# A CRITICAL REVIEW OF MICHIGAN'S SPRING WATERFOWL SURVEY

By

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**ABSTRACT**

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To monitor the status of waterfowl populations, the Michigan Department of Natural Resources (MDNR) began surveying abundance of breeding ducks and geese in 1991 and developed goals for waterfowl population and habitat management tied to the spring waterfowl survey. The spring waterfowl survey required flying a series of fixed-width transects using fixed-wing aircraft to estimate statewide abundance of Canada geese (*Branta canadensis*), mallards (*Anas platyrhynchos*), mute swans (*Cygnus olor*), and sandhill cranes (*Grus canadensis*) among others. To get consistent results, standard operating procedures (SOP) have been implemented and maintained across the years. Since observers did not see all birds from the fixed-wing aircraft, estimation of waterfowl abundance required surveying a portion of transects with helicopters to establish visibility correction factors (VCF). MDNR used the VCF to adjust fixed-wing estimates assuming observers saw all birds in transects flown with helicopters. To potentially improve precision and reduce costs, we developed alternate VCFs and aerial survey designs to understand how the accuracy and precision of the waterfowl population estimate changed from the existing SOP methodology. To meet MDNR standards, we considered alternate population estimates that produced a coefficient of variation (CV) of less than 20% to be acceptable and worth consideration. We found comparable population estimates and CVs from eleven alternate VCFs and three alternate aerial survey designs compared to the SOP.

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# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# INTRODUCTION

Highly mobile species can be difficult to monitor as they cover large areas, including areas with restricted or limited access due to terrain or private land ownership (Caughley et al. 1976, Tracey et al. 2008). Some population surveys may be difficult and expensive to conduct when surveying over a state or regional level. One solution is to conduct aerial surveys to estimate population size, particularly for large mammals and birds (Norton-Griffiths 1975, Caughley 1977). Aerial surveys have been extensively conducted to estimate regional and local abundance of North American waterfowl using fixed-wing aircraft (Martin et al. 1979, Smith 1995).

One of the largest wildlife surveys takes place during the spring to estimate population sizes of waterfowl species in important breeding areas of Canada and the United States (USFWS 2018); the Waterfowl Breeding Population and Habitat Survey provides information on a wide variety of duck and goose species and helps to inform annual waterfowl hunting regulations. The MDNR collaborates with the U.S. Fish and Wildlife Service (USFWS), the Canadian provinces, and the Canadian Wildlife Service (CWS) to conduct aerial surveys from April to June to monitor important waterfowl populations across Canada and the northern United States (USFWS 2018).

Beginning in 1991, MDNR began a pilot study to survey distribution and abundance of waterfowl. Since 1991, the MDNR has annually conducted the spring waterfowl survey to monitor population trends of breeding ducks and geese and developed goals for waterfowl population and habitat management (Cleveland 1994, Soulliere and Chadwick 2003). The MDNR spring waterfowl survey uses fixed-wing aircraft and helicopters to estimate statewide abundance of waterfowl with an emphasis on Canada geese (*Branta canadensis*), mallards (*Anas platyrhynchos*), mute swans (*Cygnus olor*), and sandhill cranes (*Grus canadensis*). These species are of management concern because Canada goose and mallard are hunted species, and in some cases, high abundances of Canada goose, sandhill crane, and mute swan has resulted in human-wildlife conflicts. In addition, waterfowl provide economic value and are good indicators of wetland habitat conditions (Grado et al. 2011, Hagy et al. 2016).

Canada goose populations in Michigan have increased in the past 50 years with a corresponding increase in management demand to reduce human-goose conflicts through harvest or nest destruction as populations increased to over 300,000 birds in 2015 (Ankney 1996, United States Department of the Interior 2005, Luukkonen et al. 2008). More recently, the MDNR has tried to reduce the population and achieve a statewide Canada goose abundance goal of between 175,000-225,000 birds based on the spring waterfowl survey (MDNR 2019).

A concern for mallard abundance has recently become prominent due to the increase in droughts which has negatively impacted the number of wetland habitats in the prairie pothole region (PPR), one of the most productive waterfowl habitats in the world (Johnson et al. 2005). Michigan mallard abundance is an indicator of breeding habitat conditions and so population monitoring can help detect wetland habitat loss. Ducks, especially mallards, use wetlands throughout their life for food, breeding, brood rearing, and cover from predators, so wetlands are an important habitat for ducks and a good predictor for where duck density may be the greatest (Krapu and Reinecke 1992, Austin et al. 2001, Anteau 2012, Bartzen et al. 2017). With a potential decrease in wetland abundance, mallard productivity could decrease and impact mallard abundance, specifically in southeast Michigan based on a predictive model of mallard distribution (Yerkes et al. 2007, Singer et al. 2016). Although Michigan’s wetland hydrology has not been as negatively affected as the PPR, recent mallard abundance estimates for Michigan have been below expectations. Estimated wetland abundance in 2018 was slightly above the long-term average, although long-term climatic change predicts decreased quantity and quality of mallard habitat (Singer et al. 2016, USFWS 2018).

Sandhill crane abundance in Michigan has rebounded from declines caused by historic overharvesting and wetland habitat loss, and now significant human-crane conflicts through crop depredation are occurring (Meine and Archibald 1996, Avers et al. 2017). Due to their aggressive behavior, mute swans have been out-competing and displacing native species including trumpeter swans (*Cygnus buccinator*) and destroying native wetland habitat (Stone and Marsters 1970, Ciaranca 1990, MDNR 2012). In the case of the invasive mute swan, a DNR policy calls for reducing their abundance with a short-term goal of stabilizing numbers and a long-term goal of fewer than 2,000 birds (MDNR 2012).

While these four species are the most abundant or important species counted using the MDNR spring waterfowl survey, other waterfowl species are recorded as well. Other species of dabbling ducks like wood duck (*Aix sponsa*), gadwall (*Mareca strepera*), American wigeon (*Anas americana*), green-winged teal (*Anas carolinensis*), northern pintail (*Anas acuta*), and northern shoveler (*Anas clypeata*) and diving ducks like ring-necked duck (*Aythya collaris*), canvasback (*Aythya valisineria*), lesser scaup (*Aythya affinis*), and greater scaup (*Aythya marila*), bufflehead (*Bucephala albeola*), long-tailed duck (*Clangula hyemalis*), hooded merganser (*Lophodytes cucullatus*), and common merganser (*Mergus merganser*) are detected on the aerial survey. Although the abundance of these waterfowl species is estimated from the spring waterfowl survey, they are not as well represented due to their low breeding abundance in Michigan. While the wood duck is a common species in Michigan, they are more prone to take cover in forested wetland habitat which makes it difficult for observers to detect them, resulting in highly variable underestimates of their population size (Bellrose and Holm 1994).

The MDNR spring waterfowl survey is a statewide survey with observers flying a series of 21 fixed-width transects using fixed-wing aircraft (Figure 1; CWS and USFWS 1987, Smith 1995). Each transect is then made up of varying numbers of segments depending on the length of the transect. To get consistent results, standard operating procedures (SOP) have been implemented and maintained across the years (CWS and USFWS 1987; see Appendix for a full description of the SOP). Fixed-wing observers can fail to detect all birds and may misidentify waterfowl species which can result in population estimates with low precision and high bias (Green et al. 2008). Since detection is imperfect for observers in fixed-wing aircraft, a sample of fixed-winged segments have historically been resurveyed using helicopters (Caughley 1974). Helicopters provided more reliable detection for observers. Additionally, helicopters are more maneuverable and efficient compared to fixed-wing aircraft (Ross 1985, Cordts et al. 2002). The MDNR has used visibility correction factors (VCFs), based on the helicopter flights, to correct fixed-wing counts, yielding species-specific statewide abundance estimates that are thought to be less biased than uncorrected estimates. Helicopter surveys have not been flown every year due to expensive costs and labor constraints, so mean statewide species-specific VCFs from all VCF years have been used to correct annual fixed-wing survey counts. A new VCF is calculated for each VCF year, with a VCF year defined as a year in which both the fixed-wing and helicopter surveys are conducted. Then, the MDNR used corrected mean fixed-wing density estimates from segments to expand for the area of Michigan to compute population estimates.

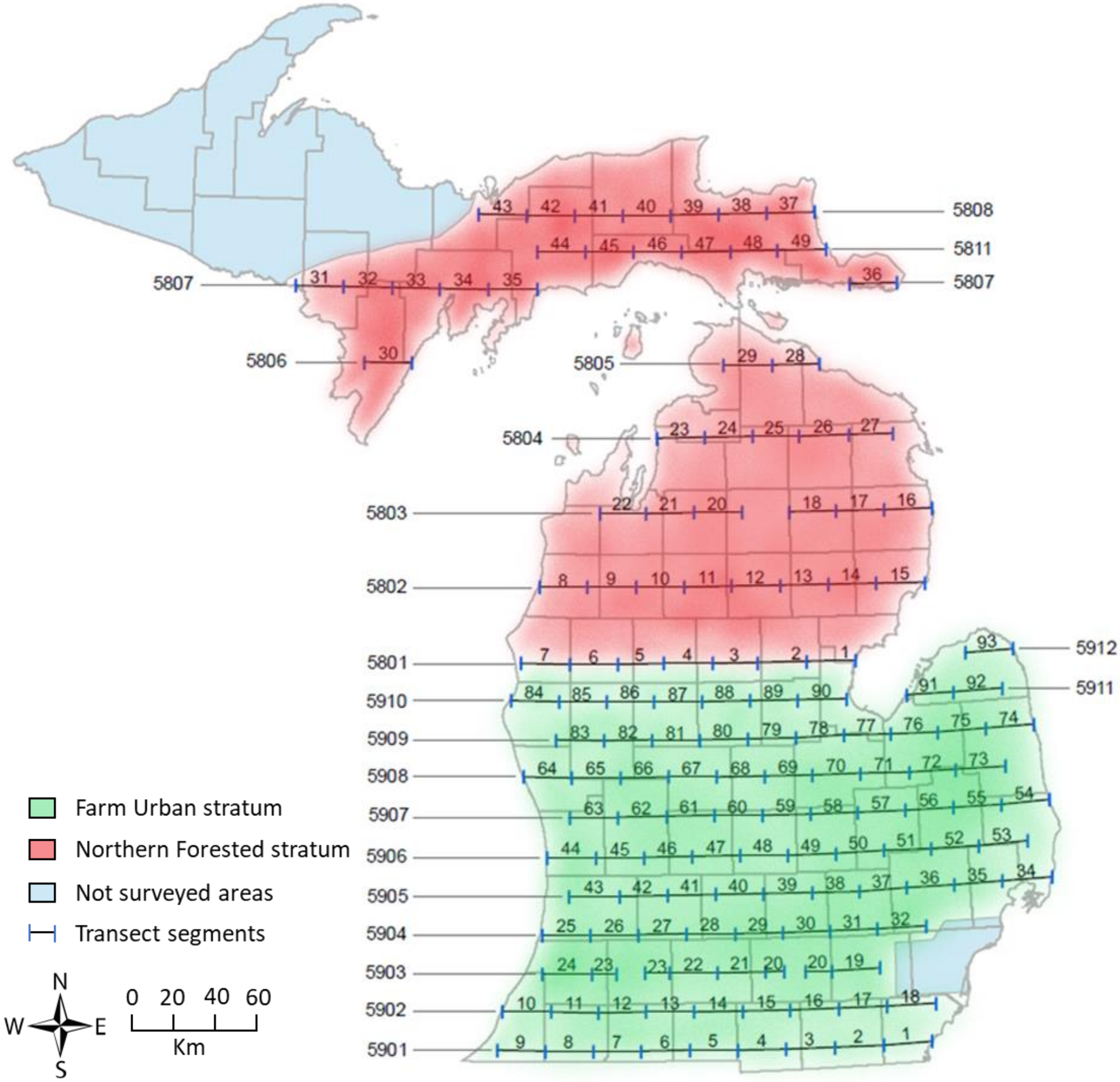



Figure 1. Map of Michigan DNR's spring waterfowl survey with east-west survey transects (4-digit numbers) shown as solid lines. Transect numbers 5901-5912 (segment numbers 1-93) define the "farm urban" survey stratum and transect numbers 5801-5811 (segment numbers 1-18 and 20-49) are in the "northern forested" stratum. Since 2014, segment 19 in the northern forested stratum was removed. Farm urban stratum is shown in green, northern forested stratum is shown in red, and non-surveyable areas are shown in light blue.

To provide reliable results, survey methodologies need to periodically be examined and reevaluated, as many factors (e.g., weather, observers, population demographics, and survey cost) could change over time (Cowardin and Blohm 1992, Tracey et al. 2008, Mills 2012, Ransom 2012, Schummer et al. 2018). Michigan's waterfowl spring survey has only been evaluated once. MDNR has not formally evaluated their current SOP survey design since 1994 (Cleveland 1994), so another evaluation of the survey is needed to determine if abundance estimates are reliable, cost-effective, and precise. Additionally, the costs of aircraft, observers, and survey stratification have changed. Since 1991, the MDNR has been using the same aerial survey field methods to provide consistent data collection.

Other aerial survey projects differ from Michigan's aerial survey and suitability of other aerial survey designs can be evaluated to determine utility for Michigan. For example, an assessment of wintering American black ducks (*Anas rubripes*) in the Atlantic flyway changed from a systematic sampling design to a stratified sampling design with multiple strata (Conroy et al. 1988). This modification in their survey methodology helped to increase precision and adjust for underestimation from fixed-wing aircraft. Moreover, a recommendation for the Atlantic Flyway Breeding Waterfowl Survey to use hierarchical models to estimate waterfowl abundance instead of stratified random sampling was based on evaluating historical aerial survey data (Sauer et al. 2014). Lastly, the CWS and the USFWS jointly monitor American black duck populations in eastern Canada and the northeastern United States (Zimmerman et al. 2012). The CWS uses a helicopter plot survey while the USFWS uses a fixed-wing transect survey. After considering alternative models, they used a hierarchical model to aggregate and analyze data from both survey methods to obtain one population estimate for this region. Since many survey approaches may meet the MDNR's objectives, it is important to consider modifications that might improve survey efficiency.

Recently, helicopter costs for MDNR were reduced through a partnership with the Michigan State Police (MSP). Helicopter surveys are expensive but detect more birds compared to the fixed-wing survey. The MDNR was able to increase the number of helicopter flights, which also opened the possibility of using alternative aerial survey designs. One possibility could be to conduct the entire spring waterfowl survey only using helicopters. If the MDNR budget was not constrained, helicopter surveys could be surveyed every year if possible, as observers in a helicopter have higher detection rates than observers in a fixed-wing aircraft. Currently, reduced expenses in helicopter costs may make a helicopter-only aerial survey design feasible. Alternatively, the MDNR could use a modified SOP where some fixed-wing transects are removed to allocate more effort to helicopter surveys. An improved aerial survey design might minimize variance or achieve comparable precision on population estimates to the SOP from fewer transects, reducing time and expenses for the spring waterfowl survey. To quantify precision, the MDNR uses the coefficient of variation (CV) which is a standardized measure of dispersion. The MDNR attempts to achieve a CV of 20% or less on annual estimates of abundance for the spring waterfowl survey.

A component that affects the accuracy of the waterfowl population estimate using the SOP survey methodology is the species-specific VCFs used to correct the fixed-wing counts. Currently, the SOP uses an all-year (long-term) average species-specific VCFs. When the helicopter survey is conducted, each historic VCF is averaged with the current VCF. For example, eight VCF years exist from 1992-1996, 2003, 2010, and 2014. To determine the 1995 all-year VCF, the MDNR averaged the 1992, 1993, 1994, and 1995 VCF values. From 1992-

1996, the number and location of helicopter surveys were determined by cost, aircraft, and personnel time which might result in bias since the VCF segments were not representative of the state of Michigan (Cleveland 1994). The number of years selected to estimate VCFs will impact population estimates as well as the variance. If the MDNR uses all years to estimate VCFs, population estimates may have increased precision, but the long-term average VCF may not accurately estimate annual detection if there are changes to the system over time (i.e., changes in weather, observers, pilots, etc.; Soulliere and Chadwick 2003). A rolling average like a three or five-year statewide VCF estimate may be a viable alternative to accurately represent how the detection may change over time while also maintaining a CV of 20% or less on population estimates.

## Research Objectives

The purpose of this research was to evaluate the current SOP for the MDNR spring waterfowl survey by analyzing historical data (1992-2017) and by conducting two years of expanded helicopter surveys (2018-2019). This research also addressed if other aerial survey designs may be more cost-effective. The specific research objectives were as follows:

1) To determine if modifications to existing MDNR survey methodologies can improve the precision of their aerial survey and estimation of waterfowl abundance.
    a. To estimate visibility correction factors (VCFs) and determine if the current aerial survey methodologies are appropriate for estimating waterfowl abundance in Michigan.
2) To develop alternative aerial survey designs that estimate waterfowl abundance precisely and are comparable to the SOP methodology (coefficient of variation [CV] less than 20%).
    a. To evaluate helicopter-only and modified SOP aerial survey designs to estimate precise waterfowl abundance (coefficient of variation [CV] less than 20%).
3) To determine the most efficient alternative aerial survey designs for Michigan's waterfowl.
    a. To conduct a statistical analysis to predict and compare waterfowl population estimates, coefficients of variation (CV), and costs to determine the best aerial survey designs.

# METHODS

## Study Area

To estimate Michigan's waterfowl abundance from the spring waterfowl survey, the MDNR developed a stratified systematic sampling framework to survey the whole state of Michigan. MDNR biologists believed that the detection probability of waterfowl was not constant throughout the state of Michigan (Cleveland 1994, Soulliere and Chadwick 2003). Thus, the MDNR considered stratification for the state of Michigan due to variations in cover type and land use. The MDNR divided Michigan into two strata, "farm urban" and "northern forested", and the MDNR surveyed a sample of segments within each stratum (Figure 1). The farm urban stratum encompasses approximately the southern 1/3 portion of Michigan. The northern forested stratum consists of the remaining northern 2/3 portion of the state.

The farm urban stratum is mostly defined by agricultural and urban land where plant productivity and waterfowl densities are high. Wetlands are abundant in the farm urban stratum as loam soils dominate this stratum while clay and sandy soils comprise the northern forested stratum which retains fewer wetlands. Ducks, geese, and swans are found in and near wetlands, so high waterfowl abundance is associated with a higher number of wetlands in the farm urban stratum. Plant productivity and waterfowl densities are more variable in the northern forested stratum but mostly lower than in the farm urban stratum. Although the spring waterfowl survey is a statewide survey, some areas of both strata were excluded from the survey. Portions of the hilly western Upper Peninsula, urban centers, and large airports, especially the Detroit Metropolitan Wayne County Airport, were not surveyed due to safety concerns.

## Data Collection

While historical data were used to conduct this project, we participated as observers for the helicopter portion of the 2018 and 2019 spring waterfowl survey. The MDNR typically conducted the spring waterfowl survey during the months of April and May, but the start and end dates were variable and based on many factors. Survey timing was critical for the MDNR spring waterfowl surveys to get the most accurate local breeding pair estimates (Dzubin 1969, CWS and USFWS 1987). The MDNR aimed to complete aerial surveys before nests from Canada geese hatched, when about half of the mallard females started nests, after migrant waterfowl have moved through an area, and when there was still good visibility by having less than 20% leaf-out on trees and shrubs (Soulliere and Chadwick 2003). Weather in Michigan can rapidly change within a season and vary among years, resulting in earlier or later springs that can impact when the survey would begin. Surveys were not conducted on days with rain, fog, high winds, or other conditions that reduced waterfowl detection and safety. Thus, long delays for the aerial survey could occur if harsh weather persisted for days.

To get consistent results, the MDNR maintained standard operating procedures (SOP) for the spring waterfowl survey (see Appendix for a full description of the SOP). Since there is a higher concentration of breeding ducks and geese in the farm urban stratum, more transects were surveyed in this stratum compared to the northern forested stratum. Hence, transects in the northern forested stratum are spaced 45.1 km (28 mi) apart while transects in the farm urban stratum are spaced 22.5 km (14 mi) apart (Cleveland 1994). Once the MDNR collected the data, they grouped waterfowl observations into six categories: singles, flocked drakes, pairs, nesting pairs, nesting singles, and groups. The MDNR entered the data into a relational database used to estimate abundance by species. The relational database was a quick and efficient way to organize large amounts of related data. The MDNR created quality control checks to eliminate most data entry errors. They then entered each waterfowl observation into the database with the transect number, segment number, date, species, grouping type, and wetland type. Waterfowl observations were adjusted to account for species' breeding biology and the total number of "indicated birds" was estimated for each segment. The number of singles, flocked drakes, pairs, nesting pairs, and nesting singles seen in a segment were each multiplied by two while the number of birds in a group were not adjusted to get the total number of indicated birds. Thus, indicated birds may include birds that were not seen but were assumed associated with a pair, for example.

Since helicopter flights are expensive, the MDNR only conducted helicopter surveys in eight years prior to 2018: 1992-1996, 2003, 2010, and 2014. The MDNR began and has maintained an all-year averaged VCF for each species. The MDNR has surveyed from 139 to 152 segments for the fixed-wing flights. The number of segments surveyed with helicopters within a year ranged from six to 29 prior to 2018. Some years had fewer segments surveyed because no flights were flown in the northern forested stratum in that year.

In 2018 and 2019, we maintained the current survey methodology for transect numbers, transect configuration, timing, and data collection for the spring waterfowl survey. However, we changed some survey methodology to evaluate changes in costs and precision. We aimed to conduct 40 helicopter segments for 2018 and 2019 VCF years, which was an increase from previous VCF years. We also changed to a new randomization for selecting helicopter segments to increase spatial representation for the state of Michigan (see below for a discussion of the new randomization).

## Data Analysis

The SOP aerial survey design used fixed-wing density estimates and a statewide species-specific VCF to compute population estimates (Smith 1995). The MDNR calculated density estimates from the fixed-wing survey through the relational database and extrapolated for the whole state of Michigan, including areas of the state that are not surveyed. They have used statewide species-specific VCF, based on the helicopter flights, to correct fixed-wing counts to add the number of indicated birds that were missed on the fixed-wing survey. The MDNR's helicopter surveys were not flown every year due to budget and labor constraints, so average statewide species-specific VCFs from all VCF years were used to correct annual fixed-wing survey counts. Then, the MDNR used corrected mean fixed-wing density estimates from segments to expand for the area of Michigan to compute population estimates. We assumed that observers in helicopter surveys had a 100% detection, detections were statistically independent events, the number of birds in surveyed areas did not change in a segment between the fixed-wing and helicopter survey, and all birds were not double-counted and did not move before detection. While these are estimates, we do not fully know the true population size so 95% confidence intervals are used to deal with uncertainty in our estimates.

We generated population estimates using the SOP methodology as:

$$\hat{Y} = \sum_{j=1}^{J} A_j \hat{B}_j \hat{R}_j \qquad (1)$$

where $\hat{Y}$ is the total abundance by species, $J$ is the total number of strata, j is the stratum type, $A_j$ is the total area in stratum j, $\hat{B}_j$ is the observed density per stratum, and $\hat{R}_j$ is the average statewide species-specific VCF that is applied to each stratum j.

We estimated $\hat{R}$ as:

$$\hat{R} = \frac{\sum_{f=1}^{F} y_f}{\sum_{f=1}^{F} x_f} \quad (2)$$

where $y_f$ is the total number of indicated birds on the helicopter in year f that is summed statewide, $x_f$ is the number of indicated birds on the fixed-wing aircraft in year f that is summed statewide, and F is the total number of years surveyed (Cochran 1977). For mallards, indicated birds can be expanded as:

Indicated birds = (2*singles) + (2*flocked drakes) + (2*pairs) + (2*nesting pairs) + (2*nesting singles) + number of birds in a group

(Cowardin et al. 1995). The formula for Canada geese, sandhill crane, and mute swan is the same, except there are no flocked drakes to consider:

Indicated birds = (2*singles) + (2*pairs) + (2*nesting pairs) + (2*nesting singles) + number of birds in a group

$\hat{B}$ is the observed density per stratum and calculated as

$$\hat{B}_j = \frac{\bar{x}_j}{\bar{m}_j} \quad (3)$$

where $\bar{x}_j$ is the mean indicated birds from the transects in stratum j from a fixed-wing, and $\bar{m}_j$ is the mean area of the transects in stratum j (Martin et al. 1979).

The variance on the population estimate is:

$$\hat{V}(\widehat{Y_T}) = \sum_{t=1}^{T}\left[\left(\hat{R}_t^2 \sum_{j=1}^{J} A_{jt}^2 \hat{V}(\hat{B}_{jt})\right) + \left(\left(\sum_{j=1}^{J} A_{jt}\hat{B}_{jt}\right)^2 \hat{V}(\hat{R}_t)\right) - \left(\hat{V}(\hat{R}_t) \sum_{j=1}^{J} A_{jt}^2\, \hat{V}(\hat{B}_{jt})\right)\right] \tag{4}$$

where T is the total number of transects in stratum j, A is the area for transect t in stratum j, R is the average statewide VCF applied to transect t, B is the observed density per segment (Martin et al. 1979). The variance components are:

$$\hat{V}(\hat{B}) = \frac{1}{m^2}\left[\frac{\sum_{i=1}^{t} x_{ij}^2 - 2\hat{B}\sum_{i=1}^{t} x_{ij}m_{ij} + \hat{B}^2\sum_{i=1}^{t} m_{ij}^2}{t_j(t_j - 1)}\right] \tag{5}$$

where $x_j$ is the fixed-wing indicated birds per transect in stratum j, and B is defined in equation 3.

The associated variance on R is:

$$\hat{V}(\hat{R}) = \frac{\left[\frac{1}{\left(\sum_{j=1}^{k} x_j\right)/k}\right]^2 \left[\sum_{j=1}^{k} (y_j)^2 - 2\hat{R}\sum_{j=1}^{k} (x_j)(y_j) + \hat{R}^{\,2}\sum_{j=1}^{k} (x_j)^2\right]}{k(k-1)} \tag{6}$$

where k is the number of VCF segments in the stratum, $y_j$ is the helicopter indicated birds in stratum j, $x_j$ are defined in equation 4, and R is defined in equation 2.

Ninety-five percent confidence intervals on population estimates for the SOP can be calculated as:

$$\hat{Y} \pm 1.96 * \sqrt{V(\hat{Y})} \tag{7}$$

where $\hat{Y}$ is defined in equation 1, $V(\hat{Y})$ is defined in equation 4, and 1.96 is the critical z value when estimating a 95% confidence interval using the normal distribution.

To determine if the estimate from the survey method was precise, the coefficient of variation (CV) was computed. The MDNR uses a CV of 20% or less on annual estimates of abundance as a guideline for reasonable precision for the spring waterfowl survey. The CV was calculated as:

$$CV = \frac{\sqrt{V(\hat{Y})}}{\hat{Y}} * 100 \tag{8}$$

Michigan's spring waterfowl survey has been active since 1991 when the MDNR did a pilot study (which will not be included in our analyses). Additionally, high helicopter costs have limited the number of years in which to conduct the helicopter survey, and the number of helicopter segments sampled. Past VCF years (1992-1996) lacked randomness in the selection of the surveyed segments and targeted areas with high waterfowl abundance. In 2003, the MDNR switched to a systematic random sampling approach. Beginning in the southernmost transect, the MDNR randomly selected a segment in every other transect, as well as the closest segment immediately north of the random segment. The MDNR attempted a target of 30 randomly selected segments across the state to achieve spatial coverage and assure representation in low and high waterfowl segments, but it was never fully achieved. The MDNR surveyed 27, 29, and 28 segments in 2003, 2010, and 2014, respectively. We decided to achieve a target of 40 segments for each of the 2018 and 2019 survey years to determine if adding more than 10 helicopter segments was feasible under reduced helicopter expenses. To evaluate the SOP survey methodology, we compared VCF years using surveys with more than 25 segments which include 2003, 2010, 2014, 2018, and 2019. Fewer than 25 segments resulted in higher variance on VCF estimates. In addition, the northern forested stratum was not surveyed with a helicopter in 1992 and 1996.

Starting in 2018, we used a generalized random tessellation stratified design (GRTS) to randomly select segments for VCF flights while maintaining a representative spatial coverage. GRTS sampling uses an algorithm that creates specific polygons called Dirichlet tessellation that is overlaid on a specified area (Gitzen et al. 2012). Then, a randomly selected point will be surveyed within each polygon. GRTS sampling is more spatially balanced than a simple random sample. Furthermore, the least spatially balanced GRTS sample is comparable to the most spatially balanced simple random sample (Gitzen et al. 2012). To compute a GRTS sample, we used R programming software (Version 3.6.1; https://www.R-project.org/) with package grts.

Mute swans and sandhill cranes have limited data compared to mallards and Canada geese. We did not analyze mute swans for alternate VCF comparisons since we assumed that mute swans had a VCF value of 1 and a standard error of 0. Mute swans are large birds that are easily detected in a fixed-wing aircraft, so both surveys should have a 100% detection of seeing a mute swan on a segment. Additionally, helicopter surveys only began to count mute swans starting in 2018, so there were only two years of mute swan data with which to compare population estimates to alternate survey designs. Similarly, the MDNR began counting sandhill cranes in 2005; however, MDNR only estimated sandhill crane abundance from 2010 forward as that is the first year VCF's were estimated for this species (Avers et al. 2017).

## Statistical Analysis

### *Alternate Visibility Correction Factors*

As an alternative to the use of long-term mean statewide species-specific VCFs, VCFs calculated for shorter intervals (e.g., annual, three-year average, or five-year average) could be used to correct fixed-wing counts. If there are temporal changes to the system, including occasional changes in observers, then alternate VCFs may better represent waterfowl species detection, thus more accurately estimating their populations. Furthermore, VCFs could be calculated for each stratum.

We considered seven alternate VCFs: yearly statewide, three-year statewide, five-year statewide, yearly stratum-specific, three-year stratum-specific, five-year stratum-specific, and all-year stratum-specific (Table 1). Comparing statewide to stratum-specific VCFs will determine if there are significant differences in visibility detection between the farm urban stratum and northern forested stratum. The northern forested stratum has a higher composition of vegetative cover in the landscape compared to the farm urban which may lead to a difference in waterfowl detection. The number of years included in the estimation also likely influences the VCF and associated variance. Detection may change over time due to observer error, change in helicopter aircraft or pilots, or covariates on the VCF (leaf-cover, weather, wind, etc.). A single-year VCF or VCF calculated by averaging shorter time periods may be significantly different than the long-term average VCF. We estimated eleven alternate VCFs to determine if the SOP VCF is appropriate for estimating waterfowl abundance as stratum-specific VCFs would yield two VCFs each year. We compared alternate farm urban, northern forested, and statewide VCFs to their all-year average VCFs for Canada goose, mallard, and sandhill crane. Analysis for alternate Canada goose and mallard VCFs used data from 2003, 2010, 2014, 2018, and 2019

Table 1. Descriptions of methods to estimate Visibility Correction Factors (VCFs) for the Michigan DNR spring waterfowl survey, including seven VCFs to compare against the Standard Operating Procedure (SOP) VCF.

| VCF Name | Definition | Equation |
|---|---|---|
| Yearly Statewide | The ratio of the total helicopter observations to the total fixed-wing observations for each species annually. | $\hat{R} = \frac{y_f}{x_f}$ (9) |
| Three-Year Statewide | The ratio of the total helicopter observations to the total fixed-wing observations from the past three VCF years. | $\hat{R} = \frac{\sum_{f=1}^{3} y_f}{\sum_{f=1}^{3} x_f}$ (10) |
| Five-Year Statewide | The ratio of the total helicopter observations to the total fixed-wing observations from the past five VCF years. | $\hat{R} = \frac{\sum_{f=1}^{5} y_f}{\sum_{f=1}^{5} x_f}$ (11) |
| SOP | All-years statewide VCF. The ratio of the total helicopter observations to the total fixed-wing observations for each species from all historic VCF years to the current VCF year. | $\hat{R} = \frac{\sum_{f=1}^{F} y_f}{\sum_{f=1}^{F} x_f}$ (2) |
| Yearly Stratum-Specific | The ratio of the total helicopter observations to the total fixed-wing observations for each species in each stratum annually. | $\hat{R}_j = \frac{y_{fj}}{x_{fj}}$ (12) |
| Three-Year Stratum-Specific | The ratio of the total helicopter observations to the total fixed-wing observations for each species from the past three VCF years for each stratum. | $\hat{R}_j = \frac{\sum_{f=1}^{3} y_{fj}}{\sum_{f=1}^{3} x_{fj}}$ (13) |

Table 1 (cont'd)

| VCF Name | Definition | Equation |
|---|---|---|
| Five-Year Stratum-Specific | The ratio of the total helicopter observations to the total fixed-wing observations for each species from the past five VCF years for each stratum. | $\hat{R}_j = \frac{\sum_{f=1}^{5} y_{fj}}{\sum_{f=1}^{5} x_{fj}}$ (14) |
| All-Year Stratum-Specific | The ratio of the total helicopter observations to the total fixed-wing observations for each species from all historic VCF years to the current VCF year for each stratum. | $\hat{R}_j = \frac{\sum_{f=1}^{k} y_{fj}}{\sum_{f=1}^{k} x_{fj}}$ (15) |

helicopter survey years. Analysis for alternate sandhill crane VCFs used data from 2010, 2014, 2018, and 2019 helicopter survey years. To meet MDNR standards, any alternative VCFs that produced a CV of less than 20% were considered potentially acceptable.

### *Alternate Aerial Survey Designs*

We analyzed data from the spring waterfowl survey to compare the current SOP survey design to a helicopter-only and modified SOP (Figure 2). A helicopter-only survey design was similar to the SOP, but there was no VCF and we derived population estimates only from helicopter counts. Helicopter data from 2003, 2010, 2014, 2018, and 2019 were used to calculate population estimates for the helicopter-only design for the given years. Comparable to the SOP, we estimated waterfowl abundance and CV from the modified SOP aerial survey design using fewer fixed-wing transects. Therefore, the modified SOP design used the same population estimate and CV formulas as the SOP, but with modified survey effort. Fixed-wing data and VCFs estimated for all years were used to calculate 2003, 2010, 2014, 2018, and 2019 population estimates for the modified SOP.

The population estimate for the helicopter-only survey design was calculated as

$$\hat{\tau} = \sum_{h=1}^{L} N_h \bar{y}_h \tag{16}$$

where $\hat{\tau}$ is the unbiased estimator for the total population, L is the total number of strata, $N_h$ is the total number of segments that can be available in stratum h, and $\bar{y}_h$ is the sample mean in stratum h (Thompson 1992). The associated variance is then

$$V(\hat{\tau}) = \sum_{h=1}^{L} (N_h)(N_h - n_h)\left(\frac{{s_h}^2}{n_h}\right) \tag{17}$$

a)

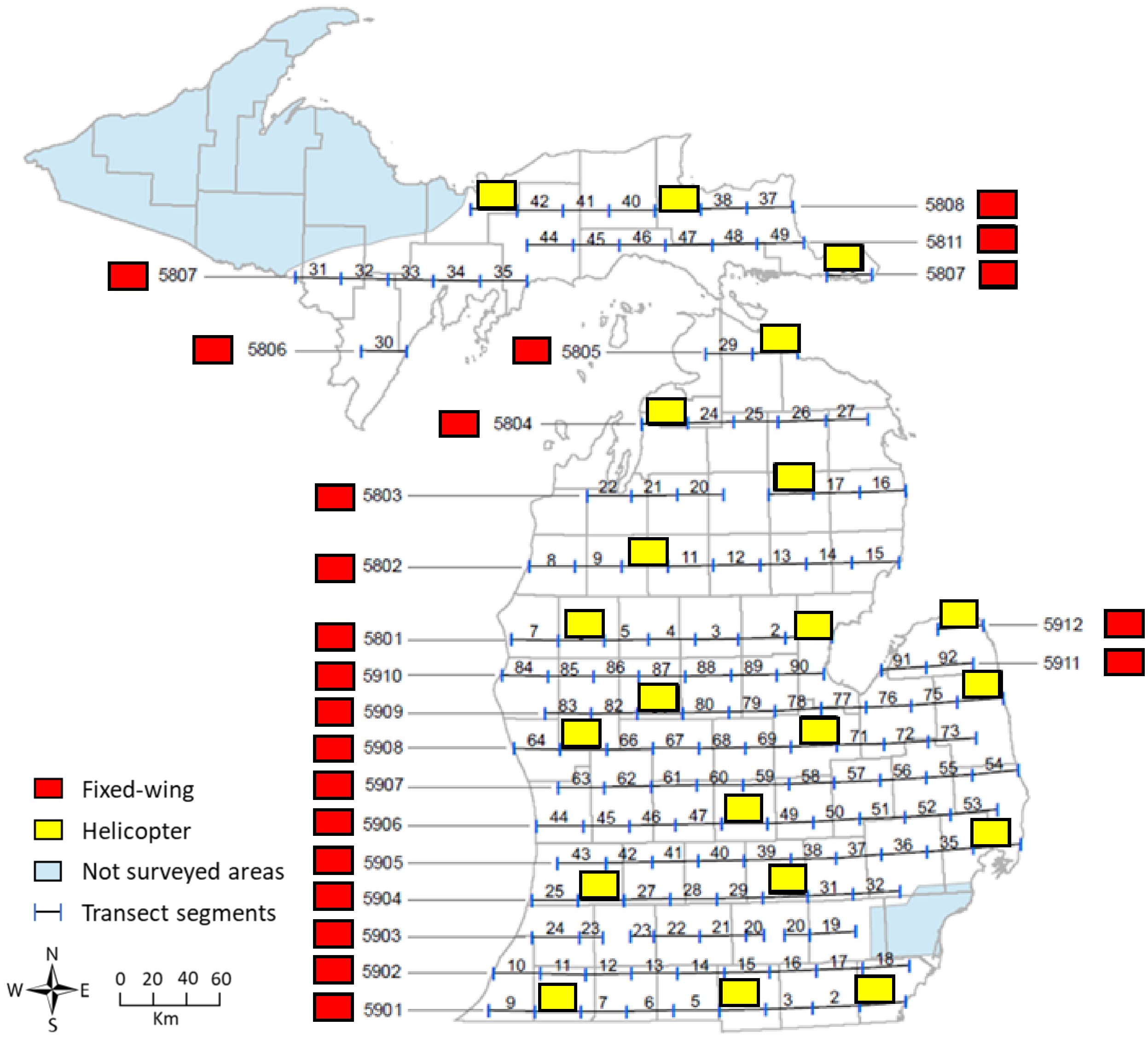



Figure 2. Maps of aerial survey designs for Michigan DNR's spring waterfowl survey including: a) Standard Operating Procedure (SOP), b) helicopter-only, and c) modified SOP. East-west survey transects (4-digit numbers) are shown as solid lines, fixed-wing surveys are shown in the red outlined box, helicopter surveys are shown in the yellow outlined box, and non-surveyable areas are shown in light blue.

Figure 2 (cont'd)

b)

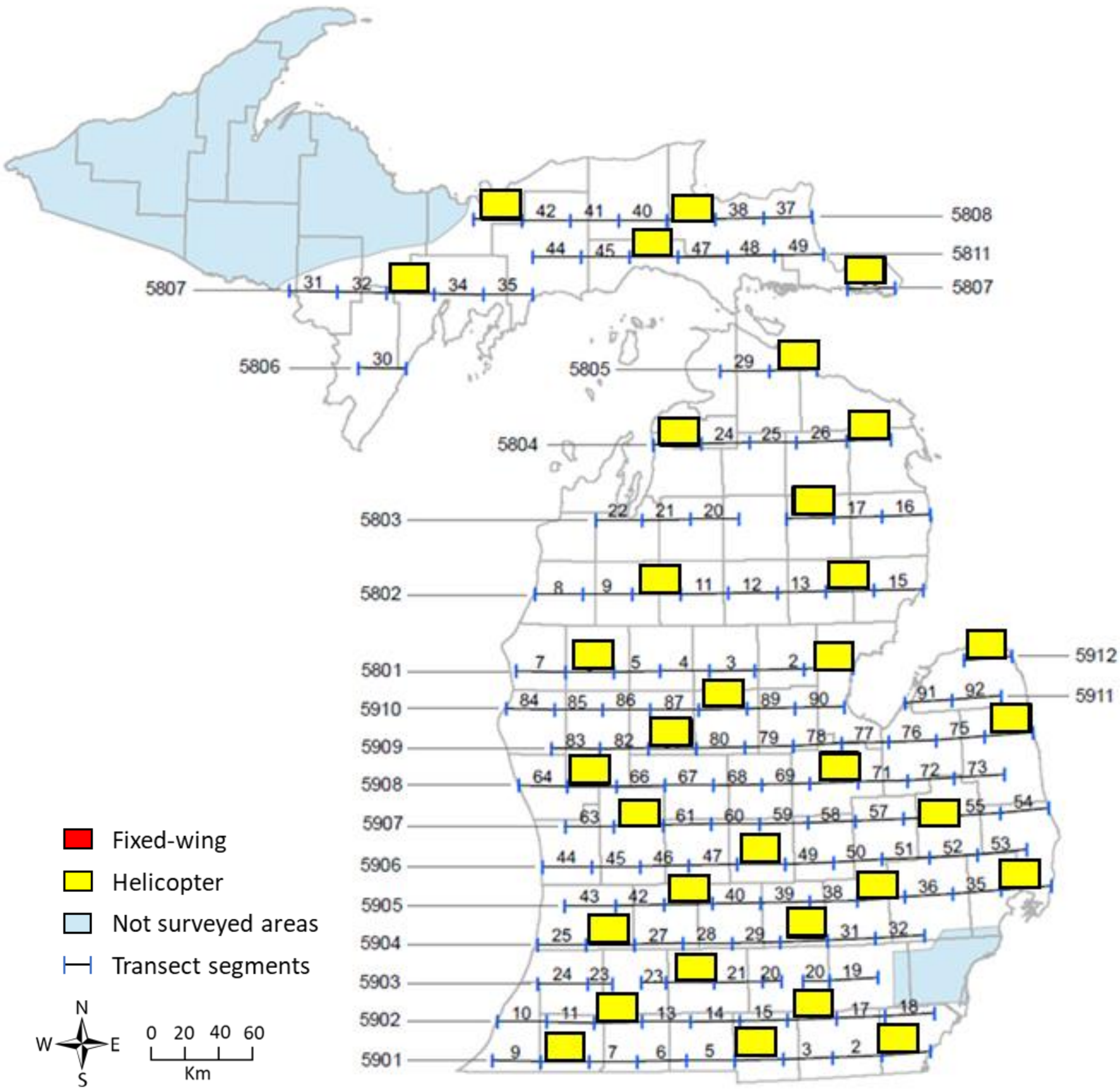
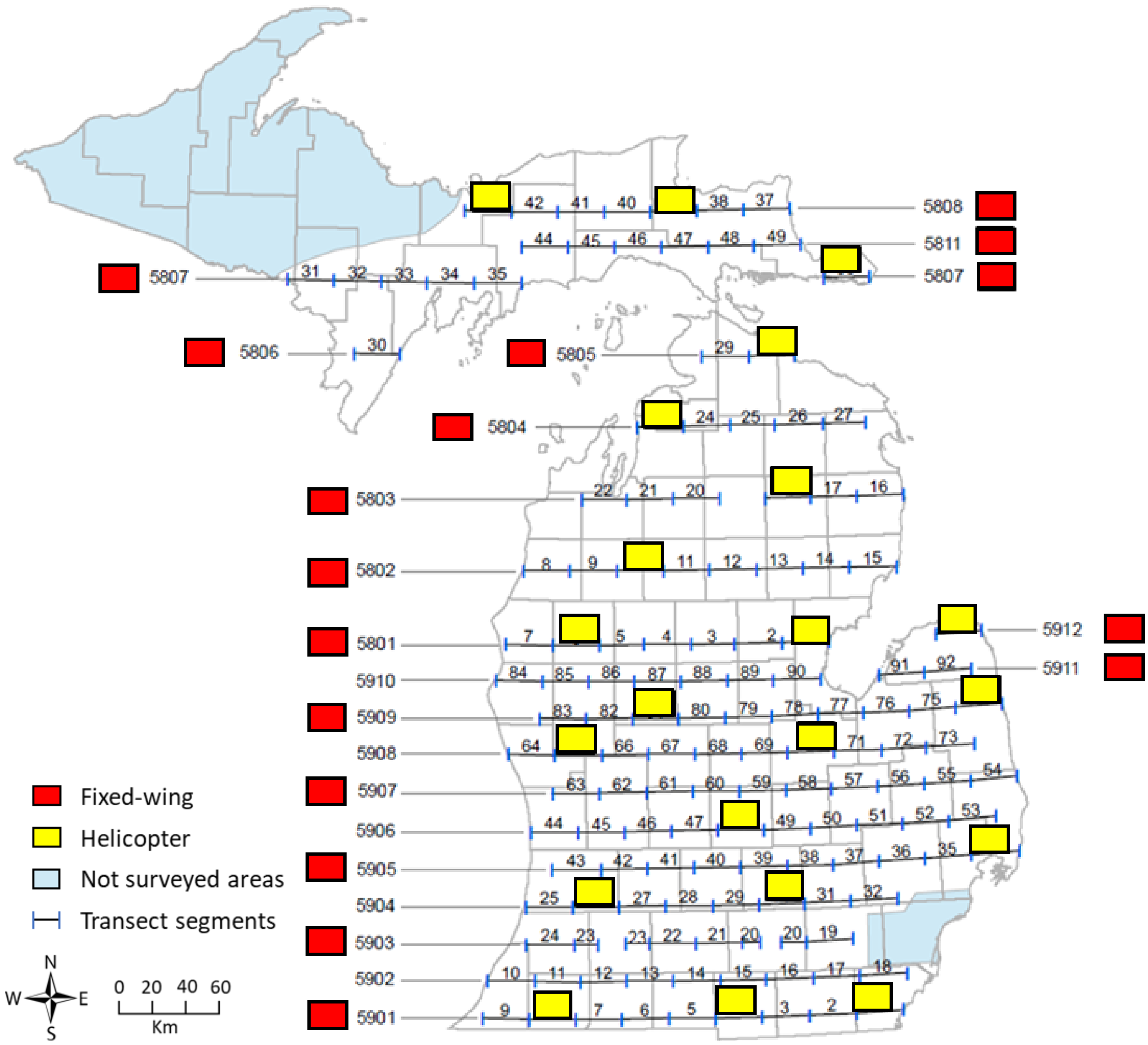


Figure 2 (cont'd)

c)



where $n_h$ is the sample size in stratum h, and $s_h$ is the sample standard error in stratum h.

Population estimates for the helicopter survey design with a ninety-five percent confidence interval were calculated as

$$\hat{\tau} \pm 1.96 * \sqrt{V(\hat{\tau})} \tag{18}$$

where $\hat{\tau}$ is defined in equation 16 and $V(\hat{\tau})$ is defined in equation 17.

The CV was calculated for each SOP population as

$$CV = \frac{\sqrt{V(\hat{\tau})}}{\hat{\tau}} * 100 \tag{19}$$

***Helicopter Bootstrap***

We used the bootstrap method to determine how many helicopter segments are needed to achieve a CV of less than 20% with feasible costs. Bootstrapping is used when the underlying statistical distribution is unknown, so the distribution of values found in random samples from the population is a reasonable guide to the distribution of the population estimate (Manly 1997). To approximate the population, the sample is resampled numerous times with replacement. We bootstrapped helicopter data from the 2003, 2010, 2014, 2018, and 2019 VCF years for Canada goose and mallard with a random sample of 10 to 90 segments with increments of 10. We randomly sampled with replacement from 27 segments in 2003, 29 segments in 2010, 28 segments in 2014, 40 segments in 2018, and 40 segments in 2019. To obtain confidence intervals for each segment sample size, we ran 1,000 iterations. We bootstrapped sandhill crane helicopter data from 2010, 2014, 2018, and 2019 and bootstrapped mute swan helicopter data from 2018 and 2019. To determine the cost for each helicopter segment interval, we used the average 2018 and 2019 helicopter costs per segment to compare among the other VCF years.

### *Fixed-wing Bootstrap*

We used bootstrap methods to determine how many fixed-wing transects can be removed to still achieve a CV of less than 20% with feasible costs. Savings in fixed-wing costs could allow more VCF segments to be surveyed and may help to reduce the variance. Based on the sampling scheme for the spring waterfowl survey, we decided to only bootstrap the farm urban transects as there were twice as many segments in this stratum as in the northern forested stratum. Two transects in the farm urban weren't removed because transect 5911 contains two segments, and transect 5912 contains one segment. We bootstrapped data from the 2003, 2010, 2014, 2018, and 2019 VCF years for Canada goose, mallard, and mute swan. We bootstrapped sandhill crane fixed-wing data from 2010, 2014, 2018, and 2019. We randomly removed from one to 10 transects with increments of one. Transect length varied among the 10 farm urban transects used for bootstrapping from six to 10 segments. To obtain the confidence interval for each transect sample size, we ran 1,000 iterations. We used the average 2018 and 2019 fixed-wing cost per transect to compare among the other VCF years. In order to make costs more comparable among years, we standardized the 2003, 2010, and 2014 costs to 2018 and 2019 costs. Based on the number of transects that was removed, we created two modified SOP survey designs. We systematically removed even-numbered transects for the modified SOP, and systematically removed odd-numbered transects for the modified SOP-2. For example, if the bootstrap method results in removing five transects, we would remove every even-numbered transect in the farm urban stratum for the modified SOP design (Figure 2c), while the modified SOP-2 design would remove every odd-numbered transect in the farm urban stratum.

We calculated the cost for each aerial survey design and separated aircraft costs into three categories: hourly rate, flight hours, and overtime charges. We estimated helicopter costs per segment as:

$$C = \frac{r * h + o}{n} \tag{20}$$

where C is the total cost, r is the hourly rate for the aircraft, h is the flight hours, o is the total overtime charges, and n is the number of segments surveyed.

We estimated fixed-wing costs per transect as:

$$C = \frac{r * h + o}{t} \tag{21}$$

where t is the number of transects surveyed.

We calculated total costs for each survey type as:

$$C = \sum_{i=1}^{D} r_i * h_i + o_i \tag{22}$$

where C is the total cost, i is day i of the aerial survey, D is the total number of aerial survey days, and r, h, and o are defined in equation 20.

# RESULTS

## Survey Timing and Sample Sizes

We initiated fixed-wing waterfowl surveys on 26 April 2018 and on 24 April 2019 and these dates were near the 1992-2017 average start date of 20 April with a range between 2 April to 30 April. The fixed-wing waterfowl survey concluded on 23 May 2018 and on 14 May 2019 and these dates were later than the 1992-2017 average end date of 11 May with a range between 19 April to 24 May. We flew a total of 40 18-mile segments with helicopters in each of 2018 and 2019 in cooperation with Michigan State Police and MDNR personnel; these flights included two observers and one trainee in addition to the helicopter pilot and were completed between 27 April and May 25, 2018 and 25 April and 17 May, 2019. These helicopter dates were near the average (1992-1996, 2003, 2010, 2014, and 2018-2019) start date of 24 April with a range between 14 April and 1 May. The 2019 helicopter survey end date was near the average (1992-1996, 2003, 2010, 2014, and 2018-2019) end date of 16 May while the 2018 helicopter end date was later than the average end date with a range between 4 May and 19 May.

We surveyed 40 helicopter segments in 2018 and 2019 and this number of segments was more than the 1992-2014 average segments of 18 with a range of six to 29 segments. The 2018 spring waterfowl survey had a 4.4-day difference between when the fixed-wing and helicopter surveys of the same segment were conducted, which was more than the average (1992-1996, 2003, 2010, 2014, and 2018-2019) time of 2.3 days with a range of one to 13 days. The 2019 spring waterfowl survey had a 1.4-day difference which was less than the average. Helicopter flight hours per segment was on average 1.16 hours in 2018 and 0.96 hours in 2019. Fixed-wing flight hours per segment was on average 0.4 hours in 2018 and 2019. Total flight hours, including commute time, for the helicopter survey was 46.4 hours in 2018 and 38.4 hours in

2019. Total flight hours for the fixed-wing survey was 51.6 hours in 2018 and 52.9 hours in 2019.

We surveyed helicopter segments in 2018 and 2019 using the GRTS methodology which resulted in a higher proportion of segments being surveyed in the northern forested stratum than in previous years. An average (1992-1996, 2003, 2010, and 2014) of 68% of the helicopter segments were located in the farm urban stratum compared to an average (1992-1996, 2003, 2010, and 2014) of 32% in the northern forested stratum. In 2018 and 2019, 52% of the helicopter segments were located in the farm urban stratum compared to 48% in the northern forested.

Canada goose VCFs ranged from 1.46 to 4.95 (Table 2a). Mallard VCFs ranged from 1.91 to 6.48 (Table 2b). Sandhill crane VCFs ranged from 1.00 to 16.00 (Table 2c).

**Alternate Visibility Correction Factors**

Ninety-two percent of alternate statewide VCFs for Canada goose showed no significant difference compared to the Canada goose SOP (all-year average statewide) VCF for the five most recent VCF years since 95% confidence intervals overlapped (Figure 3). In 2003, the Canada goose yearly statewide VCF was significantly lower than the Canada goose SOP VCF. On average, the alternate statewide Canada goose VCFs were 15% smaller than the Canada goose SOP VCF. Similarly, ninety-two percent of alternate farm urban VCFs for Canada goose showed no significant difference compared to the Canada goose all-year farm urban VCF. In 2003, the Canada goose yearly farm urban VCF was significantly lower than the Canada goose all-year farm urban VCF. On average, the alternate farm urban Canada goose VCFs were 17% smaller than the all-year farm urban VCF. All the alternate northern forested VCFs for Canada

Table 2. Annual Visibility Correction Factor (VCF) for a) Canada goose, b) mallard, and c) sandhill crane, 1992-2019. A VCF with 1 and SE of 0 is an assumed value in table c before sandhill cranes were counted on VCF flights.

a)

| Year | Number of Segments | Fixed-wing Indicated Birds | Helicopter Indicated Birds | VCF | SE |
|---|---|---|---|---|---|
| 1992 | 7 | 68 | 201 | 2.96 | 0.34 |
| 1993 | 15 | 84 | 416 | 4.95 | 1.18 |
| 1994 | 12 | 89 | 438 | 4.92 | 1.16 |
| 1995 | 6 | 77 | 212 | 2.75 | 0.26 |
| 1996 | 17 | 115 | 343 | 2.98 | 0.72 |
| 2003 | 27 | 217 | 316 | 1.46 | 0.3 |
| 2010 | 29 | 229 | 665 | 2.9 | 0.38 |
| 2014 | 28 | 223 | 648 | 2.91 | 0.46 |
| 2018 | 40 | 406 | 891 | 2.19 | 0.35 |
| 2019 | 40 | 332 | 659 | 1.98 | 0.4 |

b)

| Year | Number of Segments | Fixed-wing Indicated Birds | Helicopter Indicated Birds | VCF | SE |
|---|---|---|---|---|---|
| 1992 | 7 | 138 | 411 | 2.98 | 0.7 |
| 1993 | 15 | 283 | 961 | 3.4 | 0.56 |
| 1994 | 12 | 138 | 894 | 6.48 | 1.19 |
| 1995 | 6 | 139 | 410 | 2.95 | 0.75 |
| 1996 | 17 | 228 | 652 | 2.86 | 0.66 |
| 2003 | 27 | 212 | 404 | 1.91 | 0.43 |
| 2010 | 29 | 265 | 550 | 2.08 | 0.43 |
| 2014 | 28 | 204 | 625 | 3.06 | 0.5 |
| 2018 | 40 | 218 | 540 | 2.48 | 0.45 |
| 2019 | 40 | 235 | 525 | 2.23 | 0.37 |

Table 2 (cont'd)

c)

| Year | Number of Segments | Fixed-wing Indicated Birds | Helicopter Indicated Birds | VCF | SE |
|---|---|---|---|---|---|
| 1992 | 7 | 0 | NA | 1 | 0 |
| 1993 | 15 | 0 | NA | 1 | 0 |
| 1994 | 12 | 2 | NA | 1 | 0 |
| 1995 | 6 | 0 | NA | 1 | 0 |
| 1996 | 17 | 2 | NA | 1 | 0 |
| 2003 | 27 | 2 | NA | 1 | 0 |
| 2010 | 29 | 14 | 49 | 3.5 | 1.77 |
| 2014 | 28 | 4 | 64 | 16 | 12.03 |
| 2018 | 40 | 18 | 56 | 3.11 | 1.19 |
| 2019 | 40 | 25 | 42 | 2.68 | 1.12 |

a)

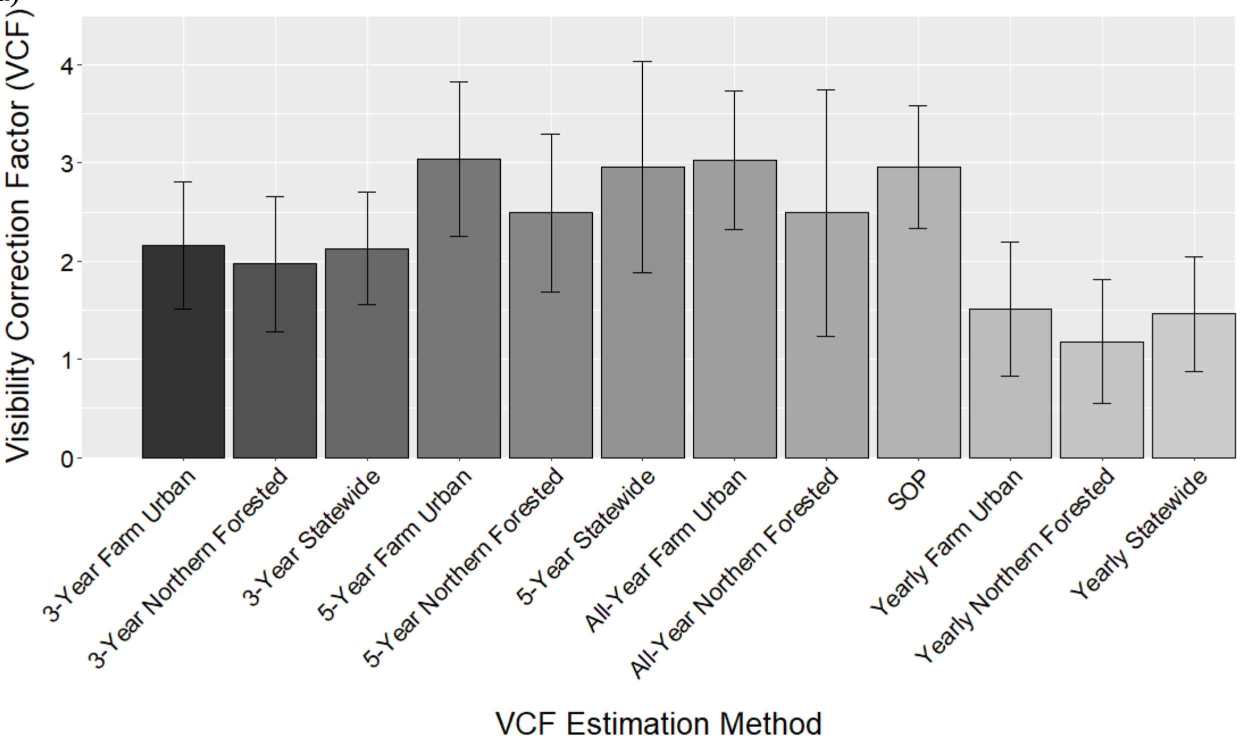
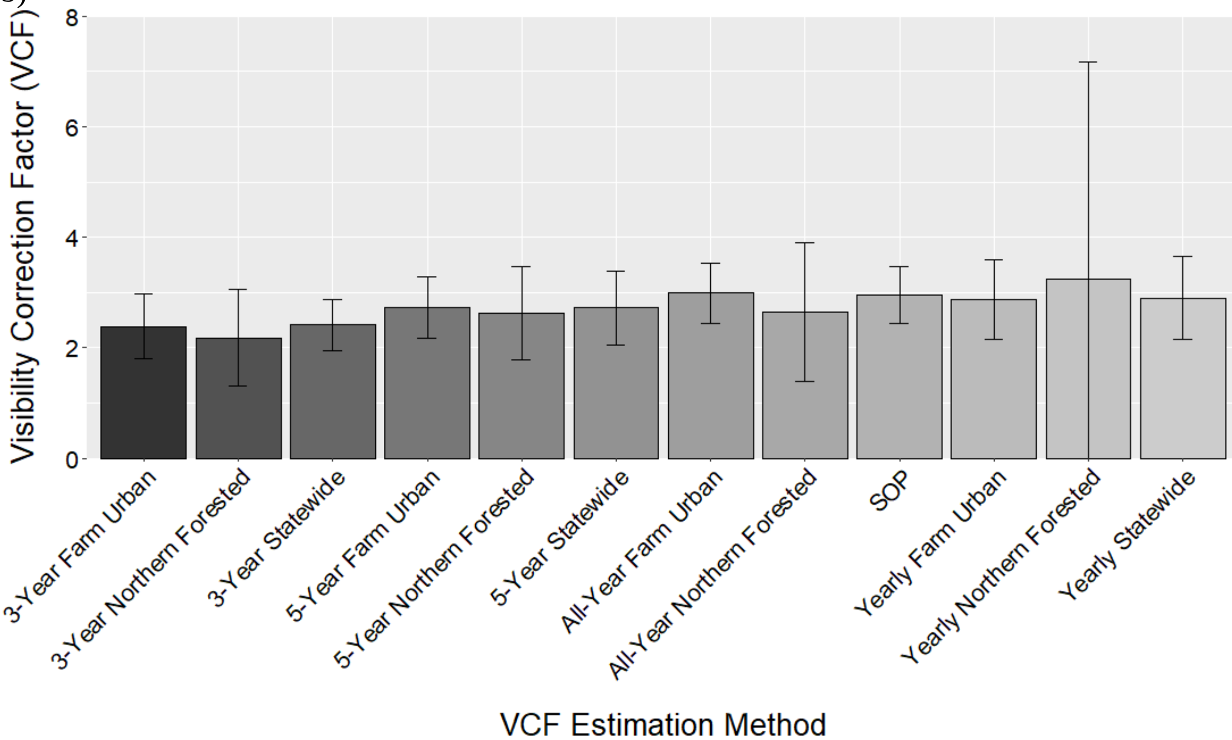



Figure 3. Comparison of Canada goose alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) 2003, b) 2010, c) 2014, d) 2018, and e) 2019. The black bars represent ninety-five percent confidence intervals.

Figure 3 (cont'd)

b)




c)

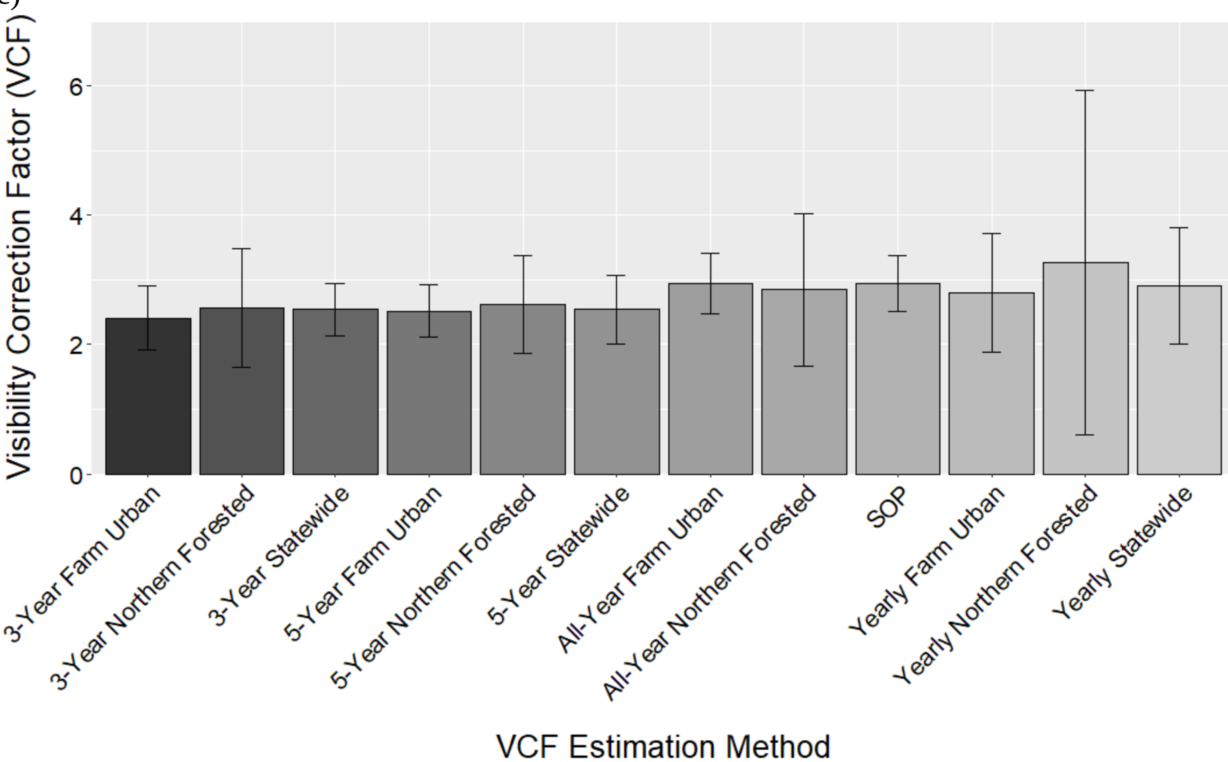
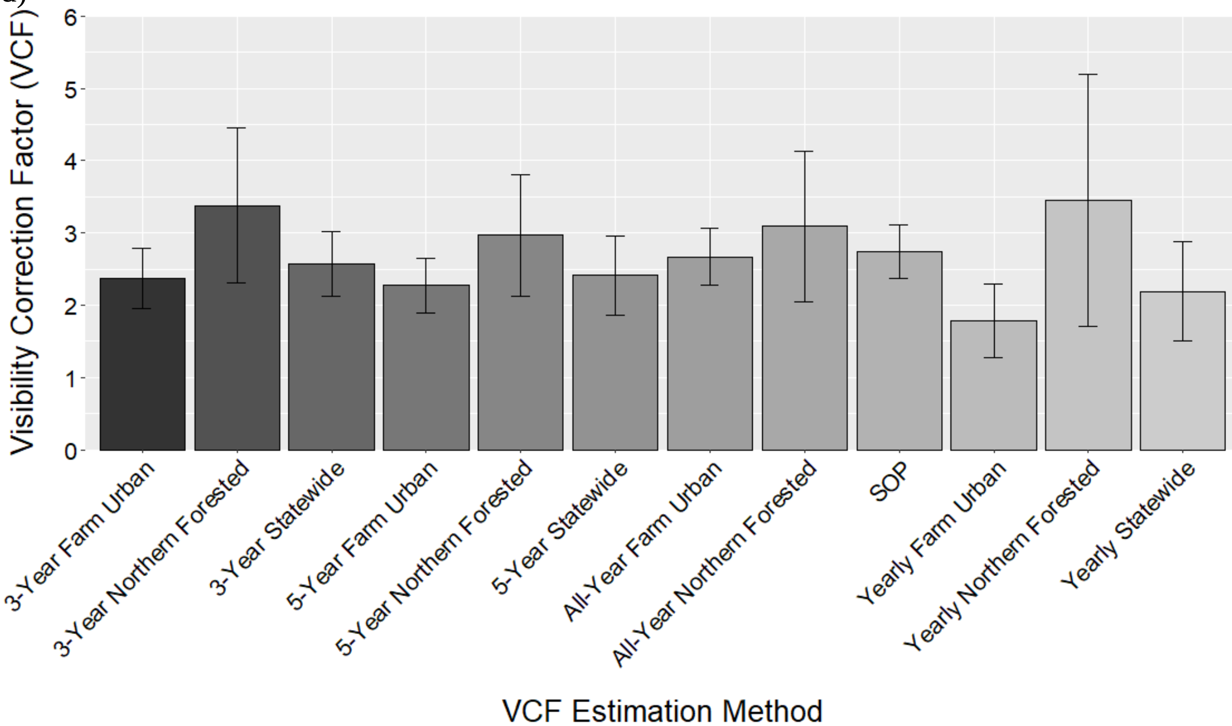
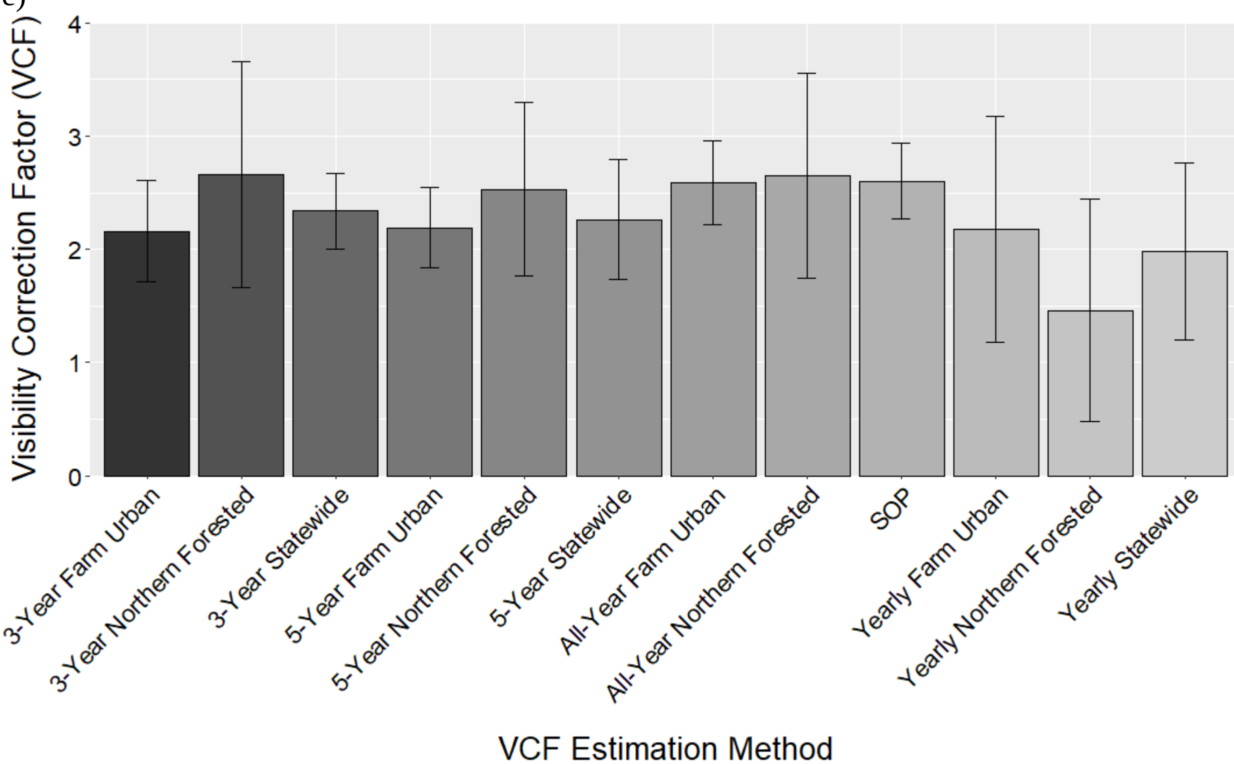


Figure 3 (cont'd)

d)




e)



goose showed no significant difference compared to the Canada goose all-year northern forested VCF. On average, the alternate northern forested Canada goose VCFs were 7% smaller than the all-year northern forested VCF. On average, alternate Canada goose VCFs were 11% smaller compared to the Canada goose SOP VCF. Alternate Canada goose VCFs ranged from 1.18 to 3.45 and standard errors ranged from 0.17 to 2.00 for the five most recent VCF years. Variations in trends occurred in the Canada goose VCFs. Canada goose five-year farm urban, five-year statewide, all-year statewide, and SOP VCFs decreased each year while the remaining alternate VCFs showed no pattern in their respective VCF values. Canada goose northern forested VCFs had noticeably larger variances than the Canada goose statewide and farm urban VCFs.

All the alternate statewide and farm urban VCFs for mallard showed no significant difference compared to the mallard SOP VCF and the all-year farm urban VCF, respectively (Figure 4). On average, alternate statewide mallard VCFs were 16% smaller and farm urban VCFs were 15% smaller compared to their respective all-year averaged VCF. Ninety-two percent of alternate northern forested VCFs for mallard showed no significant difference compared to the mallard all-year northern forested VCF. On average, the alternate northern forested mallard VCFs were 11% smaller than the all-year northern forested VCF. On average, alternate mallard VCFs were 16% smaller compared to the mallard SOP VCF. Alternate mallard VCFs ranged from 1.06 to 4.38 and standard errors ranged from 0.19 to 1.33 for the five most recent VCF years. Mallard five-year farm urban, five-year statewide, all-year statewide, and SOP VCFs decreased each year while the other alternate VCFs showed no pattern in their respective VCF values. Confidence intervals for the mallard northern forested VCFs were consistently larger than the mallard statewide and farm urban VCFs.

a)

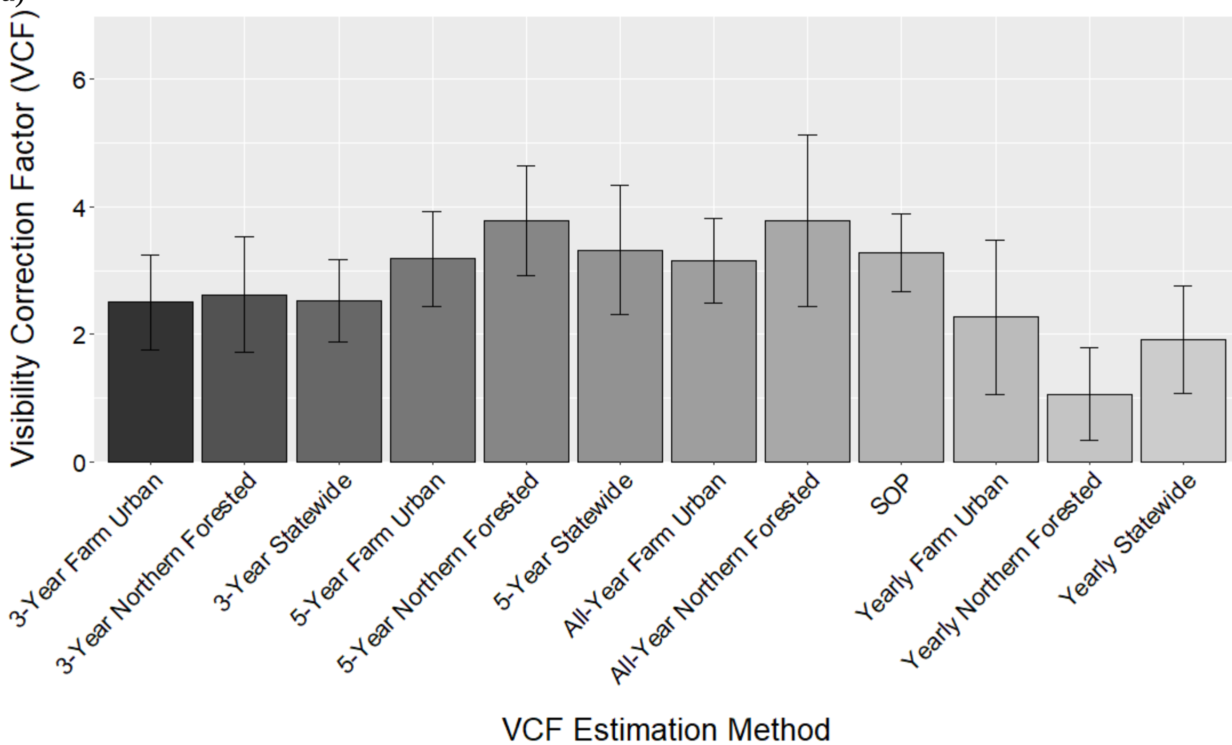
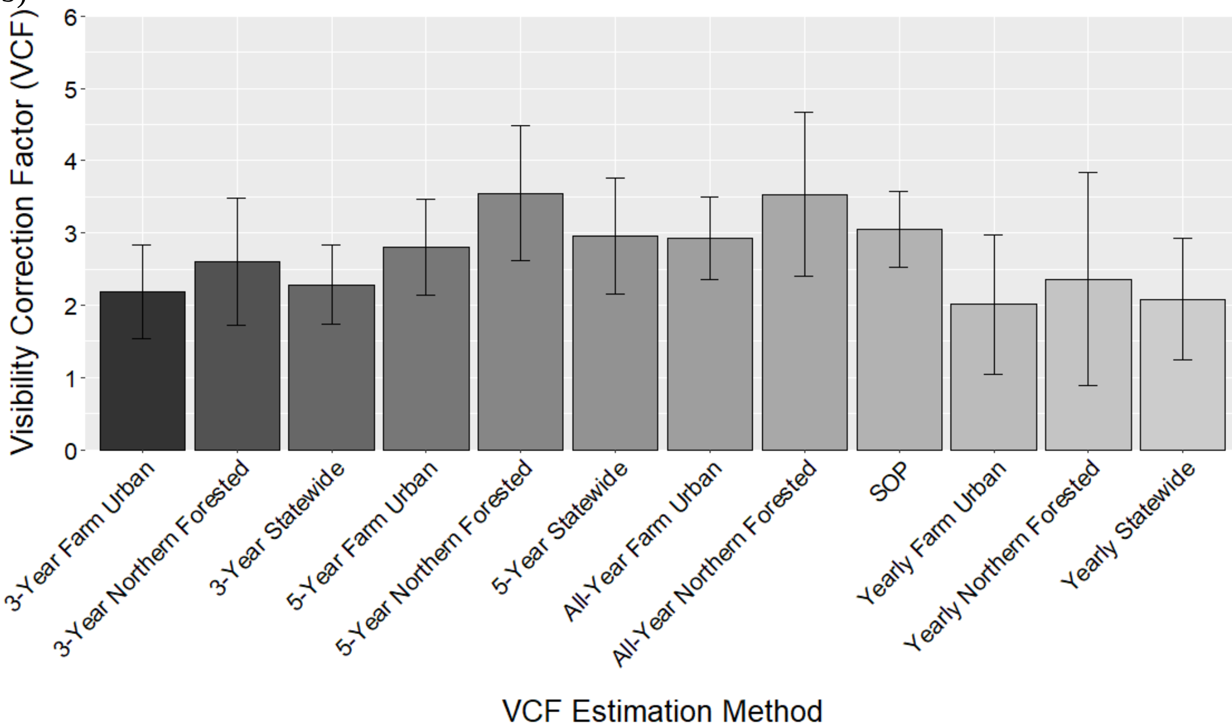



Figure 4. Comparison of mallard alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) 2003, b) 2010, c) 2014, d) 2018, and e) 2019. The black bars represent ninety-five percent confidence intervals.

Figure 4 (cont'd)

b)




c)

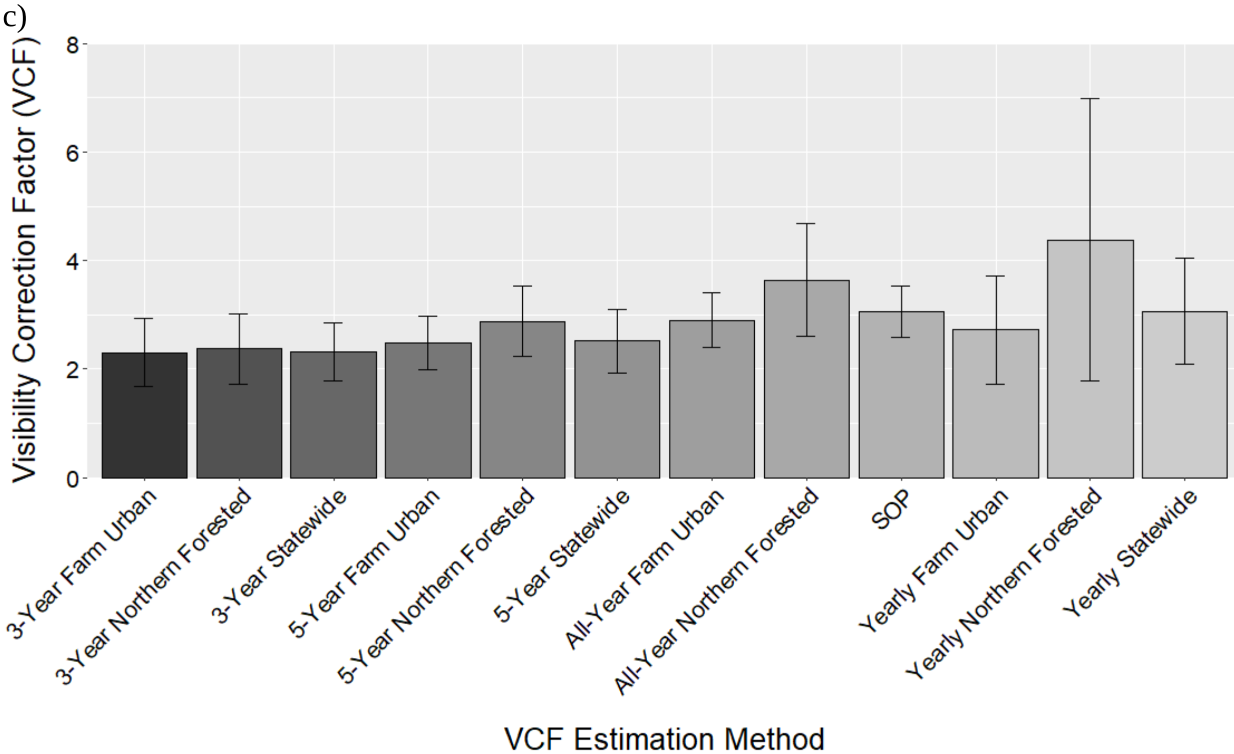
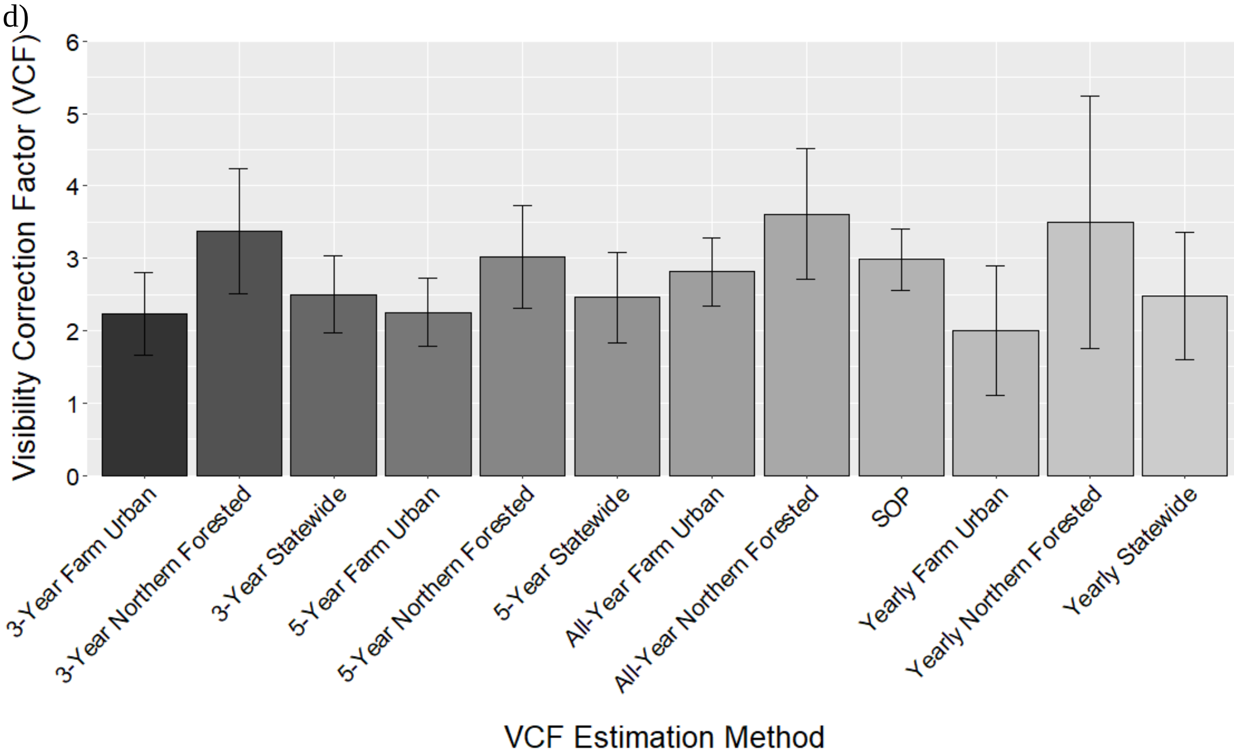
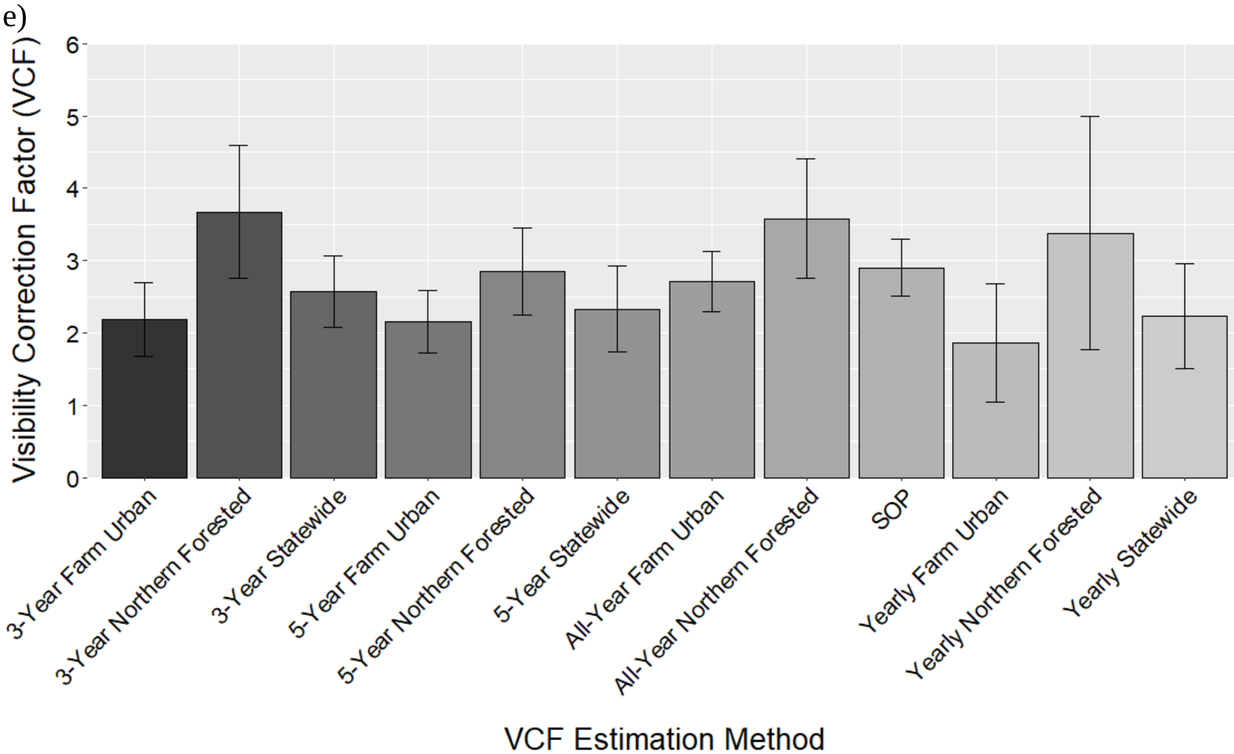


Figure 4 (cont'd)

d)




e)



Alternate statewide, farm urban, and northern forested sandhill crane VCFs showed no significant difference compared to their respective sandhill crane SOP VCF, all-year farm urban VCF, and all-year northern forested VCF (Figure 5). On average, alternate statewide VCFs were 8% larger, farm urban VCFs were 25% larger, and northern forested VCFs were 7% smaller compared to their respective all-year averaged VCF. On average, alternate sandhill crane VCFs were 15% larger compared to the sandhill crane SOP VCF. Some sandhill crane alternate VCFs were identical to each other because the observers in a helicopter did not survey for sandhill crane until the 2010 VCF year. Smaller fixed-wing observations on VCF segments for sandhill crane resulted in VCFs that ranged from 1.00 to 32.00 with standard errors ranging from 0.52 to 24.00 for the four most recent VCF years. Sandhill crane three-year northern forested and all-year northern forested VCFs decreased each year while the other alternate VCFs and SOP VCF showed no pattern in their respective VCF values. In 2010 and 2018, confidence intervals for the sandhill crane northern forested VCFs were greater than the sandhill crane statewide and farm urban VCFs. In 2014, sandhill crane yearly farm urban and statewide VCFs were considerably larger than the other sandhill crane VCFs.

Using the alternate VCFs, we then compared population estimates to the SOP population estimate. Alternate Canada goose population estimates were not significantly different from the Canada goose SOP population estimate except for the 2003 Canada goose yearly statewide and stratum-specific VCF estimation methods which resulted in lower population estimates than the 2003 Canada goose SOP population estimate (Figure 6). On average, population estimates from statewide VCFs were 19% smaller for yearly, 17% smaller for three-year, 9% smaller for five-year compared to the Canada goose SOP. Stratum-specific population estimates were on average 18% smaller for yearly, 16% smaller for three-year, and

a)

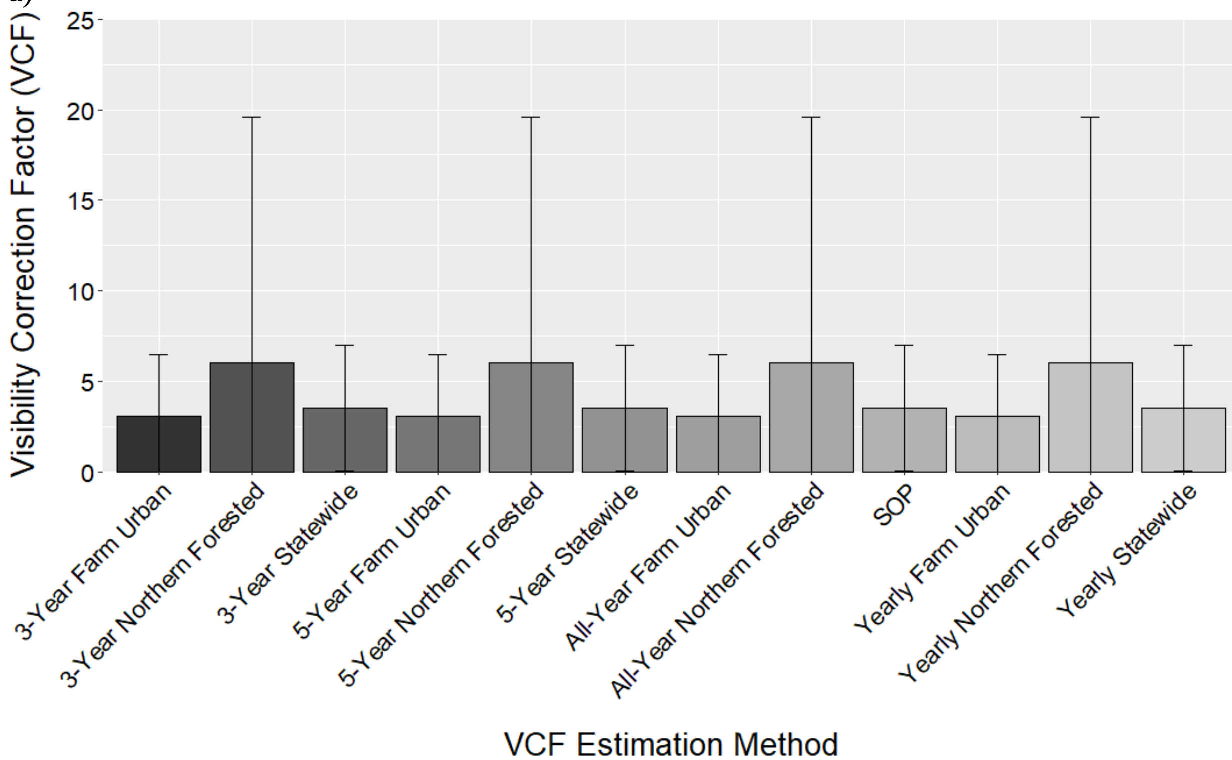
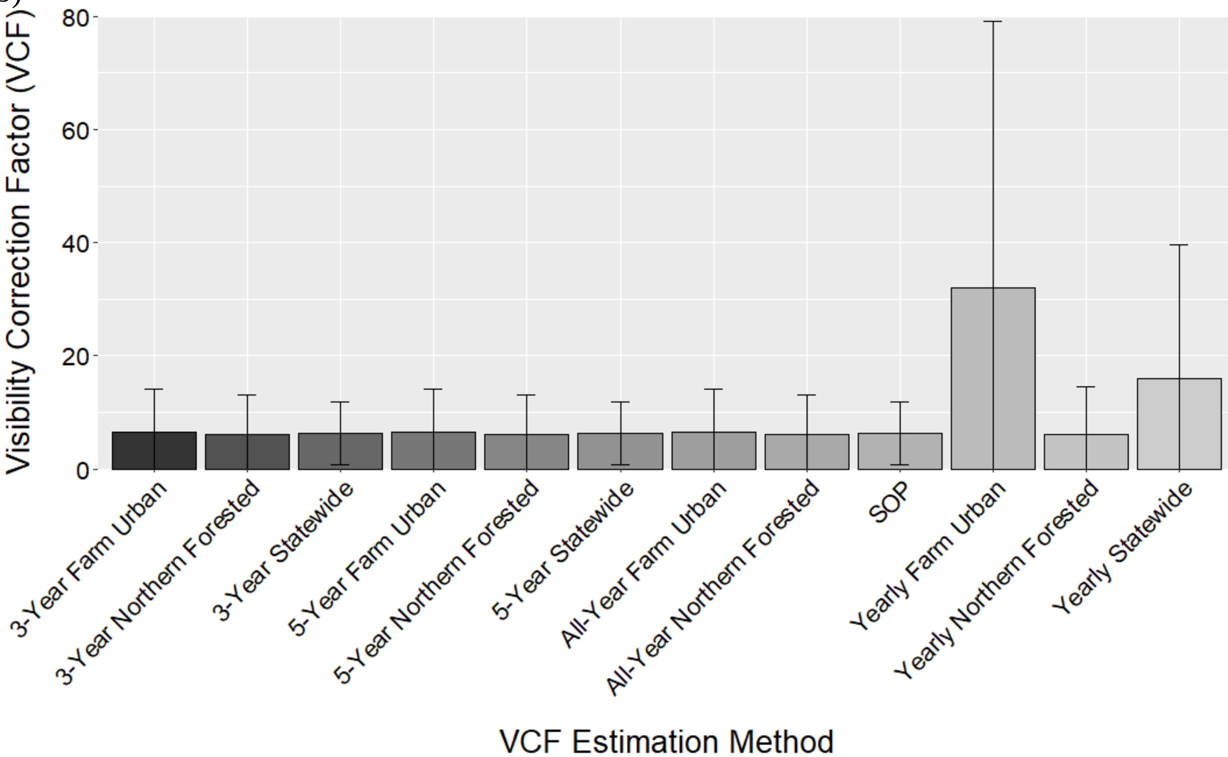



Figure 5. Comparison of sandhill crane alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) 2010, b) 2014, c) 2018, d) 2019. The black bars represent ninety-five percent confidence intervals.

Figure 5 (cont'd)

b)

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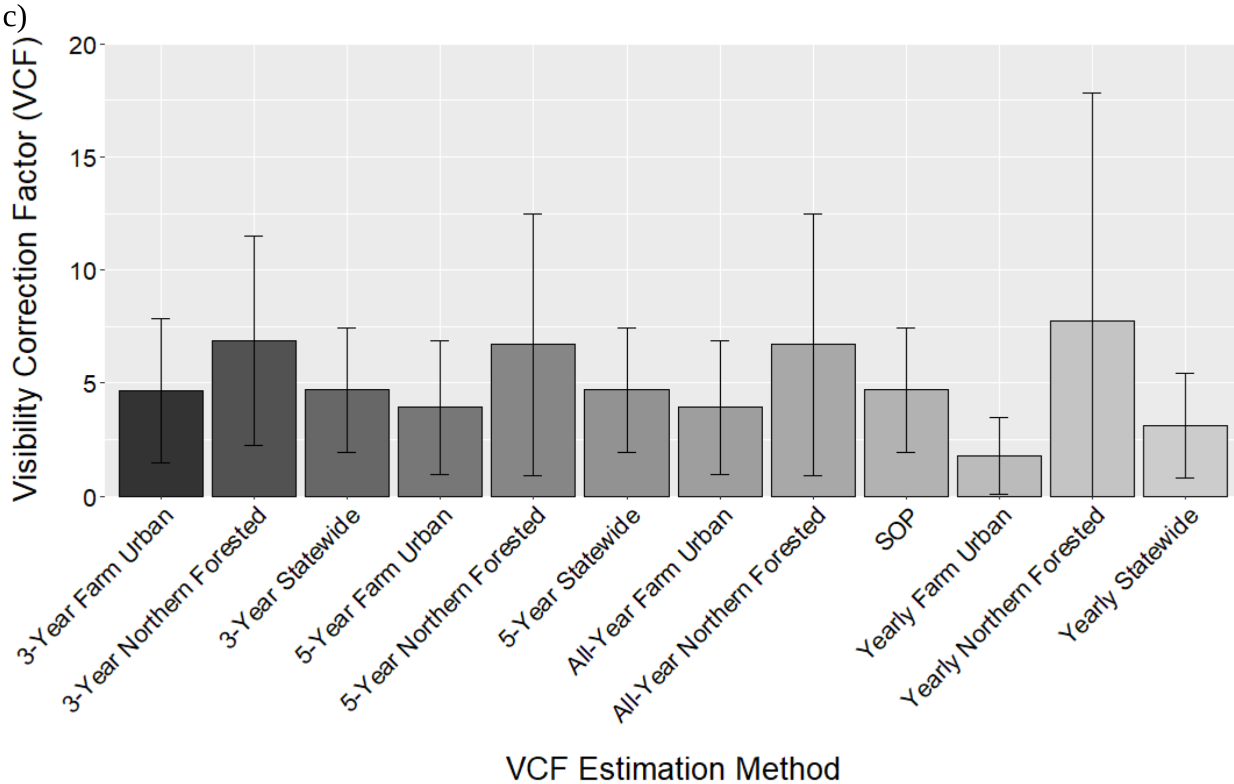

Figure 5 (cont'd)

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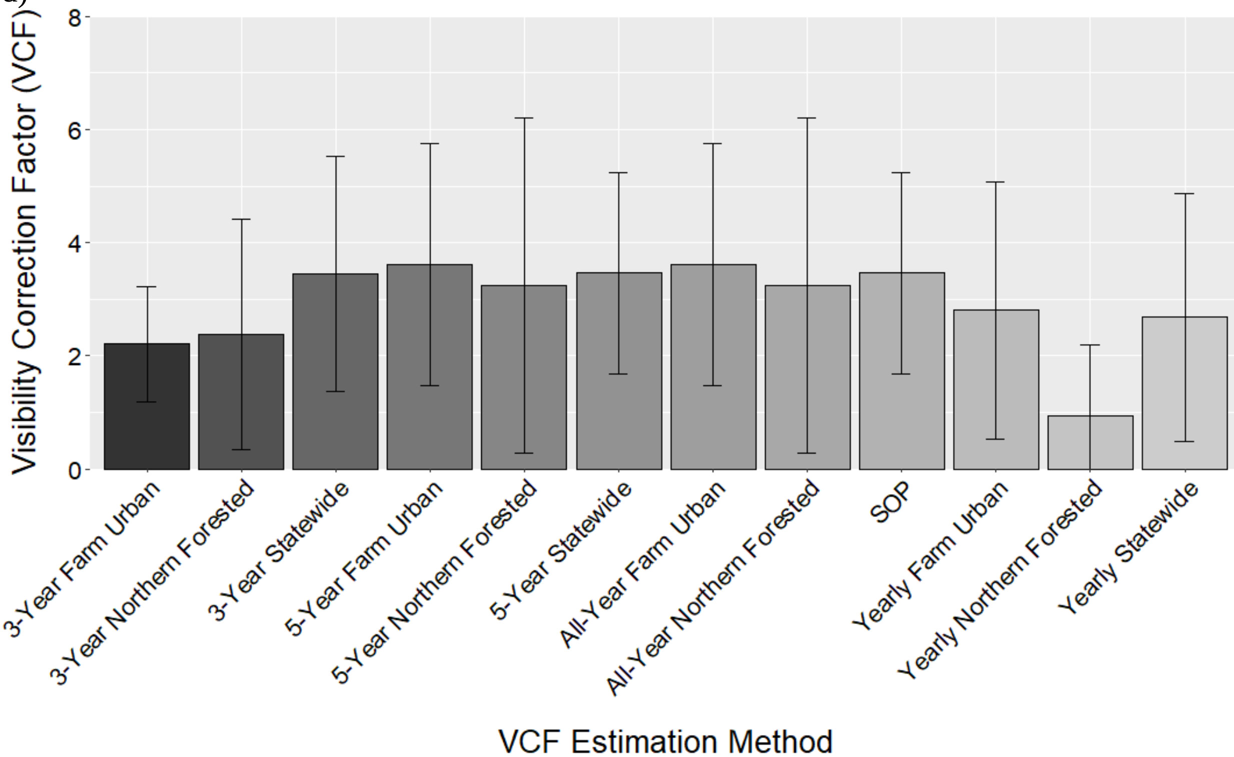


a)

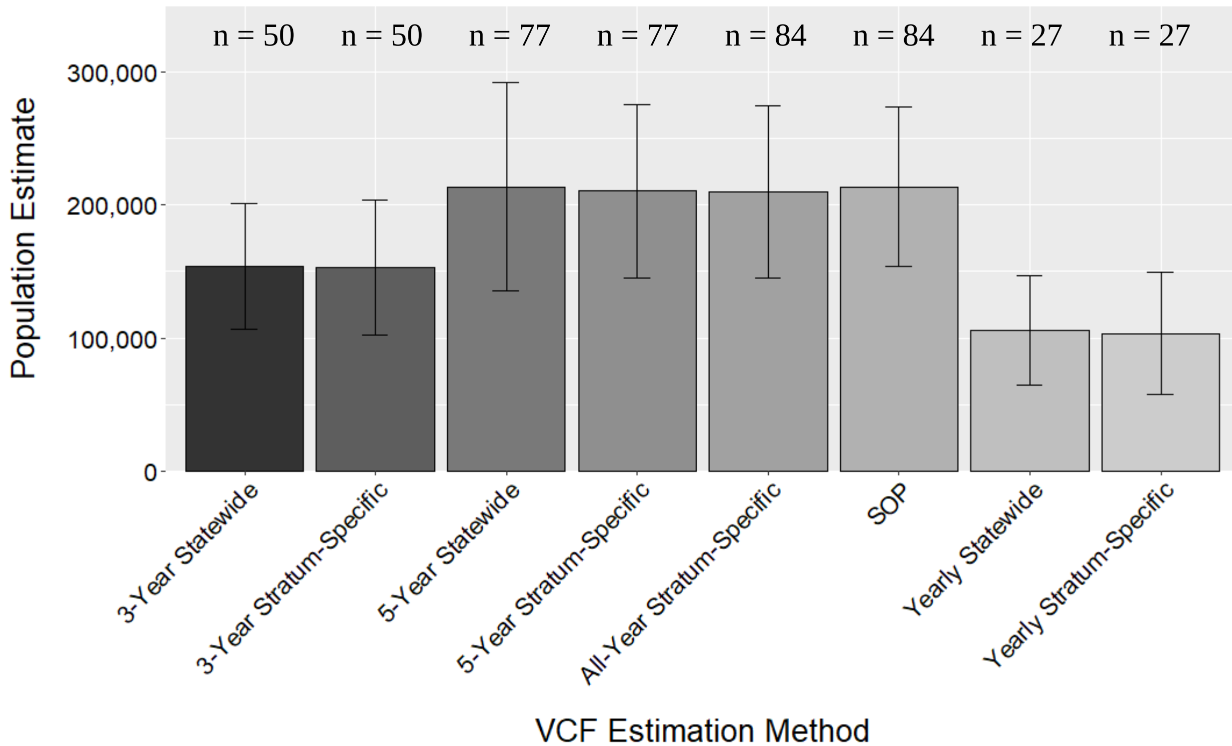
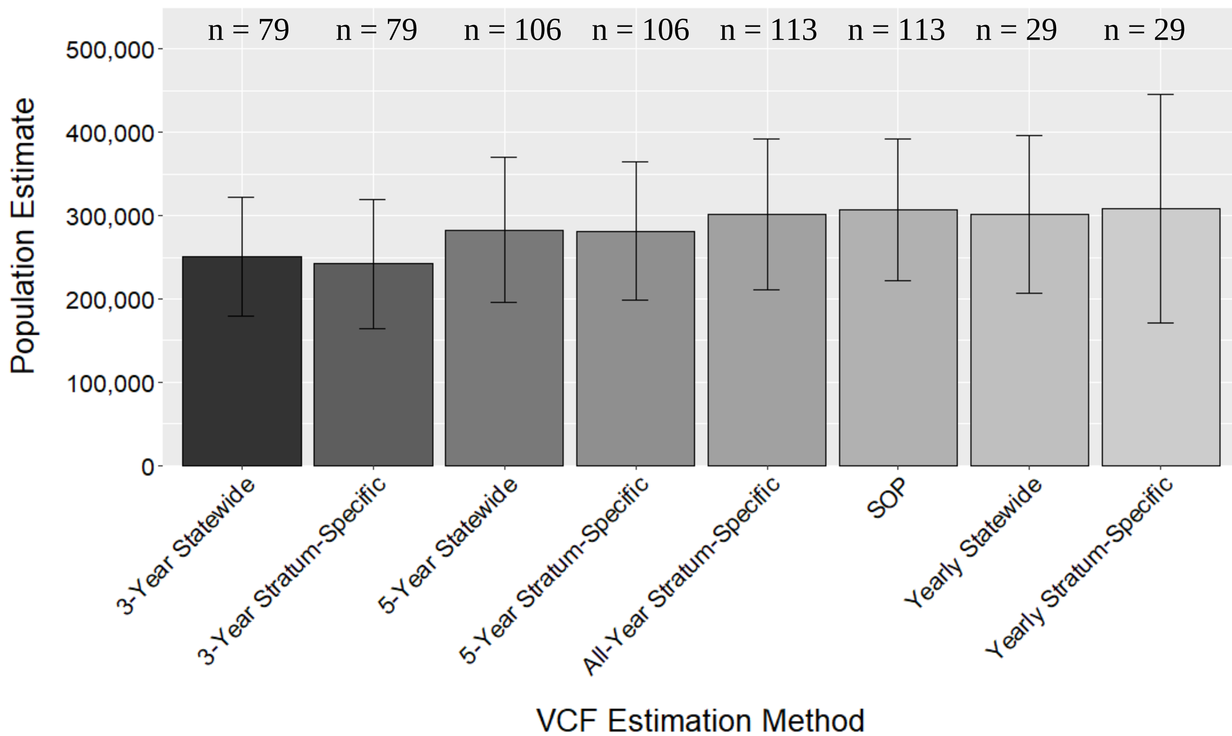



Figure 6. Comparison of Canada goose population estimates for alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) 2003, b) 2010, c) 2014, d) 2018, and e) 2019. The black bars represent ninety-five percent confidence intervals and n represents the number of segments to calculate the VCF for each VCF estimation method.

Figure 6 (cont'd)

b)




c)

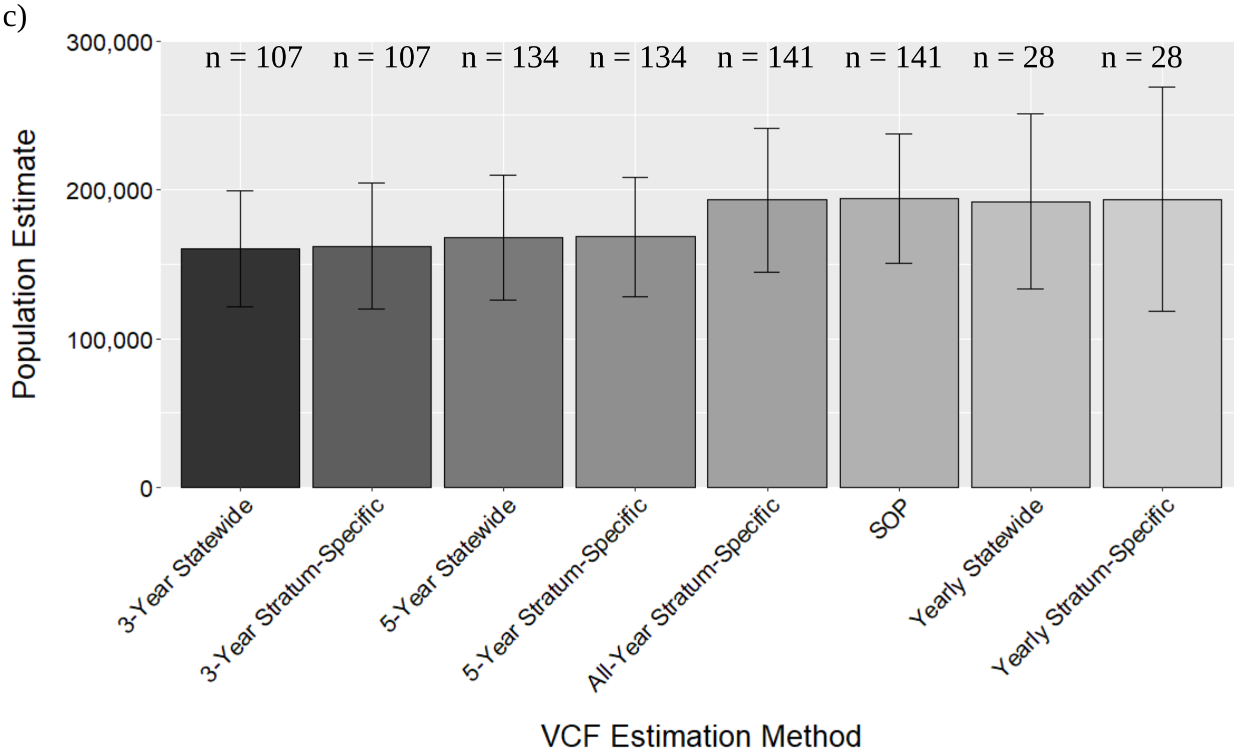
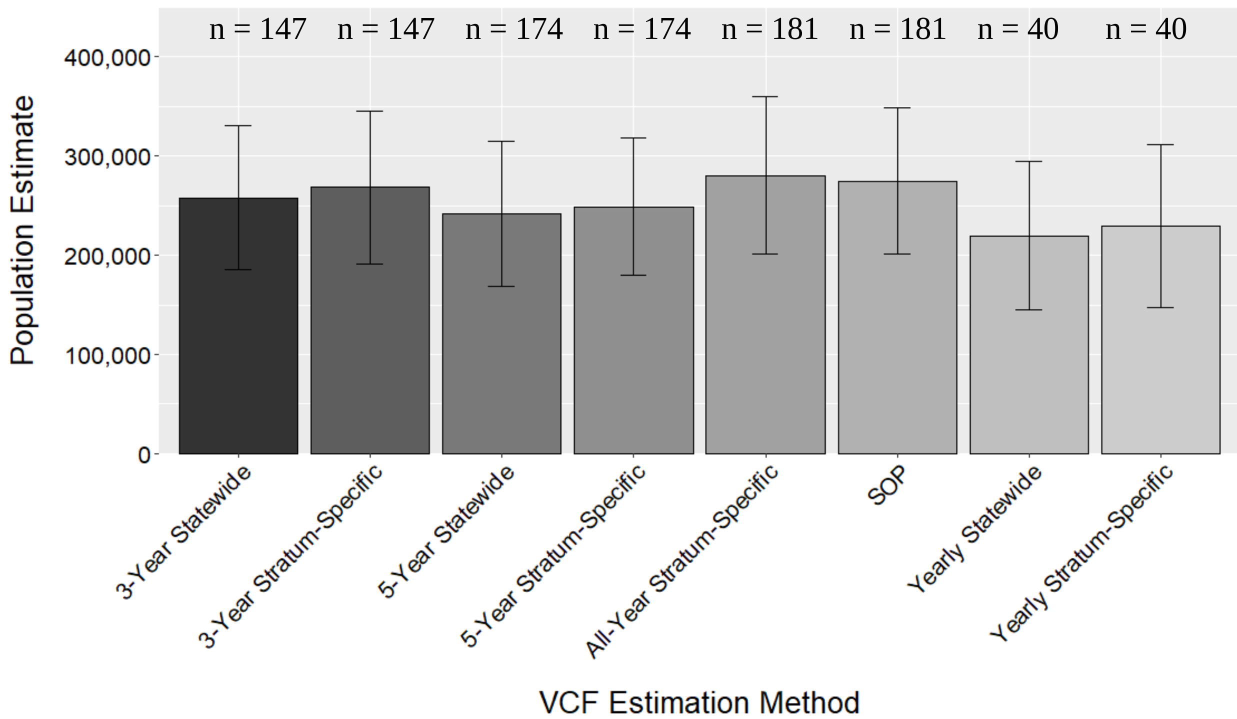
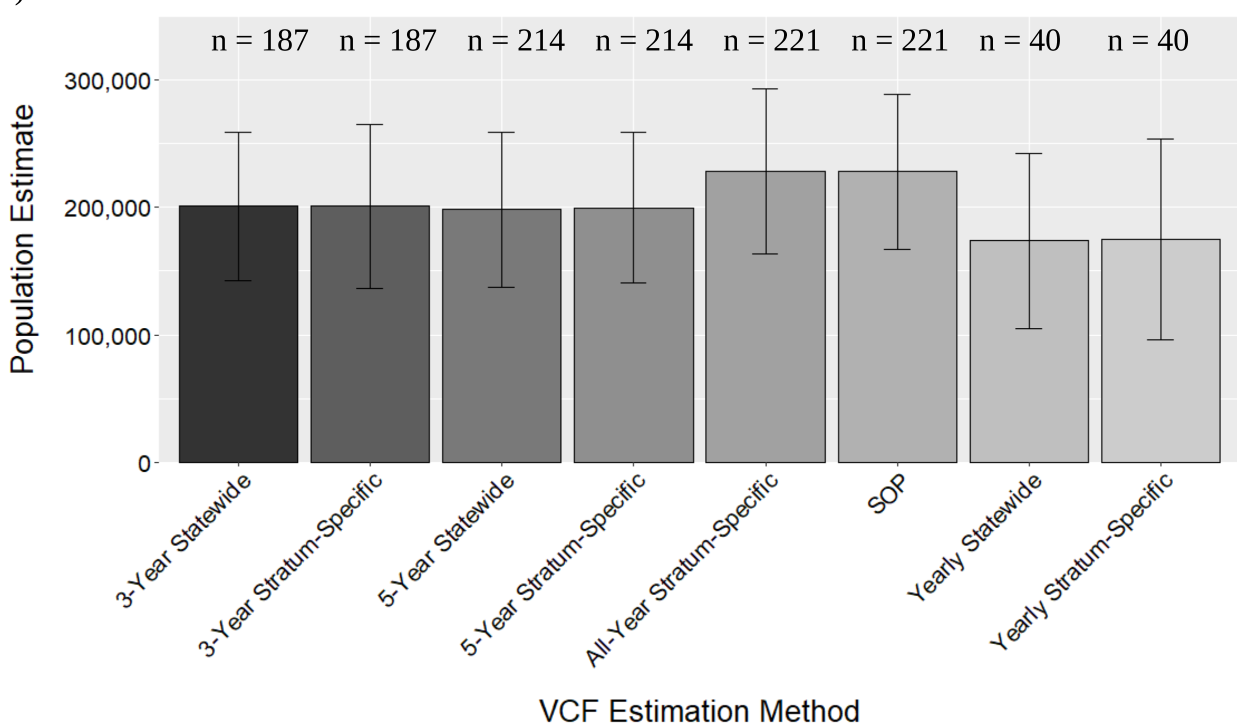


Figure 6 (cont'd)

d)




e)



9% smaller for five-year compared to the Canada goose SOP. Population estimates from all-year stratum-specific VCFs were on average less than 1% smaller compared to the SOP. Moreover, the 2003 Canada goose yearly statewide and stratum-specific VCFs resulted in 50% smaller population estimates than the 2003 Canada goose SOP population estimate. The 2003 Canada goose three-year statewide and three-year stratum-specific population estimates were around 28% smaller than the 2003 Canada goose SOP population estimate. In 2010, the Canada goose three-year statewide and three-year stratum-specific population estimates were on average lower than the Canada goose SOP by 20%. In 2014, the Canada goose three-year statewide, three-year stratum-specific, five-year statewide, and five-year stratum-specific population estimates were on average smaller than the Canada goose SOP by 15%. In 2018, the Canada goose three-year stratum-specific VCF had a similar population estimate compared to the Canada goose SOP population estimate, while the remaining alternate VCF estimates were an average of 14% smaller than their respective SOP population estimates. In 2019, the Canada goose population estimate for the all-year stratum-specific VCF was similar to the SOP population estimate. The rest of the VCF estimation methods estimated on average 16% smaller population estimates compared to the Canada goose SOP population estimate. For the five most recent VCF years, Canada goose population estimates for the stratum-specific and statewide VCF estimation methods showed marginal differences to each other per year. Variances for each alternate VCF estimation methods were similar to the Canada goose variances based on the SOP.

Few alternate mallard population estimates were significantly different from the mallard SOP (Figure 7). In 2003, the yearly statewide VCF estimation method resulted in a significantly lower population estimate than the SOP population estimate. On average, mallard population estimates from statewide VCFs were 23% smaller for yearly, 20% smaller for three-year, 11%

a)

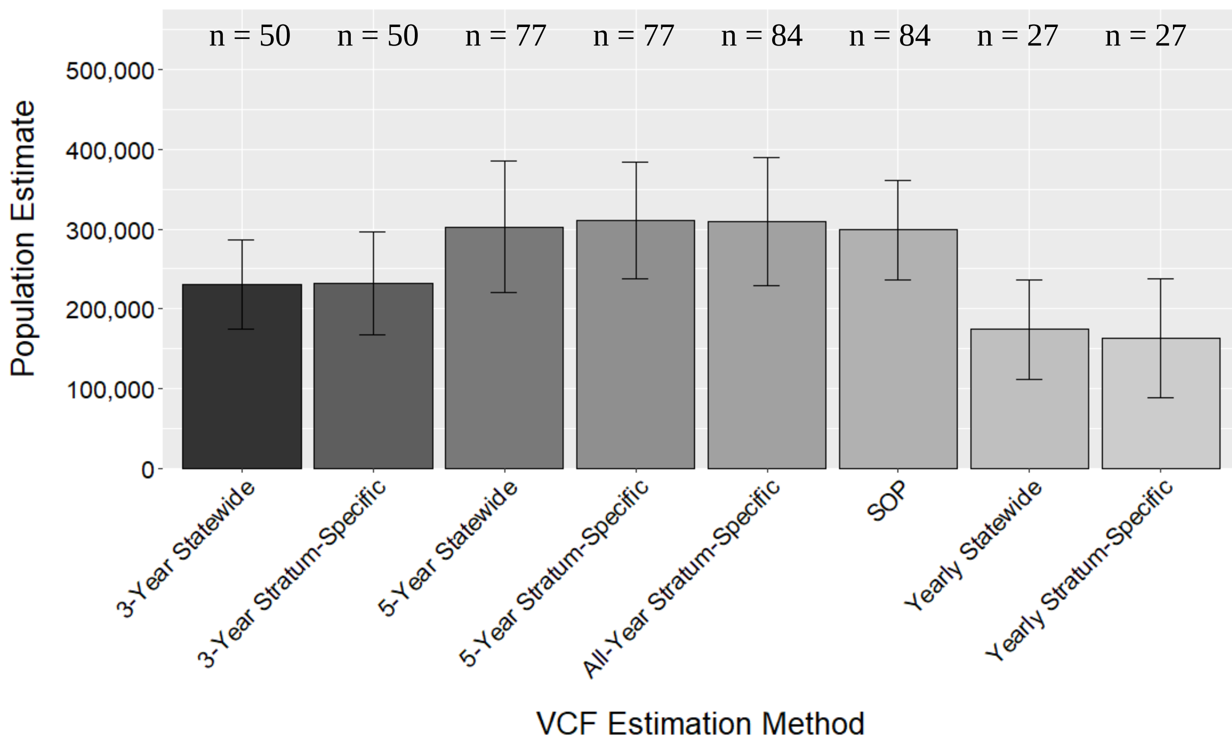
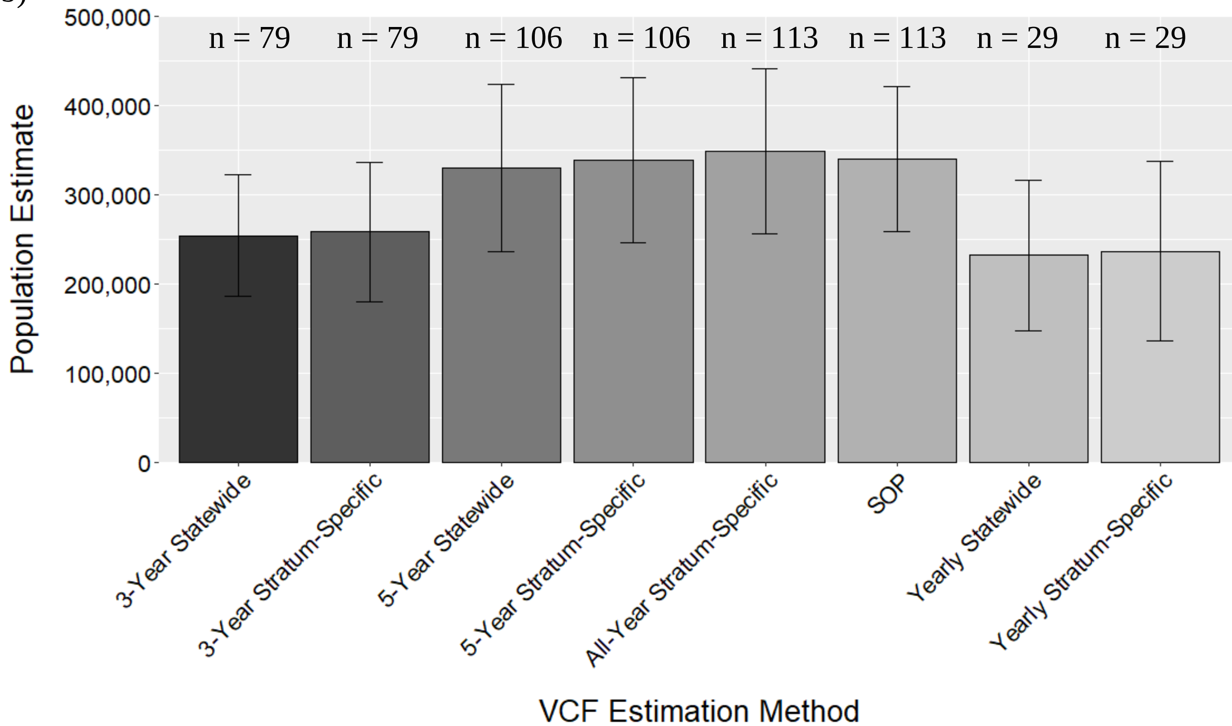



Figure 7. Comparison of mallard population estimates for alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) 2003, b) 2010, c) 2014, d) 2018, and e) 2019. The black bars represent ninety-five percent confidence intervals and n represents the number of segments to calculate the VCF for each VCF estimation method.

Figure 7 (cont'd)

b)




c)

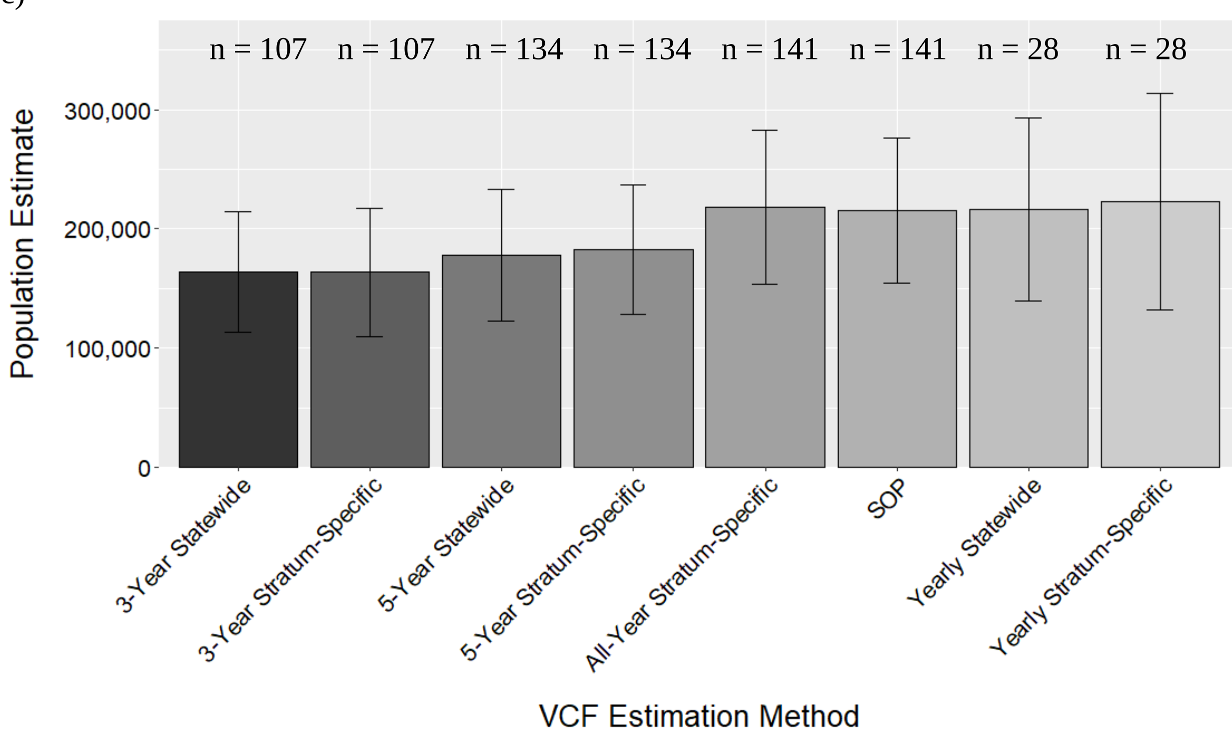
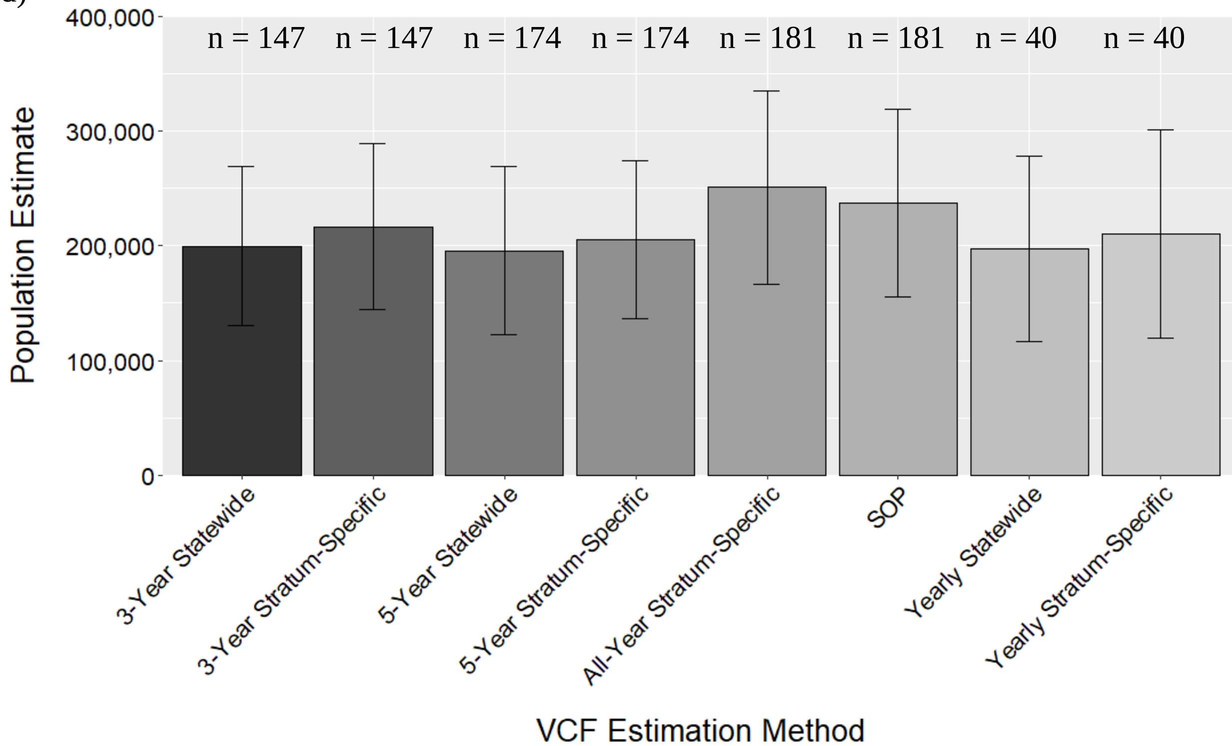
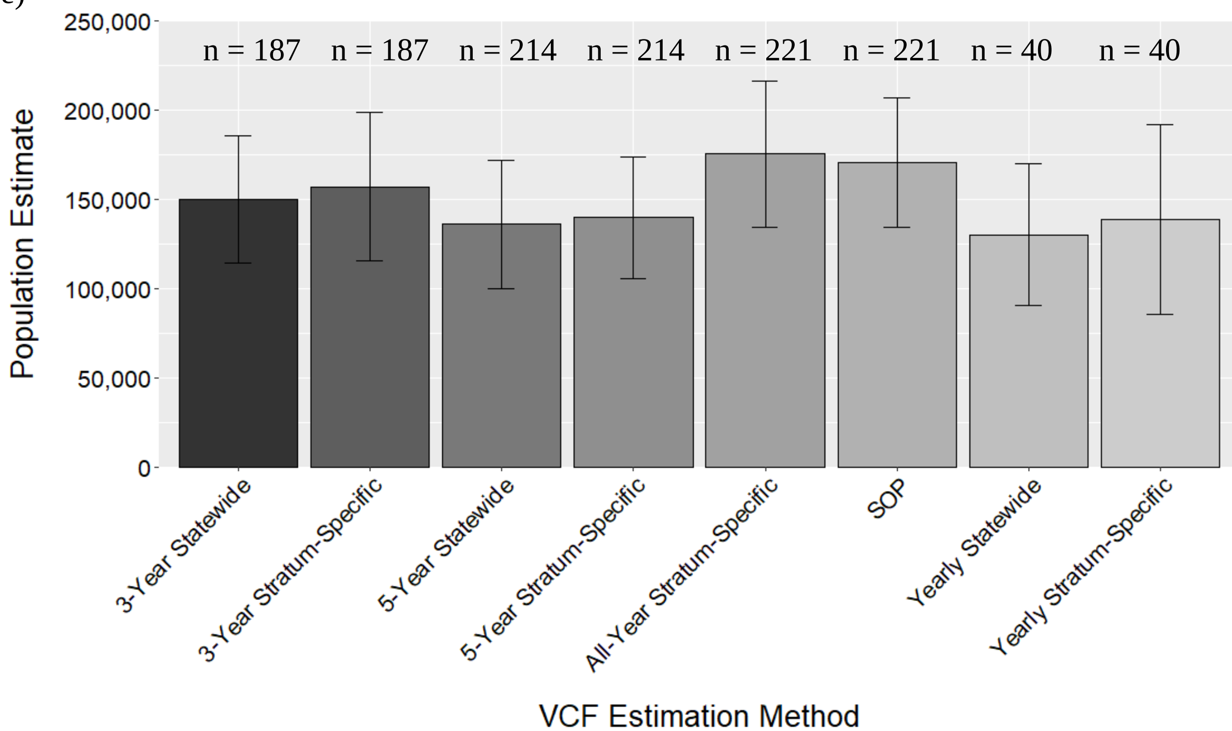


Figure 7 (cont'd)

d)




e)



smaller for five-year compared to the mallard SOP. Stratum-specific population estimates were on average 20% smaller for yearly, 17% smaller for three-year, 9% smaller for five-year, and 3% smaller for all-year compared to the mallard SOP. In 2003, population estimates from mallard yearly stratum-specific and yearly statewide VCFs were similar to each other and were around 44% smaller compared to the 2003 mallard SOP. Additionally, the 2003 mallard yearly stratum-specific VCF estimated about 11,000 fewer birds than the 2003 mallard yearly statewide but had a higher variance which resulted in no significant difference to the SOP. Similar patterns from the Canada goose population estimates repeated in the mallard population estimates. In 2003 and 2010, mallard three-year statewide and three-year stratum-specific population estimates were on average 23% smaller than their respective mallard SOP population estimates. Mallard yearly statewide and yearly stratum-specific population estimates were on average 31% smaller in 2010 than the 2010 SOP population estimate. In 2014, the mallard all-year stratum-specific, yearly stratum-specific, and yearly statewide VCFs population estimates were nearly identical to the mallard SOP population estimate, while the remaining VCF estimation methods estimated an average of 18% fewer birds. In 2018 and 2019, similar patterns occurred for the alternate mallard VCF estimation methods. The mallard all-year stratum-specific VCF population estimate was slightly higher than the mallard SOP population estimate by 6% in 2018 and 3% in 2019. The rest of the alternate VCF estimation methods were on average around 14% smaller in 2018 and 17% smaller in 2019. In 2003, 2010, and 2014, mallard population estimates were marginally different between stratum-specific and statewide VCF estimation methods. In 2018 and 2019, mallard population estimates had higher population estimate differences between stratum-specific and statewide VCF estimation methods. During 2018 and 2019, the mallard stratum-specific VCF estimation methods had higher population estimates than the statewide VCF estimation methods. Variances for each alternate VCF estimation methods were similar to the mallard SOP variances in corresponding years.

Sandhill crane alternate VCF estimation methods resulted in no significant difference compared to the SOP sandhill crane population estimates (Figure 8). On average, the population estimate from yearly statewide VCF was 25% larger compared to the sandhill crane SOP. Stratum-specific population estimates were on average 33% smaller for yearly, 5% smaller for five-year, and 5% smaller for all-year compared to the sandhill crane SOP. Population estimates from three-year statewide, five-year statewide, and three-year stratum-specific VCFs were less than 1% different than SOP population estimates. Sandhill crane population estimates were similar to each other in 2010, but all the sandhill crane stratum-specific VCF estimation methods resulted in higher variances compared to the sandhill crane statewide VCF estimation methods. In 2014, sandhill crane yearly statewide and yearly stratum-specific VCF population estimates were on average 170% more than the sandhill crane SOP and the rest of the alternate VCF estimation methods. Conversely, 2018 sandhill crane yearly statewide and yearly stratum-specific VCF population estimates were 34% smaller than the sandhill crane population estimates from SOP and other VCF estimation methods. In 2019, sandhill crane yearly stratum-specific and three-year stratum-specific population estimates were 39% smaller, while the yearly statewide population estimate was 23% smaller than the sandhill crane SOP population estimate. The remaining VCF estimation methods had negligible population estimate differences. Variances for each 2018 and 2019 alternate VCF estimation methods were similar to the variances for the sandhill crane SOP.

a)

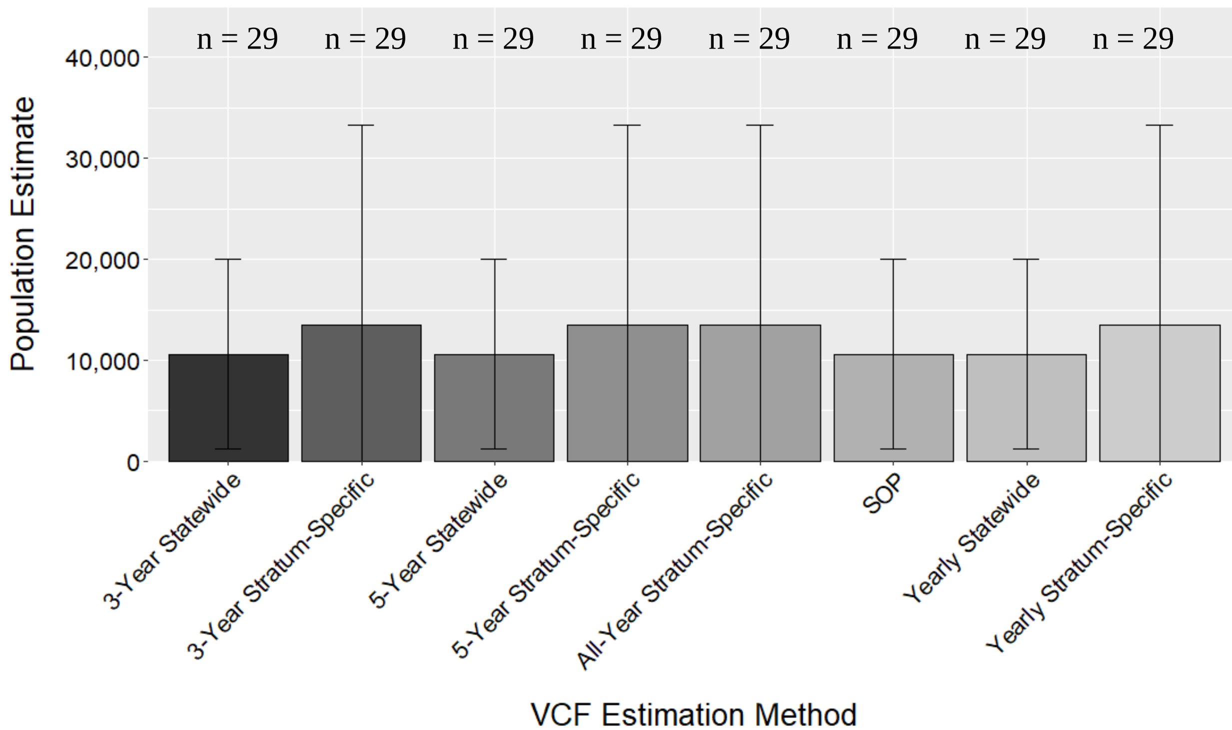
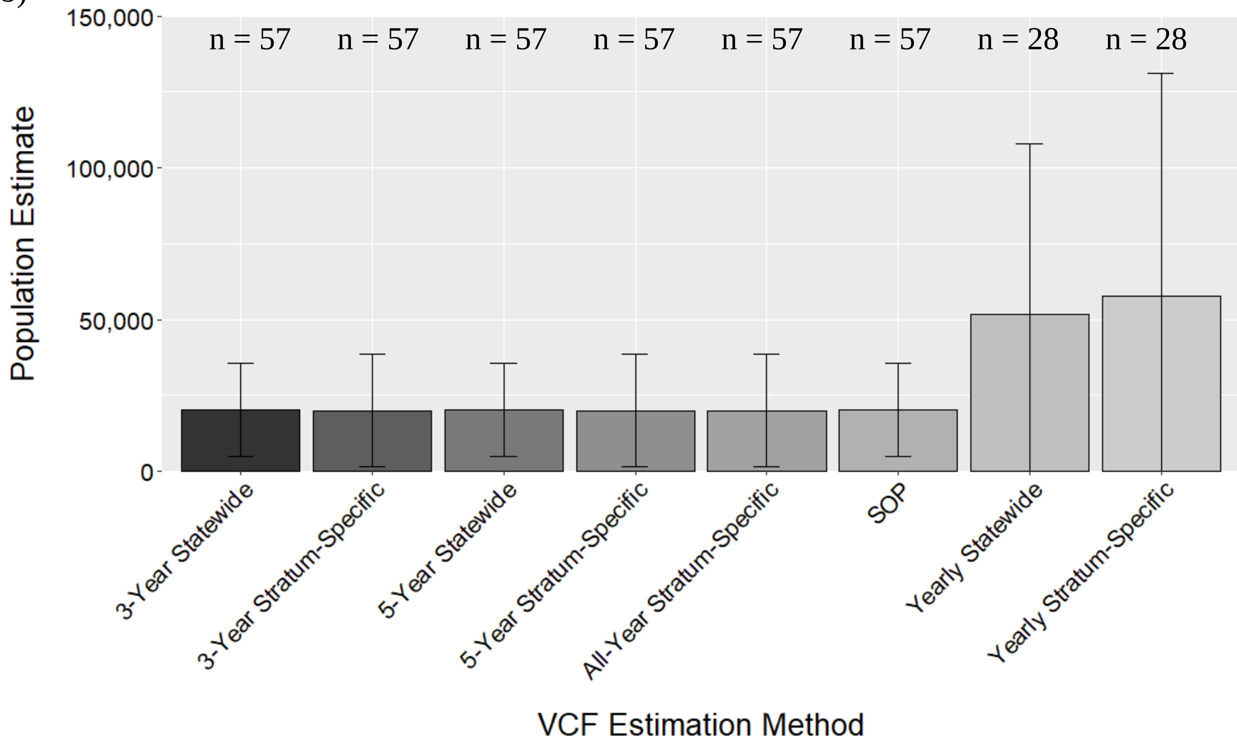



Figure 8. Comparison of sandhill crane population estimates for alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) 2003, b) 2010, c) 2014, d) 2018, and e) 2019. The black bars represent ninety-five percent confidence intervals and n represents the number of segments to calculate the VCF for each VCF estimation method.

Figure 8 (cont'd)

b)




c)

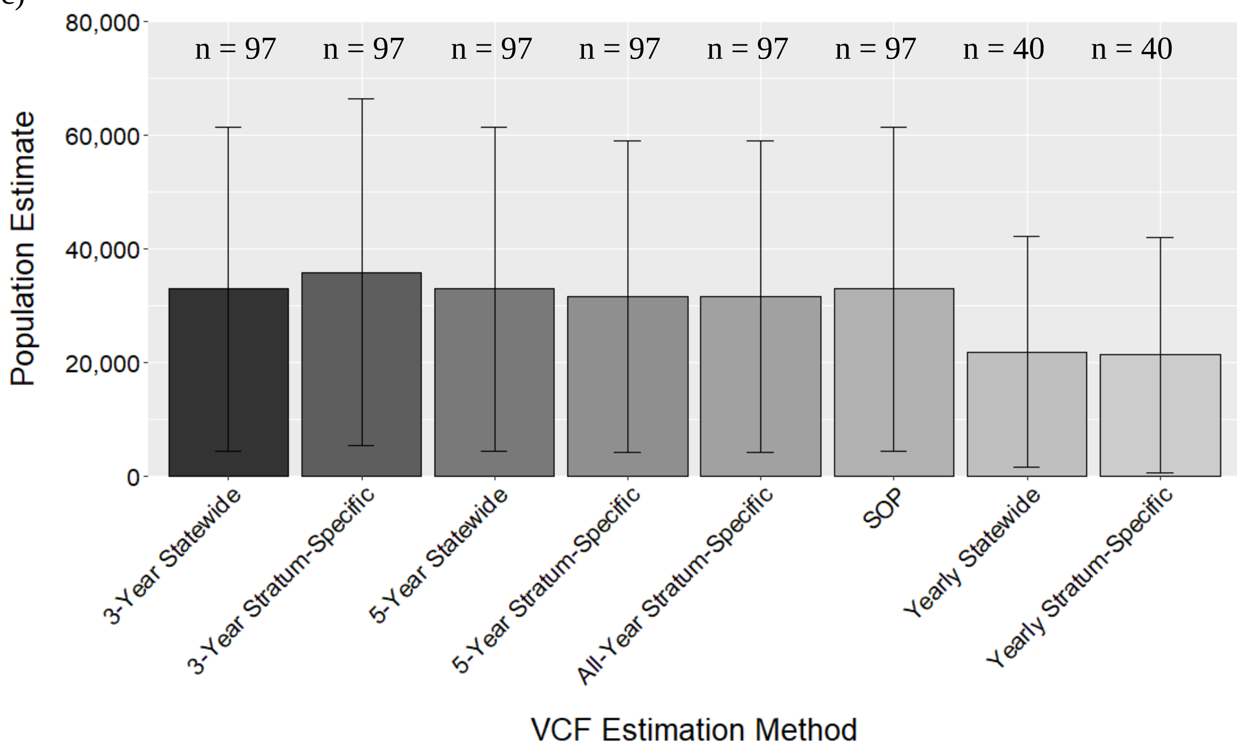
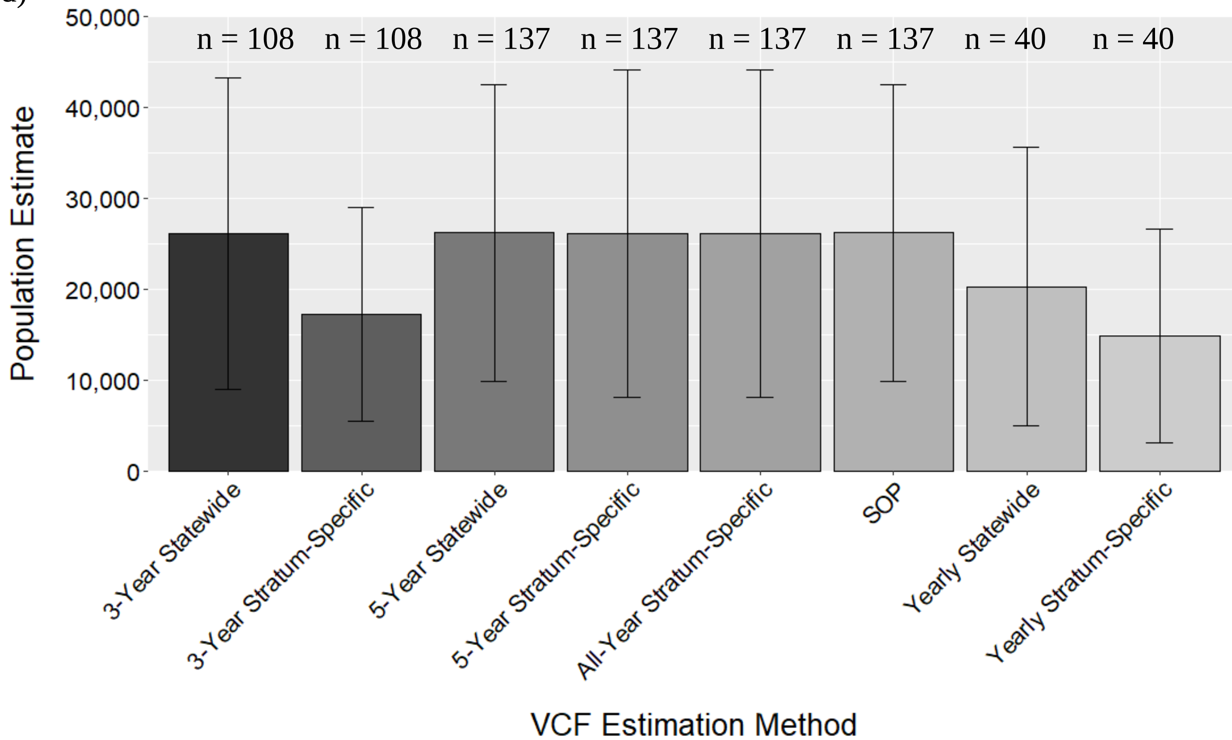


Figure 8 (cont'd)

d)



Lastly, we looked at averaged CV on population estimates from 2003, 2010, 2014, 2018, and 2019. Averaged alternate Canada goose and mallard CVs on population estimates were not significantly different than their respective SOP averaged CV except for the significantly higher yearly stratum-specific averaged CV for both species (Figures 9a and 9b). Furthermore, the yearly stratum-specific averaged CV exceeded the criteria of 20% or less with CV values at 21.2 for Canada goose and 21.6 for mallard. Based on the overlap with the 95% confidence intervals, yearly statewide averaged CVs for Canada goose and mallard may be expected to exceed 20% in some years. For Canada goose and mallard, the variances on the alternate VCF estimation methods were similar to the SOP variances. Averaged alternate sandhill crane CVs were not significantly different compared to their respective SOP averaged CV (Figure 9c). Sandhill crane three-year statewide, five-year statewide estimation methods had nearly identical averaged CVs compared to the sandhill crane SOP CV and with comparable variances. The stratum-specific methods for sandhill crane had comparable variances to each other but were exceedingly higher than the other alternate sandhill crane VCFs and SOP variances. The SOP method had the lowest averaged CV for Canada goose, mallard, and sandhill crane at 13.4, 13.1, and 39.9, respectively. Canada goose and mallard averaged CVs were less than 20% except for yearly stratum-specific. Averaged CVs for sandhill crane were always above 20%.

**Helicopter Bootstrap**

Using the five most recent VCF years, the bootstrap method resulted in decreased variance as the number of segments increased (Figure 10). Invariant population estimates were produced for each VCF year, showing that performing 1,000 iterations was sufficient for the bootstrap method. Canada goose and mallard bootstrapped CV showed that helicopter surveys

a)

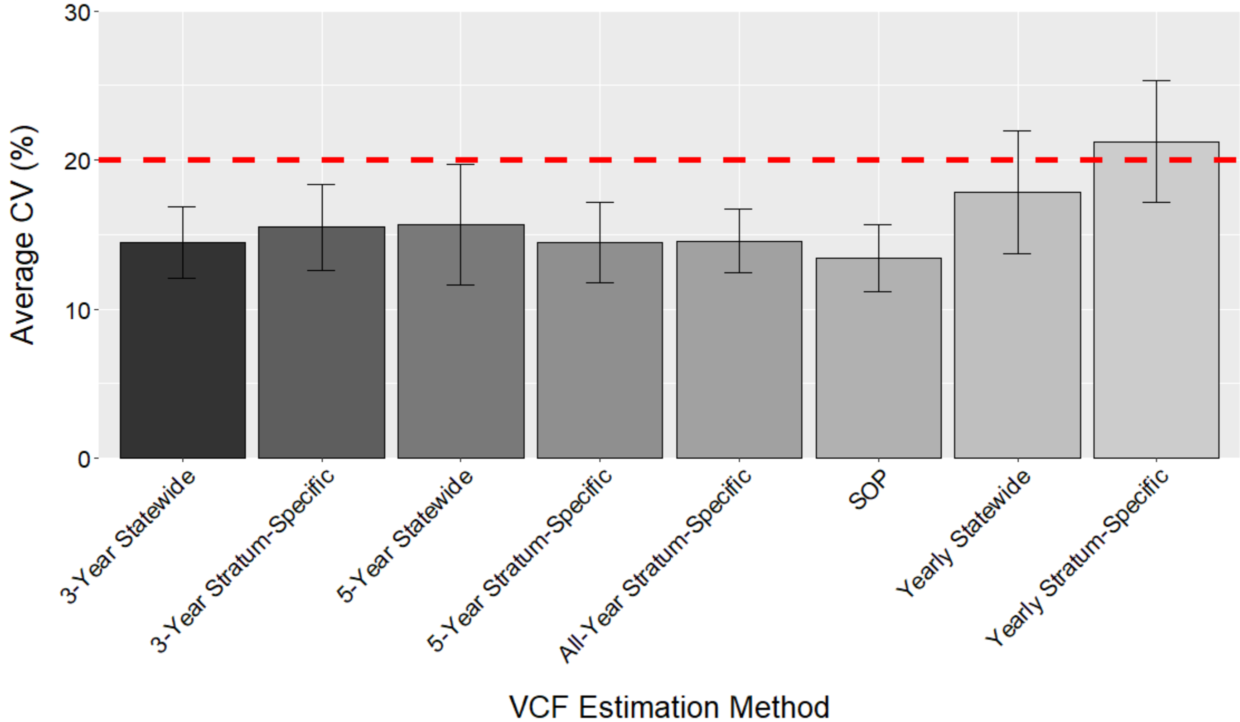
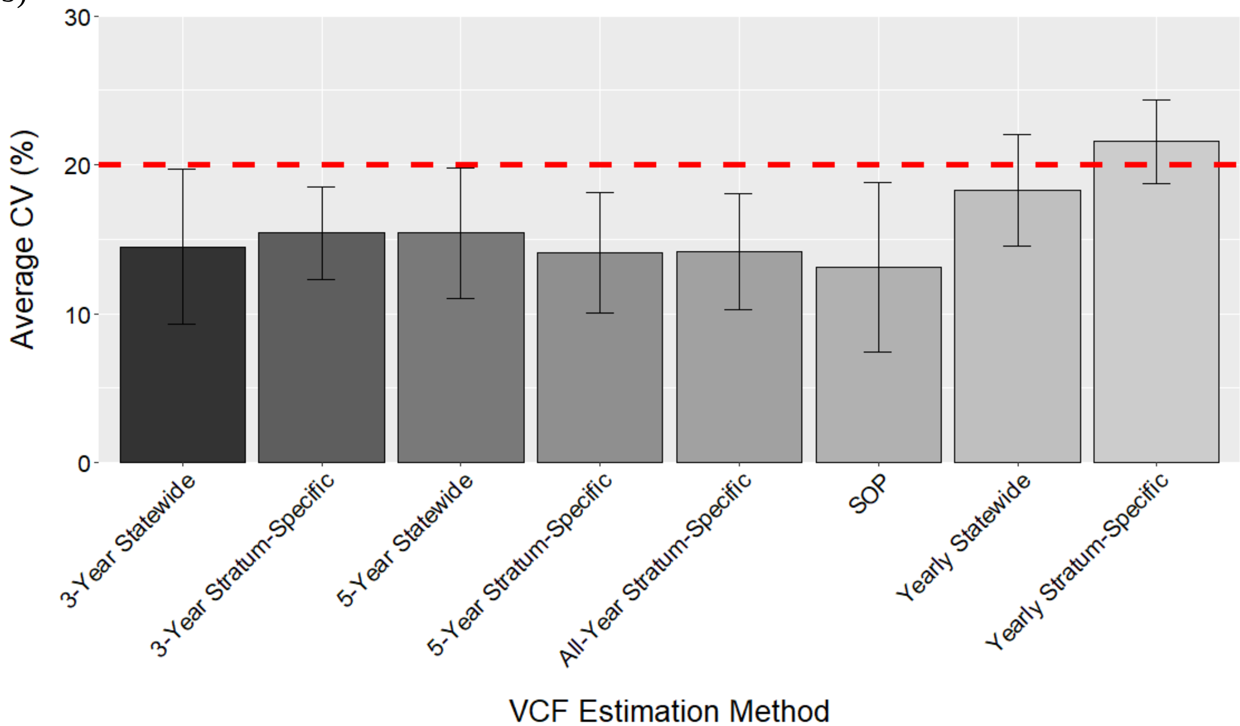


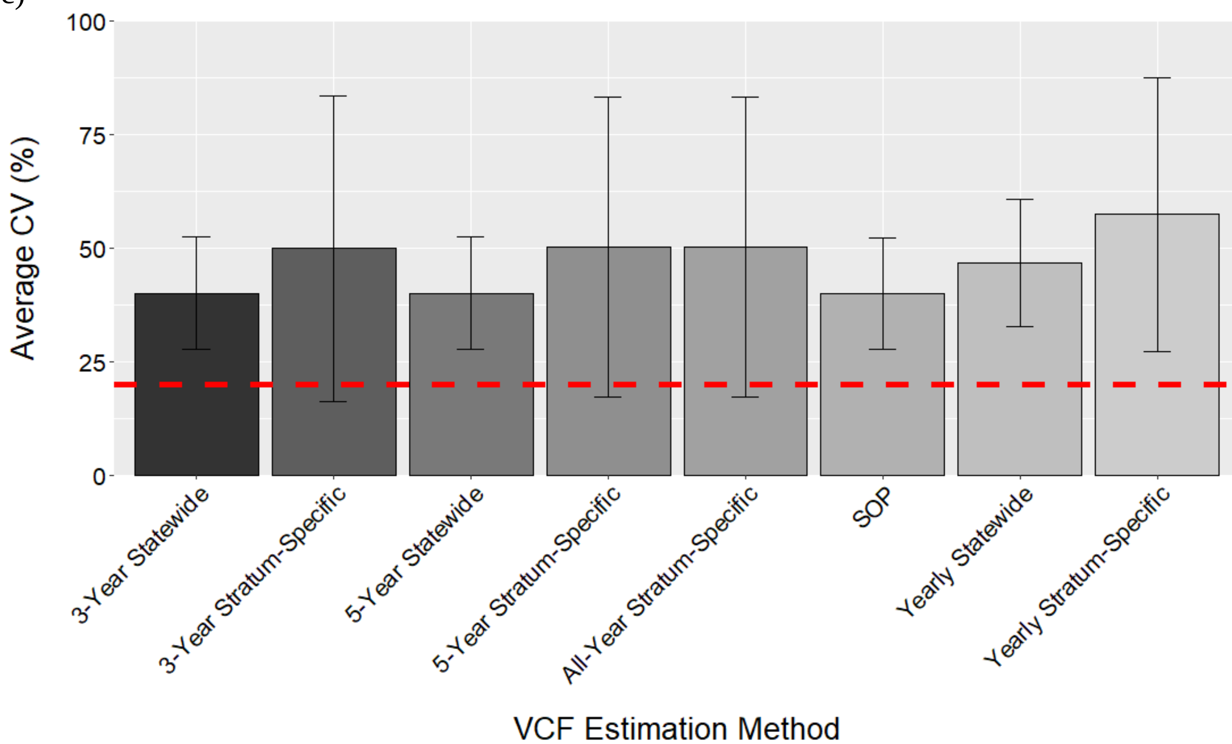

Figure 9. Comparison of average Coefficient of Variation (CV) on population estimates for alternate Visibility Correction Factors (VCFs) using fixed-wing and helicopter surveys over the state of Michigan for a) Canada goose (2003, 2010, 2014, 2018, and 2019), b) mallard (2003, 2010, 2014, 2018, and 2019), and c) sandhill crane (2010, 2014, 2018, and 2019). CV of 20% is shown as the red dashed line. The black bars represent ninety-five percent confidence intervals.

Figure 9 (cont'd)

b)




c)



a)

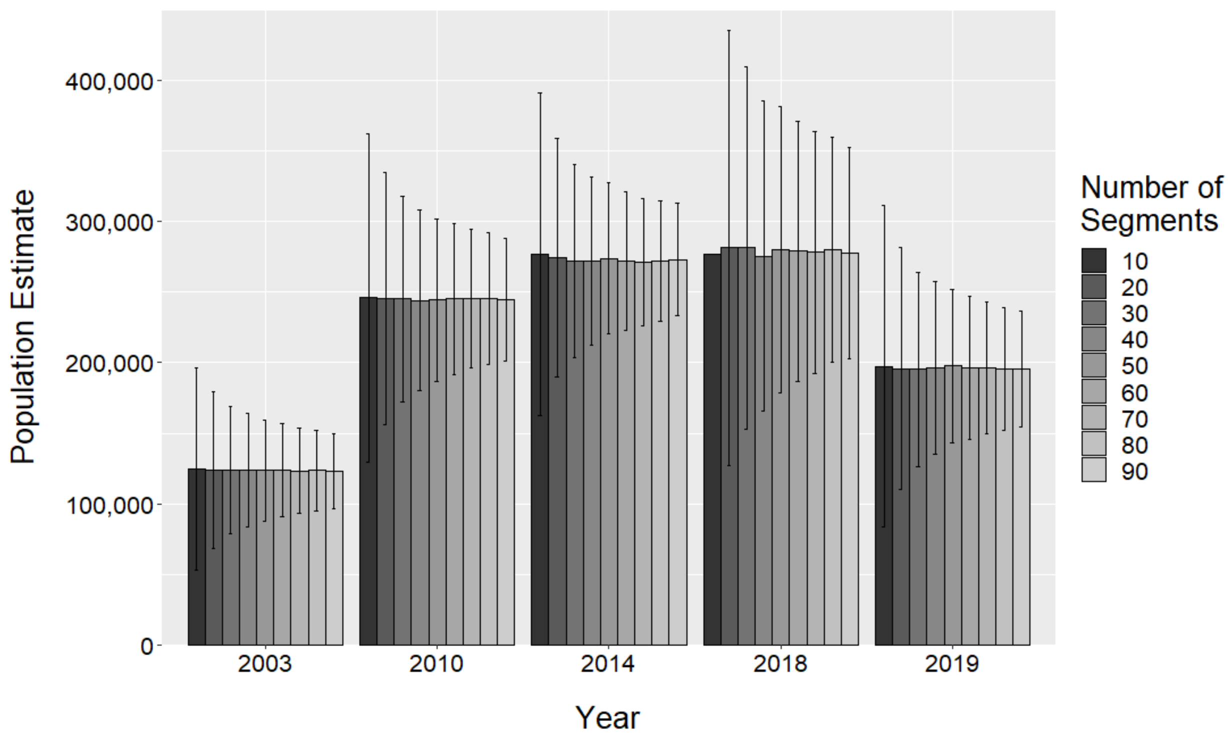
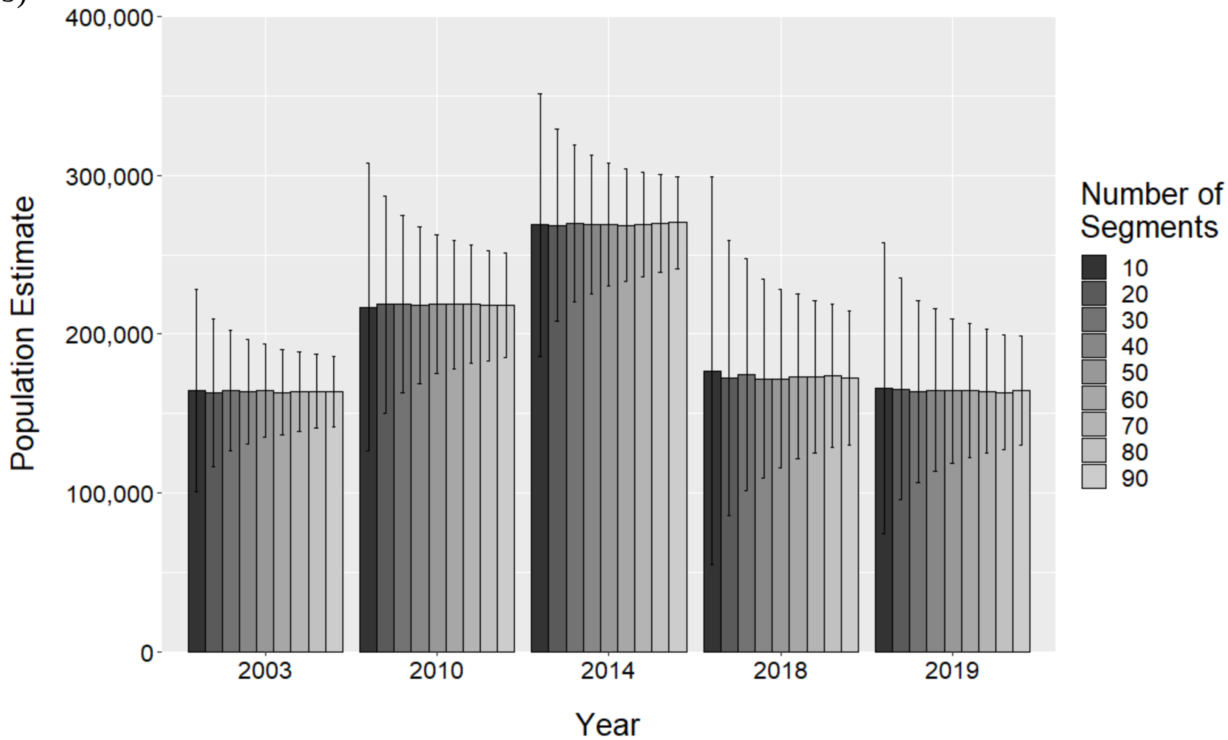



Figure 10. The bootstrap method population estimates for the helicopter-only aerial survey design using helicopter surveys over the state of Michigan for the five most recent VCF years for a) Canada goose, b) mallard, c) sandhill crane, and d) mute swan. The black bars represent ninety-five percent confidence intervals.

Figure 10 (cont'd)

b)




c)

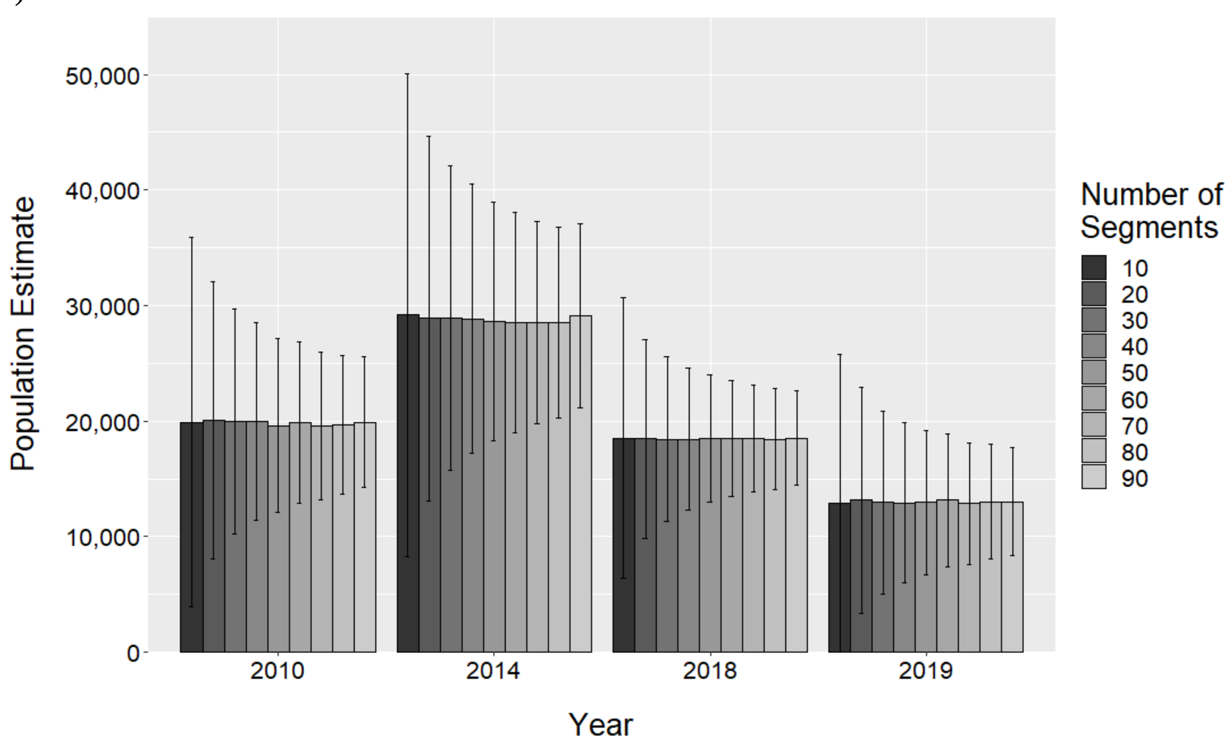
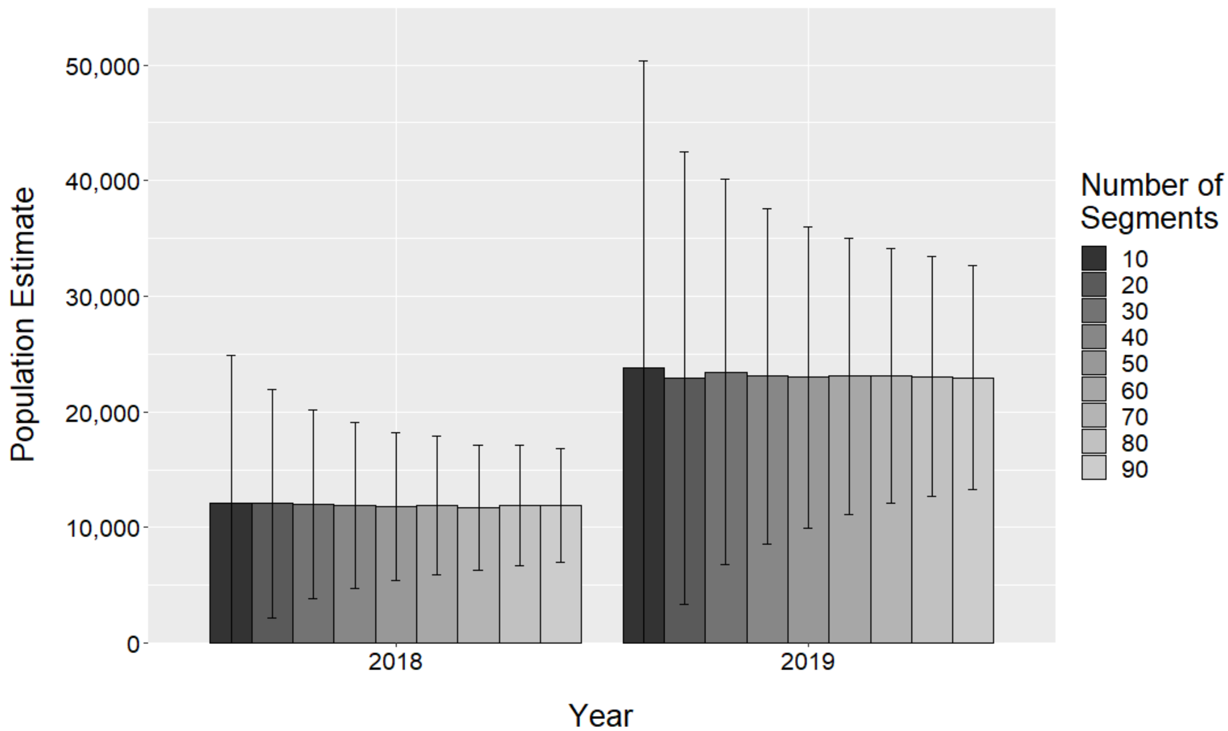


Figure 10 (cont'd)

d)



with more than 40 segments would result in a CV of 20% or less (Figures 11a and 11b). Sandhill crane and mute swan bootstrapped CV needed more than 40 segments to produce a CV of 20% or less (Figures 11c and 11d). For the five most recent VCF years, all averaged Canada goose CVs were more than 20% if 10 helicopter segments were surveyed. Three VCF years had more than 20% averaged Canada goose CV for 20 helicopter segments surveyed, while one VCF year had more than 20% averaged CV for 30 helicopter segments. At 40 helicopter segments surveyed, all the VCF years for Canada goose had an averaged CV of 20% or less. For averaged mallard CV, three VCF years at 10 helicopter segments, two VCF years at 20 helicopter segments, and one VCF year had averaged mallard CVs more than 20%. At 40 helicopter segments surveyed, all the VCF years for mallard had an averaged CV of 20% or less. Averaged sandhill crane needed more than 80 helicopter segments to produce a CV of 20% or less. At 90 helicopter segments surveyed, averaged mute swan CV was close to a 20% CV.

**Fixed-wing Bootstrap**

Similar to the helicopter bootstrap results, the bootstrap method resulted in decreased variance as the number of transects increased (Figure 12). Invariant population estimates were produced for each VCF year, showing that performing 1,000 iterations was sufficient for the bootstrap method. Canada goose and mallard bootstrapped CVs showed that no more than five transects should be removed in the farm urban stratum to maintain a CV of 20% or less (Figures 13a and 13b). Sandhill crane and mute swan bootstrapped CVs resulted in a CV of 20% or more for all number of transects in the farm urban stratum (Figures 13c and 13d). For the five most recent VCF years, all averaged Canada goose CVs were more than 20% if more than eight transects were removed in the farm urban stratum. One and two VCF years had averaged Canada goose CVs below a CV of 20% or less if seven transects or six transects were removed,

a)

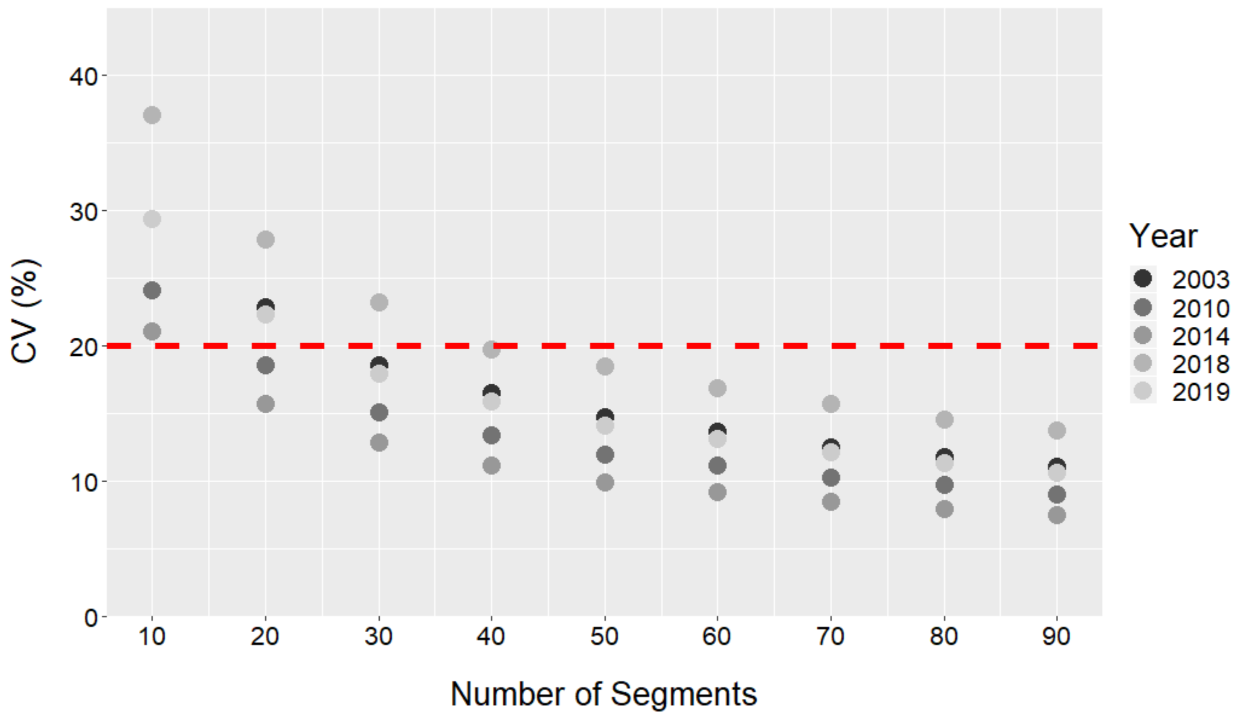
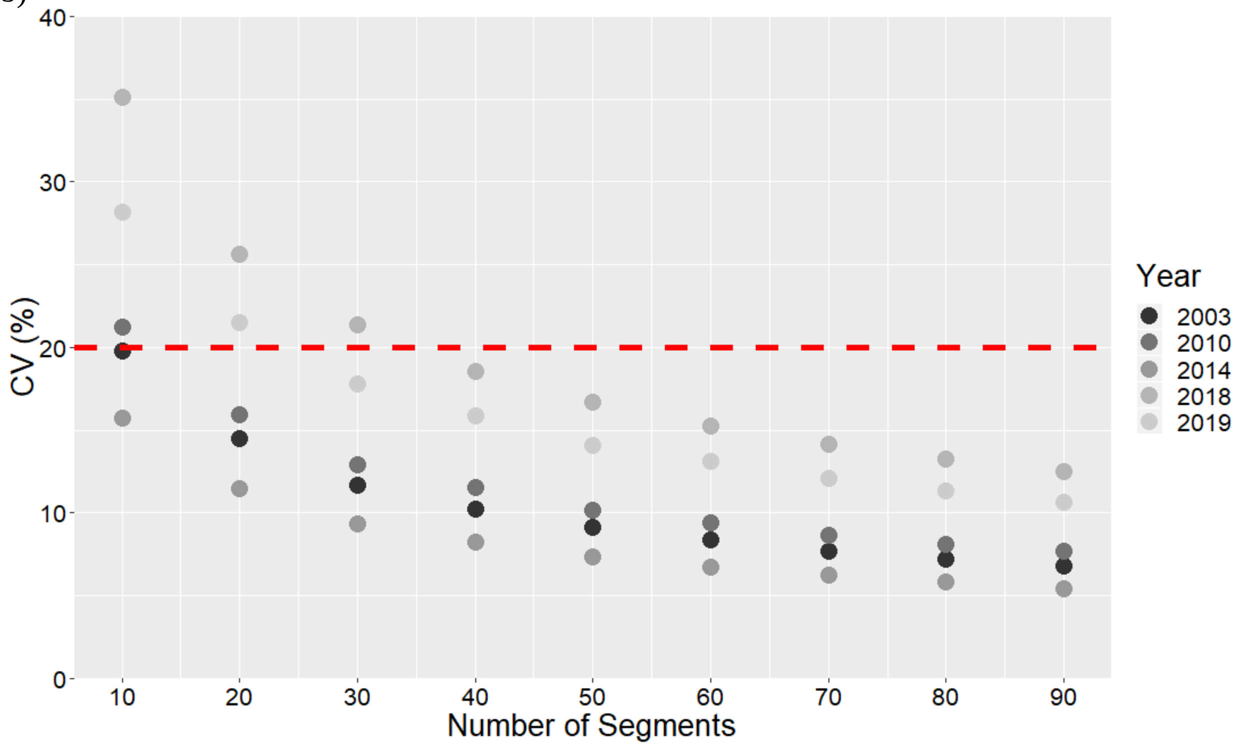



Figure 11. The bootstrap method Coefficient of Variation (CV) on population estimates from the helicopter-only aerial survey design using helicopter surveys over the state of Michigan for the five most recent VCF years for a) Canada goose, b) mallard, c) sandhill crane, and d) mute swan. CV of 20% is shown as the red dashed line.

Figure 11 (cont'd)

b)




c)

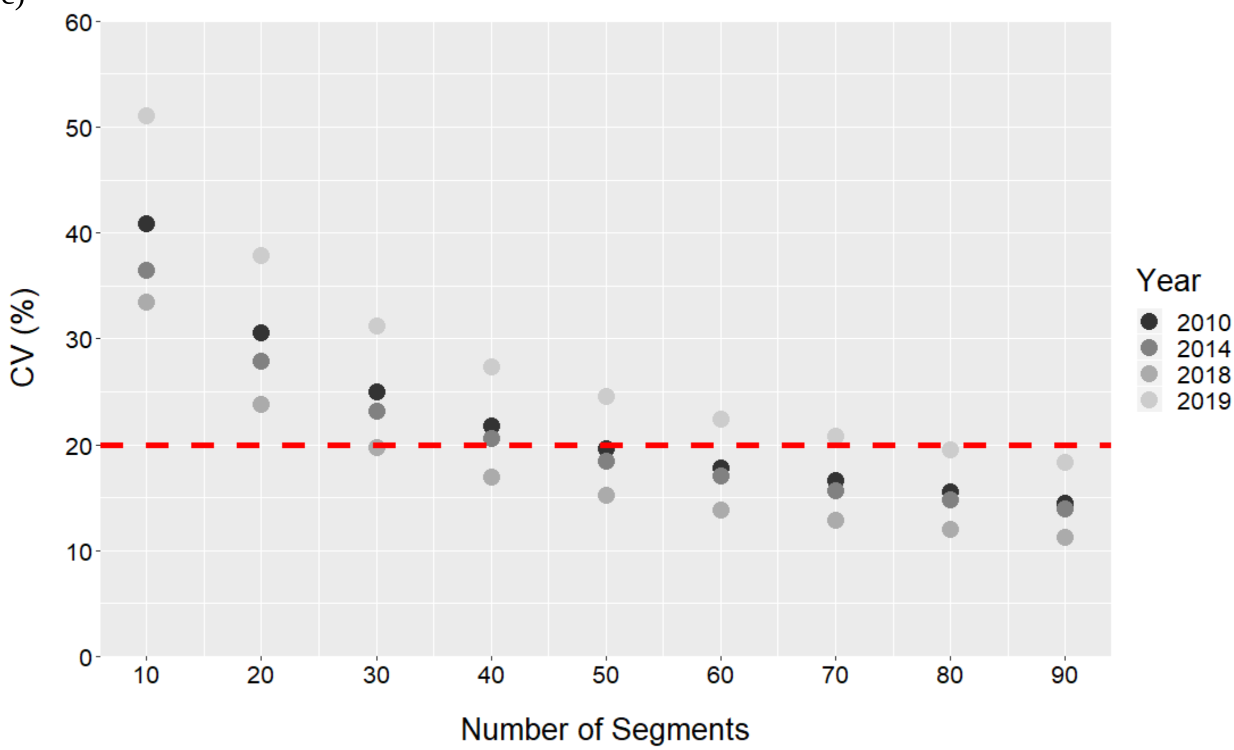
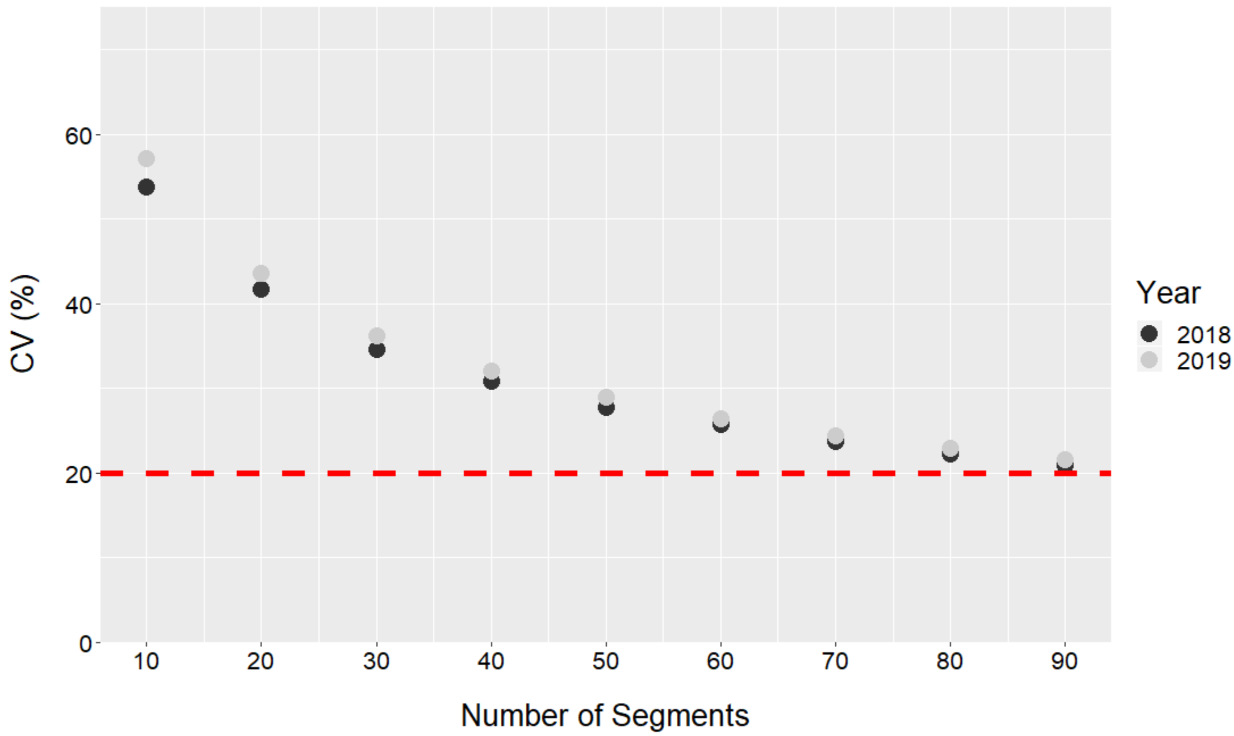


Figure 11 (cont'd)

d)



a)

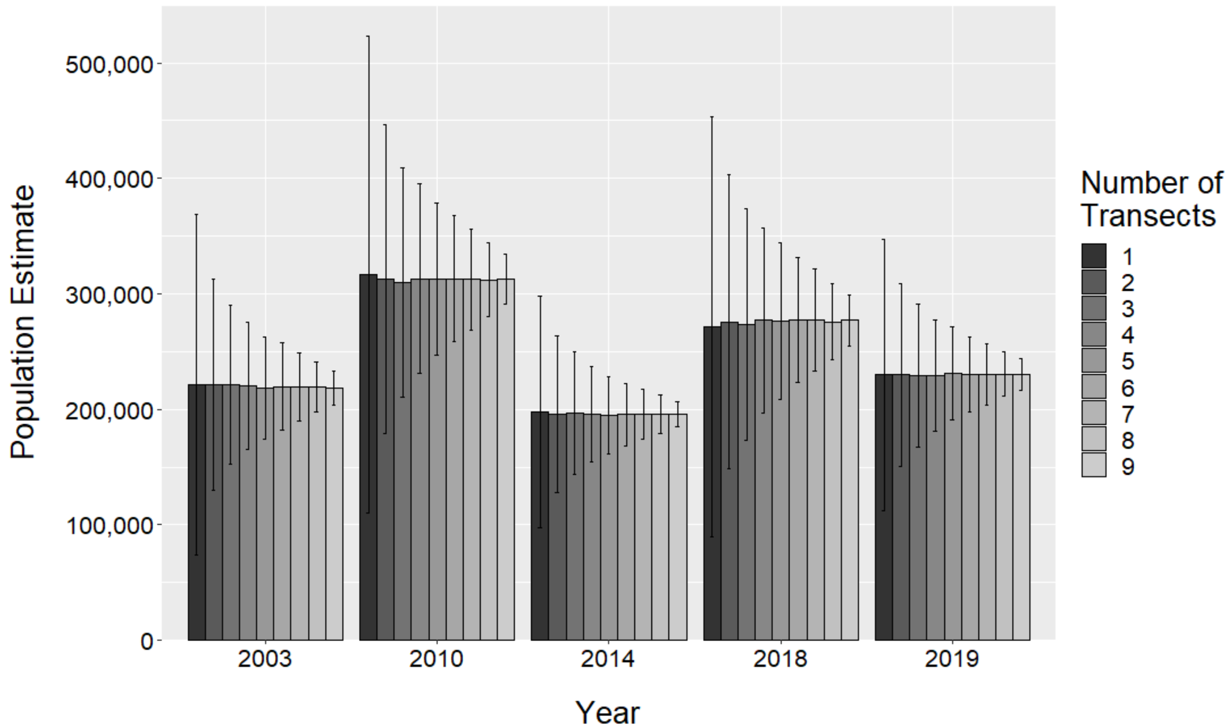
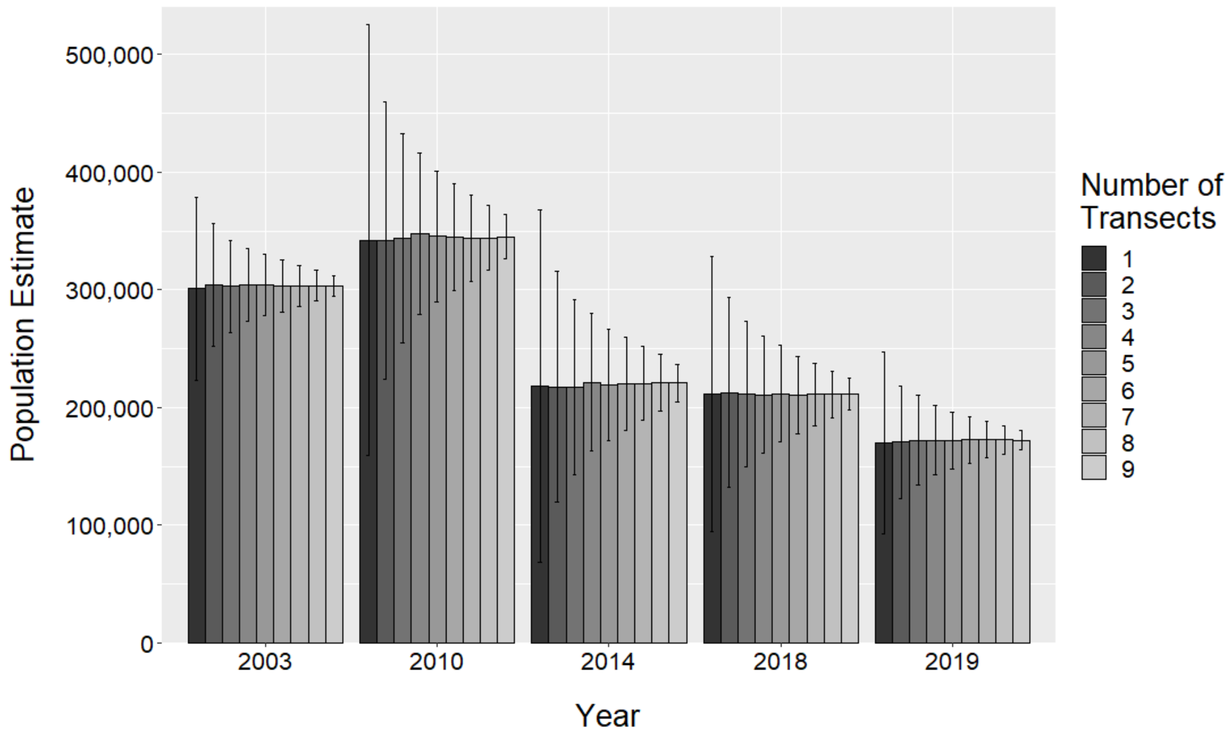



Figure 12. The bootstrap method population estimates for the modified SOP aerial survey design using fixed-wing and helicopter surveys over the state of Michigan for the five most recent VCF years for a) Canada goose, b) mallard, c) sandhill crane, and d) mute swan. The black bars represent ninety-five percent confidence intervals.

Figure 12 (cont'd)

b)




c)

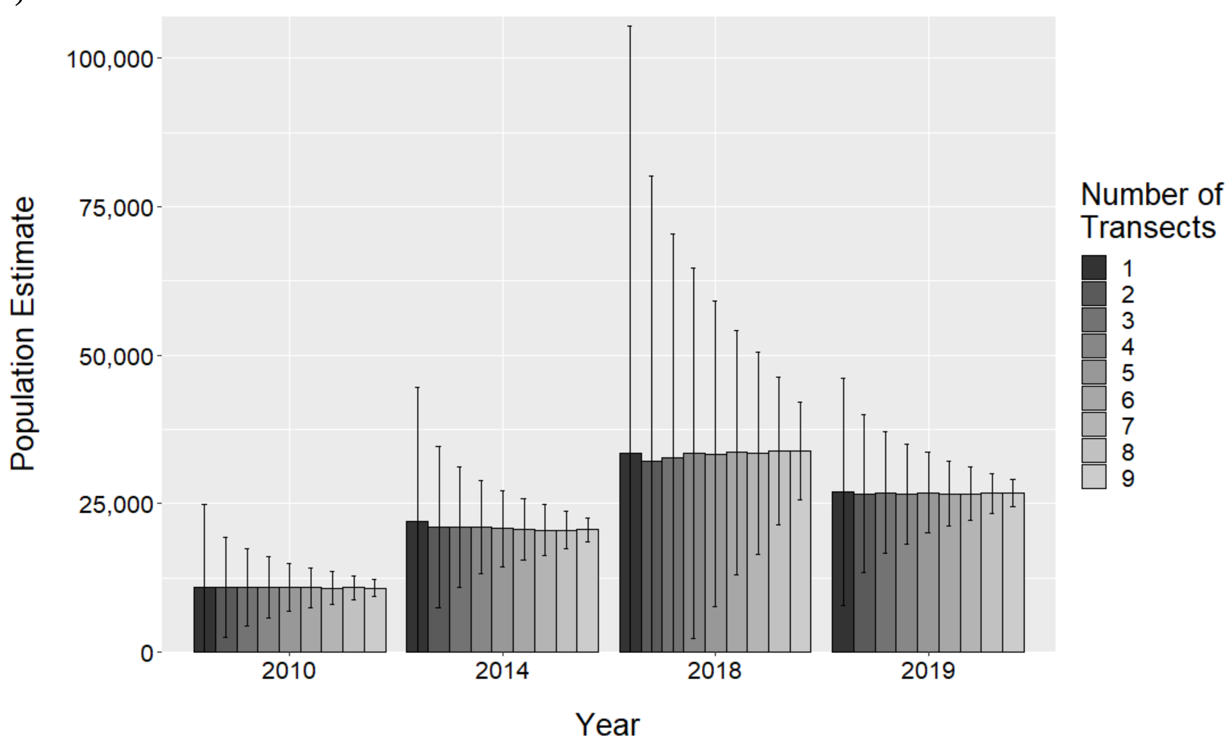
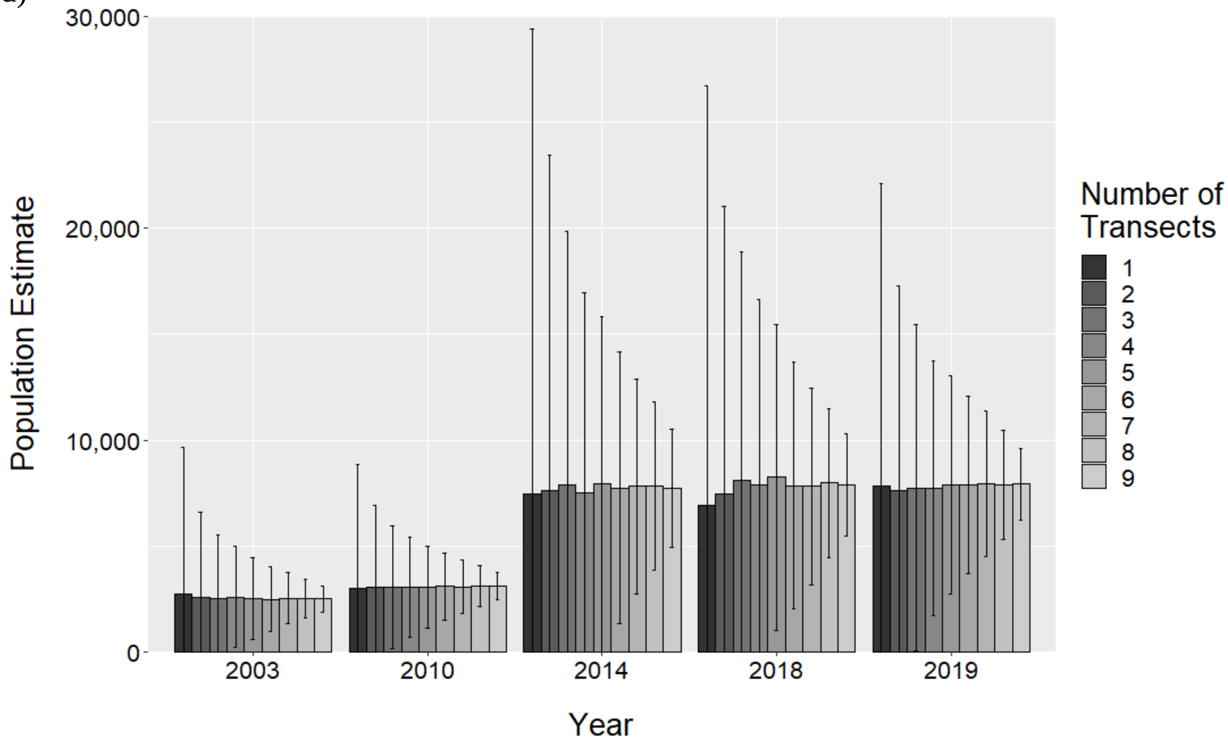


Figure 12 (cont'd)

d)



a)

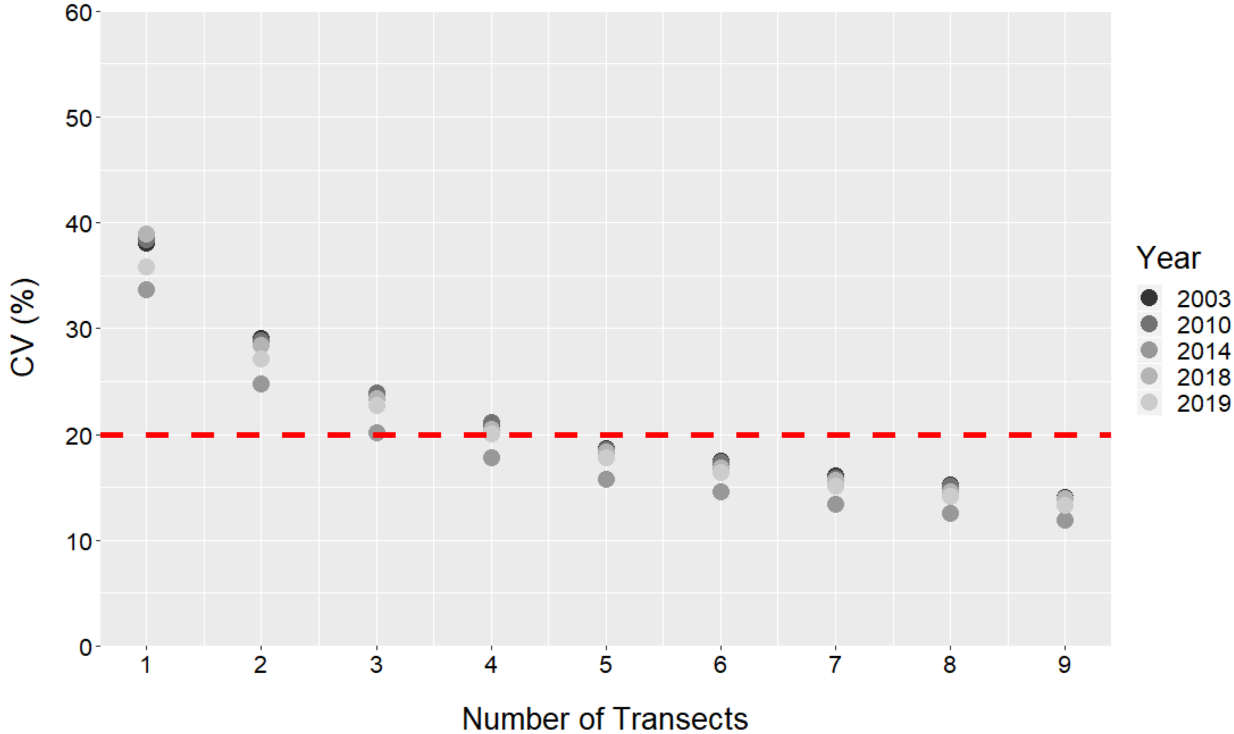
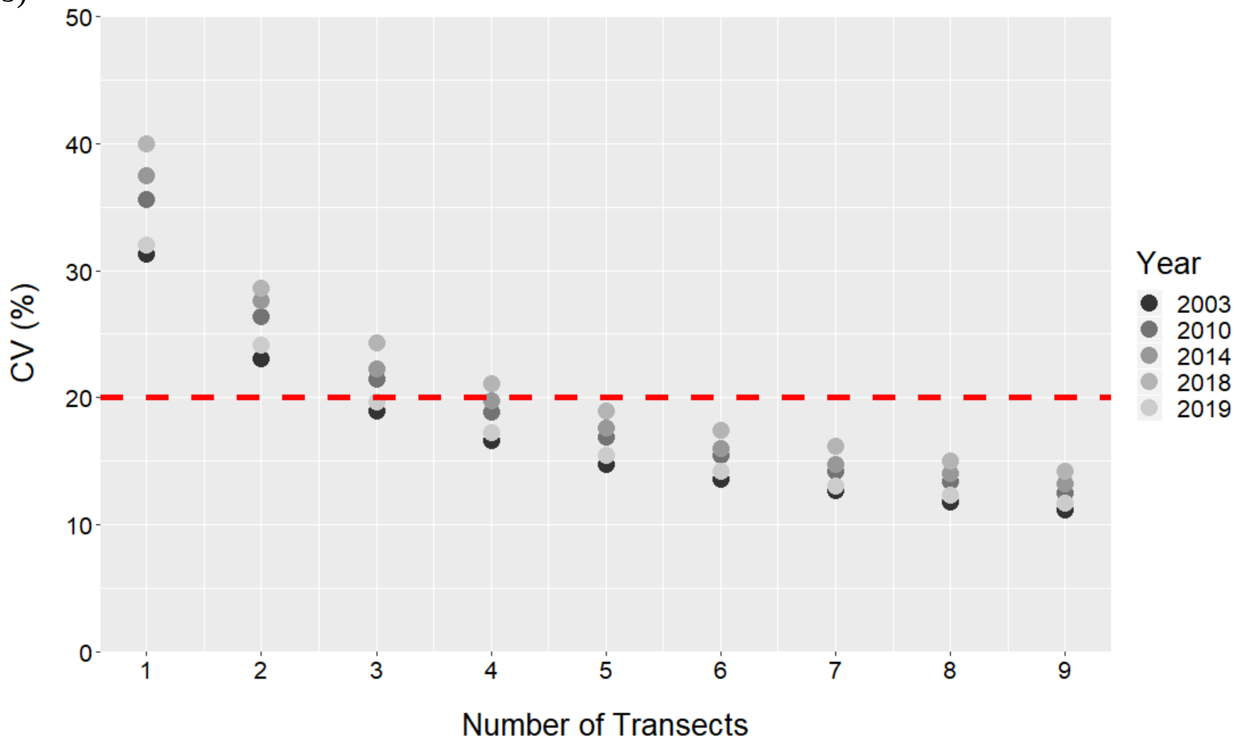



Figure 13. The bootstrap method Coefficient of Variation (CV) on population estimates from the modified SOP aerial survey design using fixed-wing and helicopter surveys over the state of Michigan for the five most recent VCF years for a) Canada goose, b) mallard, c) sandhill crane, and d) mute swan. CV of 20% is shown as the red dashed line.

Figure 13 (cont'd)

b)




c)

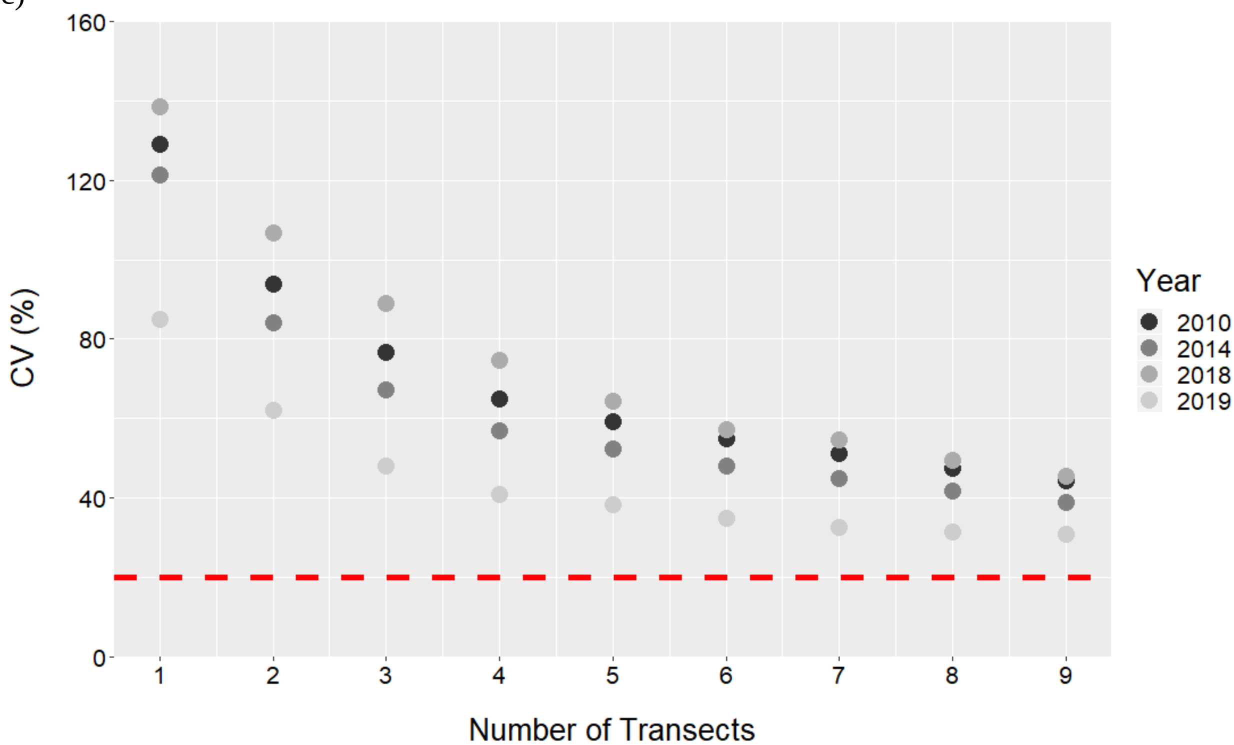
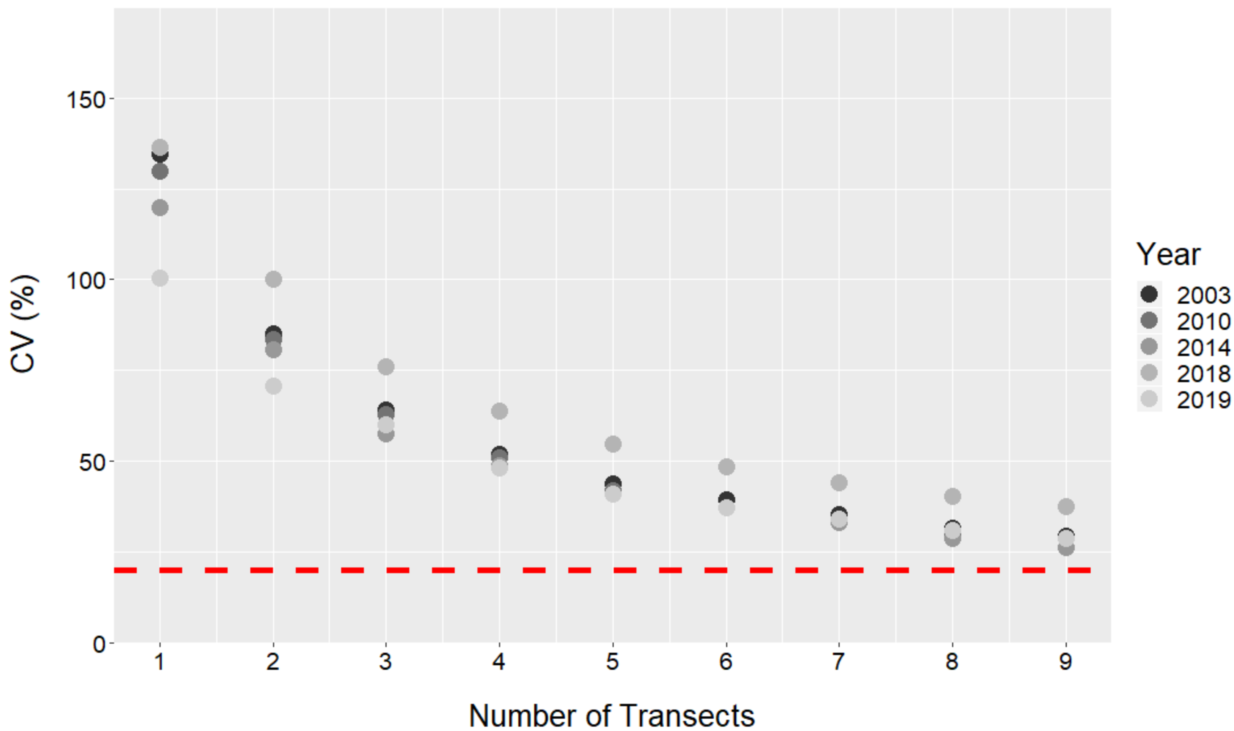


Figure 13 (cont'd)

d)



respectively. Once five transects or less were removed, all the VCF years had averaged Canada goose CVs below 20%. For the five most recent VCF years, all averaged mallard CVs were more than 20% if more than eight transects were removed. Two and four averaged mallard CVs were below a CV of 20% or less if seven transects or six transects were removed, respectively. At five transects removed, all averaged mallard CVs were below 20%. Averaged sandhill crane and mute swan CVs were always more than 20% CV.

**Alternate Aerial Survey Designs**

Although there was considerable variation among estimates from alternate aerial survey designs, there were no significant differences for Canada goose, sandhill crane, and mute swan population estimates compared to their respective SOP population estimates (Figures 14a, 14c, and 14d). Alternate mallard population estimates also showed no significant difference from the SOP except for the 2003 helicopter-only method which was significantly lower than the SOP population estimate (Figure 14b). The modified SOP population estimates were always higher than their respective SOP population estimates, while the modified SOP-2 population estimates were always lower than their respective SOP population estimates for all four species. On average, the modified SOP was 12% larger, 11% larger, 25% larger, 19% larger compared to the SOP population estimate for Canada goose, mallard, sandhill crane, and mute swan, respectively. On average, the modified SOP-2 was 16% smaller, 14% smaller, 13% smaller, and 24% smaller compared to the SOP population estimate for Canada goose, mallard, sandhill crane, and mute swan, respectively.

For Canada goose, the helicopter-only population estimates were on average 7% smaller than the SOP population estimate except for the 2014 helicopter-only population estimate which was 41% more than the SOP. Only the Canada goose helicopter-only population estimate was

a)

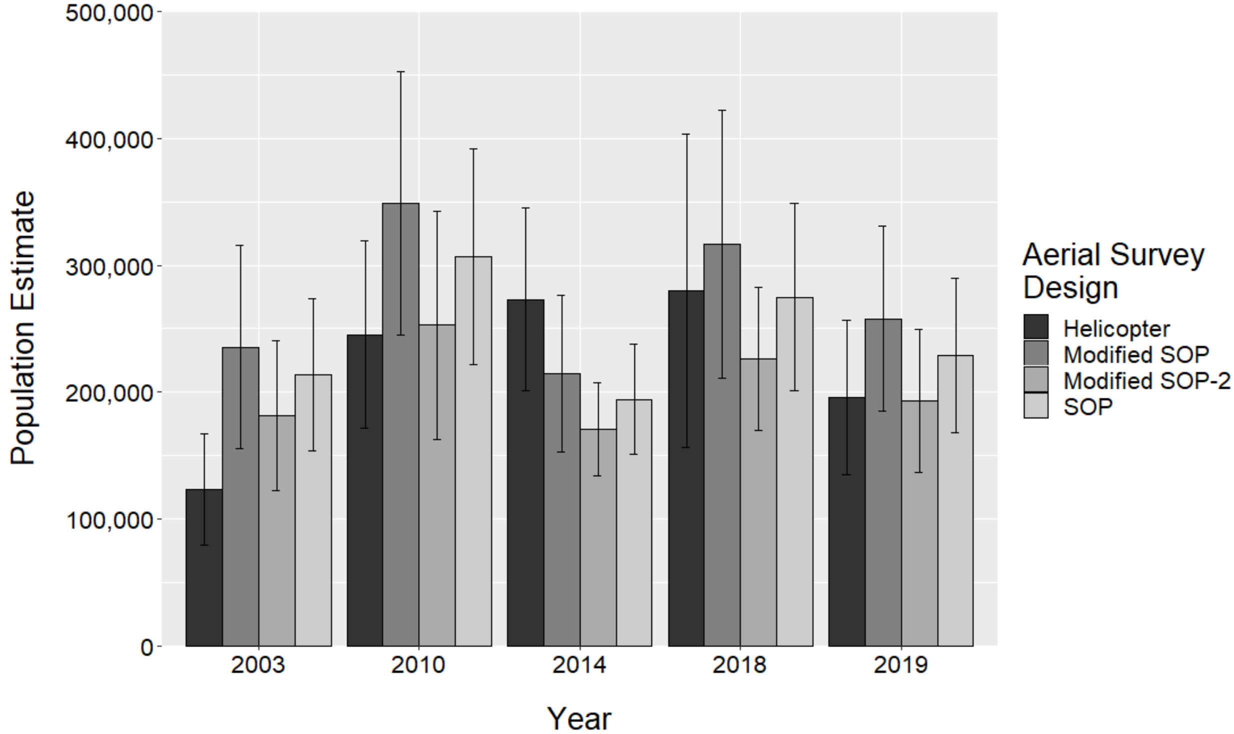
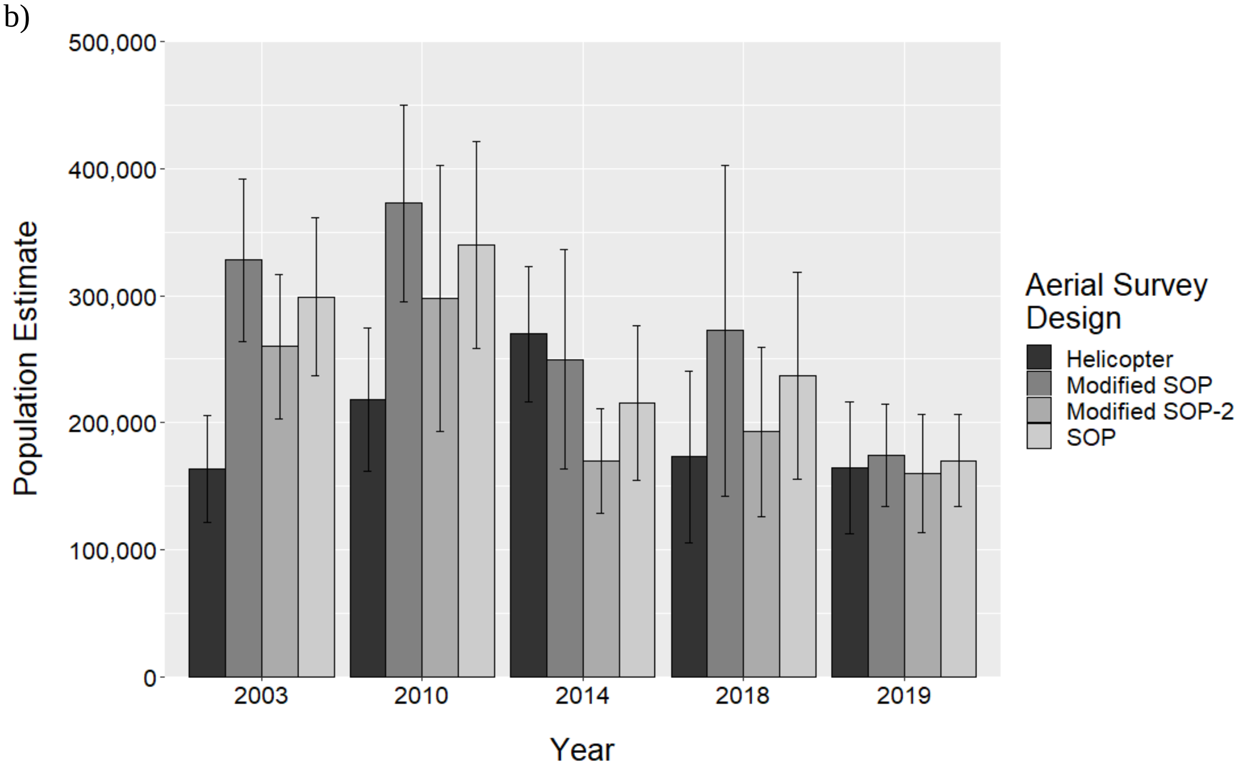



Figure 14. Comparison of population estimates among alternate aerial survey designs using fixed-wing and helicopter surveys over the state of Michigan for a) Canada goose, b) mallard, c) sandhill crane, and d) mute swan. The black bars represent ninety-five percent confidence intervals.

Figure 14 (cont'd)

b)




c)

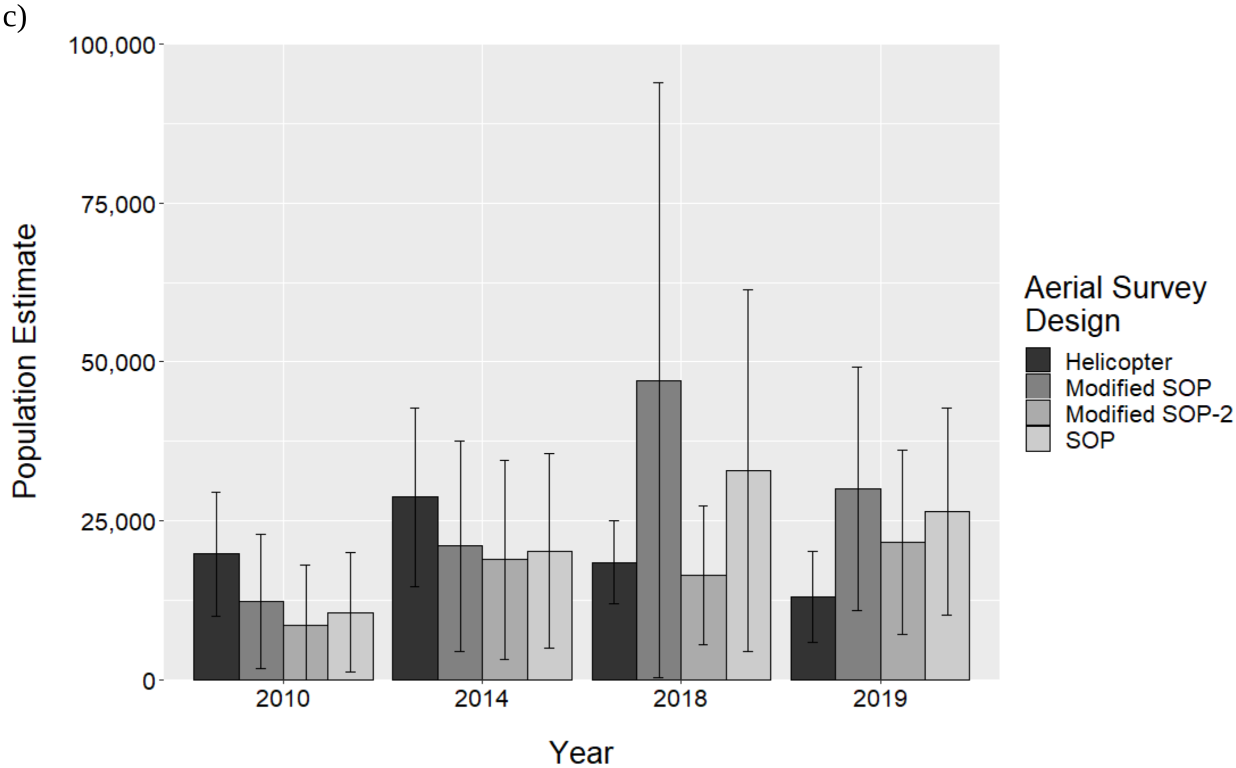
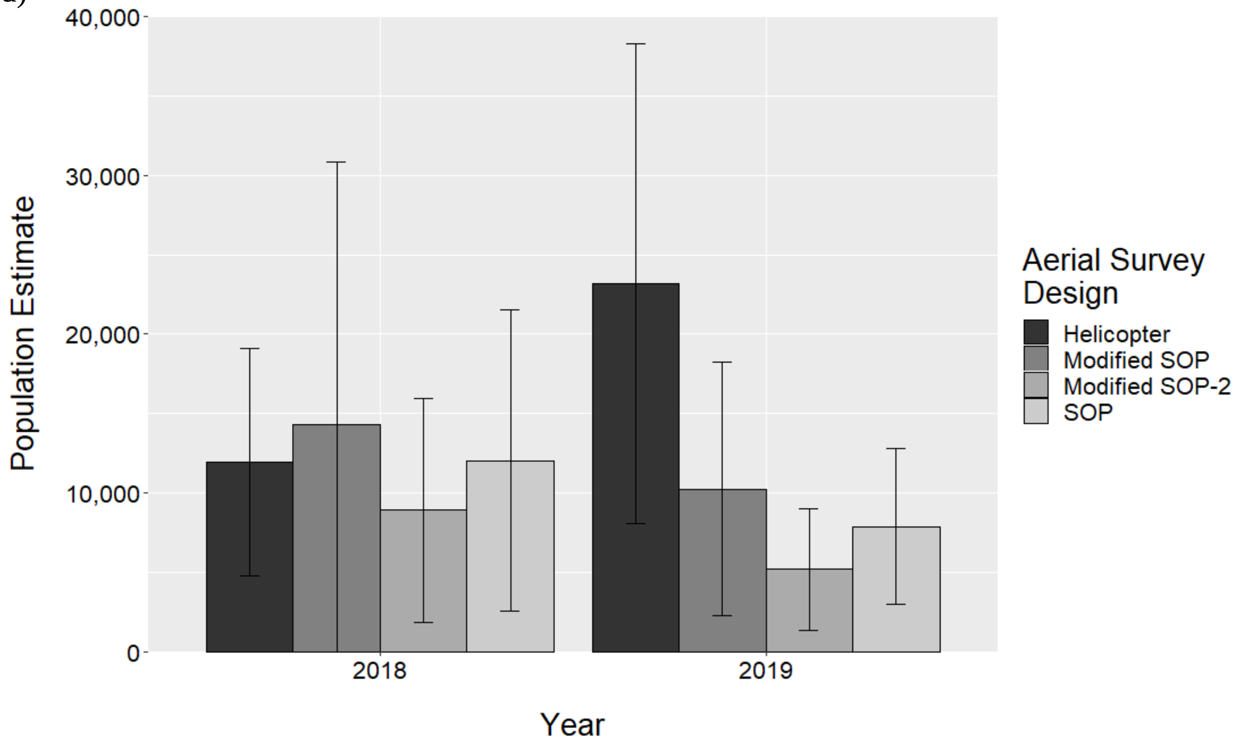


Figure 14 (cont'd)

d)



nearly identical to the SOP population estimate in 2018. For mallard, the helicopter-only population estimates were on average 17% smaller than the SOP population estimate. For 2003, 2010, and 2018, mallard population estimates averaged 36% smaller compared to the mallard SOP population estimate. In 2014, the mallard helicopter-only population estimate was 25% larger than the SOP population estimate. In 2019, the mallard helicopter-only population estimate was similar to the SOP estimate, but 4% smaller. The sandhill crane helicopter-only population estimates were on average 9% larger than the SOP population estimate. In 2010 and 2014, the sandhill crane helicopter-only population estimates averaged 64% greater than the SOP population estimate. In 2018 and 2019, the sandhill crane helicopter-only population estimates averaged 47% smaller than the SOP population estimate. The 2018 mute swan helicopter-only population estimate was similar to the SOP population estimate, while the 2019 mute swan helicopter-only population estimate was 193% larger at around 15,000 more birds than the SOP.

For each VCF year, variances on the Canada goose and mallard population estimates were similar for each aerial survey design. Variances on the population estimates for sandhill crane were comparable to the SOP variances except for the modified SOP and modified SOP-2 in 2018 which were noticeably higher and the helicopter-only in 2019 which was lower. Variances on the 2018 mute swan modified SOP and the 2019 mute swan helicopter-only population estimates were higher compared to their respective 2018 and 2019 variances for the other three aerial survey designs.

Averaged CVs on population estimates for alternate aerial survey designs were not significantly different than their respective SOP averaged CV for Canada goose, mallard, sandhill crane, and mute swan (Figure 15). The SOP was the lowest averaged CV for Canada goose and mallard at 13.4 and 13.1, while the helicopter-only design was the lowest averaged

a)

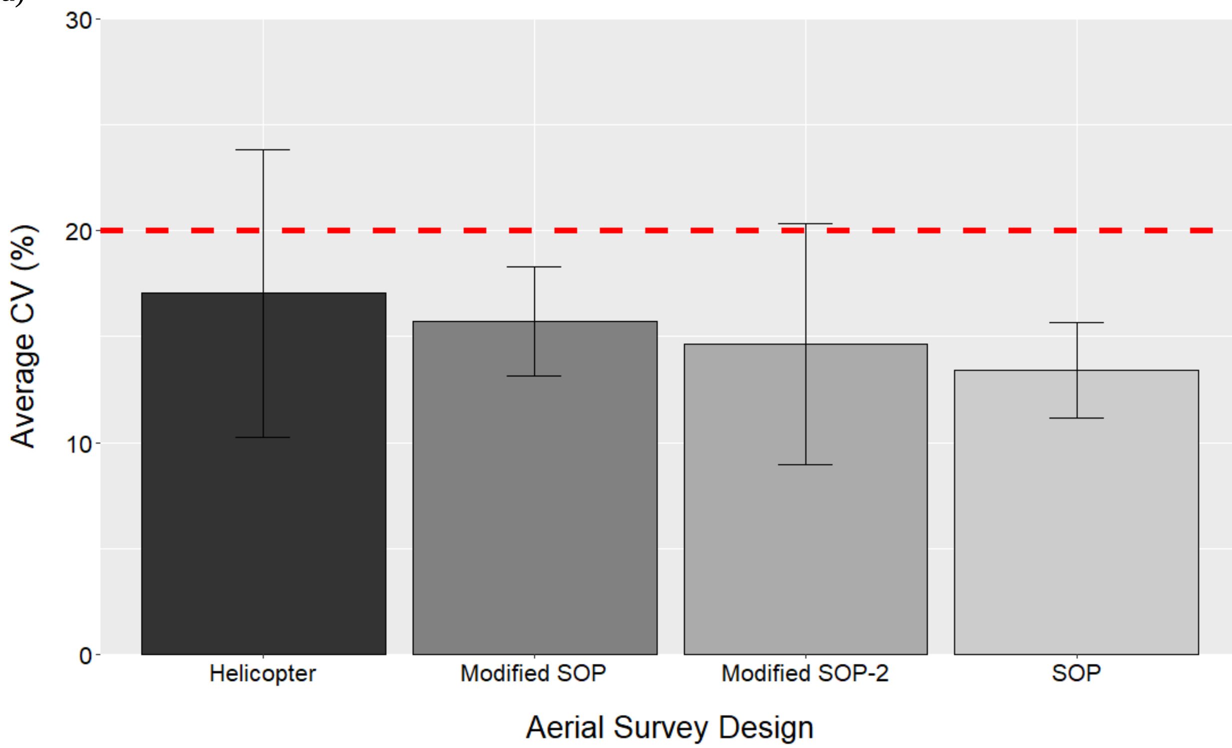
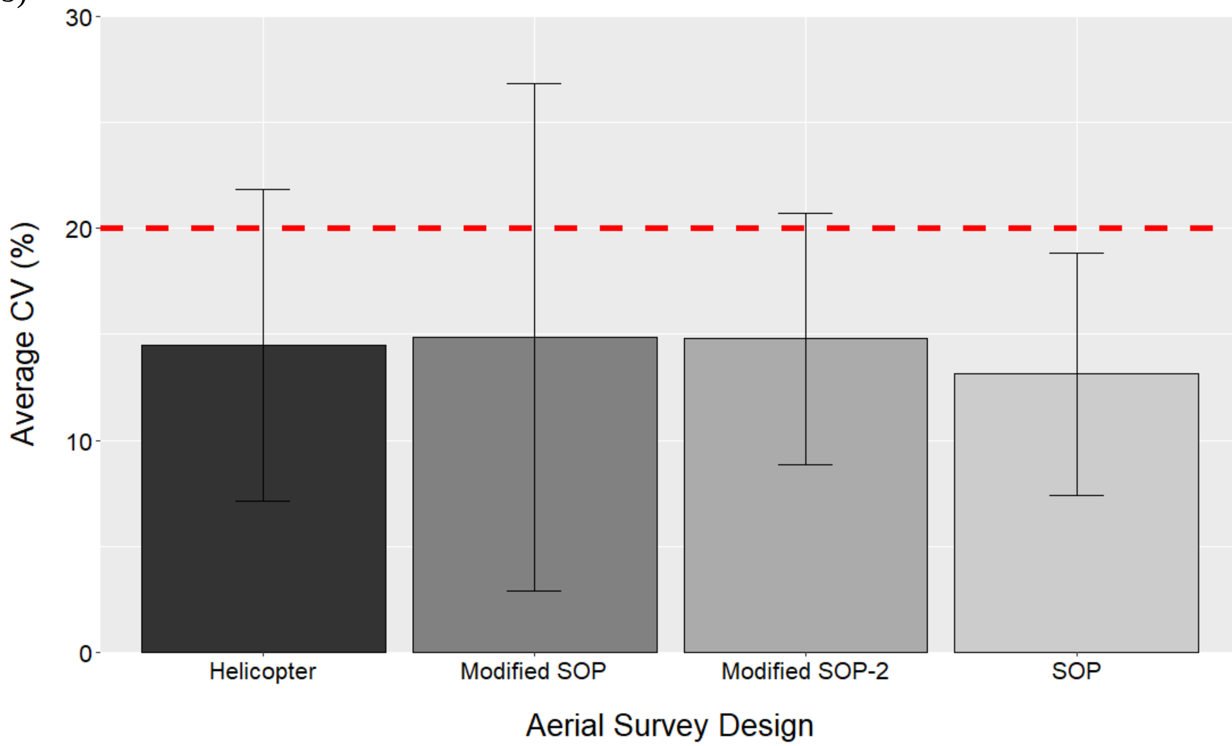



Figure 15. Comparison of average Coefficient of Variation (CV) on population estimates among alternate aerial survey designs using fixed-wing and helicopter surveys over the state of Michigan for a) Canada goose (2003, 2010, 2014, 2018, and 2019), b) mallard (2003, 2010, 2014, 2018, and 2019), and c) sandhill crane (2010, 2014, 2018, and 2019), and d) mute swan (2018 and 2019). CV of 20% is shown as the red dashed line. The black bars represent ninety-five percent confidence intervals.

Figure 15 (cont'd)

b)




c)

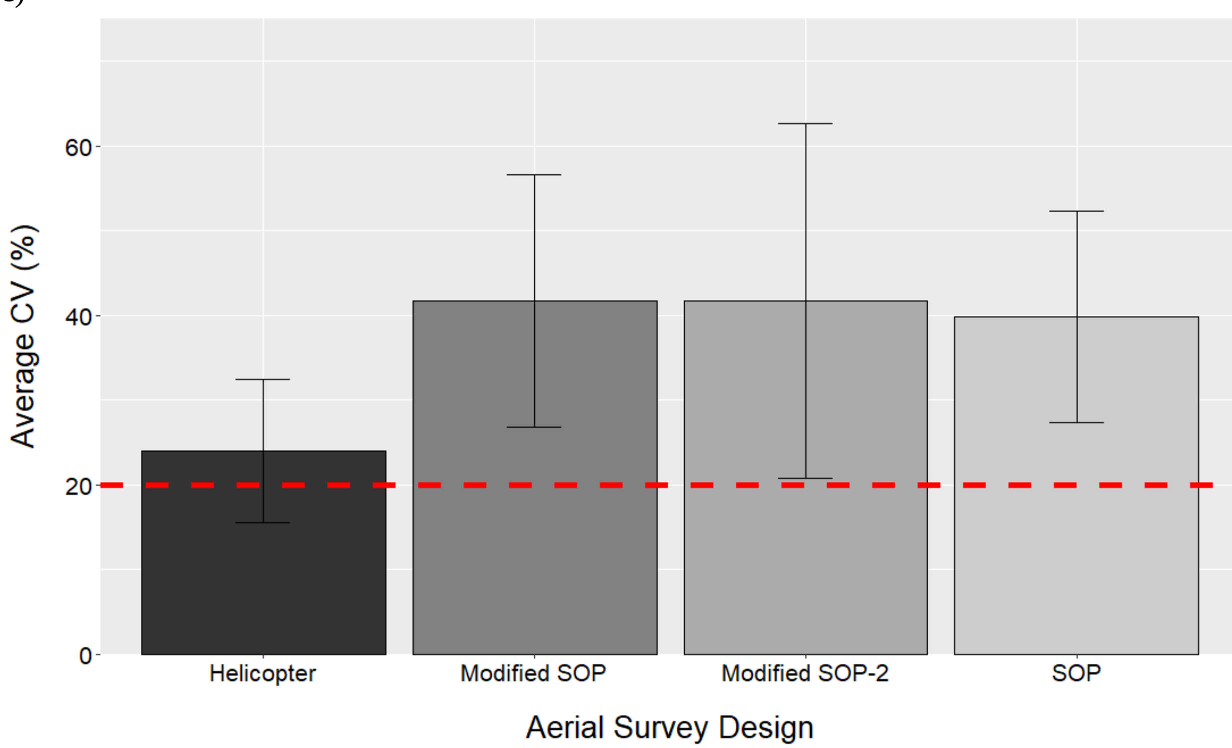
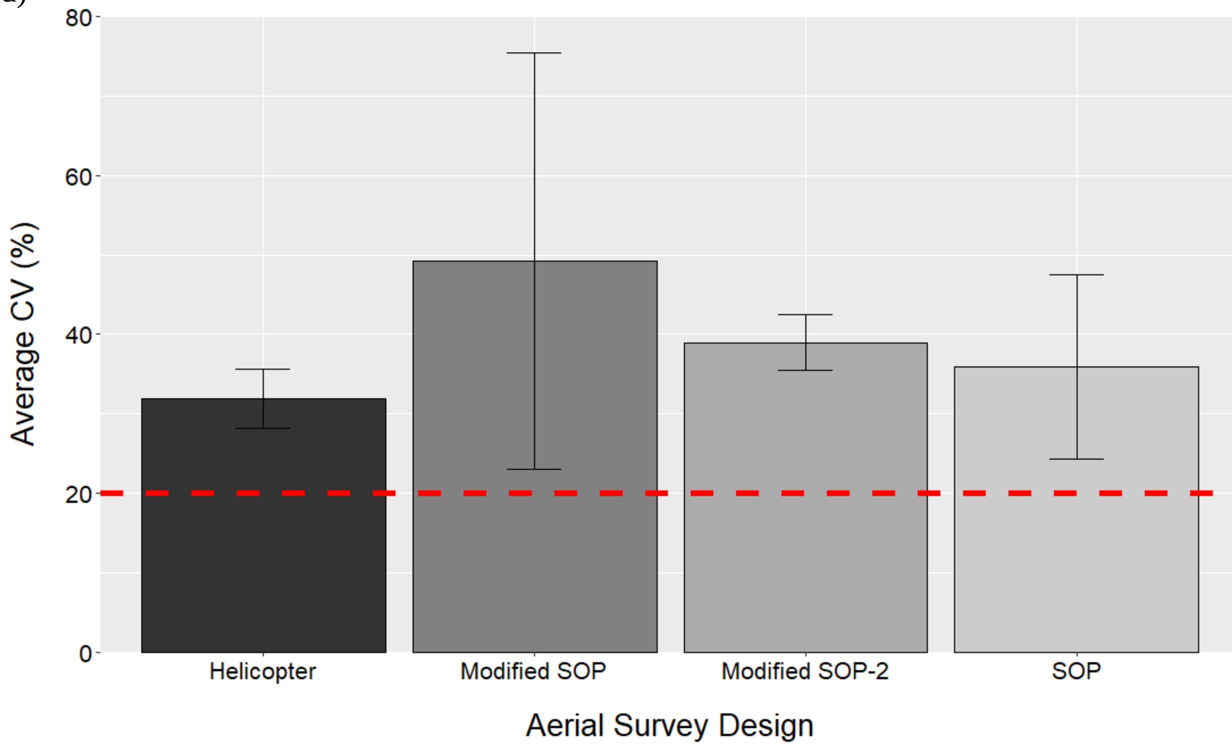


Figure 15 (cont'd)

d)



CV for sandhill crane and mute swan at 24.0 and 31.9. Canada goose and mallard CVs averaged over years were less than 20%, and averaged CVs for sandhill crane and mute swan were always above 20%. Based on the 95% confidence interval, the averaged Canada goose SOP and modified SOP CVs comprised of CV values less than 20%, while only the averaged mallard SOP CV encompassed CV values less than 20%. For averaged sandhill crane CVs, the helicopter-only design had 95% confidence intervals that consisted of CV values less than 20%. The Canada goose modified SOP had comparable variances to the SOP while the helicopter-only and modified SOP-2 variances were higher. The mallard modified SOP variance was higher than the variances on the other aerial survey designs. The sandhill crane helicopter-only variance was smaller than the variances on the other aerial survey designs. Lastly, mute swan helicopter-only and modified SOP had the smallest variances among the aerial survey designs.

Lastly, we calculated population estimates, CVs, and costs associated with the helicopter-only and modified SOP designs for Canada goose, mallard, sandhill crane, and mute swan (Tables 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12). Costs for each alternate aerial survey design were based on the 2018 and 2019 spring waterfowl surveys which were $22,921 and $23,251 in 2018 and 2019, respectively. The fixed-wing survey cost on average $260 per transect in 2018 and $336 per transect in 2019. The helicopter survey cost on average $436 per segment in 2018 and $405 per segment in 2019. The cost for the helicopter-only design would be between $4,048 (10 segments) to $39,294 (90 segments). The cost of the modified SOP design would range from $19,554 to $22,242. Average costs to achieve a 20% CV on population estimates for the helicopter-only design for Canada goose, mallard, sandhill crane, and mute swan were respectively $13,942, $12,238, $22,185, and $35,839. Average costs to achieve a 20% CV on population estimates for the modified SOP design for Canada goose, mallard, sandhill crane, and

Table 3. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the helicopter-only design for Canada goose and mallard, 2003. Two costs were calculated based on the 2018 or 2019 helicopter survey costs to determine helicopter-only design costs.

| 2003 | | | | | | |
|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Cost | |
| Number of Segments | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 10 | 124,562 | 29 | 164,330 | 20 | $4,366 | $4,048 |
| 20 | 123,923 | 23 | 163,408 | 15 | $8,732 | $8,097 |
| 30 | 124,253 | 19 | 164,376 | 12 | $13,098 | $12,145 |
| 40 | 124,080 | 17 | 163,570 | 10 | $17,464 | $16,194 |
| 50 | 123,897 | 15 | 164,376 | 9 | $21,830 | $20,242 |
| 60 | 123,653 | 14 | 163,446 | 8 | $26,196 | $24,290 |
| 70 | 123,392 | 12 | 163,821 | 8 | $30,562 | $28,339 |
| 80 | 123,562 | 12 | 163,939 | 7 | $34,928 | $32,387 |
| 90 | 122,829 | 11 | 163,907 | 7 | $39,294 | $36,436 |

Table 4. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the helicopter-only design for Canada goose, mallard, and sandhill crane, 2010. Two costs were calculated based on the 2018 or 2019 helicopter survey costs to determine helicopter-only design costs.

| 2010 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Cost | |
| Number of Segments | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 10 | 245,930 | 24 | 216,920 | 21 | 19,910 | 41 | $4,366 | $4,048 |
| 20 | 245,347 | 19 | 218,734 | 16 | 20,075 | 31 | $8,732 | $8,097 |
| 30 | 245,196 | 15 | 218,924 | 13 | 19,961 | 25 | $13,098 | $12,145 |
| 40 | 244,123 | 13 | 218,149 | 12 | 19,971 | 22 | $17,464 | $16,194 |
| 50 | 244,574 | 12 | 218,995 | 10 | 19,619 | 20 | $21,830 | $20,242 |
| 60 | 245,412 | 11 | 218,599 | 9 | 19,893 | 18 | $26,196 | $24,290 |
| 70 | 245,456 | 10 | 218,872 | 9 | 19,584 | 17 | $30,562 | $28,339 |
| 80 | 245,790 | 10 | 217,883 | 8 | 19,638 | 16 | $34,928 | $32,387 |
| 90 | 244,999 | 9 | 217,988 | 8 | 19,890 | 15 | $39,294 | $36,436 |

Table 5. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the helicopter-only design for Canada goose, mallard, and sandhill crane, 2014. Two costs were calculated based on the 2018 or 2019 helicopter survey costs to determine helicopter-only design costs.

| 2014 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Cost | |
| Number of Segments | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 10 | 276,847 | 21 | 268,710 | 16 | 29,172 | 37 | $4,366 | $4,048 |
| 20 | 274,275 | 16 | 268,286 | 11 | 28,878 | 28 | $8,732 | $8,097 |
| 30 | 271,981 | 13 | 269,460 | 9 | 28,906 | 23 | $13,098 | $12,145 |
| 40 | 272,113 | 11 | 269,000 | 8 | 28,848 | 21 | $17,464 | $16,194 |
| 50 | 273,750 | 10 | 268,940 | 7 | 28,635 | 18 | $21,830 | $20,242 |
| 60 | 272,001 | 9 | 268,602 | 7 | 28,568 | 17 | $26,196 | $24,290 |
| 70 | 271,160 | 8 | 269,281 | 6 | 28,497 | 16 | $30,562 | $28,339 |
| 80 | 272,060 | 8 | 269,852 | 6 | 28,518 | 15 | $34,928 | $32,387 |
| 90 | 273,073 | 7 | 270,087 | 5 | 29,141 | 14 | $39,294 | $36,436 |

Table 6. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the helicopter-only design for Canada goose, mallard, sandhill crane, and mute swan, 2018. Two costs were calculated based on the 2018 or 2019 helicopter survey costs to determine helicopter-only design costs.

| 2018 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Mute Swan | | Cost | |
| Number of Segments | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 10 | 276,693 | 37 | 177,032 | 35 | 18,542 | 33 | 12,107 | 54 | $4,366 | $4,048 |
| 20 | 281,330 | 28 | 172,298 | 26 | 18,468 | 24 | 12,059 | 42 | $8,732 | $8,097 |
| 30 | 281,538 | 23 | 174,273 | 21 | 18,430 | 20 | 12,044 | 35 | $13,098 | $12,145 |
| 40 | 275,425 | 20 | 171,808 | 19 | 18,431 | 17 | 11,889 | 31 | $17,464 | $16,194 |
| 50 | 280,217 | 18 | 171,823 | 17 | 18,499 | 15 | 11,798 | 28 | $21,830 | $20,242 |
| 60 | 279,130 | 17 | 173,442 | 15 | 18,458 | 14 | 11,907 | 26 | $26,196 | $24,290 |
| 70 | 278,395 | 16 | 172,918 | 14 | 18,476 | 13 | 11,701 | 24 | $30,562 | $28,339 |
| 80 | 279,816 | 15 | 173,660 | 13 | 18,430 | 12 | 11,924 | 22 | $34,928 | $32,387 |
| 90 | 277,738 | 14 | 172,477 | 13 | 18,542 | 11 | 11,916 | 21 | $39,294 | $36,436 |

Table 7. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the helicopter-only design for Canada goose, mallard, sandhill crane, and mute swan, 2019. Two costs were calculated based on the 2018 or 2019 helicopter survey costs to determine helicopter-only design costs.

| 2019 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Mute Swan | | Cost | |
| Number of Segments | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 10 | 197,432 | 29 | 165,871 | 29 | 12,893 | 51 | 23,781 | 57 | $4,366 | $4,048 |
| 20 | 195,896 | 23 | 165,528 | 22 | 13,149 | 38 | 22,896 | 44 | $8,732 | $8,097 |
| 30 | 195,284 | 18 | 163,912 | 18 | 12,955 | 31 | 23,454 | 36 | $13,098 | $12,145 |
| 40 | 196,501 | 16 | 164,772 | 16 | 12,930 | 27 | 23,074 | 32 | $17,464 | $16,194 |
| 50 | 197,611 | 14 | 164,375 | 14 | 12,978 | 25 | 22,987 | 29 | $21,830 | $20,242 |
| 60 | 196,406 | 13 | 164,468 | 13 | 13,135 | 22 | 23,083 | 26 | $26,196 | $24,290 |
| 70 | 196,155 | 12 | 164,042 | 12 | 12,867 | 21 | 23,086 | 24 | $30,562 | $28,339 |
| 80 | 195,810 | 11 | 163,444 | 11 | 13,021 | 20 | 23,065 | 23 | $34,928 | $32,387 |
| 90 | 195,696 | 11 | 164,591 | 11 | 13,012 | 18 | 22,956 | 22 | $39,294 | $36,436 |

Table 8. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the modified SOP design for Canada goose, mallard, and mute swan, 2003. Two costs were calculated based on the 2018 or 2019 MDNR spring waterfowl survey costs to determine modified SOP design costs.

| 2003 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Mute Swan | | Cost | |
| Number of Transects | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 1 | 221,195 | 38 | 301,077 | 31 | 2,726 | 134 | $19,803 | $19,554 |
| 2 | 221,119 | 29 | 303,940 | 23 | 2,575 | 85 | $20,063 | $19,890 |
| 3 | 221,058 | 24 | 303,061 | 19 | 2,544 | 64 | $20,322 | $20,226 |
| 4 | 220,429 | 21 | 304,217 | 17 | 2,584 | 52 | $20,582 | $20,562 |
| 5 | 218,472 | 19 | 304,049 | 15 | 2,517 | 44 | $20,842 | $20,898 |
| 6 | 219,697 | 17 | 303,410 | 14 | 2,492 | 40 | $21,102 | $21,234 |
| 7 | 219,174 | 16 | 303,303 | 13 | 2,546 | 35 | $21,362 | $21,570 |
| 8 | 219,372 | 15 | 303,631 | 12 | 2,532 | 32 | $21,622 | $21,906 |
| 9 | 218,746 | 14 | 303,612 | 11 | 2,521 | 29 | $21,881 | $22,242 |

Table 9. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the modified SOP design for Canada goose, mallard, sandhill crane, and mute swan, 2010. Two costs were calculated based on the 2018 or 2019 MDNR spring waterfowl survey costs to determine modified SOP design costs.

| 2010 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Mute Swan | | Cost | |
| Number of Transects | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 1 | 316,843 | 38 | 342,077 | 36 | 10,983 | 129 | 2,301 | 130 | $19,803 | $19,554 |
| 2 | 312,727 | 29 | 342,113 | 26 | 10,884 | 94 | 2,348 | 84 | $20,063 | $19,890 |
| 3 | 309,824 | 24 | 343,770 | 22 | 10,932 | 77 | 2,351 | 63 | $20,322 | $20,226 |
| 4 | 312,859 | 21 | 347,501 | 19 | 10,909 | 65 | 2,355 | 51 | $20,582 | $20,562 |
| 5 | 312,565 | 19 | 345,349 | 17 | 10,904 | 59 | 2,345 | 42 | $20,842 | $20,898 |
| 6 | 313,089 | 17 | 344,511 | 15 | 10,837 | 55 | 2,380 | 37 | $21,102 | $21,234 |
| 7 | 312,492 | 16 | 343,368 | 14 | 10,795 | 51 | 2,368 | 34 | $21,362 | $21,570 |
| 8 | 312,071 | 15 | 344,038 | 13 | 10,835 | 47 | 2,381 | 30 | $21,622 | $21,906 |
| 9 | 312,561 | 14 | 344,900 | 13 | 10,773 | 44 | 2,379 | 29 | $21,881 | $22,242 |

Table 10. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the modified SOP design for Canada goose, mallard, sandhill crane, and mute swan, 2014. Two costs were calculated based on the 2018 or 2019 MDNR spring waterfowl survey costs to determine modified SOP design costs.

| 2014 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Mute Swan | | Cost | |
| Number of Transects | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 1 | 197,440 | 34 | 218,262 | 37 | 21,918 | 121 | 7,468 | 120 | $19,803 | $19,554 |
| 2 | 195,714 | 25 | 217,733 | 28 | 21,035 | 84 | 7,641 | 81 | $20,063 | $19,890 |
| 3 | 196,597 | 20 | 217,253 | 22 | 21,005 | 67 | 7,884 | 58 | $20,322 | $20,226 |
| 4 | 195,757 | 18 | 221,602 | 20 | 21,054 | 57 | 7,537 | 49 | $20,582 | $20,562 |
| 5 | 194,398 | 16 | 219,268 | 18 | 20,826 | 52 | 7,922 | 41 | $20,842 | $20,898 |
| 6 | 195,302 | 15 | 220,242 | 16 | 20,672 | 48 | 7,742 | 37 | $21,102 | $21,234 |
| 7 | 195,654 | 13 | 220,628 | 15 | 20,563 | 45 | 7,817 | 33 | $21,362 | $21,570 |
| 8 | 195,613 | 13 | 220,930 | 14 | 20,568 | 42 | 7,818 | 29 | $21,622 | $21,906 |
| 9 | 195,594 | 12 | 220,880 | 13 | 20,623 | 39 | 7,721 | 26 | $21,881 | $22,242 |

Table 11. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the modified SOP design for Canada goose, mallard, sandhill crane, and mute swan, 2018. Two costs were calculated based on the 2018 or 2019 MDNR spring waterfowl survey costs to determine modified SOP design costs.

| 2018 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Mute Swan | | Cost | |
| Number of Transects | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 1 | 271,648 | 39 | 211,279 | 40 | 33,406 | 138 | 6,059 | 137 | $19,803 | $19,554 |
| 2 | 275,686 | 28 | 212,910 | 29 | 32,218 | 107 | 6,582 | 100 | $20,063 | $19,890 |
| 3 | 273,310 | 23 | 211,740 | 24 | 32,773 | 89 | 7,237 | 76 | $20,322 | $20,226 |
| 4 | 276,986 | 21 | 210,792 | 21 | 33,520 | 75 | 7,009 | 64 | $20,582 | $20,562 |
| 5 | 276,202 | 18 | 211,940 | 19 | 33,380 | 64 | 7,358 | 55 | $20,842 | $20,898 |
| 6 | 277,574 | 17 | 210,530 | 17 | 33,599 | 57 | 6,976 | 49 | $21,102 | $21,234 |
| 7 | 277,634 | 16 | 211,146 | 16 | 33,471 | 55 | 6,930 | 44 | $21,362 | $21,570 |
| 8 | 275,895 | 15 | 211,163 | 15 | 33,898 | 50 | 7,096 | 40 | $21,622 | $21,906 |
| 9 | 276,975 | 14 | 211,077 | 14 | 33,869 | 46 | 7,034 | 38 | $21,881 | $22,242 |

Table 12. Population estimates, Coefficient of Variations (CVs), and costs to evaluate the modified SOP design for Canada goose, mallard, sandhill crane, and mute swan, 2019. Two costs were calculated based on the 2018 or 2019 MDNR spring waterfowl survey costs to determine modified SOP design costs.

| 2019 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canada Goose | | Mallard | | Sandhill Crane | | Mute Swan | | Cost | |
| Number of Transects | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | Population Estimate | % CV | 2018 | 2019 |
| 1 | 229,720 | 36 | 169,870 | 32 | 26,971 | 85 | 7,835 | 101 | $19,803 | $19,554 |
| 2 | 229,741 | 27 | 170,621 | 24 | 26,650 | 62 | 7,602 | 71 | $20,063 | $19,890 |
| 3 | 229,394 | 23 | 172,121 | 20 | 26,878 | 48 | 7,740 | 60 | $20,322 | $20,226 |
| 4 | 229,282 | 20 | 172,312 | 17 | 26,615 | 41 | 7,722 | 48 | $20,582 | $20,562 |
| 5 | 231,166 | 18 | 172,018 | 15 | 26,832 | 38 | 7,869 | 41 | $20,842 | $20,898 |
| 6 | 230,581 | 16 | 172,521 | 14 | 26,658 | 35 | 7,894 | 37 | $21,102 | $21,234 |
| 7 | 230,086 | 15 | 172,771 | 13 | 26,691 | 33 | 7,929 | 34 | $21,362 | $21,570 |
| 8 | 230,667 | 14 | 172,749 | 12 | 26,762 | 31 | 7,879 | 31 | $21,622 | $21,906 |
| 9 | 230,233 | 13 | 172,254 | 12 | 26,773 | 31 | 7,927 | 29 | $21,881 | $22,242 |

mute swan were respectively $20,807, $20,663, $24,410, and $24,188. The SOP design has achieved a CV of less than 20% for the past five VCF years for Canada goose and mallard. On average, the CVs from SOP population estimates were 13%, 13%, 40%, and 32% for Canada goose, mallard, sandhill crane, and mute swan, respectively.

# DISCUSSION

## Alternate Visibility Correction Factors

Few of the alternate VCFs were significantly different than the SOP VCF for a given year. Although, while it should be noted that VCFs precision is positively related to sample size, we need to be cautious of using older data when estimating an all-year average statewide VCFs. Data from 1992 is now 27 years old. Changes in technology, aircraft, observers, and landscape may alter waterfowl detection. Previously, VCF segments were not surveyed randomly and not indicative of the representation of the state of Michigan, potentially violating the assumption that samples were independent and identically distributed. In addition, 1992 and 1995 VCF years did not survey the northern forested stratum. The 2003 survey added more VCF segments which increased the spatial representation within Michigan. A rolling average like a three or five-year statewide VCF estimate would be a viable alternative to accurately predict how the detection may change over time while also maintaining a CV of 20% or less on population estimates for Canada goose and mallards.

Five-year and three-year averaged VCFs were always within the 95% confidence interval of the SOP VCF for all three species. When the alternate VCFs were applied to estimate population size, five-year and three-year statewide and stratum-specific VCF estimation methods were comparable to the SOP population estimates. While the SOP had the lowest CV, the five-year and three-year statewide and stratum-specific VCF estimation methods were comparable. Additionally, the CV for the three-year statewide VCF estimation method was nearly identical to the SOP CV for the three species. With comparable population estimates and the lowest CV among the alternate VCF estimation methods, a three-year statewide VCF would be an acceptable alternative to the SOP.

Population estimates for the yearly statewide and stratum-specific VCF estimation methods were consistently below the SOP since the all-year average VCF was higher than the yearly VCFs. In 2003, the yearly population estimates were considerably smaller than the SOP since the yearly VCF estimate was at its lowest for each of the species. As more years were surveyed, the all-year average VCF started to decrease since the yearly VCFs were getting smaller too, resulting in the population estimates based on the yearly VCF estimation methods comparable to the SOP in 2010, 2014, 2018, and 2019.

Unexpectedly, the 2003 yearly statewide Canada goose and mallard population estimates and VCFs were significantly lower than their respective SOP population estimate and VCF. Soulliere and Chadwick’s (2003) MDNR wildlife report noted a higher ratio of birds missed by the helicopter survey in 2003 which contributed to a lower yearly statewide VCF and subsequent smaller population estimate. They are unsure what caused this phenomenon, but some of the 2003 survey crew members recalled that the helicopter pilots were flying the helicopters at higher altitudes and speeds than the standard operating procedures. The 2003 survey used contracted pilots, so the helicopter pilots were new to the survey. New pilots that are not familiar with the SOP may have flown the helicopter faster and higher than other VCF years, impacting the VCF. An increase in altitude and speed has a negative effect on detection (Caughley 1974). As altitude increases, waterfowl are less prone to flush from their habitat and exhibit a response to the noise (Calef et al. 1976, Shupe and Beasom 1987, Tracey and Fleming 2007). As speed increases, observers have less time to detect and record birds (Caughley 1974).

More broadly, detection could change over time due to other factors. Improvements in aircraft could impact how observers in both fixed-wing and helicopter surveys detect birds (Clancy 1999, Soulliere and Chadwick 2003). Currently, the spring waterfowl survey uses Bell

407, but Hughes 500, Bell 430, and Bell 206 were used prior to 2018. The Bell 206 was used in surveys before 2003, and the Bell 430 was used in 2010 and 2014. The Hughes 500 was used once in 2003. The difference in the helicopter model can impact visibility for front and rear seat observers (Tracey and Fleming 2007). Front seat observers in a Hughes 500 have a bigger field of view than the rear seat observer, while the inverse is evident in the Bell Jet Ranger. Changes in the field of view could affect how many birds can be seen by an observer. However, both rear and front seat observers are used for the helicopter survey so total waterfowl observations should remain the same. The difference in helicopter models can also contribute to variation in sounds produced by the aircraft. Tracey and Fleming (2007) found that Hughes 500 helicopters had a louder sound where more animals responded to the helicopter noise compared to Bell models. In 2003, waterfowl may have been alerted to the Hughes 500 much earlier than the Bell 206, resulting in waterfowl taking cover or flying out of the transect boundaries before the observers could count them. Surveys before 2003 relied on county road maps, air photos, and personal experience of the transect to follow the transect line and an imaginary line to delineate transect width. Starting in 2003, GPS technology was equipped to both the fixed-wing and helicopter surveys. Since helicopters circle wetlands and deviate from the centerline, the addition of GPS technology helped to prevent overcounting outside of the designated transect line (Soulliere and Chadwick 2003). This may have led to fewer waterfowl observations on the helicopter than previous VCF years.

Another factor potentially impacting VCF estimates was the MDNR switch to a random sampling of VCF segments in 2003, whereas before the spring waterfowl survey sampled VCF segments with high waterfowl density. In 2003, more VCF segments were randomly sampled in the northern forested stratum which is more forested and has more variable or lower waterfowl densities than the farm urban stratum. In 2018, the MDNR switched to a GRTS sampling to achieve a better spatial representation of the population than a simple random sampling design (Gitzen et al. 2012). A slightly larger proportion of segments surveyed were in the northern forested stratum. The proportion of segments in the northern forested surveyed increased from 43% to 48% in the GRTS sampling. Since 2003, GRTS and random sampling have resulted in a more accurate representation of the waterfowl density for the VCF segments than the previous sampling design from 1992-1996. Prior to 2003, fixed-wing densities on VCF segments were on average 101% larger for Canada goose and 59% larger for mallard compared to their respective fixed-wing densities on total segments. In 2003, 2010, and 2014, fixed-wing densities on VCF segments using random sampling were on average 8% larger for Canada goose and 1% smaller for mallard compared to their respective fixed-wing densities on total segments. In 2018 and 2019, fixed-wing densities on VCF segments using GRTS sampling were on average 4% larger for Canada goose and 4% smaller for mallard compared to their respective fixed-wing densities on total segments.

Observer error may impact how the VCF is estimated. Observer error can result in different visibility from one person to another. Observers may lack consistency, accuracy, or bias due to personal experience (Diem and Lu 1960). Untrained observers show high individual variation as Pagano and Arnold’s (2009) study found that on average trained observers had a 91% detection rate while untrained observers had a 79% detection rate for ground-based surveys. For the spring waterfowl survey, each observer is trained on waterfowl identification and any new observers are a trainee for a year. Different levels of years observing could have slight impacts on how a person detects a bird. In addition, high waterfowl densities can increase observer error because observers have a more difficult time simultaneously recording observations when new birds are being detected (Bart and Schoultz 1984, Nichols et al. 2000). To maintain a consistent observer error throughout the years, a consistent crew of observers is important (Pearse et al. 2008). While standardized guidelines are in place to help maintain consistent data collection, observer error can still arise.

Also, weather conditions such as cloud cover and wind speed might affect detection; for example, bright sun can produce glare obscuring visibility of birds on water, depending on viewing angle relative to the horizon and azimuth. Often, swimming waterfowl leave a visible wake on the water surface under calm conditions and these wave patterns help observers detect birds except in windy conditions when wind-created waves obscure waterfowl movements (Shirkey 2012).

Although the SOP had a higher number of segments surveyed to estimate the VCF, the alternate VCF estimation methods had comparable CVs. The SOP had the lowest CV on the population estimate, showing that more segments surveyed resulted in a lower CV and a more precise population estimate. The variances on the alternate VCFs, including yearly alternate VCFs (27 to 40 segments), were similar to the SOP variances. Thus, the variance on the alternate VCFs contributed less to the total variance on the population estimate. Instead, variation in indicated birds and therefore bird density estimates on segments had a greater impact on the variances on statewide population estimates. Since the alternate VCFs used the same fixed-wing indicated birds for each year, the variances were comparable. For example, the 2018 mallard CV had the highest mallard CV for the past five VCF years. A large group of 150 mallards was detected on a segment during the fixed-wing survey which resulted in higher variance and CV on the population estimate. Mallard indicated birds in 2018 ranged from 0 to 26 without the group of 150 mallards. When the 150-mallard group was removed from the calculation, the 2018 CV on the population estimate dropped from 17.57 to 12.13.

We found that the alternate VCF estimation methods for Canada goose and mallard resulted in comparable population estimates to the SOP since there were slight differences in the VCF values for the five most recent VCF years. On average, the alternate Canada goose VCFs were 11% smaller, and the alternate mallard VCFs were 16% smaller than their respective SOP VCFs. Alternate sandhill VCFs were on average 15% larger than their SOP VCFs due to high northern forested VCFs contributing to higher stratum-specific VCFs. Since the number of fixed-wing observations for a species remains the same to calculate the population estimate, small changes to the VCF had a low impact on population estimates. Additionally, changing the VCF had a minimal impact on the CV. On average, alternate CVs for Canada goose, mallard, and sandhill crane were respectively 20%, 25%, and 19% higher than their SOP CV.

**Survey Timing and Sample Sizes**

Survey timing has varied throughout the years, as spring weather in Michigan can change quickly. The MDNR attempted to complete surveys during the specific survey timeframe (before nests from Canada geese hatched, half of the mallard females started nests, and when there was at least 20% visibility), but it is difficult for the MDNR to monitor or to know if this survey timeframe was achieved or not. However, the historic starting date of the survey was linearly related to growing degree-days near the starting transect (MDNR, unpublished data), suggesting that the criteria used to decide when to start the survey are strongly related to annual variation in plant phenology. Warmer weather can bring leaf-out earlier than expected which impedes visibility. Survey timing in 2018 and 2019 was variable but was not noticeably different than previous years based on the dates of the survey. The 2018 survey had an unexpected later end date as wetlands and Lake Michigan in the upper peninsula were still frozen over, and a week of rain delayed the surveys. The 2019 survey commenced earlier than the 2018 survey, but a week of rain delayed the survey too. The delays in both years also led to a longer time between when the fixed-wing and helicopter surveys were completed on the same segment. The spring waterfowl survey does not operate on the weekends, so it is possible to have at least a three-day difference in surveying the same segment. Leaf-out did start to occur for the last two survey years but did not hinder waterfowl detection as leaf-out was less than 20% on trees and shrubs.

Helicopter segments are dependent on funding as early helicopter flights were costly, reducing the number of helicopter segments surveyed. In 2010, a partnership between the MDNR and MSP developed, and helicopter survey costs became reduced. Helicopter surveys were important to the spring waterfowl survey, as the observers in helicopter detected more total waterfowl observations on average compared to the inexpensive fixed-wing surveys. Contributing to the expensive costs on the helicopter survey, flight hours per segment were longer in the helicopter compared to the fixed-wing. Total flight hours on the fixed-wing were more than the helicopter, but cheaper hourly rates contributed to a more inexpensive fixed-wing survey.

**Bootstrap Methods**

We found that the bootstrap method allowed us to estimate the variability of population estimates and CVs for alternate surveys, as well as creating 95% confidence intervals based on the sample for each VCF year (Manly 1997). The bootstrap method for Canada goose and mallard on the helicopter observations showed that 40 or more segments on average would result in a 20% or less CV on the population estimate for the helicopter-only design. If the budget or time is constrained in a given year, 30 helicopter segments may be acceptable since only the

2018 VCF year resulted in an averaged CV higher than 20% for Canada goose and mallard. The bootstrap method for Canada goose and mallard on the fixed-wing observations showed that removing less than five transects on average would result in a 20% or less CV on the population estimate for the modified SOP design. If the budget or time is constrained in a given year, removing six or seven transects may be acceptable. The averaged CVs for removing six or seven transects in the farm urban stratum for Canada goose and mallard were 24% or less. The bootstrap method for sandhill crane and mute swan resulted in undesirable CVs for both the helicopter-only and modified SOP. Higher CVs for sandhill crane and mute swan could be attributed to few fixed-wing observations, resulting in a high variation on population estimates. The removal of transects would result in lower total flight hours for the fixed-wing survey which would result in a lower fixed-wing survey cost. However, the precision of the population estimate may be reduced, causing inaccurate population estimates.

**Alternate Aerial Survey Designs**

No alternate aerial survey design was better or worse than the SOP survey design since the comparison of alternate aerial survey designs found no significant difference for the four species. Thus, the current transect number and configuration should remain the same. While the 2003 mallard population estimate for the helicopter-only design was significantly smaller than the 2003 SOP population estimate, the other four VCF years found no significant differences to their respective SOP population estimate. Low helicopter observations in 2003 resulted in a lower yearly statewide VCF and helicopter population estimate. For 2003 mallard VCF segments, the helicopter survey counted 404 birds. Additionally, the helicopter survey counted 192 more birds than the fixed-wing observation which is less than the average difference of 302 birds. The 2003 mallard SOP population estimate was 130,000 birds more than what the helicopter-only method estimated. Similarly, the 2003 Canada goose SOP population estimate was about 90,000 birds more than the 2003 helicopter-only population estimate. In 2003, the helicopter survey counted 99 more Canada geese on the helicopter than the fixed-wing which is lower than the average difference of 350 birds on VCF segments. Both the 2003 helicopter-only population estimate for Canada goose and mallard could have been impacted by a change in aircraft and pilot, sampling design, or observer error which also resulted in a smaller yearly statewide VCF.

Averaged CVs showed that none of the alternate aerial survey designs are better or worse than the SOP. The SOP had the lowest averaged CV for Canada goose and mallard, showing that using both fixed-wing and helicopter surveys, including all the transects in the farm urban stratum, results in the most precise aerial survey method. Averaged CVs on sandhill crane and mute swan were higher for the SOP compared to the mallard and Canada goose CV on the SOP, but this may be attributed to low fixed-wing observations to estimate a precise population. From the historical data and the 2018-2019 surveys, at least 750 indicated birds statewide on the fixed-wing survey should result in a CV of less than 20% (Figure 16). Most VCF years were able to detect at least 750 indicated birds on the fixed-wing survey for Canada goose and mallard which resulted in CVs on population estimates less than 20%. However, low indicated bird counts from the fixed-wing survey on sandhill crane and mute swans resulted in high CVs. On average (2010, 2014, 2018, and 2019), the fixed-wing survey counted 64 indicated birds for sandhill crane, while fixed-wing surveys for Canada goose and mallard detected over 700 indicated birds from the 2003, 2010, 2014, 2018, and 2019 VCF years. Mute swan averaged CV was similar for helicopter-only and SOP, although a higher variance on the SOP could be because few mute swans were detected on the fixed-wing survey. On average (2018 and 2019), the fixed-wing

a)

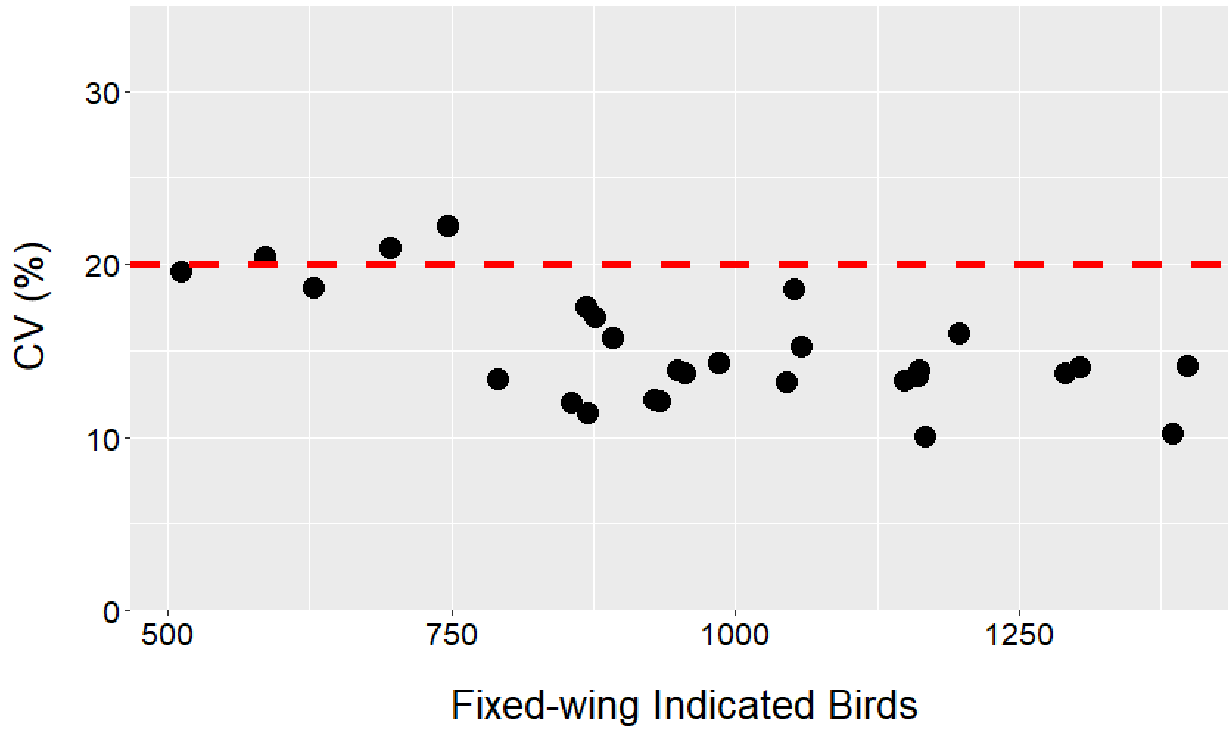
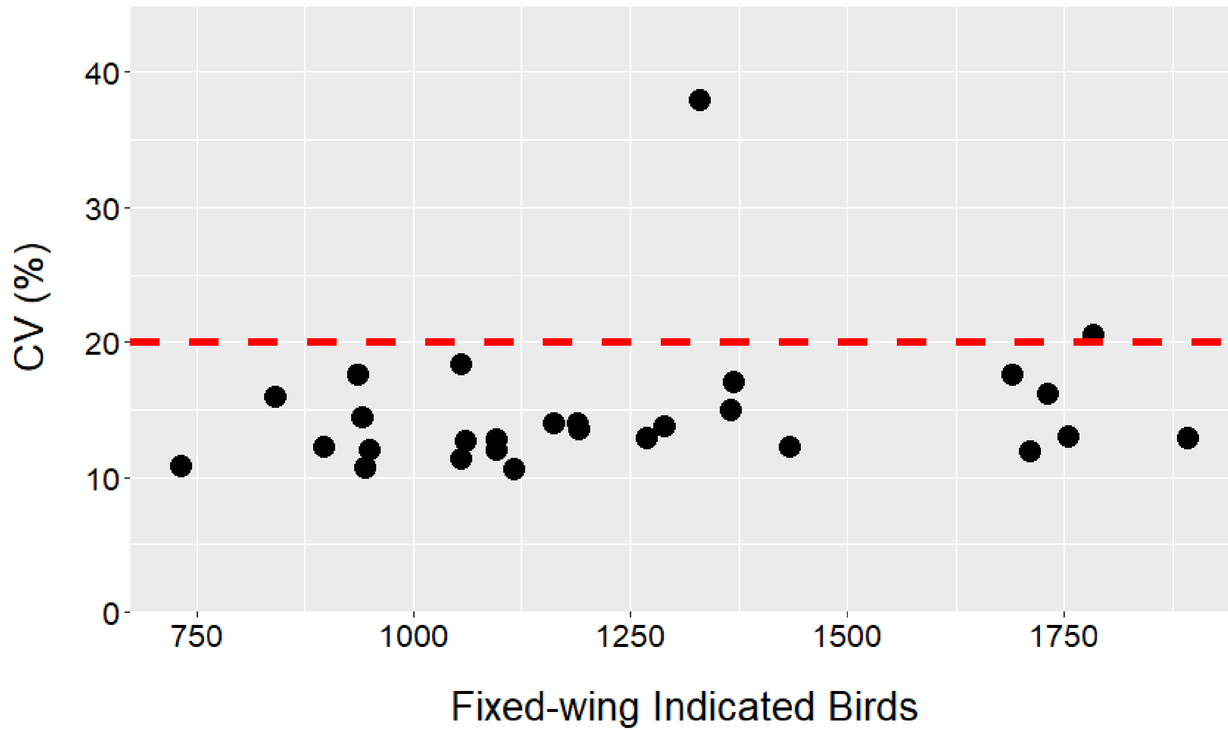



Figure 16. Comparison of indicated birds on the fixed-wing survey to the Coefficient of Variation (CV) on population estimates from the Standard Operating Procedure (SOP) aerial survey design using fixed-wing and helicopter surveys over the state of Michigan for a) Canada goose (1992-2019), b) mallard (1992-2019), c) sandhill crane (2005-2019), and d) mute swan (2007-2019). CV of 20% is shown as the red dashed line.

Figure 16 (cont'd)

b)




c)

Figure 16 (cont'd)

d)

survey detected 148 mute swans.

The helicopter-only design produced comparable population estimates and CVs to the SOP, especially for Canada goose and mallard. This shows that the helicopter-only design would be an acceptable alternate aerial survey design. Averaged CVs on the population estimates for the helicopter-only design were below 20% for Canada goose and mallard but were only slightly higher than their respective averaged SOP CV. Averaged Canada goose CV increased by 31% from the SOP while averaged mallard CV increased by 11% from the SOP using the helicopter-only design. We also noticed a pattern occurring for the helicopter population estimates. Whenever the yearly statewide VCF was smaller than the SOP VCF, the helicopter population estimate was smaller than the SOP population estimate, and the inverse occurred when the yearly statewide VCF was larger than the SOP population estimate. Since the helicopter survey corrects the fixed-wing counts, both the corrected fixed-wing and helicopter densities should be similar using a yearly statewide VCF under a randomized or GRTS sampling framework. Thus, the corrected fixed-wing density would be higher than the helicopter if the yearly statewide VCF was lower than the SOP VCF for that given year. Due to the variation of yearly statewide VCF, the helicopter population estimate should randomly be above or below the SOP population estimate.

Based on the helicopter bootstrap, the survey would cost between $16,194 and $17,464 to survey 40 segments. The helicopter-only design would cost between $5,786 and $6,726 less than the SOP design. Labor costs would also be reduced for the MDNR since they would not have to spend funds on the fixed-wing survey and take time away from their employees to conduct the survey. Savings and reduced labor costs make the helicopter-only design an affordable option if the MDNR chooses to modify the spring waterfowl survey.

We found that savings on removing fixed-wing transects in the farm urban stratum were minimal. With each transect removed, the MDNR could save on average $300 per transect. By removing five transects in the farm urban stratum, the modified SOP designed would save $1,500 and still achieve a CV of 20% or less. The MDNR could then use these funds to allocate for more helicopter segments. However, helicopter surveys cost on average $420 per segment which equates to adding three more helicopter segments. Based on the helicopter bootstrap, three additional helicopter segments would not gain enough precision to warrant the need for more helicopter segments surveyed. While the modified SOP aerial survey design is an acceptable alternate aerial survey design, there are not enough benefits gained to change from the SOP aerial survey design. Both the modified SOP and modified SOP-2 gave comparable results. Removal of only odd or even transects does not change outcomes, although the modified SOP had a higher population estimate than the SOP, and the modified SOP-2 had a lower population estimate than the SOP. The difference between population estimates on modified SOP and modified SOP-2 may be related to differences in wetland habitat conditions, resulting in slightly more birds on average in the odd-numbered transects. Averaged Canada goose and mallard CV increased by 17% and 14% from the SOP using the modified SOP, respectively. Averaged Canada goose and mallard CV increased by 9% and 13% from the SOP using the modified SOP-2. However, the MDNR may believe that a saving of $1,500 could be worthwhile. In addition to saving money, MDNR employees conducting the fixed-wing survey would have fewer days in the field and could utilize their time performing other activities. On average, observers complete the fixed-wing farm urban stratum in five days, so reducing the number of transects in half could complete the farm urban stratum in two or three days.

We also noticed that costs for fixed-wing and helicopter surveys can be dependent on expenses out of the MDNR's control. In addition to the flight expense, the MSP charges the MDNR overtime hours expense whenever the pilots go over their allotted work hours. This is something that cannot be forecasted as the MSP's schedule changes daily, and the MSP oversees scheduling a pilot for each survey day. For the fixed-wing survey, $658 and $867 were defined as overtime charges in 2018 and 2019, respectively. For the helicopter survey, $2,057 and $1,716 were charged as overtime expenses in 2018 and 2019, respectively. If future changes are to be made, the MDNR should be prudent that estimated costs could go slightly over based on overtime charges occurring.

## MANAGEMENT IMPLICATIONS

Aerial surveys with precise estimates of abundance provide important information used in setting annual hunting regulations for waterfowl and other birds. The MDNR depends on recreational waterfowl hunting as a source of funding for wildlife and habitat management, as well as providing information about waterfowl movement patterns, survival rates from band reporting, and management of overabundant species like Canada geese (Miller and Vaske 2003, Garrettson et al. 2014). Each year, the MDNR reports the waterfowl population estimates from the spring waterfowl survey to the USFWS. For waterfowl management, Michigan is part of the Mississippi flyway which consists of representatives from U.S. state and Canadian provincial wildlife management agencies within the region. Together, the USFWS and the Mississippi flyway set frameworks for harvest regulations based on the Adaptive Harvest Management program (AHM) which regulates daily bag limit, season length, and opening and closing dates (Williams et al. 1996, USFWS 2018). Although harvest of mallard populations is managed at the flyway scale and larger, the state of Michigan can make decisions to help manage mallards more locally. For example, the MDNR can propose their own specific waterfowl hunting season regulations for Michigan that cannot be more liberal than the federal framework but can be more conservative. With recommendations from the Citizens Waterfowl Advisory Committee (CWAC) and other public input, the MDNR will recommend Michigan waterfowl hunting season regulations to the Natural Resources Commission. The CWAC is a group of dedicated civilians that provides feedback on proposed Michigan waterfowl regulations for the next year, as well as any waterfowl hunting issues (MDNR 2017). Finally, the MDNR presents recommendations to the Natural Resources Commission to make the final decision for waterfowl hunting regulations in Michigan.

Considerable evaluation should be considered when choosing the type of monitoring technique depending on the species and management questions (Lancia et al. 2005). Monitoring programs like the spring waterfowl survey need to have specific objectives in place that estimate abundance with high precisions while also minimizing the cost (Reynolds et al. 2011). Alternate aerial survey designs would be considered acceptable if the estimation of waterfowl abundances is precise by meeting a CV of less than 20% without increasing the costs. We believe that the current transect number and survey configuration is still the best waterfowl monitoring program for the state of Michigan as alternative options did not produce enough benefits to outweigh the disadvantages. The modified SOP design was slightly cheaper than the SOP method but resulted in a higher CV for both the modified SOP and modified SOP-2. The helicopter-only method is about $6,000 cheaper than the SOP method but also resulted in slightly higher CVs. If helicopter survey costs continue to decline, the helicopter-only design could be a viable alternative aerial survey design as more helicopter segments could be surveyed, reducing the CV. A trade-off occurs between the fixed-wing and helicopter. Fixed-wing aircraft are cheaper but observers in a fixed-wing aircraft detect fewer birds. Helicopter surveys are more expensive and take longer than a fixed-wing survey, but observers in helicopters detect more birds. We believe it is important to combine the benefits of both aerial surveys by using the SOP aerial survey design in estimating waterfowl abundance.

We recommend that the MDNR maintain the current transect number and configuration for the spring waterfowl survey, but we caution continued use of older data. Many factors (e.g., weather, observers, population demographics, and survey cost) could change detection annually (Cowardin and Blohm 1992, Tracey et al. 2008, Mills 2012, Ransom 2012, Schummer et al. 2018). Thus, we recommend incorporating a three-year average statewide VCF as this VCF estimation method better captures annual variation than the SOP VCF. A three-year average statewide VCF would also be preferable as the CV is nearly identical to the SOP CV and lines up with decision frameworks for some species like Canada geese that use three-year cycles. On average, the three-year statewide VCF estimated 17% and 20% fewer birds than the SOP population estimate for Canada goose and mallard, respectively. If the MDNR is concerned about incorporating a shorter time interval averaged VCF in the population estimates for Canada goose and mallard, then a five-year statewide would be more appropriate. The five-year statewide population estimates were on average 9% and 11% smaller than the SOP population estimate for Canada goose and mallard, respectively. We would also advise the MDNR to conduct the helicopter survey every year if possible, to continuously update the VCF for each species, as year-to-year variability occurs. However, we understand that annual helicopter surveys are still expensive, so we would recommend conducting helicopter surveys every other year or once every three years. We recommend that a minimum of 40 VCF segments should be conducted every VCF year and to continue using the GRTS sampling. If the MDNR considers the alternate aerial survey designs, then we recommend the helicopter-only design to be surveyed with 40 or more helicopter segments and the modified SOP design to be surveyed by removing no more than five transects in the farm urban stratum. The spring waterfowl survey may be reexamined if helicopter survey costs continue to reduce and become similar to fixed-wing survey costs, as the helicopter-only design may be reconsidered. No matter what aerial survey design the MDNR chooses, the same observers should be used in each survey platform to maintain consistency and reduce observer error. Examining Michigan's spring waterfowl survey helped to inform the MDNR that modifications to the existing methodology should be incorporated.

**APPENDIX**

# APPENDIX

The MDNR spring waterfowl survey is a statewide survey that involves flying a series of 21 fixed-width transects using fixed-wing aircraft (Figure 17; CWS and USFWS 1987, Smith 1995). To get consistent results, the MDNR follow an accomplishment directive to create standard operating procedures (SOP) for the spring waterfowl survey (CWS and USFWS 1987, B. Avers, MDNR, unpublished report). The SOP survey methodology has fixed-width transects that are 0.4 km (1/4 mi) wide. Surveys are flown along an east-west orientation to avoid visibility error from the sun. Each transect is divided into segments that are 29 km (18 mi) long. The total number of historic segments have ranged from 139 to 152. Due to differences in terrain and feasibility of conducting fixed-wing surveys, the aircraft is flown at an altitude between 0.03-0.05 km (100-150 feet) and speed between 144.8-169.0 kph (90-105 mph) throughout the survey. Using a Cessna 172, 180, or 260 plane, fixed-wing surveys travel along the segment line and consist of a pilot with a front and rear seat observer. Surveys were not flown when beginning wind speeds exceeded 25 kph (15 mph) or when wind speeds reached 40 kph (25 mph) during the day.

Both observers identify all waterfowl species from 0.2 km (1/8 mi) on their side of the segment line. They also record the wetland type for each waterfowl observation and the segment number. To determine in a fixed-wing aircraft if the wetland is within 0.2 km from the segment line, a clinometer is used to measure this appropriate angle. The tape is placed on the wing struts to help guide observers on the segment edge location. Any bird above the tape line is out and not recorded. In addition to recording waterfowl observations, rear-seat observers record every wetland that they see within the segment even if there are no waterfowl observations for an estimate of total statewide wetlands.

For each segment surveyed, a front and rear seat observer record waterfowl observation and assign them to one of six grouping categories: singles, flocked drakes, pairs, nesting pairs, nesting singles, and groups (Table 13). For both fixed-winged and helicopter surveys, the total numbers of "indicated birds" for each segment are estimated from the waterfowl observations based on species' breeding biology. Drakes, flocked drakes, and pairs are adjusted by a multiplier of two while groups are not adjusted. To reduce misidentification bias, each crew member is trained in waterfowl identification.

Since not all birds are seen by observers in the fixed-wing aircraft (i.e., detection probability is <1), estimation of waterfowl abundance through the SOP survey design requires surveying a sample of segments with helicopters to establish species-specific visibility correction factors (VCF; Caughley 1974).  Helicopter surveys follow the same protocols as the fixed-wing surveys with slight variations. Segments are surveyed in a quadratic grid that is 0.2 km (1/8 mi) from either side of the segment line and wetlands within the segment are circled, allowing for more complete counts of waterfowl. To be accurate, the pilot uses Global Positioning Systems (GPS) to determine how far off the transect centerline is to the helicopter. Using Hughs 500 or Bell Jet Ranger, helicopter surveys are not flown every year because they are expensive and require additional personnel time. Historically eight VCF flights were conducted, in 1992-1996, 2003, 2010, and 2014, with 2018 and 2019 survey years conducted during this thesis. The ratio of the helicopter to fixed-wing counts creates a visibility correction factor that is applied to correct the fixed-wing counts. The SOP averages statewide species-specific VCF's from all VCF years. Corrected fixed-wing density estimates from each segment are then expanded for the area of Michigan to compute population estimates.

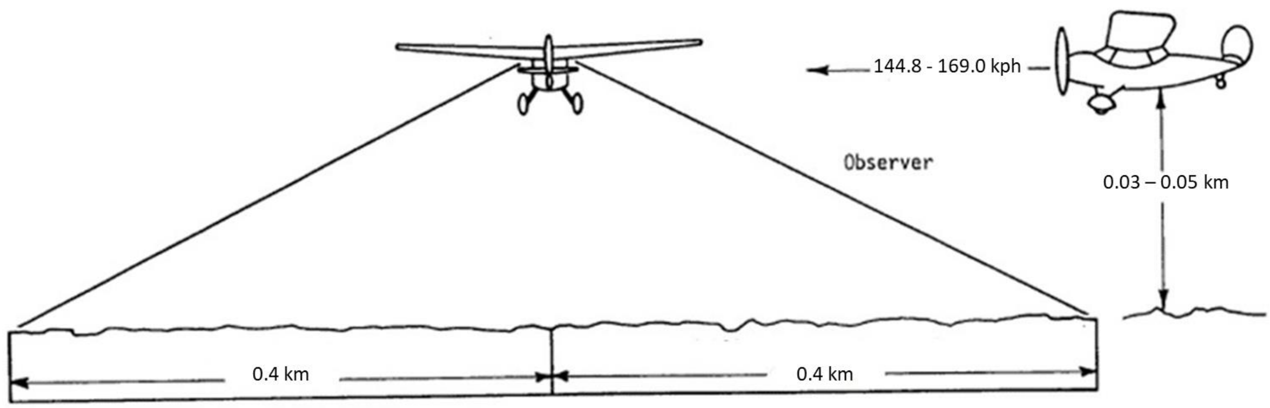



Figure 17. Fixed-wing Standard Operating Procedure (SOP) for conducting the Michigan DNR spring waterfowl survey.

Table 13. Waterfowl grouping types for the Michigan DNR spring waterfowl survey.

| Grouping Type | Species | Definition |
|---|---|---|
| Singles | All | Record the number of lone males with the absence of a female. |
| Flocked Drakes | Ducks | Record the total number of males observed together with the absence of females. Only record for two to four drakes. |
| Pairs | All | Record the number of pairs (males and females close together and can be separated). |
| Nesting Pairs | Geese, swans, and cranes | Record the number of pairs that are near or flushed from their nest. |
| Nesting Singles | Geese, swans, and cranes | Record the number of singles that are near or flushed from their nest. |
| Groups | All | Record the number of birds in mixed-sex groupings that cannot be differentiated into pairs. More than four flocked drakes become a group. |

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