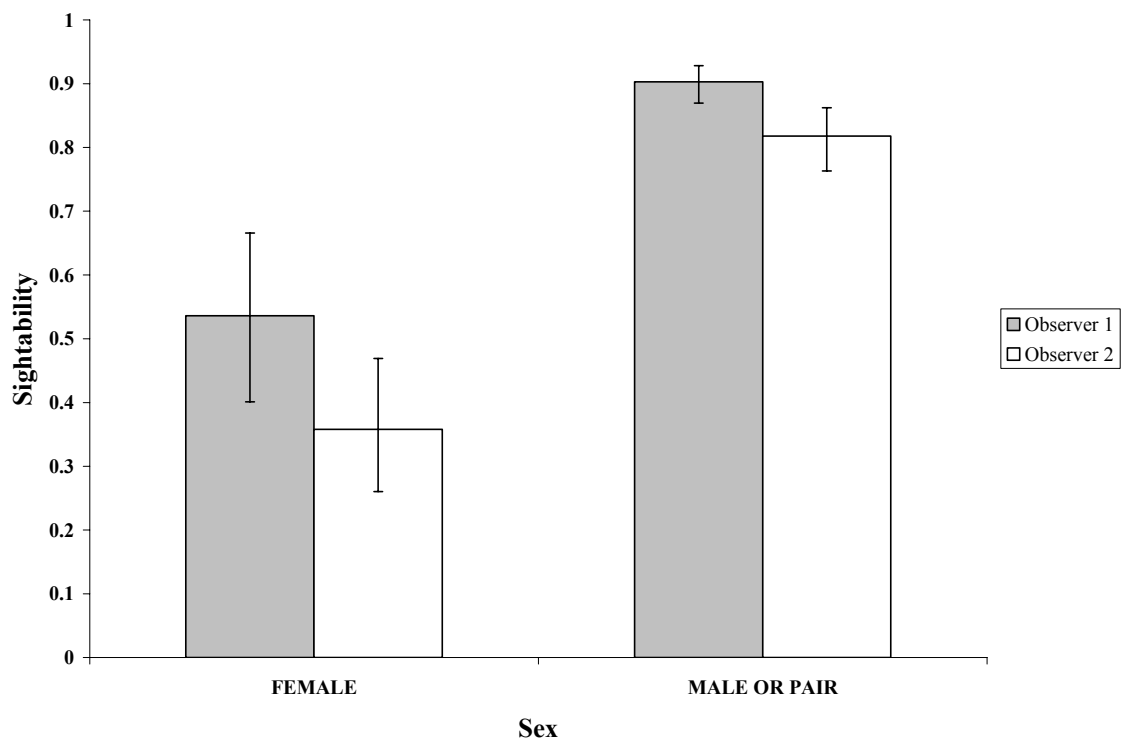


Fig. 1.6. Sighting estimates from the combined indicated breeding pairs and non-indicated breeding pairs (Full dataset) analysis calculated in Program MARK based on the best-supported model for each observer over all species illustrating the additive effect of sex of the individual recorded, while setting all other explanatory variables to their mean. Based on results examining waterfowl sighting for ducks surveyed in northeastern North Dakota, USA, 2006. Error bars represent 95% CI.

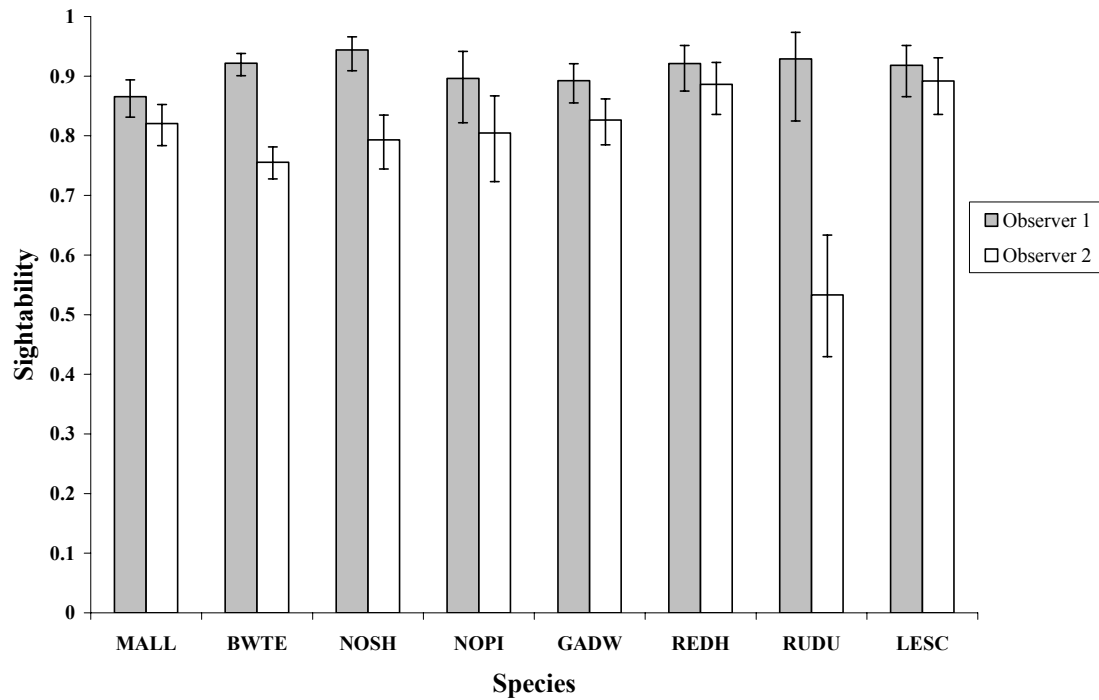


Fig. 1.7. Sightability estimates for each observer and species based on the best-supported model from the indicated breeding pairs (IBP) analysis calculated in Program MARK with all other explanatory variables set to their mean, from waterfowl surveyed in northeastern North Dakota, USA, 2006. Error bars represent 95% CI. MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall, REDH = redhead, RUDU = ruddy duck, and LESC = lesser scaup.

## Chapter 2. Estimating Sightability of Waterfowl Broods using Roadside and Walk-up Surveys

### Introduction

Estimating waterfowl breeding productivity requires either estimates of nesting success and brood survival, or estimates of breeding population numbers and brood abundance (Cowardin and Johnson 1979). The first of these 2 approaches has become standard practice in waterfowl research (Cowardin et al. 1985, Hoekman et al. 2002), despite being logistically and financially demanding (Cowardin and Blohm 1992). Ringelman and Flake (1980) suggested that brood counts could provide more accurate estimates of waterfowl productivity than either pair or nest counts because these latter methods do not account for duckling mortality. Cowardin and Blohm (1992:431) asserted that brood-to-pair ratios should provide good indices of recruitment that are “simple, direct, and easily understood.” However, the problem with using breeding population numbers and brood numbers to assess productivity is that broods of most prairie-nesting species are secretive and spend the majority of their time hidden in emergent vegetation (Diem and Lu 1960, Smith 1971, Stoudt 1971, Ringelman and Flake 1980, Cowardin and Blohm 1992). This led Cowardin and Johnson (1979) to conclude that estimates of the number of broods fledged can be heavily biased due to poor detectability. Consequently, brood surveys have fallen into disfavor due to concerns about variable detection rates.

Historical survey methods for waterfowl broods included aerial surveys (Pospahala et al. 1974), roadside transects (Hammond 1970), brood beat-outs (Smith

1971, Stoult 1971, Hammond and Johnson 1984), and fixed observation points (Evans and Black 1956, Rumble and Flake 1982). However, none of these survey techniques specifically accounted for incomplete sightability (Giudice 2001).

A number of statistical methods have been developed for estimating sightability and have been used to improve counts of rare or secretive animals (e.g., Thompson 2004, MacKenzie et al. 2005). These include double-sampling (Bart and Earnst 2002), distance-sampling (Rosenstock et al. 2002), removal methods (Farnsworth et al. 2002), and various mark-recapture approaches. Double-sampling requires an ability to conduct complete counts for comparison with incomplete counts (Bart and Earnst 2002).

Distance sampling requires the ability to measure observed distances from a point or transect line to the objects being surveyed (Rosenstock et al. 2002). Removal methods (Farnsworth et al. 2002) break a long observation period into several smaller intervals and examine the rate at which new individuals are acquired through time, allowing for estimation of the proportion of individuals that are never observed. Closed-population mark-recapture approaches can be utilized with 2 or more independent observers, or 2 or more sequential observation periods (Otis et al. 1978, Moore et al. 2004). All of these methods provide a means to estimate the probability of detection ( $p$ ). This estimate can then be applied to count estimates to reduce sightability bias, where:  $\hat{N} = \frac{C}{\hat{p}}$ , in which  $C$  represents the apparent count,  $\hat{p}$  is the estimated probability of detection, and  $\hat{N}$  is an estimate of true abundance.

The use of sightability adjustments in estimating brood numbers is not new. Bennett (1967) used multiple observation periods over a period of less than a week and

calculated abundance based on a removal method in which the probability of observing previously unrecorded broods declined in relation to the total number of broods recorded. Rumble and Flake (1982) derived correction factors using a Lincoln-Petersen estimator in which they combined brood numbers through beat-outs with numbers seen by hidden observers. Gabor et al. (1995) utilized mark-recapture analysis as a means of estimating sightability in aerial brood surveys conducted in the Great Clay Belt of northern Ontario. Broods were observationally marked according to species, brood size, and age class (Gollop and Marshall 1954). Broods marked in the first survey were compared to broods observed in the second survey, conducted 1 to 2 days later (Gabor et al. 1995). A comparison of the number of resighted versus newly sighted broods in the second survey allowed them to calculate a visibility correction factor and estimate total brood density using a simple Lincoln-Petersen estimator (Gabor et al. 1995). Although these studies provided a means to estimate brood sightability, they usually only accounted for 1 variable (species) in influencing sightability, despite the recognition that multiple variables influence brood sightability (Diem and Lu 1966, Hammond 1970, Ringelman and Flake 1980, Giudice 2001). Recently developed modeling approaches provide a means to examine the influence of multiple variables on sightability, thereby providing less biased estimates of population size (White 2005). Giudice (2001) used radio-marked mallards (*Anas platyrhynchos*) in Alberta, Saskatchewan, and Manitoba to estimate sightability correction factors for known broods using both roadside and walk-up surveys. This allowed him to not only estimate sightability of mallard broods, but also to examine the influence of multiple variables including brood age, observer experience, weather, time of day, and percent visual obstruction (Giudice 2001).

The main objective of my study was to examine the potential for using closed-population mark-recapture techniques to estimate detection probabilities of duck broods in the Prairie Pothole Region. In addition, I examined multiple factors that might influence sightability of duck broods, including the effects of species, observers, time of day, brood age, wetland characteristics, duckling densities, weather, and survey methodology (roadside vs. walk-up surveys).

### **Study Area**

I conducted my study in 2006, in the Devils Lake Wetland Management District of northeastern North Dakota within Benson, Cavalier, Nelson, Ramsey, Towner, and Walsh counties. This study was integrated with a number of ongoing studies conducted by the Delta Waterfowl Foundation to investigate the effects of predator management on waterfowl breeding biology and productivity. I conducted my research on 8 93-km<sup>2</sup> (6 x 6 mile) study sites comprised of both public and private land (see Chapter 1 for further description of study sites).

### **Methods**

#### *Assumptions of Closed-population Mark-recapture Models*

1. The population is spatially and demographically closed over the entire sampling period (Otis et al. 1978, Williams et al. 2002).
2. Animals are correctly marked and these marks are not lost over the course of the sampling period (Otis et al. 1978, Williams et al. 2002).
3. All animals within the population have equal probabilities of being recorded (Otis et al. 1978).
4. Observers perform surveys independently and each replicate is independent of previous replicates.

*Walk-up surveys*

I conducted 2 rounds of walk-up brood surveys from 2-25 June 2006 for early hatching broods and from 2-25 July 2006 for late-hatching broods. Order of surveys within rounds for each study site followed the same order as the first, such that roughly 30 days elapsed between the date I surveyed the study site on the first round and the date I surveyed the same study site on the second round. This timing was designed to ensure that no early-hatching broods would fledge before the first round ended, broods would not fledge between rounds, and very few late-hatching broods would be missed.

Each survey consisted of 3 separate replicates, with the first conducted between 0800-1230, the second between 1300-1730, and the third between 1800-2130. Observers conducted surveys on 5 randomly selected 32-ha (800 x 400 m) plots per study site. All plots were located in areas dominated by perennial cover (e.g., Conservation Reserve Program (CRP) fields) because it would have been difficult to get landowner permission to conduct surveys on croplands when growing crops may have been damaged by investigators (Fellows and Buhl 1995). Two observers worked independently and separately for brood surveys, with 1 observer surveying wetlands on roughly half of each plot while the other observer surveyed the remainder. One of the observers had conducted brood surveys the previous year, whereas the other observer was a novice and had received 2 weeks training prior to collecting data. Observers selected 1-3 vantage points (based on wetland size and visibility) that maximized visibility of the wetland basin while minimizing brood disturbance. Observers conducted surveys using binoculars and 15-60x spotting scopes. Observers rotated between replicates to avoid confounding observer effects with time of day effects, such that each wetland would be

surveyed by 1 observer twice and another observer once, but both observers collected data during all 3 time periods. Only wetlands in which the entire basin was visible from 1 or more vantage points were included in the survey. I excluded wetlands  $> 5$  ha to reduce the potential for broods being inaccurately identified. I also excluded wetlands that were completely obscured by emergent vegetation (about 20% of all the wetlands available to be surveyed) from brood surveys because any broods using such wetlands would be completely undetectable. Observers spent a minimum of 5 minutes at each wetland or as long as needed to record all visible broods. Broods were identified based on species, brood size, and age class (Gollop and Marshall 1954, as cited in Bellrose 1980). I considered an individual brood on a given wetland observationally marked based on Gollop and Marshall's protocol (1954) of brood size, age-class, and species (e.g., a brood of 7 Ila gadwalls). I assumed that broods remained on the same wetland for all 3 replicates (i.e., a closed population over 1 day). I further assumed that a brood from a later replicate that differed from an earlier replicate by  $\leq 1$  sub-age class (e.g., Ila versus I Ib) or  $\leq 3$  ducklings represented the same brood as in the earlier replicate (this was necessary because broods were often observed for only short periods and counts and aging were therefore imprecise). Observers recorded wetland cover type (Stewart and Kantrud 1971), percent inundation (in intervals of 20%) (compared to printouts from the U.S. Fish and Wildlife Service's (USFWS) National Wetland Inventory), and percent of the wetland perimeter surrounded by tall emergent vegetation (in categories of 0, 20, 40, 60, 80, or 100%). Observers also recorded weather conditions at the start of each survey, including air temperature ( $^{\circ}\text{C}$ ), cloud cover and precipitation (sunny, light rain, cloudy),

and wind speed (km/h). I measured temperature and wind speed using a Skymate wind meter SM-18.

### *Roadside surveys*

Two rounds of roadside surveys were conducted from 3-26 June 2006, and 3-26 July 2006 on the same study sites used for walk-up surveys, using all passable roads within each study site. The order of roadside surveys followed the same order as used for walk-up surveys. I included all wetlands within 150 m of the roadside for which 100% of the basin was visible from the road. Three replicates were conducted following the same time intervals as used for walk-up replicates; travel direction was reversed for the second replicate, but both the first and the third replicates were run in the same direction. One observer conducted each replicate using binoculars and a 15-60x spotting scope, while the second person recorded data. The observer and recorder rotated assignments between replicates. Surveys of each wetland lasted a minimum of 1 minute, but observers could spend any length of time beyond that to record all visible broods. Data recording procedures were identical to those used for walk-up surveys and observers recorded weather conditions at the start of the survey and at hourly intervals thereafter. I did not conduct roadside or walk-up surveys under conditions of heavy rain, fog, or wind speeds  $\geq 20$  mph (32 km/hour), and any surveys canceled due to weather conditions were conducted on the following day.

### *Data Analysis*

I determined the area of each wetland basin by comparing estimates of wetland inundation (determined at the time of the survey) to estimates taken during pair surveys on the same wetlands (3-18 May 2006). I applied this adjusted estimate (in intervals of

20%) to estimates of wetland area derived by creating and measuring a digital layer using ArcGIS (Version 9.1, ESRI Inc. 2005), based on georeferenced aerial photos taken by the USFWS in late April to early May 2006. I constructed an encounter history for each brood using 0 to indicate that a brood was not detected during a particular replicate and 1 to indicate that it was detected during that replicate. For example, a brood recorded during all 3 replicates would have an encounter history of 111, whereas a brood recorded only during the first replicate would have an encounter history of 100. Ignoring broods that went undetected over all 3 replicates (and were therefore unknown to me), this produced 7 possible capture histories (Williams et al. 2002). I used maximum-likelihood estimators calculated in Program MARK (White and Burnham 1999) to estimate detection probabilities based on these capture histories. Overall sightability ( $\hat{p}$ ) can be calculated as  $\hat{p} = 1 - (1 - p_1)(1 - p_2)(1 - p_3)$ , which is 1 minus the probability that a brood went undetected over all 3 occasions (Williams et al. 2002). These encounter histories were analyzed using the Huggins' closed-capture model (Huggins 1989, 1991) in Program MARK, which allows for temporal variation in sightability and observable heterogeneity among broods. The Huggins' model is a linear-logistic multinomial model in which the likelihood is conditioned on the number of animals detected, meaning that only broods that were encountered at least once are included in analyses (Huggins 1989, 1991; Moore et al. 2004; Fletcher and Hutto 2006). This allows for the incorporation of individual covariates in the closed population mark-recapture analyses in which

$$p_i = \frac{e^{\beta_0 + \beta_1 x_i}}{1 + e^{\beta_0 + \beta_1 x_i}} \text{ where } x_i \text{ represents the covariate value for individual } i \text{ (Huggins 1989,}$$

1991; Williams et al. 2002). In the Huggins' model, estimates of abundance are derived

parameter and where individual covariates are included estimates of abundance are

based on the Horvitz-Thompson estimator:  $\hat{N} = \sum_{i=1}^n \frac{x_i}{\hat{p}_i}$  meaning that detection

probabilities are uniquely calculated for each individual (Horvitz and Thompson 1952, Williams et al. 2002, Alldredge et al. 2006).

I considered each replicate a separate capture event and allowed capture probabilities to vary for each replicate. Recapture probability ( $c$ ) was constrained to equal capture probability,  $c_{2,3} = p_{2,3}$ , meaning that observations were treated as being independent, such that a detection on a prior occasion does not influence a detection on a subsequent occasion (Moore et al. 2004, Fletcher and Hutto 2006). I used the logit link function in MARK for all analyses (White and Burnham 1999), which constrains detection probabilities to fall within the logical parameter space of 0 - 1. I used the small-sample extension of Akaike's Information Criterion ( $AIC_c$ ; Burnham and Anderson 2002) to determine the best-supported models.

I considered 4 different *a priori* variables to be potential main effects: time of day, species, study site, and observer. With 3 time periods (morning, afternoon, evening), up to 6 species groups, 8 study sites, and 2 observers, I could not consider a fully factorial model ( $3 \cdot 6 \cdot 8 \cdot 2 = 288$  total parameters), so I first fit univariate models to determine if each variable acting alone was explanatory (i.e., led to a reduction in  $AIC_c$  over a null model incorporating no variation in that parameter). I further examined the relationship of species effects by testing both a hybrid model that pooled all dabblers versus all divers and another hybrid model that pooled all dabblers versus divers, but treated gadwalls (*Anas strepera*) as similar to divers (Hammond 1970). If 2 or more

variables were explanatory, I considered multivariate combinations that incorporated either factorial (e.g., time \* species) or additive (e.g., time + species) relationships between all explanatory pairs of variables (see Lebreton et al. 1992 for discussion of model notation). If 3 or more variables were explanatory, I added a third and/or fourth variable to the best-supported 2-variable model.

I used the best-supported model (i.e., the model with the lowest AIC<sub>c</sub> score) from these *a priori* analyses for exploratory testing of the additive effects of individual covariates. I selected 13 individual covariates (Table 2.1), based primarily on previously documented factors identified as potentially influencing brood sightability (Diem and Lu 1960, Hammond 1970, Ringelman and Flake 1980, Giudice 2001). Two of my initial covariates were highly correlated with other variables (wetland size squared and an interaction between wetland size and percent emergent vegetation surrounding the wetland), so I excluded them from further consideration. I treated the covariates representing time of day, observers, species, study site, survey type, and cloud cover as dummy variables (i.e., values coded as 0 or 1), whereas all other remaining variables were either ordinal or continuous and I transformed them using Z-transformations

$(\frac{x - \bar{x}}{sd})$  so that each covariate would have a mean of 0 and a SD of 1 (Table 2.1).

I used a stepwise forward-selection approach to determine if the best-supported main-effects model could be improved by incorporating a single individual covariate, which was modeled to have a similar effect over all species and observers (i.e., utilizing ‘logit parallelism,’ sensu Lebreton et al. 1992). If a covariate did not lead to a reduction in AIC<sub>c</sub>, I discarded it from further analysis and the model including that covariate was

discarded from the model set. If 2 or more single covariates improved the support of the main-effects model, I considered 2-covariate models by adding to the top-supported single-covariate model any other covariates that improved the support over the main-effects model. I retained any models that led to reductions in  $AIC_c$ , and discarded from further consideration any models (and covariates) that led to increases in  $AIC_c$  over the previous best-supported model. I continued this approach, sequentially adding additional covariates, until none of them led to improvements (reductions in  $AIC_c$  values) over the prior model.

## Results

I detected a total of 1,367 broods, including 306 mallards, 503 blue-winged teal (*Anas discors*), 158 northern shovelers (*Anas clypeata*), 43 northern pintails (*Anas acuta*), and 225 gadwalls. I treated each of these species separately, and pooled a group of 123 diver broods, which included 55 redheads (*Aythya americana*), 10 canvasbacks (*Aythya valisineria*), 31 ruddy ducks (*Oxyura jamaicensis*), 26 lesser scaup (*Aythya affinis*), and 1 ring-necked duck (*Aythya collaris*). My first analysis examined the influence of univariate models compared to a null model treated to have no variation in sightability. The model including a full species effect among all 6 groups was best-supported by the data. However, given the small sample size for pintails, I tested 2 post-hoc models that pooled pintail broods with either shovelers (Hammond 1970) or mallards (Diem and Lu 1960, Rumble and Flake 1982). The model pooling pintails with shovelers had more support than either the full species model or the model pooling pintails with mallards ( $AIC_c$  weights = 0.48, 0.24, and 0.23; respectively, Table 2.2) and was the best-supported

of the univariate models, so I pooled pintails with shovelers for all remaining analyses. I then tested for multivariate relationships. The model incorporating a factorial effect between time and species and an additive effect of observer had the best-support of all models tested ( $AIC_c$  weight = 0.87, Table 2.3).

I used this best-supported main-effects model as my base model for conducting a stepwise approach to examine the influence of the remaining 13 individual covariates. This analysis identified 8 individual covariates that better described the data than the base model alone (Table 2.4), with total ducklings per wetland and brood size being the most important ( $AIC_c$  weights = 0.87 and 0.13, respectively). Using a forward-selection approach, I sequentially added individual covariates starting with these 2 covariates until all 8 covariates had been ranked and the addition of another covariate no longer reduced the  $AIC_c$  value. The best-supported model from this analysis included the factorial effects of species and time of day with the additive effects of observers, total ducklings per wetland, brood size, mean wind speed, date of survey, and percent emergent vegetation surrounding the wetland perimeter ( $AIC_c$  weight = 0.60, Table 2.4).

Observers, total ducklings per wetland, brood size, mean wind speed, and date of the survey all had positive effects on sightability (Table 2.5, Fig. 2.1-2.4), whereas percent emergent vegetation surrounding the wetland perimeter had a negative effect (Table 2.5, Fig. 2.5). Based on the best-supported model, I estimated sightability rates for each species during each time period (Fig. 2.6), while setting all other variables equal to their mean. Mean sightability was highest during the evening (0.420, 95% CI = 0.354, 0.488), was intermediate in the morning (0.403, 95% CI = 0.337, 0.471), and was lowest in the early afternoon (0.369, 95% CI = 0.306, 0.435). Mean sightability was 0.316 (95% CI =

0.263, 0.375) for mallard broods, 0.307 (95% CI = 0.266, 0.352) for blue-winged teal, 0.373 (95% CI = 0.304, 0.447) for shovelers and pintails, 0.417 (95% CI = 0.349, 0.488) for gadwalls, and 0.574 (95% CI = 0.479, 0.663) for combined divers. Mean sightability for observer 1 was 0.443 (95% CI = 0.415, 0.471), whereas mean sightability for observer 2 was 0.350 (95% CI = 0.287, 0.417). Mean sightability over all variables was 0.379 (95% CI = 0.332, 0.465). The probability that any given brood was detected on at least 1 of the 3 replicates on an individual day (overall sightability ( $\hat{p}$ )) was 0.681 for mallards, 0.671 for blue-winged teal, 0.755 for northern shovelers and northern pintails, 0.803 for gadwalls, and 0.923 for divers.

## **Discussion**

Results from my study demonstrate that sightability adjustments could result in considerable reduction of bias in brood abundance estimates. The use of 3 sampling occasions in conjunction with sightability-adjustment provides dramatically different estimates than if a standard brood survey protocol had been used with only 1 survey occasion. Using the median brood numbers from broods recorded on each replicate to represent a standard single survey brood estimate, such a survey would have only detected 30 – 55% of the available broods, depending upon species (Table 2.6).

Mallards and blue-winged teal had the lowest sightability rates, shovelers, pintails, and gadwalls were intermediate, and divers had the highest sightability. These results are similar to those suggested by other studies. Hammond (1970) provided sightability correction factors based on comparisons of brood numbers to pair numbers in which estimates were derived by comparison to canvasback numbers considered to have 100% sightability. These correction factors were equivalent to 0.455 for mallards, 0.442

for blue-winged teal, 0.352 for northern shovelers, 0.287 for northern pintails, 0.709 for gadwalls, and a range from 0.676 to 1.0 depending on the species of diver (Hammond 1970). While these estimates are generally higher than the estimates in this study, the differences between species are comparable, except that I found pintails and shovelers had higher sightability than mallards and blue-winged teal. Rumble and Flake (1982) used a Lincoln-Petersen estimator to combine observation (lasting 2.5 hours) and flush techniques to develop sightability correction factors. Average sightability estimates were 0.709 for mallards, 0.758 blue-winged teal, 0.606 northern pintails, and 0.758 for gadwalls. These estimates are considerably higher than the estimates in this study, however the methodologies used were drastically different. Giudice (2001) used radio-marked broods and ground-based methodologies similar to those used in this study, and reported an average sightability of mallard broods of 0.37, which is similar to the estimate obtained in this study.

The main factors related to sightability of waterfowl broods in this study were species, time of day, observers, density of ducklings on the wetland, wind speed, and percent emergent vegetation surrounding the wetland. Previously documented factors influencing brood sightability include species, time of day, observers, wind speed, brood age, survey methods, percent visual obstruction, cloud cover, and survey date (Diem and Lu 1960, Hammond 1970, Ringelman and Flake 1980, Giudice 2001). I found sightability of waterfowl broods was about 1.3-fold higher for a more experienced observer who had conducted brood surveys in the previous year, compared to a novice assistant who had received 2 weeks of training prior to collecting data. Giudice (2001) also found more experienced observers detected more broods than less experienced

observers. These results indicate the importance of incorporating observer effects in sightability estimates. I had only 2 observers in this study, which allowed me to readily model individual observer effects. However, in studies with multiple observers, accounting for observer variability would not be as straightforward, although observers could potentially be grouped according to previous survey experience.

Time of day strongly influenced sightability, particularly for blue-winged teal, shovelers, and pintails, with sightability being more than 10% lower in the early afternoon than in either the morning or evening. These results corroborate the suggestions of Hammond (1970) and Ringelman and Flake (1980), who suggested that brood surveys should occur in the early morning and evening, whereas Diem and Lu (1960) found that brood counts were highest at dawn. However, Giudice (2001) found that time of day did not strongly influence sightability of mallard broods when other predictors were included in his analyses, and similarly, time of day did not strongly affect sightability of mallard broods in my study (Fig. 2.6).

The number of ducklings per wetland and brood size both were positively related to sightability. This suggests that broods may behave differently at higher brood densities (i.e., remain in the center of wetlands), or that observers may have spent more time at wetlands with higher brood densities, either of which could have improved sightability. In addition, my results suggest that sightability increased on days with higher wind speeds. Although I used a wind speed cutoff of 32.2 km/h this result contradicts most previously documented reports on the influence of wind speed. Diem and Lu (1960) found that when wind speeds exceeded 24.1 km/h most dabbling broods were found along the shore or in emergent vegetation, whereas Ringelman and Flake (1980) and Giudice

(2001) concluded that even mild winds ( $\geq 7$  km/h) could influence brood sightability.

However, my results suggest that broods that were out in open water on days of higher wind speeds may have behaved differently (i.e., less readily hid in cover).

Survey date had a positive albeit modest effect on sightability, suggesting that observer experience may have improved over the course of the study, or that brood behavior may have changed as the season progressed. Other factors that change seasonally and might improve sightability, such as older broods, reduced wetland inundation, or more favorable species composition (i.e., more gadwalls and divers, fewer pintails and mallards) were included as alternative covariates. Ringelman and Flake (1980) found sightability of broods increased with Julian date and this variable had the strongest relationship of any variable they tested. They speculated that this result was caused by either changes in wetland characteristics or duckling behavior (Ringelman and Flake 1980). However, Giudice (2001) suggested brood age and visual obstruction was driving this relationship and found brood age to be a better predictor of brood sightability than survey date. Neither of these authors speculated that observer experience could be driving this positive relationship.

Percent of the wetland surrounded by tall emergent vegetation had a negative, but weak effect on sightability. However, cover type was not related to sightability, although I excluded wetlands completely inundated with vegetation (i.e., extreme cover type I) because broods would have been undetectable with the methods used in this study. Giudice (2001), who used radiomarked mallard broods and did not depend on broods being observable, found that visual obstruction and percent cover both influenced sightability of mallard broods.

Other factors generally considered to influence brood sightability had little effect in this study. These factors included duckling age class, survey methodology (roadside vs. walk-up), upland habitat type, and wetland size. Age class was not related to sightability and had the least support of any covariates included in models, but Diem and Lu (1960) and Giudice (2001) found older broods had lower sightability than younger broods, whereas Ringelman and Flake (1980) found older broods had higher sightability than younger broods. Survey methodology (roadside vs. walk-up) received minimal support and sightability estimates indicated that walk-up surveys had only slightly higher sightability than roadside surveys (1.8%). Giudice (2001) found roadside surveys had slightly greater sightability than walk-up surveys. These results suggest roadside surveys do not bias sightability of waterfowl broods. Provided roadside surveys can be designed to ensure samples are representative of the population of interest, the simpler-to-implement roadside surveys could be used in place of walk-up surveys.

#### *Evaluation of Assumptions*

The primary assumption of the survey methodology and analyses that I used is that the population is closed over the entire sampling period (Otis et al. 1978, Williams et al. 2001). Kendall (1999) examined the effect of violating this assumption and determined that in cases where movement on or off study areas was random, individual capture probabilities were affected and precision was reduced, but overall estimates for the population of interest were not biased. Kendall (1999) concluded that, provided estimates were robust, the advantages of closed population models over open population models (i.e., variability in capture probabilities) outweigh the potential for closure violation. To reduce the potential for violating this assumption, sampling occasions were

conducted within a short time frame (roughly 13 hours from start to finish). Given typical rates of interwetland brood movements (e.g., Evans et al. 1952, Beard 1964, Rotella and Ratti 1992), this sampling frequency should have minimized problems caused by immigration or emigration. In addition, observers took precautions to reduce influencing the behavior of broods. Smith (1971), who used brood beat-out techniques to estimate brood abundance, believed that mallard and pintail broods left wetlands for upland cover at the first sign of investigator disturbance. However, Evans et al. (1952) marked ducklings to evaluate waterfowl brood movement caused by researcher activity and concluded that although broods in some cases moved off wetlands, researcher activity generally had little effect in driving broods to other wetlands, and in some cases researchers were unable to drive broods from wetlands. Consequently, although it is impossible to entirely avoid investigator disturbance of duck broods (Dzubin and Gollop 1972), the methods used in this study should have caused minimal movement of broods, and so estimates should not have been biased by violation of the closure assumption.

The second assumption is that marks are not lost or overlooked, and that all animals are correctly marked (Otis et al. 1978, Williams et al. 2001). To reduce the possibility of violating this assumption I conservatively assumed that brood differences of  $\leq 3$  ducklings or  $\leq 1$  sub-age classes were the same brood previously recorded. In addition, I used a roadside transect width of 150 m and excluded wetlands  $> 5$  ha to further ensure broods were correctly identified and counted.

The third assumption, that all animals have equal probability of being captured (Otis et al. 1978), is biologically unrealistic, but the use of maximum likelihood estimators, grouping of species, including time variation, and the use of individual

covariates allows for incorporating heterogeneity in estimates. This should reduce the potential for bias as a result of violation of this assumption. The final assumption, that observers worked independently and that each replicate was independent of other replicates required diligence by observers to avoid assisting one another and to avoid surveying wetlands differently as a result of previous observations from earlier replicates. In this study, observers rotated among each replicate, which minimized the potential for allowing previous observations to bias surveys. In addition, brood numbers and wetland numbers were relatively high, which likely kept observers too busy to behave differently based on experience from previous replicates.

Unlike other methodologies designed to account for reduced sightability such as the use of radio transmitters to provide a known population (Giudice 2001) or conducting brood beat-outs (Rumble and Flake 1982), the methodology used in this study requires less labor and fewer resources. However, one draw back to this method, is that weather conditions remain suitable throughout all 3 replicates. In instances when this does not occur, all 3 replicates needed to be conducted again.

### **Management Implications**

Sightability was not influenced by study site variation in this study, but I used the same 2 observers for all 8 study sites and sightability did vary among observers. These results indicate the importance of experience, training, attentiveness, and the physical ability of surveyors. Beyond the use of multiple sampling, the methods used in this study were not dramatically different from traditional roadside or walk-up surveys of broods, but estimates of abundance from this method accounted for a considerable amount of sightability bias. Three sampling occasions were used in this study. Although it would

be possible to use only 2 replications, this would reduce the precision of results (MacKenzie and Royle 2005). In addition, this study was conducted in an area with a high abundance of breeding ducks, which facilitated large samples of broods; on areas with lower numbers of broods, precision will be reduced. This could potentially be offset by increased replication, but replicates should be kept as close together as possible to ensure the closure assumption is not violated. The results from my study indicate that roadside or walk-up brood surveys that do not account for sightability dramatically underestimate brood abundance of prairie-nesting waterfowl.

Table 2.1. Explanatory variables used in the analyses of waterfowl brood sightability in northeastern North Dakota, USA, 2006.

Codes refer to binomial (Bin.), ordinal (Ord.), categorical (Cat.), or continuous (Cont.) variables.

Variable	Description	Code	Mean	Range
Time	Encounter occasion, 0 = undetected, 1 = detected	Bin.	AM = 0.51 AFT = 0.44 PM = 0.53	0 or 1
Species	6 groups	Cat.		0 or 1
Site	8 study sites	Cat.		0 or 1
Age	Duckling age class (Gollop and Marshall 1954), where Ia-Ic = 1-3 and III = 7	Ord.	3.6	1-7
BS	Brood size, number of ducklings within a brood (maximum from all 3 replicates)	Cont.	6.3	1-20
Ducklings	Total number of ducklings observed on wetland (max. from all 3 replicates)	Cont.	33.6	1-128
Cover	Wetland cover type (Stewart and Kantrud 1971), 1 = closed and 4 = open	Ord.	2.99	2-4
Size	Wetland size in ha	Cont.	1.05	0.04-4.49
WetVeg	Wetland perimeter surrounded by tall emergent vegetation (intervals of 20%)	Cont.	87.2	0-100
Date	Date of survey (expressed as Julian date for analysis)	Cont.	7 Jul	2 Jun – 26 Jul
Clouds	Cloud cover, where 0 = sunny, 1 = cloudy	Bin.	0.1	0 or 1
Wind	Average wind speed in km/h	Cont.	10.7	2.0 - 23.7
Temp	Average temperature in °C	Cont.	24.6	14.9-31.8
Method	Survey type: 0 = roadside or 1 = walkup survey	Bin.	0.22	0 or 1
Obs	Observer, where 0 = novice, 1 = experienced	Bin.	0.58	0 or 1

Table 2.2. Univariate analyses in which competing sightability models were ranked according to  $\Delta AIC_c$  in Program MARK for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006. The best-supported model had an  $AIC_c$  value of 5059.74.

Model	K <sup>a</sup>	$\Delta AIC_c$ <sup>b</sup>	$w_i$ <sup>c</sup>	Dev <sup>d</sup>
p(spp4) <sup>e</sup>	5	0	0.480	5049.73
p(spp) <sup>f</sup>	6	1.37	0.242	5049.09
p(spp5) <sup>g</sup>	5	1.48	0.229	5051.21
p(spp3) <sup>h</sup>	2	4.59	0	5060.33
p(spp2) <sup>i</sup>	2	28.55	0	5084.30
p(obs)	2	30.62	0	5086.36
p(time)	3	57.75	0	5111.49
p(.)	1	72.28	0	5130.02
p(site)	8	72.41	0	5116.12

<sup>a</sup> Number of estimable parameters in model.

<sup>b</sup>  $AIC_c$  difference of the current model versus the highest-ranked model.

<sup>c</sup> Relative likelihood of the current model (*i*) based on  $AIC_c$  value.

<sup>d</sup> Model deviance.

<sup>e</sup> Species variability treating pintails = shovelers.

<sup>f</sup> Full species variability.

<sup>g</sup> Species variability treating pintails = mallards.

<sup>h</sup> Variability between dabblers and divers with gadwalls grouped with divers.

<sup>i</sup> Variability between dabblers and divers.

Table 2.3. Multivariate analyses in which competing sightability models were ranked according to  $\Delta AIC_c$  values calculated in Program MARK for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006. Models were tested for both factorial (\*) or additive (+) effects. The best-supported model had an  $AIC_c$  value of 4991.24.

Model	K <sup>a</sup>	$\Delta AIC_c$	$w_i$	Dev
P((spp4 <sup>b</sup> *time)+obs)	16	0	0.870	4959.11
P((spp4*time)+obs+site)	23	3.80	0.130	4948.76
p(spp4+time+obs)	8	14.83	0.001	4990.03
p(spp4+obs)	6	26.01	0	5005.23
p(spp4*obs)	10	26.08	0	4997.26
p(spp4+site+obs)	13	29.64	0	4994.79
p(spp4*time)	15	38.09	0	4999.21
P((spp4*site)+obs)	41	51.90	0	4960.29
p(spp4+time)	7	53.86	0	5031.07
p(spp4+site)	12	76.31	0	5043.47
p(time+obs)	4	88.01	0	5071.24
p(time*obs)	6	88.58	0	5067.80
p(site+obs)	9	94.20	0	5067.40
p(site*obs)	16	95.24	0	5054.34
p(spp4*site)	40	97.81	0	5008.24
p(time*site)	24	101.85	0	5044.79
p(time+site)	10	126.38	0	5097.57

<sup>a</sup> Column descriptions as in Table 2.2.

<sup>b</sup> Species variability treating pintails = shovelers.

Table 2.4. Competing sightability models ranked according to  $\Delta AIC_c$  values calculated in Program MARK for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006. Models tested the support of the effects of species, time of day, and observer variation  $p((\text{time}*\text{spp4})+\text{obs})$ , and the additive influence (+) of individual covariates. The best-supported model had an  $AIC_c$  value of 4918.02.

Model <sup>a</sup>	K <sup>b</sup>	$\Delta AIC_c$	$w_i$	Dev
$p((\text{spp4}^{\text{c}}*\text{time})+\text{obs}+\text{ducklings}+\text{bs}+\text{wind}+\text{date}+\text{wetveg})$	21	0	0.603	4875.80
$p((\text{spp4}*\text{time})+\text{obs}+\text{ducklings}+\text{bs}+\text{wind}+\text{date})$	20	0.86	0.392	4878.68
$p((\text{spp4}*\text{time})+\text{obs}+\text{ducklings}+\text{bs}+\text{wind})$	19	10.72	0.003	4890.55
$p((\text{spp4}*\text{time})+\text{obs}+\text{ducklings}+\text{bs})$	18	10.87	0.003	4892.73
$p((\text{spp4}*\text{time})+\text{obs}+\text{ducklings})$	17	37.36	0	4921.24
$p((\text{spp4}*\text{time})+\text{obs}+\text{bs})$	17	41.24	0	4925.12
$p((\text{spp4}*\text{time})+\text{obs}+\text{wind})$	17	66.16	0	4950.03
$p((\text{spp4}*\text{time})+\text{obs}+\text{date})$	17	70.64	0	4954.51
$p((\text{spp4}*\text{time})+\text{obs}+\text{size})$	17	71.72	0	4955.60
$p((\text{spp4}*\text{time})+\text{obs}+\text{wetveg})$	17	72.38	0	4956.25
$p((\text{spp4}*\text{time})+\text{obs}+\text{temp})$	17	72.66	0	4956.54
$p((\text{spp4}*\text{time})+\text{obs}+\text{method})$	17	73.03	0	4956.90
$p((\text{spp4}*\text{time})+\text{obs})$	16	73.21	0	4959.11

<sup>a</sup> Abbreviations correspond to explanatory variables listed in Table 2.1.

<sup>b</sup> Column headings as in Table 2.2.

<sup>c</sup> Species variability treating pintails = shovelers.

Table 2.5. Beta estimates calculated in Program MARK based on the best-supported model for the analysis of waterfowl brood sightability in northeastern North Dakota, USA, 2006.

Parameter <sup>a</sup>	Estimate	SE	95% CI
$\beta_0$	0.257	0.200	-0.135 – 0.649
$\beta_{\text{obs}}$	0.410	0.061	0.291 – 0.530
$\beta_{\text{ducklings}}$	0.210	0.045	0.122 – 0.298
$\beta_{\text{bs}}$	0.279	0.048	0.185 – 0.372
$\beta_{\text{wind}}$	0.116	0.049	0.020 – 0.212
$\beta_{\text{date}}$	0.165	0.053	0.060 – 0.269
$\beta_{\text{wetveg}}$	-0.079	0.046	-0.168 – 0.011
$\beta_{\text{MALL}}$	-1.346	0.238	-1.812 – -0.880
$\beta_{\text{BWTE}}$	-0.974	0.226	-1.417 – -0.532
$\beta_{\text{NOSH/NOPI}}$	-0.745	0.254	-1.244 – -0.246
$\beta_{\text{GADW}}$	-0.954	0.246	-1.437 – -0.471
$\beta_{\text{AM}}$	-0.284	0.253	-0.780 – 0.212
$\beta_{\text{AFTERNOON}}$	-0.233	0.252	-0.727 – 0.261
$\beta_{\text{MALL*AM}}$	0.423	0.292	-0.149 – 0.995
$\beta_{\text{MALL*AFTERNOON}}$	0.407	0.291	-0.164 – 0.977
$\beta_{\text{BWTE*AM}}$	-0.027	0.276	-0.568 – 0.513
$\beta_{\text{BWTE*AFTERNOON}}$	-0.432	0.278	-0.976 – 0.112
$\beta_{\text{NOSH/NOPI*AM}}$	0.023	0.310	-0.585 – 0.631
$\beta_{\text{NOSH/NOPI*AFTERNOON}}$	-0.263	0.312	-0.874 – 0.349
$\beta_{\text{GADW*AM}}$	0.529	0.309	-0.076 – 1.135
$\beta_{\text{GADW*AFTERNOON}}$	0.433	0.308	-0.171 – 1.037

<sup>a</sup> Abbreviations correspond to explanatory variables listed in Table 2.1. MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall.

Table 2.6. Abundance estimates of waterfowl broods surveyed in northeastern North Dakota, USA, 2006. Abundance estimates based on single-occasion surveys and sightability adjustment ( $\hat{N}$ ).

Species <sup>a</sup>	Single-survey Estimate <sup>b</sup>	SE	Adjusted Estimate ( $\hat{N}$ ) <sup>c</sup>	SE <sup>c</sup> ( $\hat{N}$ )	95% CI <sup>c</sup>
MALL	147	5.5	480.6	30.4	430.5 – 550.9
BWTE	236	31.0	778.8	37.7	714.2 – 863.1
NOSH	79	8.2	218.9	14.1	196.9 – 253.2
NOPI	21	2.6	62.3	6.6	53.1 – 79.9
GADW	125	4.6	272.1	10.9	255.1 – 298.7
DIVERS	75	2.2	136.2	5.0	129.5 – 150.0

<sup>a</sup> MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall, DIVERS = combined redheads, canvasbacks, ruddy ducks, lesser scaup, and a ring-necked duck.

<sup>b</sup> Estimate derived by taking the median value of the 3 replicates.

<sup>c</sup> Sightability-adjusted estimate derived in Program MARK using the Horvitz-Thompson estimator (Horvitz and Thompson 1952).

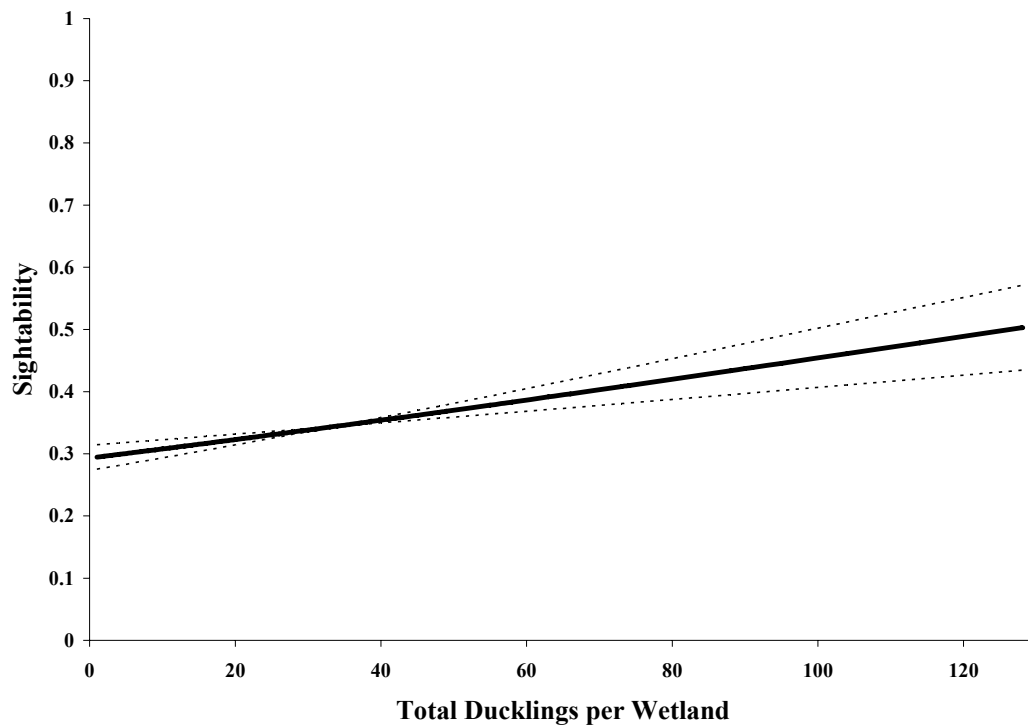


Fig. 2.1. Waterfowl brood sightability estimates over all species illustrating the additive effect of the total number of ducklings recorded per wetland based on the best-supported model calculated in Program MARK, while setting all other explanatory variables to their mean. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

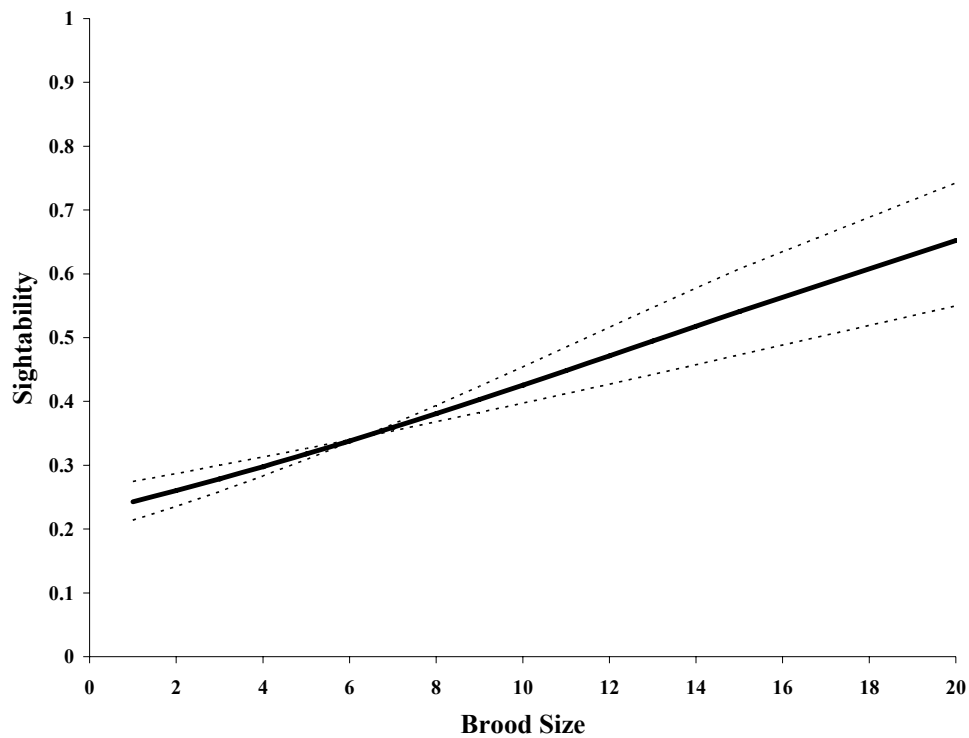


Fig. 2.2. Waterfowl brood sightability estimates over all species illustrating the additive effect of brood size based on the best-supported model calculated in Program MARK, while setting all other explanatory variables to their mean. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

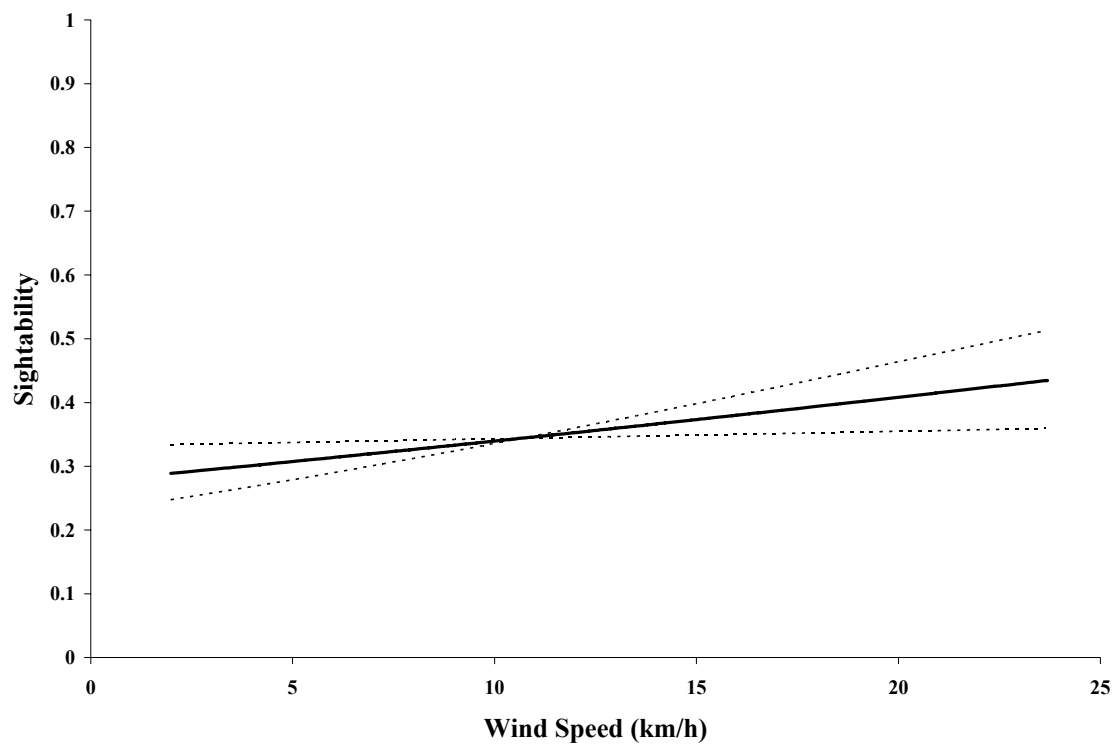


Fig. 2.3. Waterfowl brood sightability estimates over all species illustrating the additive effect of mean wind speed (km/h) over the 3 replicates based on the best-supported model calculated in Program MARK, while setting all other explanatory variables to their mean. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

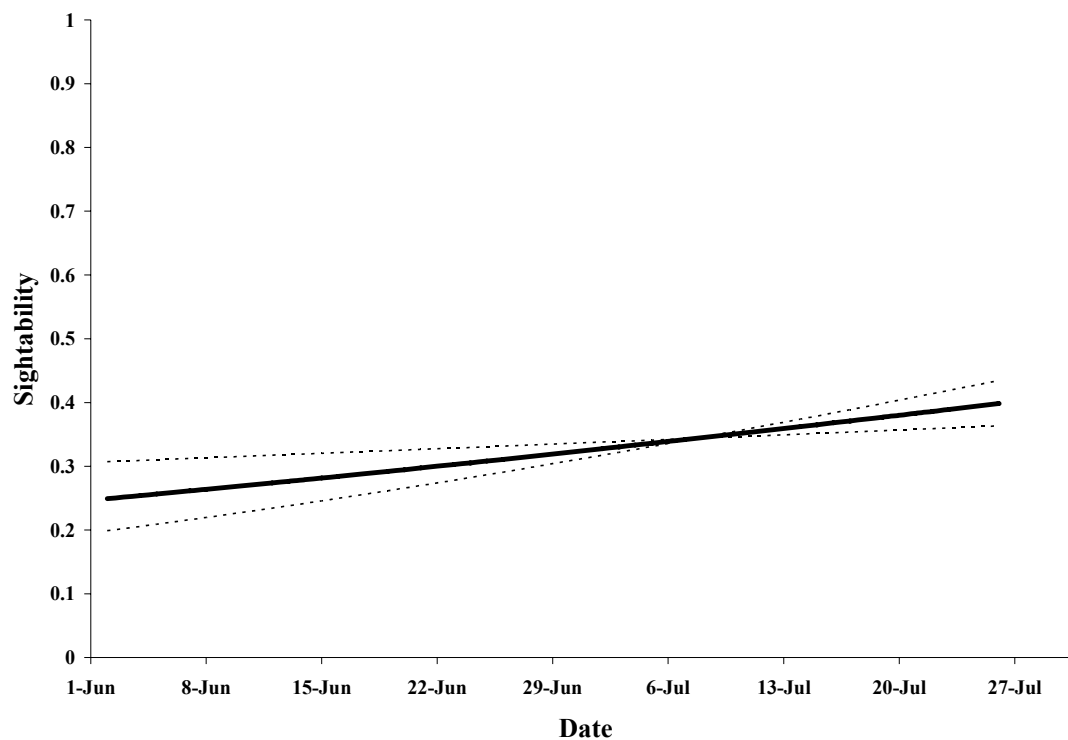


Fig. 2.4. Waterfowl brood sightability estimates over all species illustrating the additive effect of date the survey was conducted based on the best-supported model calculated in Program MARK, while setting all other explanatory variables to their mean. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

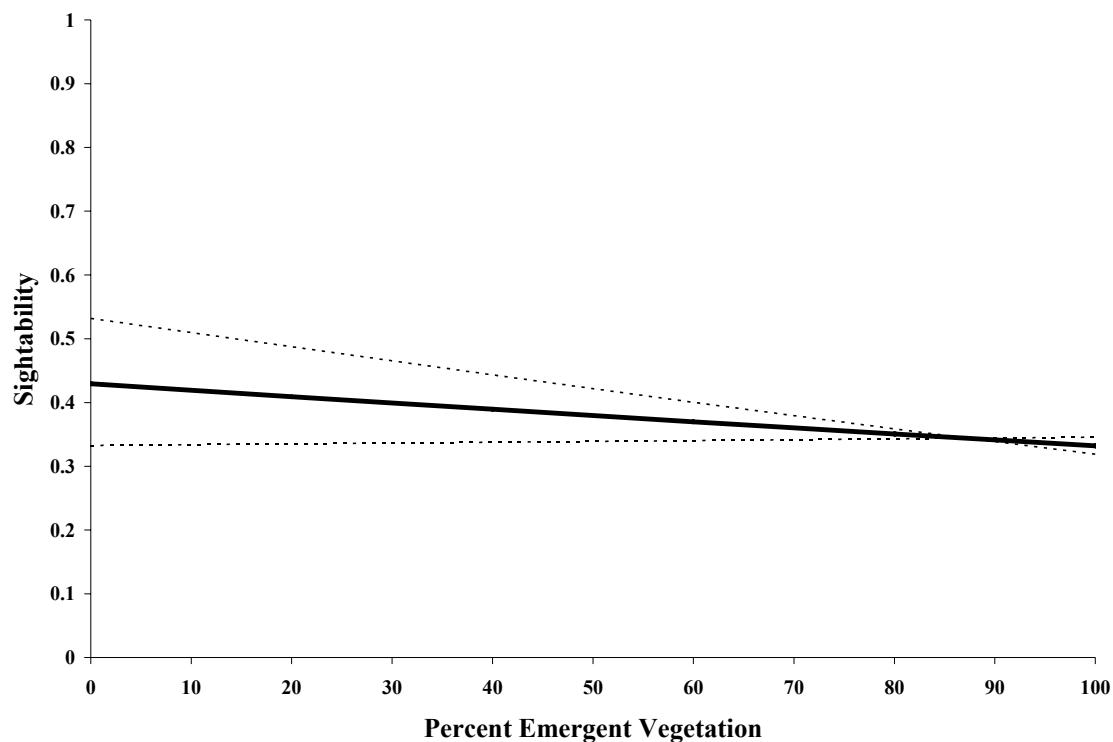


Fig. 2.5. Waterfowl brood sightability estimates over all species illustrating the additive effect of percent tall emergent vegetation surrounding the wetland perimeter based on the best-supported model calculated in Program MARK, while setting all other explanatory variables to their mean. Results based on duck broods surveyed in northeastern North Dakota, USA, 2006. Dashed lines represent 95% CI.

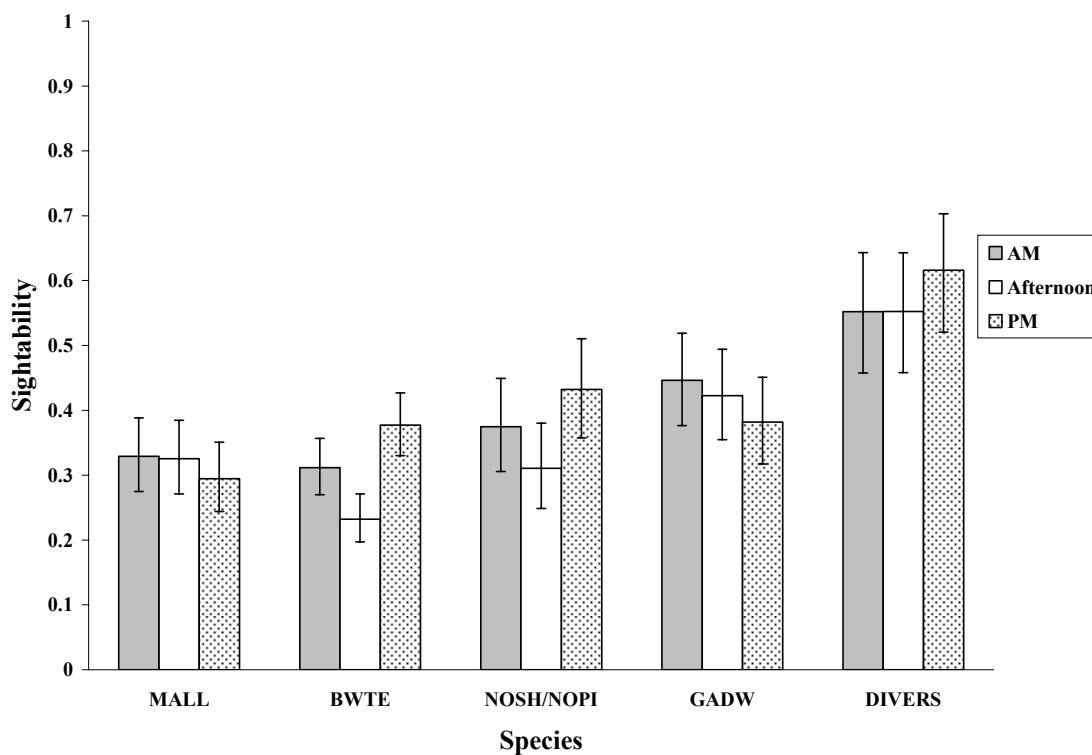


Fig. 2.6. Waterfowl brood sightability estimates for each replicate and each species based on the best-supported model calculated in Program MARK, while setting all other explanatory variables to their mean, where obs = 0.58, ducklings = 33.6, bs = 6.3, wind = 10.7 (km/h), date = 10 May, and wetveg = 87.2 (Table 2.1). Results based on duck broods surveyed in northeastern North Dakota, USA, 2006. MALL = mallard, BWTE = blue-winged teal, NOSH = northern shoveler, NOPI = northern pintail, GADW = gadwall, DIVERS = combined redheads, canvasbacks, ruddy ducks, lesser scaup, and a ring-necked duck. Error bars represent 95% CI.

## **Chapter 3. The Use of Sightability-Adjusted Brood-to-Pair Ratios to Estimate Waterfowl Productivity**

### **Introduction**

Traditional methods for evaluating waterfowl productivity include nest monitoring to determine clutch size, nesting success, and hatchability (Cowardin et al. 1985, Klett et al. 1986) and radiotelemetry to measure survival of ducklings and breeding females (Talent et al. 1983, Cowardin et al. 1985, Rotella and Ratti 1992). Brood-to-pair ratios are a simple alternative to measure waterfowl breeding productivity (Cowardin and Blohm 1992) and were used historically as a measure of waterfowl productivity. Sugden and Butler (1980) estimated that pair counts required 40 times less effort than nest searches for estimating breeding population size. Ringelman and Flake (1980) suggested that brood counts could provide more accurate estimates of waterfowl productivity than either pair or nest counts because these latter methods do not account for duckling mortality. Pospahala et al. (1974:50) stated that “brood indices presently provide the most reliable pre hunting season indication of annual reproductive performance” and Hammond and Johnson (1984:11) stated that “the brood to pair ratio, despite various drawbacks, is the most widely known and used index to productivity, and is perhaps the best currently available.” The brood-to-pair ratio is an index to hen success (the probability a hen will be successful in one or more nesting attempts; Cowardin and Blohm 1992) and early brood survival, under the assumptions that all breeding pairs and broods are detected and that all broods come from previously recorded pairs (i.e., there is

no ingress; Cowardin and Blohm 1992). A number of prominent studies have used brood-to-pair ratios to examine the long-term reproductive success of waterfowl (Evans and Black 1956, Smith 1971, Stoudt 1971, Hammond and Johnson 1984, Leitch and Kaminski 1985). In addition, Pagano et al. (University of Minnesota, unpublished report) found that duckling-to-pair ratios for mallards (*Anas platyrhynchos*) were significantly correlated with estimates of nesting success, hen success, and fledging rate, based on data from 16 study sites in the Canadian parkland.

Dzubin and Gollop (1972) identified 4 primary areas of waterfowl population ecology that required special attention. The first of these was “the formulation of statistically and biologically sound pair and brood surveys” (Dzubin and Gollop 1972:141). Although Dzubin’s (1969) recommendations have led to a standardization of techniques in counting breeding waterfowl, costs and feasibility have restricted the ability to heed all of his proposals for ensuring the accuracy of waterfowl surveys (Cowardin and Blohm 1992). One source of concern is that standard ground-based waterfowl surveys are conducted without taking into account detection probabilities. Instead, surveys use standardized methods to minimize differences in detection probabilities among surveys with the implicit assumption that detection rates are consistent (Anderson 2001, 2003; White 2005, but see Bart et al. 2004). This assumption of consistent sightability among observers, species, time periods, and habitats has come under intense scrutiny within the wildlife literature (Nichols et al. 2000; Anderson 2001, 2003; Rosenstock et al. 2002; Thompson 2002; White 2005) and in one case has been shown to be false for ground-based pair and brood surveys in the Prairie Pothole Region (Chapters 1 and 2).

I used an independent double-observer methodology (Nichols et al. 2000, Moore et al. 2004) to estimate detection probabilities in ground-based waterfowl pair surveys on 8 study sites in northeastern North Dakota (Chapter 1). Later that year, I used closed-population mark-recapture techniques to estimate sightability-bias in ground-based waterfowl brood surveys on the same 8 study sites (Chapter 2). I determined that traditional ground-based surveys would have detected 71 – 90% of the available indicated breeding pairs and 30 – 55% of the available broods, depending upon species. My results demonstrated that sightability was  $<1$  for both surveys, and more importantly, was of unequal magnitude between pair and brood surveys. This suggested that brood-to-pair ratios adjusted for sightability should provide improved estimates of waterfowl productivity versus unadjusted estimates. Using nesting success as an estimate of breeding productivity, I examined the potential for using sightability-adjusted brood-to-pair ratios as an alternative estimate of productivity for prairie-nesting waterfowl.

### **Study Area**

I conducted my study in 2006, on 8 93-km<sup>2</sup> (6 x 6 mile) study sites in the Devils Lake Wetland Management District of northeastern North Dakota within Benson, Cavalier, Nelson, Ramsey, Towner, and Walsh counties. As described in Chapter 1, 5 of these sites were part of Delta Waterfowl's predator management research involving the lethal removal of medium-sized mammalian predators, whereas the other 3 study sites had no ongoing predator trapping and served as controls for the predator management study.

## Methods

### *Brood-to-Pair Ratios*

As early-nesting species (e.g. mallards) were the species of primary interest in this study, I conducted 1 round of walk-up and roadside pair surveys from 3-18 May 2006 using an independent double-observer methodology (see Chapter 1 for a further description of methods). I used an indicated breeding pair (IBP) criteria following Dzubin (1969), such that lone pairs, grouped pairs, lone males, and males in groups of  $\leq 5$  were treated as paired individuals. Later that year, I conducted 2 rounds of walk-up and roadside brood surveys from 2-26 June 2006 for early hatching broods and from 2-26 July 2006 for late-hatching broods using closed-population mark-recapture techniques to estimate sightability of waterfowl broods (see Chapter 2 for a further description of methods). Order of surveys within rounds for each study site followed the same order as the first, such that roughly 30 days elapsed between the date I surveyed the study site on the first round and the date I surveyed the same study site on the second round. This timing was designed to ensure that no early-hatching broods would fledge before the first round ended, broods would not fledge between rounds, and very few late-hatching broods would be missed. Based on results from a concurrent nesting study, 24% (494 nests) of all nests found were projected to hatch after 2 July and only 0.3% (7 nests) were projected to hatch after 25 July (M. Pieron, Louisiana State University, unpublished data).

As described in Chapters 1 and 2, I analyzed both pair and brood data using Huggins' closed-capture models (Huggins 1989, 1991) in Program MARK (White and Burnham 1999). I used the small sample extension of Akaike's Information Criterion

(AIC<sub>c</sub>; Burnham and Anderson 2002) to determine the best-supported models. The best-supported model describing sightability of IBPs included the effects of species, observers, duck densities, wetland size, precipitation, and time of day (model selection approaches and analyses are described in Chapter 1). Using the best-supported model, I estimated sightability for all IBPs recorded for each species. The best-supported model describing sightability of waterfowl broods included the effects of species, observers, time of day, duckling densities, wind speed, date of the survey, and percent tall emergent vegetation surrounding the wetland perimeter (model selection and analyses are described in Chapter 2). Based on the best-supported model, I estimated sightability for all broods recorded for each species.

To calculate brood-to-pair ratios, I excluded all IBPs recorded on wetlands that were not surveyed in either round of brood surveys because vegetation obscured the wetland from being surveyed (about 20% of the indicated breeding pairs). To ensure broods recorded in the second round of surveys were not the same broods recorded in the first round, I excluded all broods recorded in the second round that were older than roughly 36 days of age (> class IIb; Gollop and Marshall 1954). Because roughly 30 days elapsed between rounds of surveys, this should have minimized the potential for double-counting. I calculated 2 estimates of brood-to-pair ratios. The first estimate represents a traditional single-occasion and single-observer survey in which I used the median number of broods recorded between the 3 replicates conducted within an individual day divided by the mean IBPs recorded between the 2 observers. For the second estimate, I calculated sightability-adjusted brood-to-pair estimates in which I divided my sightability-adjusted estimate of brood abundance by my sightability-adjusted

estimate of pair abundance determined in Program MARK as described in Chapters 2 and 1, respectively.

### *Nesting Success*

I used estimates of nesting success for mallards, blue-winged teal (*Anas discors*), and gadwalls (*Anas strepera*) and combined estimates per study site that consisted of mallards, blue-winged teal, northern shovelers (*Anas clypeata*), northern pintails (*Anas acuta*), and gadwalls from a concurrent nesting study conducted on the same study sites on 6 – 7 32-ha (800 x 400 m) plots per study site (M. Pieron, Louisiana State University, unpublished data). Plots were located in areas dominated by perennial cover (primarily in the form of federal Waterfowl Production Areas or Conservation Reserve Program fields) because it would have been difficult to gain landowner permission for work on cropland. The nesting study conducted 3 rounds of nest searches from 5 May to 25 June using methodology similar to Klett et al. (1986). Estimates of nesting success were derived using the Mayfield estimator (Mayfield 1961, 1975). I compared brood-to-pair ratios from both single-occasion and sightability-adjusted estimates for each species from all 8 study sites with measures of nesting success using simple Pearson correlations.

### **Results**

Mallards, blue-winged teal, and gadwalls were the most abundant species in this study. Sightability-adjusted estimates of indicated breeding pairs ranged from 30 – 104 for mallards, 55 – 137 for blue-winged teal, and 27 – 62 for gadwalls. Nest numbers ranged from 21 – 125 for mallards, 32 – 117 for blue-winged teal, and 46 – 134 for gadwalls. Sightability-adjusted brood numbers ranged from 20 – 65 for mallards, 37 – 99 for blue-winged teal, and 7 – 67 for gadwalls. Estimates of productivity varied among

sites (Table 3.1). Nesting success ranged from 19 – 100% for mallards, 34 – 75% for blue-winged teal, and 40 – 80% for gadwalls. Single-occasion estimates of brood-to-pair ratios ranged from 10 – 29% for mallards, 13 – 39% for blue-winged teal, and 13 – 117% for gadwalls, whereas sightability-adjusted estimates of brood-to-pair ratios ranged from 29 – 83% for mallards, 36 – 109% for blue-winged teal, and 24 – 218% for gadwalls (Table 3.2). Although estimates of abundance were much lower for single-occasion estimates than for sightability-adjusted estimates, correlations to nesting success were similar (Table 3.3). Correlations between brood-to-pair ratios and nesting success ranged from 34 – 77% for single occasion estimates and from 32 – 74% for sightability-adjusted estimates (Table 3.3, Fig. 3.1-3.4). However, correlations were significant only for combined data from the 5 most abundant upland-nesting species (Table 3.3, Fig. 3.1).

## **Discussion**

I used nesting success as an index of productivity to test the potential for using sightability-adjusted brood-to-pair ratios as an alternative estimate of waterfowl productivity. Provided they are accurate, brood-to-pair ratios provide an index of waterfowl productivity that incorporates nesting success, renesting effort, and early brood survival (Cowardin and Johnson 1979), whereas nesting success provides only 1 measure of productivity (Cowardin and Blohm 1992). Although simple models have been developed to convert estimates of nesting success into estimates of hen success (Cowardin and Johnson 1979; T. W. Arnold, personal communication), I did not use them in this study because, unless these models incorporate variable estimates of renesting effort, they are simply non-linear transformations of nesting success. Nevertheless, nesting success is the most important and most widely used determinant of

recruitment rates in prairie-nesting mallards (Cowardin and Johnson 1979, Klett et al. 1988, Hoekman et al. 2002).

I found that brood-to-pair ratios explained about 60% of the variation in nesting success when data from the 5 most abundant upland-nesting species were combined per study site, whereas estimates for mallards and blue-winged teal explained about 25% of the variation in nesting success. Nesting success was exceptionally high in this study (averaging 36 – 76% over all upland-nesting species combined; Table 3.1), which given potential renesting effort, reduced the amount of variability among sites necessary to show strong correlations. In addition, with only 8 study sites and 1 year of data (6 degrees of freedom), it would have been necessary to observe an effect size of  $R^2 \geq 0.50$  to support significant ( $\alpha = 0.05$ ) correlations between nesting success and brood-to-pair ratios. Unlike estimates of nesting success, brood-to-pair ratios incorporate multiple measures of productivity (including renesting effort and early brood survival), which could also explain why I did not find stronger correlations (i.e., lack-of-fit might be due to the poor performance of nesting success as a measure of productivity, and not vice versa).

The assumption in using brood-to-pair ratios is that pairs produce broods on the wetlands where they were recorded and that broods do not move into or out of the sampling area (Cowardin and Blohm 1992). Although these 2 assumptions are undoubtedly false, brood movements would not produce biased estimates of productivity provided that movements on or off wetlands was random (Flint et al. 1995), which would be expected provided that the initial sample of wetlands was random. Given that I excluded wetlands completely obscured by vegetation, this exclusion could influence my

results if broods preferentially selected (or avoided) wetlands with more abundant vegetative cover. Another difference between the estimates of nesting success and brood-to-pair ratios is that nesting success was examined only on sites containing perennial cover. I conducted walk-up surveys of pairs and broods entirely on perennial cover, but roadside surveys included wetlands from varying upland habitats. Nesting success has been found to vary depending upon habitat type (Klett et al. 1988, Johnson et al. 1992, Emery et al. 2005) and this habitat variation between nesting success estimates and brood-to-pair ratios could have potentially influenced correlations in my study.

Gadwalls and blue-winged teal had brood-to-pair ratios on some sites that were  $>1$ . One explanation for this is that I only conducted 1 round of pair surveys. As mallards were the species of primary interest in this study, I timed pair surveys to occur when approximately half of the female mallards had started nesting, so that males in small groups could be presumed to reflect paired males whose mates were on nests, whereas unmated males could be presumed to occur in groups  $>5$  (Dzubin 1969, but see Brasher et al. 2002). Consequently, my pair surveys may not have adequately documented later-breeding species, including gadwalls and blue-winged teal (Hammond 1969, Bellrose 1980), which would explain why I had some unrealistically high estimates of brood-to-pair ratios for these species.

Although my analysis generally failed to show significant correlations between estimates of nesting success and brood-to-pair ratios, sightability-adjustment in most cases had similar correlations to my single-occasion ratios. Sightability-adjusted brood-to-pair ratios were dramatically higher than single-occasion brood-to-pair ratios and these estimates of productivity were much more similar to nesting success estimates than

single-occasion estimates (Tables 3.1-3.2, Fig. 3.1-3.4), even if differences between sites did not follow a linear trend. These results indicate brood-to-pair ratios that do not account for sightability-bias would underestimate productivity of prairie-nesting species.

### **Management Implications**

Brood-to-pair ratios provide an index to waterfowl productivity that is inexpensive, and provide information early enough in the regulatory process to be used in setting hunting regulations (Pospahala et al. 1974, Cowardin and Blohm 1992). I found single occasion brood-to-pair ratios dramatically underestimated productivity compared to sightability-adjusted estimates. In addition, correlations of sightability-adjusted brood-to-pair ratios to nesting success were generally high, although only statistically significant when all species were combined. Nevertheless, these results indicate traditional brood-to-pair ratios that do not account for sightability-bias dramatically underestimate productivity and the potential for using sightability-adjusted brood-to-pair ratios to estimate waterfowl productivity should be further explored.

Table 3.1. Nesting success and brood-to-pair ratio (BPR) estimates for upland-nesting waterfowl species combined consisting of mallards, blue-winged teal, northern shovelers, northern pintails, and gadwalls from 8 study sites in northeastern North Dakota, USA, 2006.

Site	Nesting success <sup>a</sup>	Nesting success 95% CI <sup>a</sup>	Single BPR <sup>b</sup>	Adjusted BPR <sup>c</sup>
Can	0.758	0.673 – 0.853	0.389	0.906
Minn	0.638	0.572 – 0.710	0.243	0.604
Har	0.680	0.592 – 0.781	0.259	0.654
Whit	0.469	0.401 – 0.547	0.184	0.460
McV	0.633	0.538 – 0.744	0.355	0.914
Cal	0.459	0.383 – 0.551	0.270	0.656
Cra	0.362	0.299 – 0.438	0.156	0.418
Lee	0.533	0.461 – 0.617	0.165	0.413

<sup>a</sup> Calculated using the Mayfield estimator (Mayfield 1961, 1975).

<sup>b</sup> Single-occasion brood-to-pair ratios. Calculated using the median number of broods recorded over 3 replicates divided by the mean number of indicated breeding pairs recorded by 2 independent observers.

<sup>c</sup> Sightability-adjusted brood-to-pair ratios. Calculated by dividing sightability-adjusted estimates of brood abundance by sightability-adjusted estimates of indicated breeding pair abundance.

Table 3.2. Nesting success (NS) and associated 95% CI, single-occasion brood-to-pair ratio (S BPR), and sightability-adjusted brood-to-pair ratio (A BPR) estimates for mallards (MALL), blue-winged teal (BWTE), and gadwalls (GADW) from 8 study sites in northeastern North Dakota, USA, 2006.

Site	NS <sup>a</sup>	95% CI	S BPR	A BPR	NS	95% CI	S BPR	A BPR	NS	95% CI	S BPR	A BPR
	MALL	MALL	MALL	MALL	BWTE	BWTE	BWTE	BWTE	GADW	GADW	GADW	GADW
Can	1.000	N/A	0.294	0.827	0.515	0.338 – 0.782	0.258	0.715	0.749	0.601 – 0.931	1.170	2.177
Minn	0.534	0.429 – 0.664	0.136	0.384	0.752	0.582 – 0.969	0.252	0.698	0.681	0.583 – 0.794	0.379	0.705
Har	0.669	0.511 – 0.874	0.268	0.755	0.495	0.344 – 0.711	0.208	0.575	0.799	0.665 – 0.959	0.344	0.640
Whit	0.445	0.292 – 0.674	0.104	0.294	0.340	0.245 – 0.47	0.219	0.607	0.575	0.464 – 0.711	0.283	0.527
McV	0.267	0.109 – 0.637	0.253	0.712	0.719	0.589 – 0.877	0.395	1.093	0.666	0.498 – 0.887	0.367	0.682
Cal	0.399	0.258 – 0.614	0.222	0.626	0.622	0.478 – 0.809	0.183	0.508	0.396	0.278 – 0.561	0.610	1.135
Cra	0.191	0.118 – 0.307	0.154	0.433	0.481	0.369 – 0.625	0.175	0.484	0.472	0.342 – 0.649	0.130	0.243
Lee	0.462	0.294 – 0.737	0.235	0.663	0.546	0.447 – 0.668	0.128	0.355	0.486	0.338 – 0.696	0.327	0.608

<sup>a</sup> Column descriptions as in Table 3.1.

Table 3.3. Pearson correlations ( $r$ ) between estimates of Mayfield nesting success and brood-to-pair ratio (BPR) estimates from single-occasion and sightability-adjusted estimates from 8 study sites in northeastern North Dakota, USA, 2006.

Species <sup>c</sup>	Single-occasion		Sightability-adjusted	
	BPR <sup>a</sup>		BPR <sup>b</sup>	
	$r$	P-value	$r$	P-value
MALL	0.50	0.25	0.49	0.21
BWTE	0.48	0.23	0.48	0.23
GADW	0.32	0.44	0.32	0.45
Combined	0.76	0.03	0.74	0.04

<sup>a</sup> Calculated using the median number of broods recorded over 3 replicates divided by the mean number of indicated breeding pairs recorded by 2 independent observers.

<sup>b</sup> Calculated by dividing sightability-adjusted estimates of brood abundance by sightability-adjusted estimates of indicated breeding pair abundance.

<sup>c</sup> MALL = mallard, BWTE = blue-winged teal, GADW = gadwall, Combined = mallard, blue-winged teal, northern shoveler, northern pintail, and gadwall.

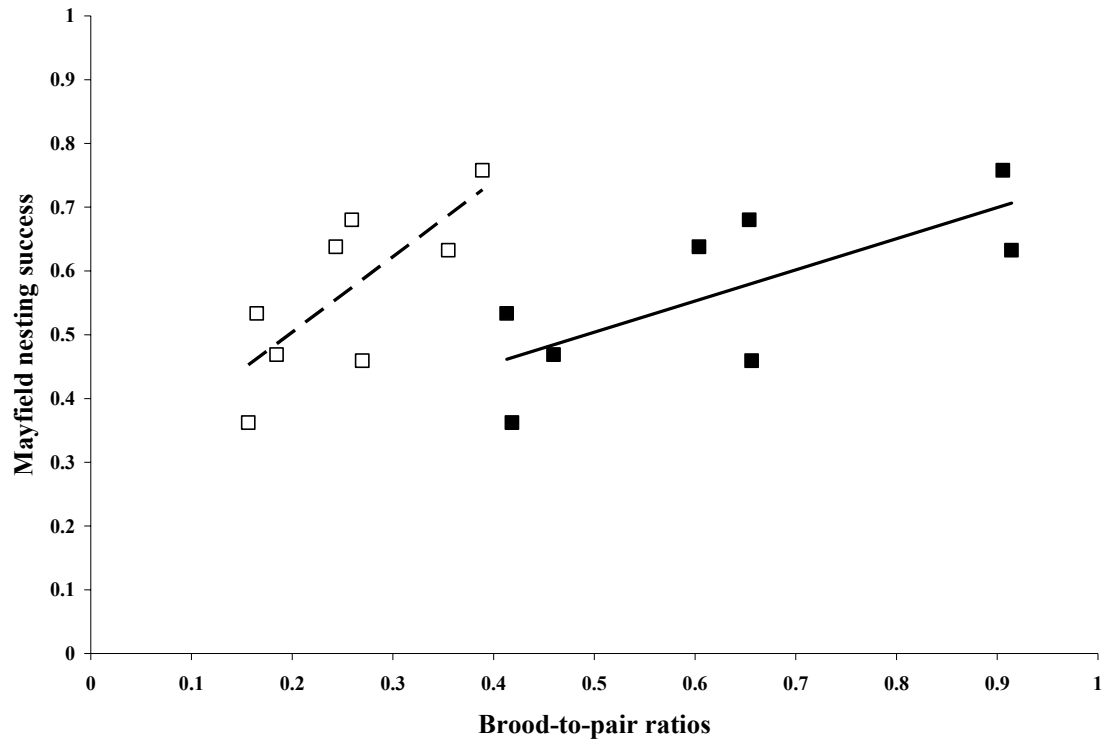


Fig. 3.1. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for combined mallards, blue-winged teal, northern shovelers, northern pintails, and gadwalls from 8 study sites in northeastern North Dakota, USA, 2006.

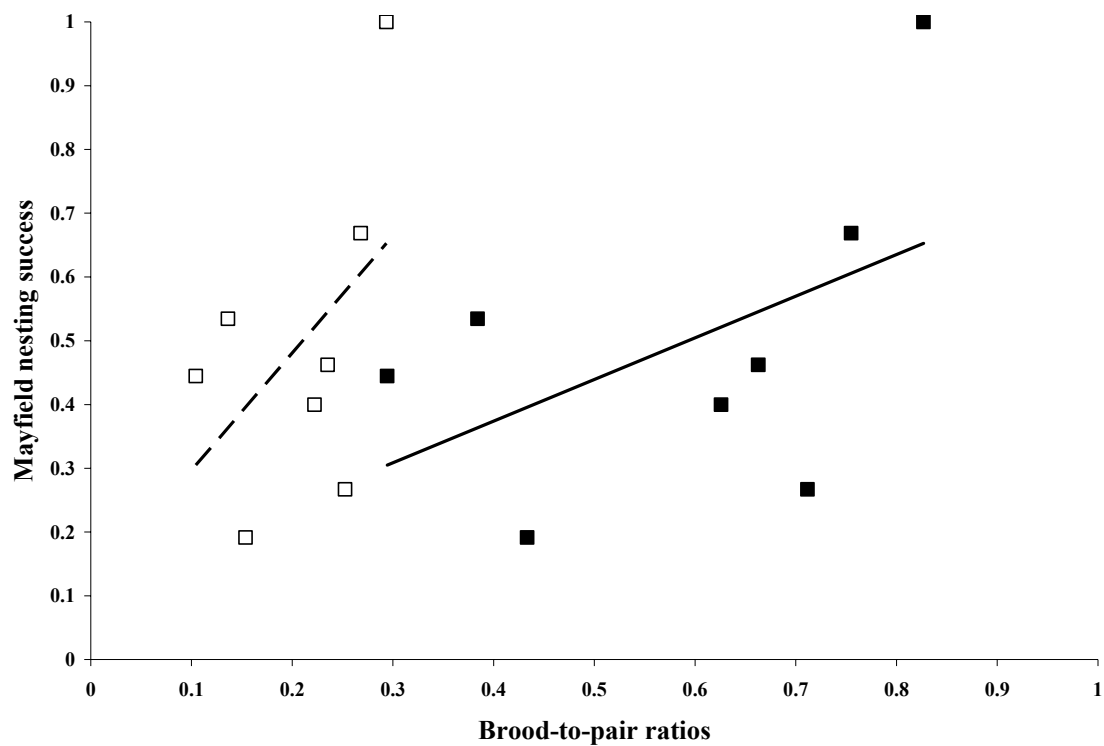


Fig. 3.2. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for mallards from 8 study sites in northeastern North Dakota, USA, 2006.

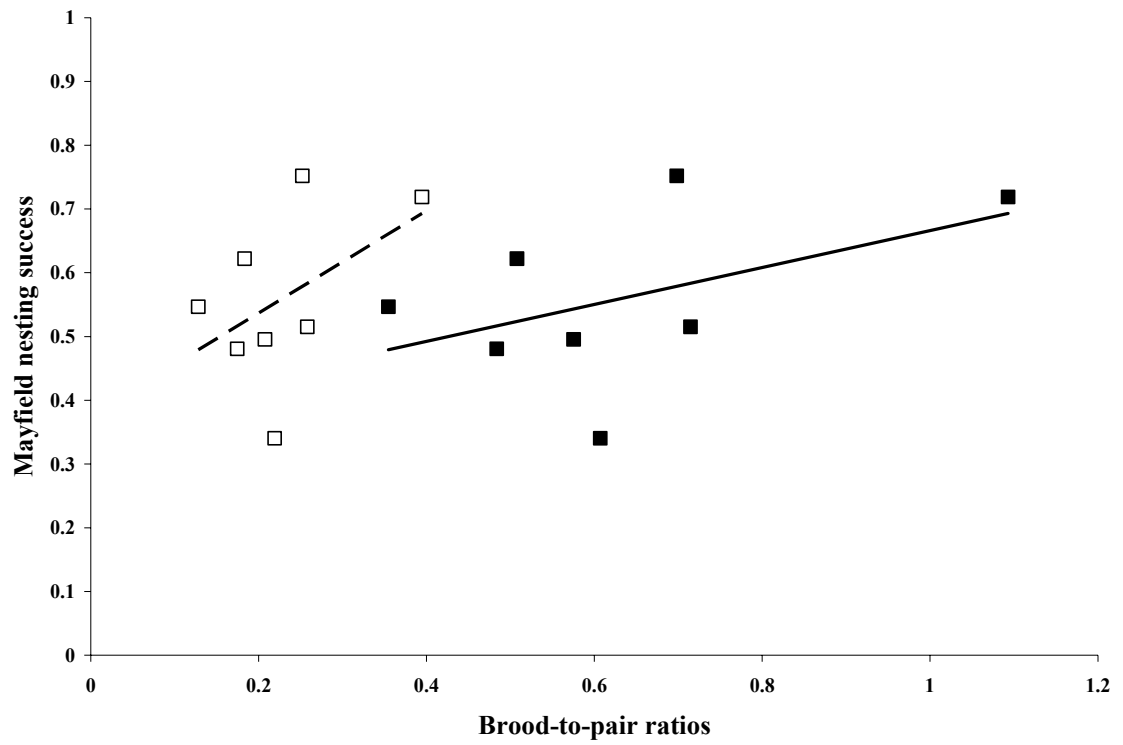


Fig. 3.3. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for blue-winged teal from 8 study sites in northeastern North Dakota, USA, 2006.

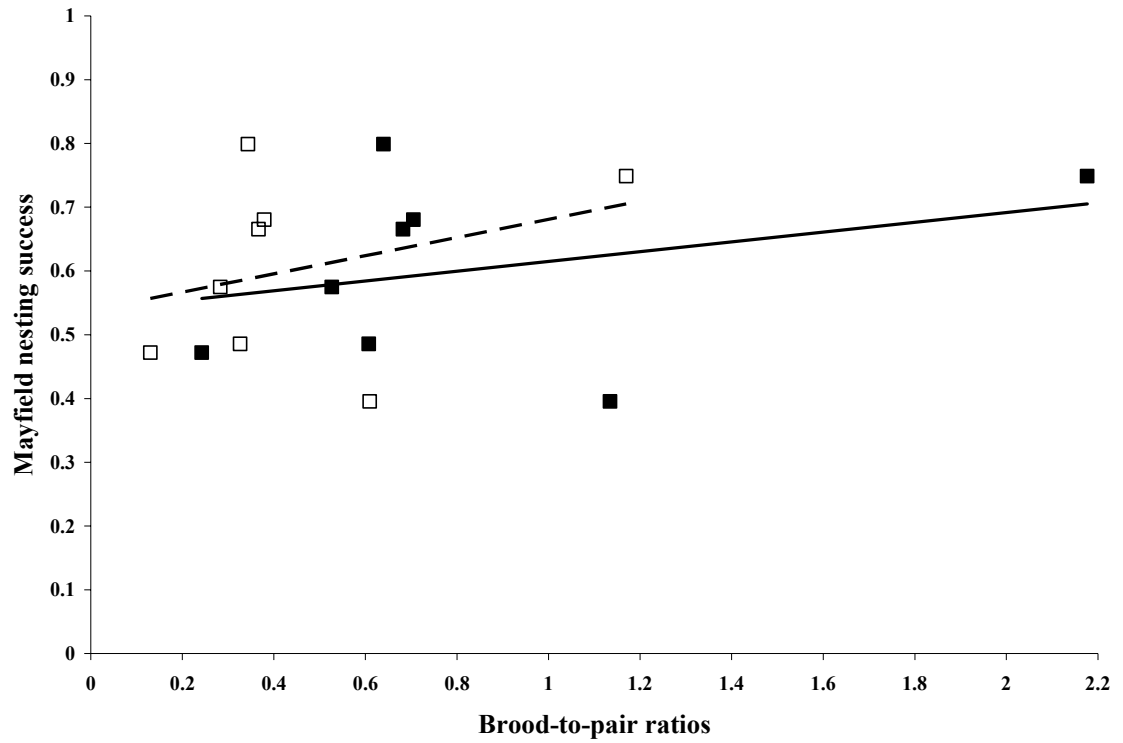


Fig. 3.4. Linear regression showing the relationship between single-occasion (open points, dashed line) and sightability-adjusted (solid points, solid line) brood-to-pair ratios and Mayfield nesting success for gadwall from 8 study sites in northeastern North Dakota, USA, 2006.

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