

# **An Assessment of the Harvest Potential of North American Teal**

Compiled by the Teal Harvest Potential Working Group

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## Contributors

The information contained in this report is the result of the efforts of not only the members of the teal assessment group, but also many individuals outside the group. The Introduction was written by Doug Howell and Adam Phelps; they also formatted and assembled the report. Population demographic analyses were conducted by Tom Aldrich, Matt Dibona, James Dubovsky, Kathy Fleming, Shaun Oldenberger, Dave Olson, Paul Padding, and Nathan Zimpfer. Kathy Fleming conducted the population modeling analyses, and Matt DiBona, James Dubovsky, Larry Reynolds, and Michael Szymanski served on the population modeling subgroup. Khristi Wilkins (USFWS) provided harvest data. Kammie Kruse and Dave Sharp provided a detailed history of early teal and regular waterfowl harvest seasons. Mike Szymanski provided state pond counts. Scott Boomer (USFWS), Emily Silverman (USFWS), Nate Zimpfer (USFWS), Guthrie Zimmerman (USFWS), and Mike Runge (USGS) provided help and advice with demographic and statistical analyses. Guthrie Zimmerman, James Dubovsky, Mark Koneff (USFWS), Josh Richardson (Oklahoma DWC), Ron Gatti (Wisconsin DNR), and Guy Zenner (Iowa DNR) reviewed parts of the draft report and provided helpful comments. Banding and recovery data were acquired from the USGS Bird Banding Laboratory, and made possible through the efforts of many waterfowl banders from USFWS, CWS, state and provincial agencies, cooperators, and hunters. Waterfowl population data were collected by the many pilot-biologists and observers who have participated in the Waterfowl Breeding Population and Habitat Survey.

# An Assessment of the Harvest Potential of North American Teal

## Executive Summary

In 2009, the Service Regulations Committee (SRC) requested an assessment of the harvest potential of the three North American teal species: blue-winged teal (*Anas discors*), American green-winged teal (*A. crecca*), and cinnamon teal (*A. cyanoptera*). The assessment, as envisioned by the SRC, would include: (1) a description of the population dynamics of each species; (2) the derivation and distribution of the harvest; (3) past and current harvest pressure; (4) population response to harvest pressure; and (5) the impacts of incremental regulatory changes on harvest, particularly with regard to special seasons. A teal assessment advisory group was formed in late 2009, consisting of two state representatives from each flyway and several staff from U.S. Fish and Wildlife Service, Division of Migratory Bird Management. Additionally, in 2010, two members from the Canadian Wildlife Service were invited to join. The assessment was completed in January of 2013 and is summarized in this report. Below is a summary of how each component of the assessment was addressed. Due to lack of information on cinnamon teal demography, we limited the assessment of harvest potential to blue- and green-winged teal, whose populations are most impacted by special teal seasons. However, we present analyses of survival and recovery rates for all 3 species.

### Description of the population dynamics of each species

We conducted survival and recovery analyses for each species using banding and recovery data from the USGS Bird Banding Laboratory. We fitted Brownie dead recovery models in program MARK to estimate survival and recovery rates, including the effects of age, sex, geographic region (defined by analyses of the derivation of harvest), and time, as well as effects of changing harvest regulations packages. From 1965 to 2009, blue-winged teal survival rates averaged, for adult males, 0.64 (SE = 0.003); adult females, 0.58 (0.004); juvenile males, 0.47 (0.008); and juvenile females, 0.50 (0.01). Overall recovery rates (SE) were, for adults: east group, 0.02 (0.0003); west group, 0.01 (0.0001); central group, 0.01 (0.0002); for juveniles: east group, 0.04 (0.0006); west group, 0.01 (0.0004); central group, 0.03 (0.0003). Green-winged teal overall survival rates from 1970 to 2008 averaged, for adult males, 0.58 (0.09); adult females, 0.50 (0.11); juvenile males, 0.52 (0.06); and juvenile females, 0.41 (0.07). Overall recovery rates (SE) were, for adults: east group, 0.04 (0.007), mid-continent group, 0.03 (0.006), west group, 0.03 (0.005); for juveniles: east group 0.05 (0.001), mid-continent, 0.04 (0.005), and west group, 0.03 (0.005). Although fewer banding and recoveries existed for cinnamon teal (including unidentified teal recoveries), average survival and recovery rates were estimated by sex and species designation: for cinnamon teal males, 0.55 (0.02); for females, 0.53 (0.03); for unidentified teal males, 0.57 (0.02); females, 0.05 (0.03). Cinnamon teal recovery rates were, for males, 0.02 (0.001); females, 0.02 (0.002); unidentified teal recovery rates were, for males, 0.01 (0.001); females, 0.01 (0.001).

Differential vulnerability to harvest and indices of recruitment (preseason age ratios) were estimated for blue- and green-winged teal from harvest wing-collection data and direct recovery rates of banded birds. Age ratios and associated variances were estimated for both females and males (juveniles/adults) from 1970 to 2009 using either an annual varying estimate of differential vulnerability (DV) or a 1970-2009 average estimate of DV. Evidence of an increasing male sex ratio in both blue- and green-winged teal suggested that female age ratios were a less biased estimate of annual recruitment.

### Derivation and distribution of the harvest

The derivation and distribution of the blue- and green-winged teal harvest were investigated as separate analyses prior to this assessment. The derivation of the harvest was used to identify groupings within each teal species, based on direct band recoveries, which captured spatial patterns in demographic parameters. These groupings were used to investigate differences in survival and recovery rates within continental blue- and green-winged teal populations.

### Past and current harvest pressure

We estimated annual harvest rates for blue- and green-winged teal using recovery rates from Brownie dead recovery models, correcting for birds harvested but not reported with an annual composite reporting rate. The composite reporting rate combined reporting rates from different regions, different band types, and different reporting methods into a weighted average reporting rate per year. For blue-winged teal we did not include south of the border recoveries due to uncertainty in the reporting rate; instead we estimated a combined US + Canada harvest rate for each age and sex cohort. For green-winged teal we used all recoveries to estimate an annual harvest rate for each age and sex cohort. Harvest rates for both species have become less annually variable over time (from 1965 to 2009) and less variable among cohorts.

### Population response to harvest pressure

To assess the harvest potential of blue- and green-winged teal, we developed models that described the population dynamics of each species, and simulated equilibrium dynamics to predict the optimal harvest rates possible under average habitat conditions. We used balance equations based on the structure of the mid-continent mallard population model to predict the breeding population size for blue- and green-winged teal in year  $t+1$  from the previous year's population size, cohort-specific survival, and recruitment based on female age ratios. The balance equation for blue-winged teal predicted population size relatively well (correlation between observed and predicted change in population = 0.6), but for green-winged teal, predictions were relatively poor (correlation = 0.22). We used age ratio bias correction factors to correct for overprediction in both models (33% for blue-winged teal and 46% for green-winged teal). To simulate equilibrium dynamics, we used a modified balance equation where survival rates were replaced with survival submodels and age ratios were replaced with recruitment models. Survival submodels predicted survival rates at different levels of harvest, under hypotheses of either additive harvest (any amount of harvest reduces survival) or compensatory harvest (harvest up to a point does not affect survival). For blue-winged teal, survival submodels related survival to harvest rates from the US and Canada only, due to uncertainty in south of the U.S. border reporting rates. Recruitment models predicted pre-season age ratios as a function of population size and habitat conditions (number of May ponds in Canada and the US counted during the Waterfowl Breeding Population and Habitat Survey). We simulated equilibrium dynamics under 3 scenarios of habitat conditions: average number of ponds, plus or minus 95% confidence intervals around the average. For each scenario we estimated the optimal harvest rate (i.e., the harvest rate resulting in the highest sustainable harvest), given either additive or compensatory harvest, for each species. For blue-winged teal, simulated optimal harvest rates under the additive harvest model ranged from 0.047 for adult males to 0.105 for juvenile females, and were about 2–2.5 times higher than average observed harvest rates on blue-winged teal from 1965 to 2009; optimal harvest rates predicted for the compensatory model were about 7-9 times higher than observed harvest rates. For green-winged teal, optimal harvest rates under the additive model ranged from 0.098 for adult females to 0.177 for juvenile males, and were 1.3 to 1.5 times higher than average observed harvest rates from 1965 to 2009, while optimal

compensatory rates were 2.6 to 3 times higher than average observed harvest rates. Based on these simulations, we believe that additional harvest opportunity exists for both blue-winged and green-winged teal. However, our uncertainty about how both species' abundance might respond to harvest at higher levels makes it difficult to quantify what that additional harvest opportunity might be. Also, the estimates of harvest potential for blue-winged teal depend on the assumption that the proportion of the U.S. + Canada harvest rate to the total harvest rate (all countries) remains constant. The most conservative estimate of optimal harvest rates is based on the additive hypothesis, that any amount of harvest reduces survival rates. The most liberal approach would be to follow the compensatory hypothesis, although this assumes harvest mortality has no effect on population demography up to the compensation threshold and only then impacts abundance, which is unrealistic. More likely, teal populations respond to harvest in some manner intermediate to the two hypotheses.

#### *Impacts of incremental regulatory changes on harvest, particularly with regard to special seasons*

To determine how teal harvest is influenced by changes to the framework of the U.S. early teal harvest season, we investigated the relationship between either the number of early season days or number of early season states in each flyway (Atlantic, Mississippi and Central) and early teal harvest. We estimated early season harvest either as the number of birds harvested during the early season in each flyway from the Mail Survey Questionnaire (MSQ) (1992–1998) and Harvest Information Program (HIP) surveys (1999–2010), or by the harvest rate, based on direct recoveries of birds harvested during the early season in each flyway. Blue-winged teal early harvest models were better fit by the data than those of green-winged teal. The number of days in the early teal season was a better predictor than the number of states with an early teal season for both species, and was more important in predicting harvest rate than early harvest. However, these relationships were weak, due to the small number of changes in the structure of the early harvest season, the influence of other factors not included in the models, and error in the estimates of harvest or harvest rate.

#### *Uncertainties in the assessment of teal harvest potential*

Challenges exist in understanding and quantifying teal harvest potential, due to (1) a lack of information about blue-winged teal (and to some extent, green-winged teal) distribution, harvest, and reporting rates south of the U.S. border, (2) the degree to which harvest is additive or compensatory, especially given the long distance migration of blue-winged teal and substantial harvest south of the U.S. border, and (3) uncertainty about the functional form of density dependence. Further work to quantify uncertainty in model parameters and better understand the response of teal populations to harvest will improve our ability to predict harvest potential for these species.

## Chapter 1. Introduction

### Review of Charge from the Service Regulations Committee

In 2009, the Atlantic Flyway Council requested that the 9-day season in the Atlantic Flyway be expanded to 16 days when the May breeding survey estimate exceeds 4.7 million blue-winged teal (*Anas discors*). The Service Regulations Committee (SRC) allowed this change, but stated that it would not support additional changes to special September teal seasons until an assessment of harvest potential took place (Appendix 1). The assessment, as envisioned by the SRC, would include:

1. A description of the population dynamics of each species.
2. The derivation and distribution of the harvest.
3. Past and current harvest pressure.
4. Population response to harvest pressure.
5. The impacts of incremental regulatory changes on harvest, particularly with regard to special seasons.

The SRC indicated that all 3 North American teal species should be included in this assessment, and that the assessment should be continental in scale. The Atlantic, Mississippi, and Central Flyways were asked to provide representation (2 each) to a working group intended to assist the U.S. Fish and Wildlife Service (hereafter, Service) with completing this task within 3 years. Because of the importance of green-winged teal to the harvest of the Pacific Flyway, the Service also extended an invitation to that Flyway to provide 2 representatives. In 2011, two representatives from Canada also were invited to the working group.

### Management History

During the prairie drought of the late 1950s and early 1960s, when waterfowl hunting regulations became very restrictive due to concern about duck populations, biologists and managers began analyzing information to determine whether any species or populations could provide additional hunting opportunities (Bateman 1978, Schroeder 1978, Blandin 1981). "Special" waterfowl seasons might be possible to increase harvest on species or populations that were believed to be under-utilized. Bateman (1978:155) described a special duck season as "one that provides an extra period of hunting and separate bag limit for a particular duck or group of ducks when the regular season is not in progress." Further, "Game ducks that are normally selected for special seasons are those that exhibit an unusual migration or distribution pattern which results in them being lightly affected by hunting. The purpose of a special season is to provide additional hunting recreation at times when and in areas where under-utilized game ducks will be more available for hunting purposes." Thus, special seasons are appropriate when the target species or stocks are temporally or spatially segregated from non-target stocks so that additional harvest pressure can be applied primarily to the target stock(s) with minimal impacts to nontarget stocks (59 FR 42475, 1994).

Blue-winged teal migrate to southern wintering areas earlier than most other species of waterfowl nesting in the prairies, and many already have passed through Canada and the U.S. on their way to

wintering areas in Mexico, Central America, and South America by the end of September. Because waterfowl hunting seasons in the U.S. historically opened around October 1 in northern states, this species was subjected to relatively low harvest pressure by hunters in the U.S. However, because hunting seasons in Canada typically begin on September 1 (the earliest date allowed by the Treaty between the U.S. and Great Britain to open sport hunting for migratory birds), the potential loss of hunting opportunity was not as great in Canada. Therefore, managers believed a special blue-winged teal season could be conducted prior to the opening of regular duck seasons in the U.S. to allow a greater harvest of this species. In 1957, the Mississippi Flyway Council recommended a special teal season for the state of Louisiana, but no additional action was taken to implement this proposal (Bateman 1978). Interest in this potential additional hunting opportunity increased, and in 1962 representatives from the Atlantic, Mississippi, and Central Flyways met to discuss species-management options, and identified blue-winged teal as a potential candidate for special seasons because it seemed to have a low rate of hunting kill and, due to its early migration, tended to isolate it from other species of ducks in the autumn (Martinson et al. 1965). American green-winged teal (*A. crecca*; hereafter green-winged teal) were included because it was felt that hunters would not be able to differentiate between the two species. In addition, take of green-winged teal was expected to be low, because they are not early migrants like blue-winged teal. The report resulting from this meeting was forwarded to the Central and Mississippi Flyway Councils, and the Mississippi Flyway Council passed a recommendation in August 1963 supporting the first experimental hunt be conducted in the fall of 1964. However, the Mississippi Flyway Council subsequently deemed that necessary data-gathering procedures for the experiment could not be completed in time for a season in 1964, so the experimental hunt was delayed until the fall of 1965. During this time, the Central Flyway Council also considered implementing such a season and was preparing their plans for data gathering. Ultimately, the Service approved a 3-year experimental teal season that included both the Mississippi and Central flyways, where 4 blue-winged teal, green-winged teal, and cinnamon teal (*A. cyanoptera*) in the aggregate could be taken during any 9 consecutive days in September. Several reports were produced during and following the experimental seasons detailing results pertaining to harvest of teal and non-target species, hunter participation, and hunter performance (Martinson et al. 1965, 1967; Croft et al. 1968; Martin and Kaczynski 1968; Kimball 1970).

Table 1 illustrates a timeline of special teal seasons in the United States. The first special teal season occurred in September 1965 in 20 Mississippi and Central Flyway states. One Central Flyway state (Montana) and three Mississippi Flyway states (Alabama, Tennessee, and Wisconsin) did not have seasons that first year. Minnesota discontinued the teal season in 1966 due to excessive numbers of non-teal ducks in open areas and much larger than expected hunter participation and harvest of their local teal populations (Bateman 1978). Montana joined the other Central Flyway states in conducting a season in both 1966 and 1967, and Alabama joined the Mississippi Flyway states with a season in 1967.

Following the third experimental season in 1967, the Service compiled all of the information collected during the special seasons to determine next steps. A teal season was not authorized by the Service in 1968. Biologists expressed concern about the unexpected high take of green-winged teal during the special seasons, the take of non-target birds (particularly in more northern states), and the ability of



hunters to comply with the species-specific nature of the special teal season. Although the take of green-winged teal during the special teal seasons was high, it added only about 1 percent to the total take of this species during hunting seasons (Martinson et al. 1967, Bateman 1978), and the take of non-target ducks generally was low. Take of blue-winged teal during the 3-year experiment averaged 83% of all ducks taken, green-winged teal comprised 16%, and non-target ducks 1% (Martin and Kaczynski 1968).

Ultimately, the season was approved for operational status beginning in 1969. However, due to continued concern about the take of non-target ducks, the Service authorized that additional (“bonus”) blue-winged teal could be taken (2 per day during any 9-day period of a state’s regular season) in lieu of selecting a special September teal season, provided the state was not using the point system (Geis and Crissey 1973) for harvesting ducks. In 1970, the bonus teal option was offered to all states in the Atlantic Flyway, and Maine was allowed to initiate an experimental teal season (which it ended in 1972 due to low hunter interest and concern over adverse impacts on waterfowl populations available at the time of the regular season opening). Beginning in 1971, the Service did not permit northern “production” states in the Central Flyway (North Dakota, South Dakota, Nebraska, Montana, and Wyoming) and the Mississippi Flyway (Michigan, Wisconsin, Minnesota, and Iowa) to select September teal seasons due to continued take of non-teal ducks on breeding areas. However, those states were allowed the option of bonus teal during their regular duck seasons. All non-production states in the Central and Mississippi Flyways were allowed the option of either a September teal season or bonus teal during their regular season, and all states in the Atlantic Flyway not using the point system could select the bonus blue-winged teal limit.

These teal hunting opportunities remained largely unchanged (with exceptions for Iowa, Kentucky, and Tennessee, and a few other issues – see Table 1) until 1988, when September teal seasons and bonus teal bags were suspended due to concern about declines in blue-winged teal breeding abundance and extended drought conditions in key duck breeding areas. Following reviews of several special regulations (e.g., special seasons, bonus bags, point system) by the Service’s Office of Migratory Bird Management, the Service chose to continue September teal seasons, which were reinstated for non-production states of the Central and Mississippi Flyways in 1992. The criteria adopted allowed a 4-teal, 9-consecutive day season whenever the breeding population index for blue-winged teal was >3.3 million. At population indices lower than that value, or band-recovery rates higher than those experienced historically, more restrictive regulations for teal would be considered. However, the Service in 1990 (55 FR 38901, 1990) determined that the effects of bonus teal bags on populations of teal had not been adequately assessed, offered limited potential for adequate evaluation, and could increase the harvest of non-target species; thus, the Service chose to discontinue bonus teal bags indefinitely. Essentially, this eliminated additional hunting opportunities on teal for production states and states in the Atlantic Flyway.

Subsequent to the reinstatement of September teal seasons in 1992, a modification to the teal season criteria was adopted in 1998, allowing a 4-teal, 16-consecutive day September teal season when the breeding population index of blue-winged teal is >4.7 million birds. In that same year, several states in the Atlantic Flyway where >80% of their teal harvest is derived from midcontinent area (Pennsylvania

and Delaware southward) were allowed a 4-bird, 9-consecutive day experimental teal season (some of which became operational in 2001). In 2000, Nebraska was allowed to conduct an experimental teal season in the southern portion of the state, which subsequently was granted operational status in 2004. Blue-winged teal and green-winged teal abundance estimates remained high through 2009. These high abundances and potential loss of hunting opportunity resulted in additional requests for liberalizations in both southern and northern states in the 3 eastern flyways, which prompted this review.

Table 1. Timeline of special September teal seasons in North American Flyways, 1957–2009.

1957	Louisiana requests first special teal season; no action is taken to implement the proposal.
1962	Discussions begin regarding special teal seasons in Atlantic, Mississippi, and Central Flyways.
1963	Mississippi and Central Flyway Councils propose experimental teal season to begin in 1965; Service approves 3-year experiment to run from 1965–67.
1965	First early teal seasons allowed in Central and Mississippi Flyways (AL, MT, TN, and WI choose not to participate).
1966	Year two of experiment — MT joins experiment, but MN withdraws.
1967	Year three of experiment — AL joins experiment.
1968	Season suspended to analyze data from the experiment, and due to unexpectedly large harvest of green-winged teal and harvest of non-teal species in some areas.
1969	Experimental season becomes operational in Central and Mississippi Flyways. “Bonus bag” of 2 blue-winged teal per day for 9 consecutive days allowed if September season/point system not used.
1970	Maine authorized to conduct experimental teal season. Also, ND, SD, and WY of Central and IN, KY, MN, WI, MI, and IA of Mississippi Flyway excluded from season. Bonus blue-winged teal bag offered to Atlantic Flyway.
1971	No duck “production” states allowed to have a September teal season (Central Flyway: MT, WY, ND, SD, NE; Mississippi Flyway: MN, IA, WI, MI).
1972	Maine chooses to discontinue their teal season. All states in the Atlantic Flyway not choosing the point system could select bonus blue-winged teal limit (was not available to other flyways).
1975	Kentucky added to eligible states.
1979	Green-winged teal added to bonus blue-winged teal limit in the Atlantic Flyway. IA allowed a 5-day September duck season with days to be taken out of their regular duck season.
1981	KY, TN, and FL allowed a 5-day wood duck and teal season in lieu of a teal-only season.
1987	“Bonus bags” eliminated.
1988	September teal seasons, bonus teal, IA September duck season, and wood duck/teal seasons in KY, TN, and FL suspended due to concerns regarding blue-winged teal population levels and extended drought on key duck breeding areas.
1992	September teal and wood duck/teal seasons reinstated with specific criteria in same states as those prior to the suspension. Pre-sunrise shooting allowed in states that could show attempt rates at non-targets was no different during pre-sunrise period compared to post-sunrise period.
1994	IA September duck season reinstated.
1998	4-teal, 16-day September teal seasons allowed in Central and Mississippi Flyways when blue-winged teal breeding population estimate > 4.7 million birds; DE, GA, MD, NC, PA, SC, VA, WV in Atlantic Flyway authorized to conduct experimental 4-bird, 9-day teal seasons.
2000	NE authorized to conduct 4-bird, 9-day experimental Sept. teal season in southern portion of the state.
2001	DE, GA, MD, and VA seasons granted operational status. PA and WV choose to discontinue seasons.
2004	NE September teal season granted operational status.
2009	Atlantic Flyway allowed the 16-day season under the Sept. teal season criteria. SRC requires harvest assessment before any other expansions of special seasons will be allowed

## Life Histories of North American Teal

### *Blue-winged Teal*

*General.*—The blue-winged teal is among the smallest ducks in North America, larger only than the bufflehead (*Bucephala albeola*) and green-winged teal. They are very closely related to cinnamon teal, from which blue-winged teal appear to have diverged very recently. Besides cinnamon teal, their other closest relatives are the 4 species of shovelers (Rohwer et al. 2002). Blue-winged teal hybridize with northern shoveler (*Anas clypeata*) and cinnamon teal in the wild, though they are sympatric with cinnamon teal in only a narrow portion of their range.

*Spring Migration.*— Blue-winged teal are a late spring migrant, some not leaving Central America until April (Ridgely and Gwynne 1989). They generally arrive on the breeding grounds from late March to late April, but some arrive as late as mid-May (Bellrose 1980). Food during spring migration is primarily of animal origin, but with a significant component of seeds (Taylor 1978).

*Nesting.*— Blue-winged teal nest throughout much of central and northern North America, with highest densities occurring in the Prairie Pothole region of South and North Dakota and southern Manitoba, Saskatchewan, and Alberta (Rohwer et al. 2002). They prefer to nest in grassy uplands, nearer to wetlands than other dabbling ducks. They avoid forest or shrubby cover. They begin the season using temporary and seasonal wetlands, but once nesting begins their preference shifts to seasonal and semi-permanent wetlands. Blue-winged teal select wetlands based upon the density of preferred invertebrates in the forage base.

Blue-winged teal nest after pintails and mallards, but before such late nesters as gadwall (*A. strepera*) and American wigeon (*A. americana*). Despite very high nest failure rates, renesting occurs uncommonly. Renesting is most common when nests fail during laying and much less common if nest failure occurs after incubation begins (Bellrose 1980). Mean clutch size is 10 eggs. Hens incubate eggs for an average of 24 days, and young blue-winged teal fledge at about 40 days (Dane 1965).

Food of nesting adults is heavily focused on invertebrates, with very little plant material being taken (Swanson and Myer 1977, Swanson et al. 1974). After breeding, but before migration, blue-winged teal food choice shifts to a diet more heavily based on plant material, including seeds (Dubowy 1985).

*Fall Migration.*—Blue-winged teal are an early southbound migrant. They leave the nesting grounds from August through September, with numbers building on the Gulf Coast through October, although some arrive as far south as Panama as early as September (Ridgely and Gwynne 1989). They are among the longest distance migrants among waterfowl, traveling from as far as northern Canada to central or southern South America. Foods on fall migration are nearly 100% seeds (Sell 1979).

*Wintering.*—Most winter in Central America (Rohwer et al. 2002). Little information is available on habitat use on Central and South American wintering grounds. In southern North America, blue-winged teal seem to prefer freshwater to brackish coastal marshes with moderate vegetative cover, though they also use salt marshes in Mexico (Thompson and Baldassarre 1991). Cultivated rice fields are also

important usage areas. Food habits of blue-winged teal during winter are poorly known, and seem to differ based on habitat. However, rice seems to be an important component, as well as other aquatic seeds and, later in the season, invertebrates.

### ***Green-winged Teal***

*General.*—The green-winged teal is the smallest duck in North America, being slightly smaller on average than the bufflehead. Although generally considered conspecific with Eurasian green-winged teal (*A. c. crecca*), Livezey (1991) suggested that the 2 subspecies be lumped. Green-winged teal do not readily hybridize, though hybrids are known with American wigeon, mallard (*A. platyrhynchos*), northern pintail (*A. acuta*), and northern shoveler (Johnson 1995).

*Spring Migration.*—Green-winged prefer shallow, muddy wetlands during both spring and fall migrations. This probably reflects their preference for invertebrates and foraging on mud flats. They arrive on the breeding grounds as early as March in the southern part of the breeding range to mid-May in the Northwest Territories (Bellrose 1980).

*Nesting.*—In North America, nests across northern North America, from boreal forest wetlands south through the prairies. Highest nesting densities occur in the Canadian parklands and into the mixed grass prairies of the northern U.S. (Bellrose 1980, Johnson 1995). It frequently occurs in wooded areas, often on beaver ponds (Baldassare and Bolen 1994). Egg-laying begins in May in most of the range to early June in the far northern reaches. Nest sites are frequently brushy thickets near water, better concealed than most other dabbling ducks (Keith 1961). Mean clutch size is 8, and incubation is 20 – 23 days (Palmer 1976). Green-winged teal have the fastest growth rate of any duck (Bellrose 1980), fledging in 34 days. Foods taken during the nesting season are largely plant-based (Coulter 1955, Dubowy 1988), but little work has been done on this aspect of their biology, presumably due to the inaccessibility of the main portion of their nesting range.

*Fall Migration.*—Green-winged teal that nest in northwestern North America typically migrate down the west coast. Birds that nest in the central portion of North America primarily use the Central and Mississippi Flyways to the Gulf of Mexico, and eastern-nesting birds use the Atlantic coast during migration. Similar to their preferences during spring migration, green-winged teal also prefer shallow, muddy wetlands during fall migration.

*Wintering.*—Green-winged teal are hardy, wintering on both coasts of the United States, and as far north as Alaska and Maine. They also occur throughout the interior during winter from as far north as Montana and Wyoming to as far south as southern Central America (Johnson 1995). Migration seems to follow the freeze line south as winter progresses. In coastal areas it, like the blue-winged teal, prefers fresh and brackish marshes over open water and frequently utilizes cultivated rice fields. During winter, they seem to focus on invertebrates, though (as in many ducks) their diet seems to shift from a more plant-based diet to invertebrates as winter progresses.

### ***Cinnamon Teal***

*General.*—The cinnamon teal is among the most striking and most poorly studied ducks in North America. It hybridizes with blue-winged teal and northern shovelers in the wild. Five subspecies are recognized, with 4 of the 5 occurring in South America and only one (*A. c. septentrionalum*) occurring in North America. Unlike green-winged and blue-winged teal, some aggregations of cinnamon teal are likely year-round residents in the southern portion of the breeding range. Unless otherwise indicated, this species account refers only to *A. c. septentrionalum* in North America.

*Spring Migration.*—Because this species is a relatively short-distance migrant, cinnamon teal arrive on the southern nesting grounds early (late February in California) (Heitmeyer and Raveling 1988), with most birds arriving in the northernmost breeding areas in early May. Food habits focus on invertebrates in spring, with only 21% of the diet made up of plant material in one study (Thorn and Zwank 1993).

*Nesting.*—Cinnamon teal nest from southern Alberta and southwest Saskatchewan south through the Great Basin and the intermountain western US, continuing south through the central Mexican highlands (Gammonley 1996). They nest near water in herbaceous vegetation or occasionally woody vegetation. Where upland cover is poor, they are known to nest over water in emergent vegetation (Gammonley 1996). The peak of nesting occurs mid-May to mid-June. Mean clutch size is approximately 10 (Gammonley 1996). Incubation lasts 21 – 25 days. Cinnamon teal nests are known to be parasitized by redheads (*Aythya americana*). Young fledge at approximately 49 days. Food habits of adults during the nesting season appear to be equally comprised of plant and animal food items. As the season progresses and fall migration grows closer, their food preference shifts toward plants.

*Fall Migration.*—Like the closely related blue-winged teal, cinnamon teal are a very early migrant. Most have left the northernmost portions of the breeding range by late October (Bellrose 1980). However, because they are a relatively short-distance migrant, migration routes are not well-defined. Habitat preferences during migration are similar to those during the breeding season, generally marshes with dense emergent vegetation. One study found that immature birds fed predominantly on seeds (Thorn and Zwank 1993).

*Wintering.*— In some portions of its range (such as the western half of California), the cinnamon teal is a year-round resident. The winter range stretches from northwest California into Arizona, and south to northern Central America. Habitat preferences are similar to nesting habitats: the species prefers diverse seasonal wetlands. In coastal regions such as the Pacific and southern Gulf coasts, they use tidal areas, including estuaries and marshes. Food during winter tends to be primarily plant-based. Invertebrates comprise more of the diet as spring migration nears.

## Review of Data: Abundance and Harvest

### *Abundance*

*Blue-winged Teal.*— Blue-winged teal are currently the second most abundant duck in North America, having replaced scaup (*Aythya affinis* and *Aythya marila*, combined) in the mid-1990's (U.S. Fish and Wildlife Service 2012b). In the eastern Dakotas and Montana, they are the most abundant breeding waterfowl. In remaining portions of prairie breeding areas, including Alberta, Saskatchewan, and Manitoba, they rank second only to mallards. In eastern breeding areas, blue-winged teal are much less abundant, and are greatly outnumbered by other ducks including the mallard, American black duck (*Anas rubripes*), ring-necked duck (*Aythya collaris*), common goldeneye (*Bucephala americana*), and in most years by green-winged teal and bufflehead.

Abundance has fluctuated greatly (Table 2), following trends in water conditions (May ponds) in the prairie pothole region over time. The estimate of blue-winged teal abundance is currently 94% (U.S. Fish and Wildlife Service 2012b) above the North American Waterfowl Management Plan (NAWMP) goal of 4.7 million birds (NAWMP 1998). Abundance has averaged 4.7 million over the period 1955–2011 (U.S. Fish and Wildlife Service 2012b). They were at their lowest in 1990, with an estimate of only 2.8 million birds. Following an extended period of excellent water conditions in primary nesting areas, abundance increased dramatically but fluctuated with wetland abundance in prairie areas. The population is currently at a record level of 9.2 million birds (Table 2).

*Green-winged Teal.*—In the traditional survey area, green-winged teal abundance has exhibited a generally increasing trend, particularly since 1986 (U.S. Fish and Wildlife Service 2012b), and the current population estimate of 3.4 million birds is 89% above the NAWMP goal of 1.8 million (Table 2). Abundance is currently significantly above their 1955–2011 long-term average within survey strata in Alaska-Yukon-Old Crow Flats, central and northern Alberta-northeast British Columbia-Northwest Territories, Southern Saskatchewan, and Southern Manitoba (U.S. Fish and Wildlife Service 2012b). In the eastern survey area, where surveys began in 1990, green-winged teal have been one of the 10 most abundant ducks (Table 3). Their abundance has been fairly stable, averaging 257,000 birds over that time (U.S. Fish and Wildlife Service 2012b).

*Cinnamon Teal.*—Accurate estimates are unavailable because no operational monitoring programs are conducted to estimate their abundance. Therefore, long-term trends are poorly known. Bellrose (1980) estimated a breeding abundance of 260,000–300,000, making it one of the least abundant ducks in North America. Counts of blue-winged and cinnamon teal are combined in the annual Waterfowl Breeding Population and Habitat Survey (WBPHS), and most cinnamon teal nest outside the established survey area. Several western states (CA, NV, OR, UT, WA) have conducted independent breeding waterfowl surveys since 1994, but like the WBPHS both blue-winged teal and cinnamon teal estimates are combined. In 2009, blue-winged-cinnamon teal abundance for all western states was estimated at 124,285 birds, which was 16.4% above the 1994–2008 average (106,846 birds).

Table 2. Abundance estimates and standard errors (in thousands) for blue-winged and green-winged teal in the traditional survey area (1955–2012).

Year	BWTE		AGWT		Year	BWTE		AGWT	
	N	SE	N	SE		N	SE	N	SE
1955	5305.2	567.6	1807.2	291.5	1984	3979.3	267.6	1408.2	91.5
1956	4997.6	527.6	1525.3	236.2	1985	3502.4	246.3	1475.4	100.3
1957	4299.5	467.3	1102.9	161.2	1986	4478.8	237.1	1674.9	136.1
1958	5456.6	483.7	1347.4	212.2	1987	3528.7	220.2	2006.2	180.4
1959	5099.3	332.7	2653.4	459.3	1988	4011.1	290.4	2060.8	188.3
1960	4293.0	294.3	1426.9	311.0	1989	3125.3	229.8	1841.7	166.4
1961	3655.3	298.7	1729.3	251.5	1990	2776.4	178.7	1789.5	172.7
1962	3011.1	209.8	722.9	117.6	1991	3763.7	270.8	1557.8	111.3
1963	3723.6	323.0	1242.3	226.9	1992	4333.1	263.2	1773.1	123.7
1964	4020.6	320.4	1561.3	244.7	1993	3192.9	205.6	1694.5	112.7
1965	3594.5	270.4	1282.0	151.0	1994	4616.2	259.2	2108.4	152.2
1966	3733.2	233.6	1617.3	173.6	1995	5140.0	253.3	2300.6	140.3
1967	4491.5	305.7	1593.7	165.7	1996	6407.4	353.9	2499.5	153.4
1968	3462.5	389.1	1430.9	146.6	1997	6124.3	330.7	2506.6	142.5
1969	4138.6	239.5	1491.0	103.5	1998	6398.8	332.3	2087.3	138.9
1970	4861.8	372.3	2182.5	137.7	1999	7149.5	364.5	2631.0	174.6
1971	4610.2	322.8	1889.3	132.8	2000	7431.4	425.0	3193.5	200.1
1972	4278.5	230.5	1948.2	185.8	2001	5757.0	288.8	2508.7	156.4
1973	3332.5	220.3	1949.2	131.9	2002	4206.5	227.9	2333.5	143.8
1974	4976.2	394.6	1864.5	131.2	2003	5518.2	312.7	2678.5	199.7
1975	5885.4	337.4	1664.8	148.1	2004	4073.0	238.0	2460.8	145.2
1976	4744.7	294.5	1547.5	134.0	2005	4585.5	236.3	2156.9	125.8
1977	4462.8	328.4	1285.8	87.9	2006	5859.6	303.5	2587.2	155.3
1978	4498.6	293.3	2174.2	219.1	2007	6707.6	362.2	2890.3	196.1
1979	4875.9	297.6	2071.7	198.5	2008	6640.1	337.3	2979.7	194.4
1980	4895.1	295.6	2049.9	140.7	2009	7383.8	396.8	3443.6	219.9
1981	3720.6	242.1	1910.5	141.7	2010	6328.5	382.6	3475.9	207.2
1982	3657.6	203.7	1535.7	140.2	2011	8948.5	418.2	2900.1	170.7
1983	3366.5	197.2	1875.0	148.0	2012	9242.3	425.1	3471.2	207.9



Table 3. Abundance estimates and 90% credible intervals (in thousands) for green-winged teal in the eastern survey area (1990–2012).

Year	<i>N</i>	90% CI	Year	<i>N</i>	90% CI
1990	249.3	(195.7, 323.6)	2002	279.4	(220.9, 364.6)
1991	242.0	(189.2, 317.8)	2003	270.7	(213.8, 352.4)
1992	230.4	(178.8, 303.1)	2004	311.9	(245.6, 409.4)
1993	210.5	(161.4, 278.5)	2005	248.0	(196.3, 320.7)
1994	220.2	(170.1, 293.1)	2006	251.7	(198.6, 326.5)
1995	225.4	(173.7, 299.0)	2007	280.5	(221.9, 361.3)
1996	296.3	(235.1, 385.4)	2008	298.4	(228.3, 411.2)
1997	232.0	(182.3, 300.8)	2009	289.4	(226.3, 384.0)
1998	220.6	(174.1, 284.6)	2010	273.4	(217.4, 354.4)
1999	256.7	(201.6, 335.0)	2011	255.5	(201.5, 332.3)
2000	277.2	(222.0, 353.4)	2012	259.3	(205.7, 333.6)
2001	233.8	(185.1, 300.7)			

## Harvest

Eighty-seven percent of the total U.S. teal harvest from 1961 to 2009 occurred during the regular season, and was comprised of approximately 64% green-winged and 36% blue-winged–cinnamon teal (Table 4). Two percent of all green-winged teal harvest was taken during the early (September) season; the remainder (98%) was taken during the regular season. Thirty-two percent of all blue-winged–cinnamon teal harvest was taken during the early season; the remainder (68%) was taken during the regular season. During the early season, most green-winged and blue-winged–cinnamon teal harvest occurred in the Central and Mississippi Flyways. During the regular season, most green-winged teal harvest occurred in the Mississippi and Pacific Flyways, while most blue-winged–cinnamon teal harvest occurred in the Central and Mississippi Flyways. The distribution of the total U.S. teal harvest between seasons (early, regular) and flyways has remained relatively consistent during 1999–2009 as compared to 1961–2009 (Table 5).

Table 4. Proportion of total U.S. teal harvest taken during the early (September) and regular harvest seasons by Flyway, average 1961–2009.

	Green-winged teal		Blue-winged–cinnamon teal		All Teal	
	Early	Late	Early	Late	Early	Late
Flyway						
Atlantic	0.00044	0.06107	0.00277	0.02451	0.00321	0.08557
Mississippi	0.00715	0.22094	0.07678	0.12707	0.08393	0.34801
Central	0.00747	0.13066	0.03849	0.03639	0.04596	0.16705
Pacific	0.00000	0.22891	0.00000	0.03231	0.00000	0.26122
Alaska	0.00004	0.00492	0.00000	0.00008	0.00004	0.00500
Flyway Total	0.01510	0.64649	0.11805	0.22036	0.13315	0.86685
Species Total	0.64409		0.35591			

Table 5. Proportion of total U.S. teal harvest taken during the early (September) and regular harvest seasons by Flyway, average 1999–2009.

	Green-winged teal		Blue-winged–cinnamon teal		All Teal	
	Early	Late	Early	Late	Early	Late
Flyway						
Atlantic	0.00162	0.05767	0.00598	0.02318	0.00760	0.08084
Mississippi	0.00623	0.25217	0.09230	0.11916	0.09943	0.37133
Central	0.00879	0.11384	0.06186	0.04606	0.07065	0.15990
Pacific	0.00000	0.18444	0.00000	0.02216	0.00000	0.20660
Alaska	0.00000	0.00362	0.00000	0.00004	0.00000	0.00365
Flyway Total	0.01664	0.61173	0.16104	0.21059	0.17768	0.82232
Species Total	0.62748		0.37252			

## Chapter 2. Demographic Analyses

### Survival Estimates and Recovery Rates

Survival and Recovery Rates of Blue-winged Teal, 1965–2009

*Kathy Fleming, USFWS*

#### Introduction

I used banding and recovery data to estimate survival and recovery probabilities for blue-winged teal from 1965 to 2009. Blue-winged teal survival and recovery probabilities have been previously estimated by Wilkins (2005), Schroeder (in Johnson et al. 1992), and Johnson (unpublished data). The objectives of this analysis were to provide updated survival and recovery rate estimates, and examine the effects of age, sex, breeding reference group, and early and regular harvest season structure on these estimates.

#### Methods

I obtained preseason banding records (July, August, September) of normal, wild birds of known age captured and released in the same 10-min block (Table 1). Analysis of the derivation of harvest (Szymanski and Dubovsky in press) suggests that a geographic pattern exists in harvest of the continental population of blue-winged teal. Therefore, I assigned bandings to 1 of 3 banding reference areas (hereafter termed west, central, and east groups) identified in the harvest derivation (Fig. 1, Table 1).

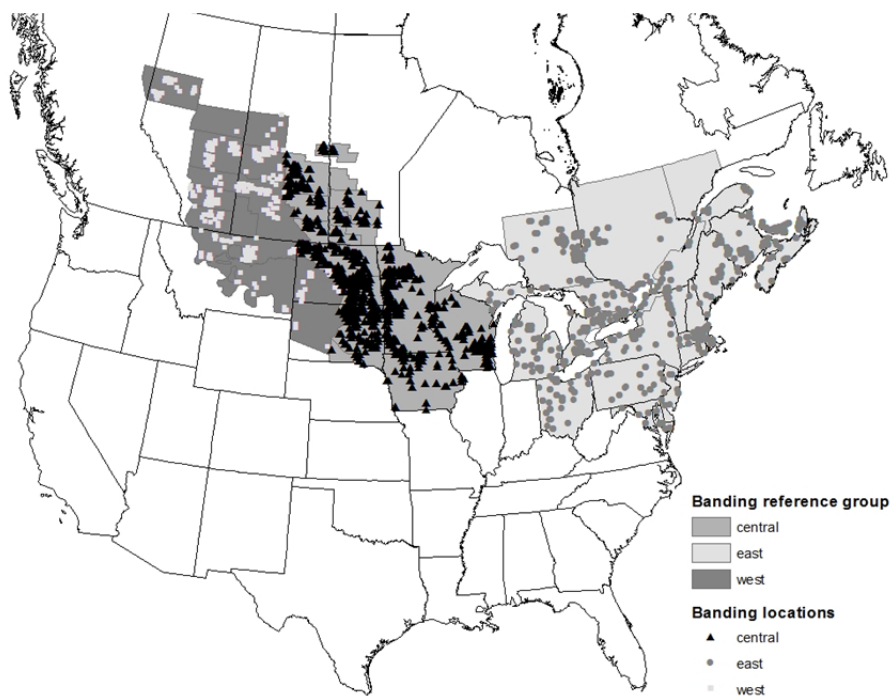


Fig. 1. Blue-winged teal banding reference areas and banding locations based on analysis by Szymanski and Dubovsky (in press).

I selected recoveries from these bandings of birds shot or found dead during the hunting season (recovery months from September to April, and inexact codes representing hunting season or fall). I performed two analyses: one using all recoveries of birds banded within these 3 reference groups, and one using only U.S. recoveries (including Puerto Rico). The latter was used to provide U.S.-only recovery rate estimates for models containing U.S. harvest-season structure covariates.

Table 1. Sample sizes of blue-winged teal bandings and recoveries by cohort and reference area (all recoveries), 1965-2009.

	Banding reference area		
	Central	East	West
<b>Bandings:</b>			
Adult male	145,569	24,024	139,120
Adult female	70,144	14,207	55,227
Juvenile male	213,236	68,097	72,943
Juvenile female	183,742	65,259	61,184
<b>Total</b>	<b>612,691</b>	<b>171,587</b>	<b>328,474</b>
<b>Recoveries:</b>			
Adult male	4,850	938	3,734
Adult female	2,299	687	1,262
Juvenile male	9,785	3,704	2,078
Juvenile female	8,160	3,991	1,547
<b>Total</b>	<b>25,094</b>	<b>9,320</b>	<b>8,621</b>

*Dataset containing all recoveries banded in banding reference areas.*—All survival and recovery models were estimated using program MARK (White and Burnham 1999). I fit Brownie dead recovery models to estimate sex-, age- (i.e., hatch year vs. after hatch year), and group-specific (either 3 groups: west, central, and east, or 2 groups: west/central combined and east) annual survival and recovery rates. I fit the full model (survival and recovery rates by age, sex, 3 groups, and year) and a set of reduced models representing alternate hypotheses about effects of age, sex, and/or group on survival and recovery rates. I used a sine link function when possible; for some models that did not converge using the sine link I used a log-log link function. I also considered a set of models containing the interactive effects of age, sex, and group along with additive effects of time and early or regular (or both) harvest season structure. I included time as an additive effect ( $T$ ) to fit the time series of survival and harvest rates to a linear trend. The additive time model contained many fewer parameters (14 compared to 446 in the selected model) but constrained the parameter estimates as a linear function of time. To determine if the annual variation in survival or recovery rates was related to harvest season structure, I used the total (over all states) number of regular duck season days  $\times$  bag each year as an index of regular harvest season structure, and the total number of early season days  $\times$  square mile (all states with an early season combined) as an index of early teal season structure; both of these variables were individually scaled as z scores (mean = 0, sd = 1) and included as additive effects on survival and/or recovery rates. I also used the early season days  $\times$  bag plus regular season days  $\times$  bag as a combined index of both

seasons' structure (also scaled). For additive models, I included all possible interactions among effects. I evaluated the fit of the full model based on the degree of overdispersion (estimated as deviance/df using the median  $\hat{c}$  procedure in MARK). I adjusted the  $AIC_c$  (AIC corrected for small samples) values using median  $\hat{c}$  to derive quasi-likelihood AIC values ( $QAIC_c$ ), and used this criterion for model selection (Cooch and White 2010). I determined differences in overall survival and recovery rates among groups and cohorts based on overlap of confidence intervals.

*Dataset containing U.S. recoveries only.*—I conducted a similar analysis using the same bandings from the 3-group analysis, but included only recoveries from the U.S. and Puerto Rico, in order to investigate the effect of US harvest season structure on recovery rates. I used the same banding dataset but, due to small sample sizes in the recovery dataset, I did not separate records into breeding reference areas. Total number of recoveries was 28,945: adult males, 7,127; adult females, 3,046; juvenile males, 10,140; and juvenile females, 8,632. I ran a subset of candidate models that contained age, sex, and time effects, and models with harvest season structure as additive effects. I evaluated model fit and selection in the same manner as with the full recovery dataset.

## Results

*Dataset containing all recoveries from banding reference groups.*—The full model with annual survival and recovery rates by age, sex and group contained 1068 parameters and converged using a log-log link function. Over dispersion ( $\hat{c}$ ) of the full model was 1.2, indicating that the model fit the data fairly well. This model was initially best supported by the data based on its  $AIC_c$  value; however, when  $\hat{c}$  was used to adjust  $AIC_c$  values ( $QAIC_c$ ), the order of models changed (Table 2) and the reduced model  $s(a*s*t)f(a*3g*t)$  was selected (here  $s(a*s*t)$  denotes survival rates by age, sex, and time;  $f(a*3g*t)$  denotes recovery rates by age, 3 banding reference groups, and time). All other model weights equaled zero, so no other models were considered. The selected model  $s(a*s*t)f(a*3g*t)$  contained age-, sex, and year-specific survival rates, and age-, group-, and year-specific recovery rates (Figs. 2 and 3, Table 4). However, 5 of the survival parameters in this model were not estimable due to small sample sizes in some years. Overall (all years combined) survival and recovery rates were estimated from the model  $s(a*s)f(a*3g)$  (Fig. 6). These were, for adult males, 0.64 (SE = 0.003); adult females, 0.58 (0.004); juvenile males, 0.47 (0.008); and juvenile females, 0.50 (0.01). Although juvenile female survival rates were slightly higher than that of juvenile males, this difference was not significant. Overall recovery rates (SE) were, for adults: east group, 0.02 (0.0003); west group, 0.01(0.0001); central group, 0.01 (0.0002); for juveniles: east group, 0.04 (0.0006); west group, 0.01 (0.0004); central group, 0.03 (0.0003). Recovery rates were higher for juveniles than adults, and differed by region, decreasing from east to west.

Models with harvest- season- structure variables as additive effects did not fit the data well, despite the substantially fewer number of parameters than in the models with annual estimates. However, of these 6 models, those with early-season-structure effects ranked higher than regular-season or both-season variables. Models with time as an additive effect also did not fit the data well.

*Dataset with U.S. recoveries only.*—AIC<sub>c</sub> results for this dataset were similar to the analysis using all recoveries. Median  $c$ -hat was 1.42, indicating reasonably good fit of the full model. The selected model was  $s(a*s*t)f(a*t)$ , similar to the dataset with all recoveries but without the group effect in recovery rates (Table 3). Although no models containing harvest season structure variables as additive effects ranked highly, models with early season structure variables ranked higher than regular season or both combined. The model with time as an additive effect (big T) did not fit the data well.

### **Discussion**

*Survival rates.*—Although the model with survival rates estimated by year ranked higher than models without a year effect, the large confidence intervals on annual survival estimates made it difficult to observe any temporal pattern in survival. Survival rates did not appear to be related to early or regular season structure, or region. In a previous analysis of survival and recovery rates of blue-winged teal, Wilkins (2005) found a weak region effect on survival using banding data from 1970 to 2003 that was not evident in this dataset, but the 3 regions were defined slightly differently in that analysis. An earlier study by L. Schroeder (reported in Johnson et al. 1992) of blue-winged teal survival and recovery rates based on bandings and recoveries from 1948 to 76 reported similar survival rates (adult males, 0.59; adult females, 0.52; juvenile males, 0.44; juvenile females, 0.32) except for juvenile females, the survival rate of which was considerably lower than in this analysis. I did not report survival rates from the analysis using US recoveries only, due to the potential bias in estimating survival without including a set of recoveries from regions with likely different recovery (and harvest) rates.

*Recovery rates.*— Annual juvenile recovery rates from the selected model fluctuated more widely than adult recovery rates although the temporal patterns of both were similar. Overall, in both the east and central groups, juvenile recovery rates were more than twice as high as adult rates. The differences in recovery rates among cohorts and regions are similar to those reported by Johnson (unpublished data) of direct recovery rates from 1980 to 1984 and by Wilkins (2005) from 1970 to 2003, although unlike the latter analysis, there was no effect of sex on recovery rates in the selected model from this dataset. Although there was not a strong effect of harvest season structure on recovery rates, there appeared to be a general trend in the time series: recovery rates appeared to decrease in years when the early season was closed and/or the regular season was restrictive (1968 and 1988–93; Figs. 4 and 5). This trend was more pronounced in recovery rates based on US recoveries only (Fig. 7). The low ranking of models containing effects of U.S. harvest season structure could be due to the contribution of harvest of blue-winged teal from countries south of the U.S. border, although models with recovery rates based on U.S. recoveries alone with harvest season effects also ranked lower. However, AIC selection of these models does not provide a definitive test of harvest season effects because (1) recovery rates are not corrected for reporting rates, and (2) lack of selection does not rule out the presence of relationships between covariates, it only reflects their strength relative to the selected model. A more direct evaluation of the relationship between harvest rates and season structure is provided in Chapter 3.

There were also regional differences in trends in annual recovery rates (Figs. 4, 5 and 7). A sharp spike in recovery rates in 1970 for adults and juveniles in the eastern group was not present in the recovery rates of U.S. only recoveries, suggesting that it was a result of increased recoveries in that year from

outside the US. Differences in group trends could be the result of differences in season structure among flyways; however, mixing of blue-winged teal from the 3 groups which occurs during migration made it difficult to assign flyway-specific harvest season effects to regions on the breeding grounds.

Table 2. Model selection results for Brownie dead recovery models (using all recoveries) containing age ( $a$ ), sex ( $s$ ), group (3 groups =  $3g$ , 2 groups =  $2g$ ), and/or year effects ( $t$ ), and models containing time ( $T$ ), early and regular harvest season structure, and both combined (earlyharv, regharv, bothharv) as additive effects on survival and recovery rates.

Model	QAICc	$\Delta$ QAICc	AICc Weights	Model Likelihood	No. of Param.	QDeviance
$s(a^* s^* t)f(a^* 3g^* t)$	383076.1	0.0	1	1	446	5928.7
$s(a^* s^* 3g)f(a^* 3g^* t)$	383219.8	143.7	0	0	282	6400.7
$s(a^* s^* 2g)f(a^* 3g^* t)$	383229.8	153.7	0	0	278	6418.7
$s(a^* s^* t)f(a^* s^* 3g^* t)$	383237.0	160.9	0	0	716	5549.1
$s(a^* s)f(a^* 3g^* t)$	383275.1	199.0	0	0	274	6472.0
$s(a^* s^* 3g)f(a^* s^* 3g^* t)$	383362.3	286.2	0	0	552	6002.8
$s(a^* s^* 2g)f(a^* s^* 3g^* t)$	383366.5	290.4	0	0	548	6015.0
$s(a^* s)f(a^* s^* 3g^* t)$	383369.6	293.5	0	0	544	6026.0
$s(a^* s^* 3g^* t)f(a^* s^* 3g^* t)$	383642.8	566.7	0	0	1068	5249.7
$s(a^* s^* 3g^* t)f(a^* 3g^* t)$	383786.4	710.3	0	0	798	5934.2
$s(a^* s^* 3g)f(a^* s^* 2g^* t)$	383786.6	710.5	0	0	372	6787.4
$s(a^* s^* t)f(a^* s^* 2g^* t)$	383789.2	713.1	0	0	536	6461.7
$s(a^* s^* 2g)f(a^* s^* 2g^* t)$	383857.2	781.1	0	0	368	6866.0
$s(a^* s)f(a^* s^* 2g^* t)$	383864.0	787.9	0	0	364	6880.8
$s(a^* s^* 3g^* t)f(a^* s^* 2g^* t)$	384246.0	1169.9	0	0	840	6309.8
$s(a^* s^* 3g)f(a^* s^* t)$	384547.1	1471.0	0	0	192	7908.1
$s(a^* s^* 2g)f(a^* s^* t)$	384615.6	1539.5	0	0	188	7984.5
$s(a^* s^* t)f(a^* s^* t)$	384641.5	1565.4	0	0	356	7674.2
$s(a^* s^* t)f(a^* t)$	384663.3	1587.2	0	0	266	7876.2
$s(a^* s^* 2g)f(a^* t)$	384668.3	1592.2	0	0	98	8217.2
$s(a^* s^* 3g)f(a^* t)$	384738.7	1662.6	0	0	102	8279.7
$s(a^* s^* t)f(a^* s^* t)$	384753.5	1677.4	0	0	356	7786.3
$s(a^* s)f(a^* s^* t)$	384759.2	1683.1	0	0	184	8136.1
$s(a^* s^* \text{earlyharv})f(a^* 3g^* \text{earlyharv})$	385691.6	2615.5	0	0	19	9398.6
$s(a^* s^* t)f(a^* 3g^* \text{earlyharv})$	385807.5	2731.4	0	0	190	9172.4
$s(a^* s^* t)f(a^* 3g^* T)$	386101.0	3024.9	0	0	155	9535.9
$s(a^* s^* \text{regharv})f(a^* 3g^* \text{regharv})$	386326.1	3250.0	0	0	19	10033.1
$s(a^* s^* \text{bothharv})f(a^* 3g^* \text{bothharv})$	386354.7	3278.6	0	0	19	10061.7
$s(a^* s^* T)f(a^* 3g^* T)$	386373.0	3296.9	0	0	19	10080.0
$s(a^* s^* t)f(a^* 3g^* \text{regharv})$	386544.9	3468.8	0	0	154	9981.8
$s(a^* s^* t)f(a^* 3g^* \text{bothharv})$	386617.2	3541.1	0	0	165	10032.2
$s(a^* s^* T)f(a^* 3g^* t)$	386744.0	3667.9	0	0	232	10024.9

Table 3. Model selection results for Brownie dead recovery models (using only US recoveries) containing age ( $a$ ), sex ( $s$ ), and/or year effects ( $t$ ), and models containing time ( $T$ ) and early, regular, and both harvest season structure (earlyharv, regharv, and bothharv) as additive effects on survival and recovery rates.

Model	QAICc	$\Delta$ QAICc	AICc Weights	Model Likelihood	No. of Param.	QDeviance
$s(a*s*t)f(a*t)$	240159.5	0	1	1	266	2106.4
$s(a*s*t)f(a*s*t)$	240269	109.5	0	0	356	2035.8
$s(a*s*earlyharv)f(a*s*earlyharv)$	242474.3	2314.7	0	0	16	4921.2
$s(a*s*earlyharv)f(a*earlyharv)$	242925.2	2765.7	0	0	12	5380.2
$s(a*s*t)f(a*earlyharv)$	243581.4	3421.8	0	0	158	5744.3
$s(a*s*t)f(a*regharv)$	244120.4	3960.9	0	0	16	6567.4
$s(a*s*regharv)f(a*s*regharv)$	244191.3	4031.7	0	0	159	6352.2
$s(a*s*t)f(a*bothharv)$	244218.5	4058.9	0	0	16	6665.4
$s(a*s*bothharv)f(a*s*bothharv)$	244243.8	4084.3	0	0	160	6402.7
$s(a*s*regharv)f(a*regharv)$	244662.9	4503.4	0	0	12	7117.9
$s(a*s*regharv)f(a*s*regharv)$	244728.2	4568.7	0	0	16	7175.2
$s(a*s*bothharv)f(a*bothharv)$	244764.4	4604.8	0	0	12	7219.3
$s(a*s*T)f(a*T)$	245091.5	4931.9	0	0	12	7546.4

Table 4. Range of survival and recovery rates during the period 1965–2009 by cohort from the selected Brownie model  $s(a*s*t)f(a*3g*t)$ .

Survival rates:	Cohort			
	Adult males	Adult females	Juvenile males	Juvenile females
All groups	0.5–0.85	0.31–0.77	0.29–0.68	0.28–0.72
Recovery rates:	Adults		Juveniles	
West	0.003–0.024		0.003–0.026	
Central	0.003–0.032		0.006–0.062	
East	0.006–0.035		0.015–0.074	



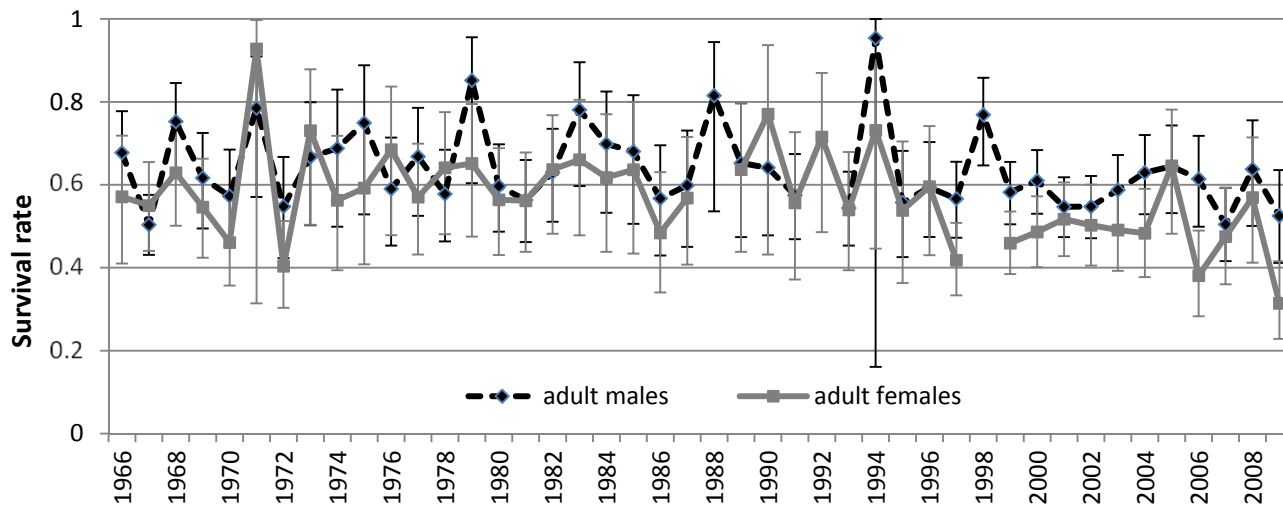


Fig. 2. Blue-winged teal survival rates (with 95% confidence intervals) for adult males and females from the selected model  $s(a*s*t)f(a*3g*t)$ . Missing values indicate years for which rates were inestimable.

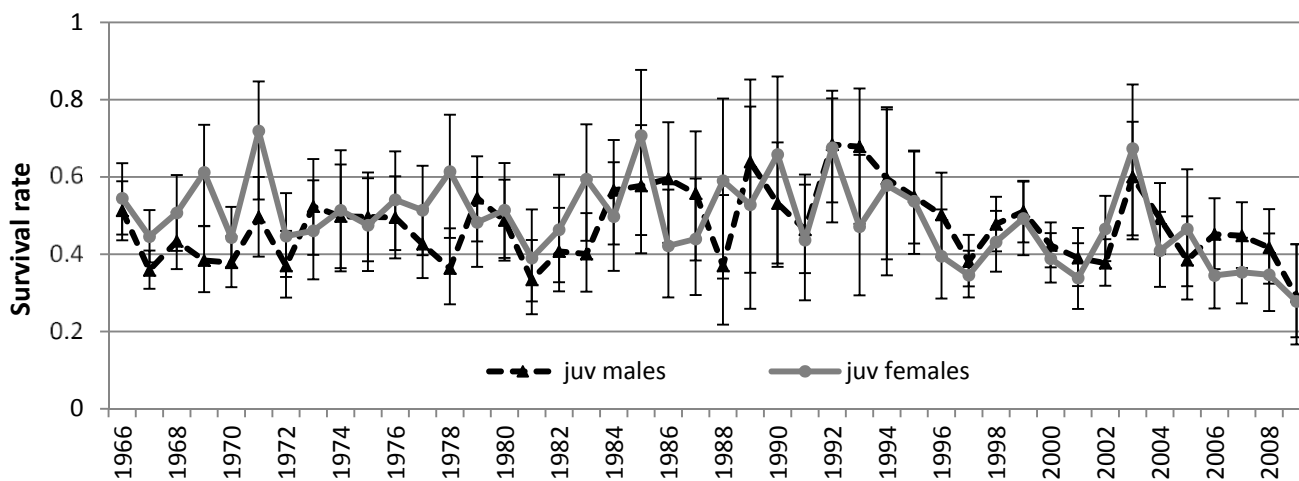


Fig. 3. Blue-winged teal survival rates (with 95% confidence intervals) for juvenile males and females from the selected model  $s(a*s*t)f(a*3g*t)$ .

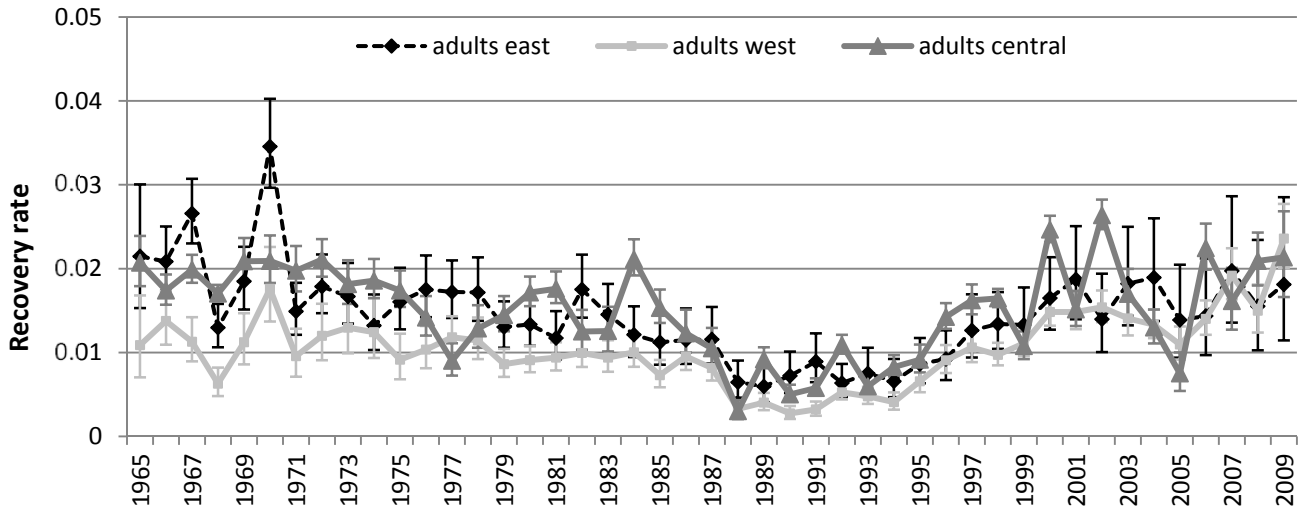


Fig. 4. Blue-winged teal recovery rates (with 95% confidence intervals) for adults by group from the selected model  $s(a*s*t)f(a*3g*t)$ .

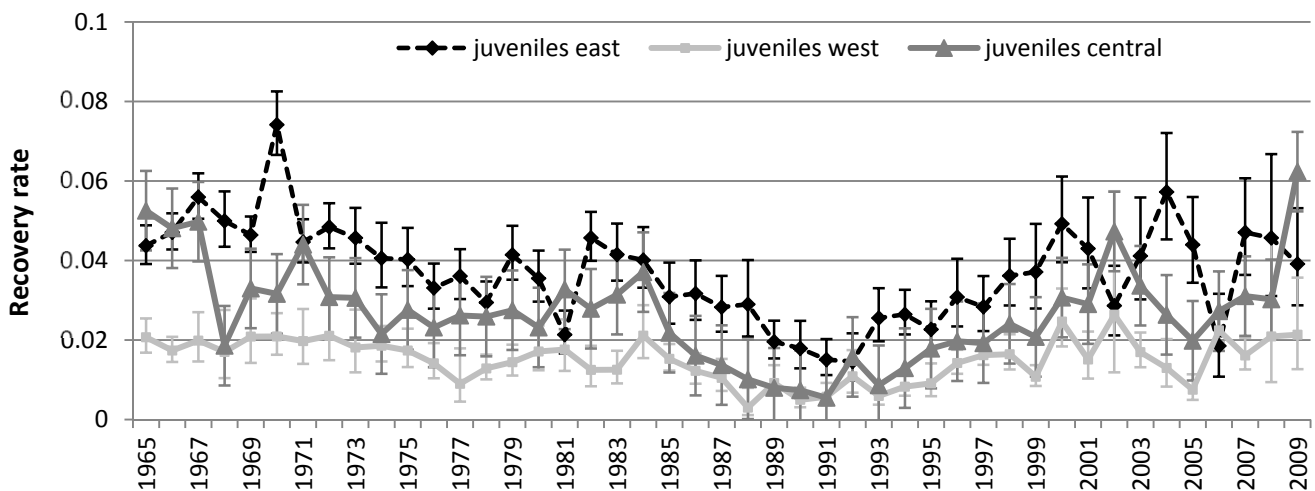


Fig. 5. Blue-winged teal recovery rates (with 95% confidence intervals) for juveniles by group from the selected model  $s(a*s*t)f(a*3g*t)$ .

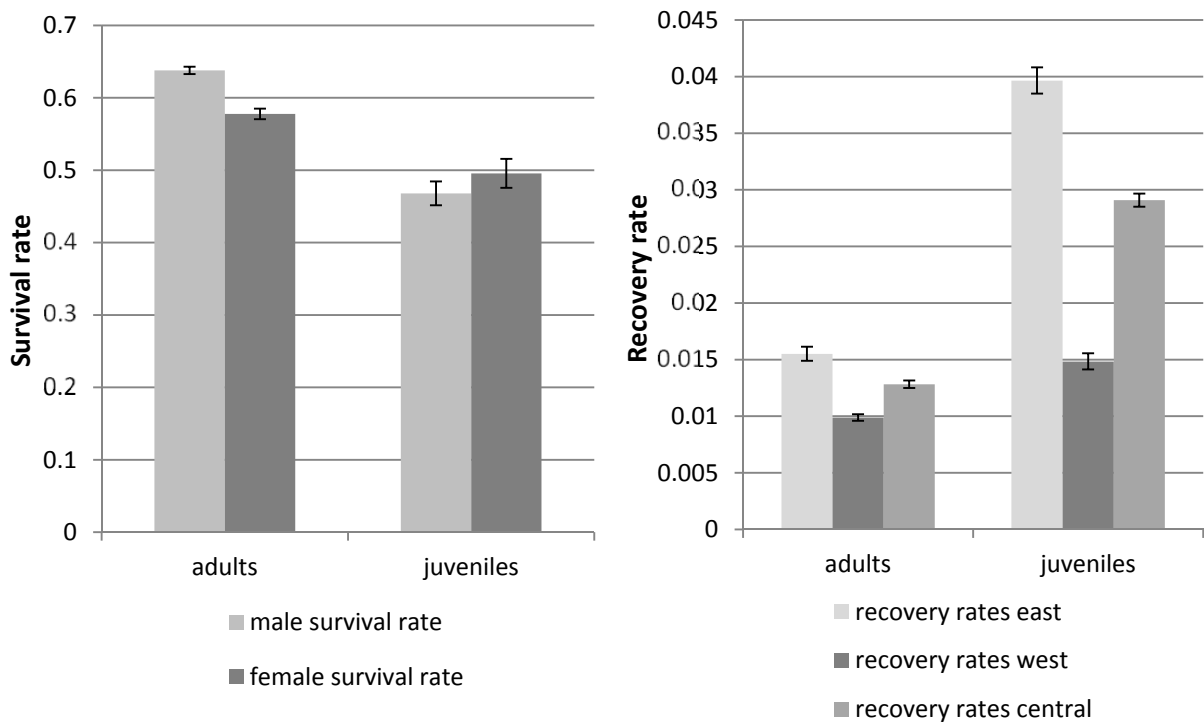


Fig. 6. Overall (all years combined) blue-winged teal survival and recovery rates from the model  $s(a*s)f(a*3g)$ .

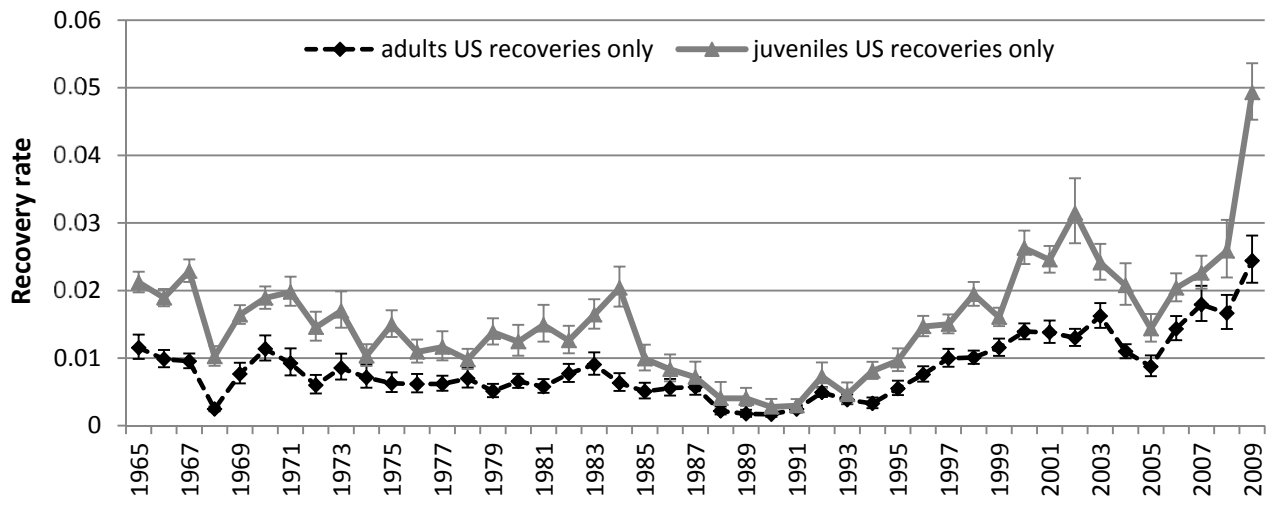


Fig. 7. Recovery rates for adults and juveniles (with 95% confidence intervals) from Brownie model  $s(a*s*t)f(a*t)$  using U.S. recoveries only.

## Survival Estimates and Recovery Rates (continued)

Survival and Recovery Rate Analysis of Green-winged Teal, 1970–2008

*Dave Olson, USFWS*

### **Background**

In July 2009 the SRC directed the Division of Migratory Bird Management and the Flyways to assemble a teal assessment group to assess the harvest potential of the 3 North American teal species. This report deals with the charges assigned to the assessment team for green-winged teal and pertains to:

1. Description of the population dynamics of green-winged teal.
2. Derivation and distribution of the harvest for green-winged teal.
3. Assessment of the impacts of incremental regulatory change on harvest, particularly with regard to special seasons for green-winged teal.

The distribution of green-winged teal recoveries were analyzed using multi-response permutation procedures (MRPP; Biondini et al. 1988, Zimmerman et al. 1985) in combination with a clustering routine (Romesburg 1990), which delineated 3 primary banding reference areas for the species: East Coast which covered the Atlantic Flyway, Mid-continent which covers the combined Mississippi and Central Flyways, and West Coast which covers the Pacific Flyway. Both group-specific and pooled analyses were conducted to estimate survival and recovery rates.

### **Methods**

The goals of this analysis were: (1) calculate updated survival and recovery rate estimates for green-winged teal in North America; and (2) determine if survival and recovery rates varied by age, sex, and banding region.

Banding and recovery data were obtained from the U.S. Geological Survey (USGS) Bird Banding Laboratory for green-winged teal. Banding records were selected for normal, wild, green-winged teal banded pre-season (July, August, and September) in Canada and the U.S. (above latitude 37) from 1970 to 2008. Recovery records were from green-winged teal shot or found dead during the hunting season (September – March) from 1970 to 2008. A total of 204,134 banding records and 16,245 recovery records were available for this 39-year period.

Records were grouped according to age, sex, and banding region resulting in 12 groups (Table 1). Forty-one percent of the bandings occurred in the eastern reference area while the mid-continent and western reference areas were close to being equally divided with 29% and 30% of the bandings, respectively. Juvenile males were banded more frequently in the eastern and mid-continent reference areas while adult males were banded more frequently in the western reference area. Adult females were banded the least in all reference areas. Recovery records indicated 49% of all recoveries occurred

in the eastern reference area while 28% and 22% occurred in the mid-continent and western reference areas, respectively. Juvenile males were the most recovered while adult females were the least.

Table 1. Summary by group of banding and recovery data used in survival rate analysis of green-winged teal, 1970–2008.

Bandings	East Coast	Mid-continent	West Coast	TOTAL
Adult Male	17,601	15,325	21,010	53,936
Adult Female	10,910	8,243	8,895	28,048
Juvenile Male	30,632	20,962	17,517	69,111
Juvenile Female	24,053	15,488	13,498	53,039
TOTAL	83,196	60,018	60,920	204,134
% of Continental Total	41%	29%	30%	

Recoveries	East Coast	Mid-continent	West Coast	TOTAL
Adult Male	1,699	1,195	1,407	4,301
Adult Female	817	436	402	1,655
Juvenile Male	3,421	2,001	1,263	6,685
Juvenile Female	2,070	955	579	3,604
TOTAL	8,007	4,587	3,651	16,245
% of Continental Total	49%	28%	22%	8%

Data were analyzed using the Brownie model in program MARK (White and Burnham 1999). Model parameters were defined as follows:

$S_{i,t}$  = probability a banded bird of group  $i$  survives from time  $t$  to  $t+1$

$f_{i,t}$  = probability a banded bird of group  $i$  is shot, recovered, and reported at during the hunting season at time  $t$

Survival rate was modeled as a function of age and sex or age, sex, and banding region. Most recovery rates were year specific. I used a one-way ANOVA to test for differences of survival estimates among the different harvest regulations packages. Survival rates were summarized by the following harvest regulations package: LIBERAL, MODERATE, RESTRICTED, CLOSED, and BONUS SEASONS.

## Results

*Model selection.*—The most parameterized model could not be fit to the data due to convergence issues. This was most likely due to sparse banding and recovery data when analyzed at fine scales. As a result of convergence issues I could not use the suite of tools available in MARK to determine how well the data fit other models. However, the highest ranked model was used to look at survival and recovery estimates for green-winged teal across North America. The model that ranked highest contained 380 parameters (Table 2).

Table 2. Model selection results for Brownie dead-bird recovery models (using all recoveries) containing age ( $a$ ), sex ( $s$ ), group ( $g$ , EC<sup>a</sup>, MCWC<sup>b</sup>), and year effects ( $t$ ), from analysis of green-winged teal banded in Canada and the U.S., 1970–2008.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
$S(a*s*t) f(a*g*t)$	152621.6049	0	0.99546	1	380	4268.6177
$S(EC s*t* MCWC s*t) f(EC s*t*MCWC s*t)$	152632.3863	10.7814	0.00454	0.0046	308	4423.8943
$S(EC a*s*t*MCWC a*s*t) -$ $f(EC a*s*t* MCWC a*s*t)$	152965.1838	343.5789	0	0	595	4180.1289
$S(EC* MCWC a*t) f(EC*MCWC a*t)$	153011.3263	389.7214	0	0	308	4802.8286
$S(EC* MCWC *t) f(EC*MCWC*t)$	153110.2147	488.6098	0	0	154	5210.4156
$S(t) f(a*s*t)$	153175.532	553.9271	0	0	194	5195.6023
$S(a*s*g) f(t)$	153205.0461	583.4412	0	0	51	5511.4596
$S(a*s*t) f(t)$	153329.6883	708.0834	0	0	185	5367.7912
$S(a*s*g*t) f(t)$	153536.2119	914.607	0	0	467	5008.5004
$S(t) f(t)$	153650.209	1028.6041	0	0	77	5904.5868
$S(a*s*g) f(a*s*g)$	154010.0359	1388.431	0	0	24	6370.4647
$S(EC a*s* MCWC a*s) f(EC a*s*MCWC a*s)$	154155.0527	1533.4478	0	0	16	6531.4866
$S(a*s) f(g*a*s)$	154158.7327	1537.1278	0	0	16	6535.1651
$S(s) f(g)$	154243.1527	1621.5478	0	0	16	6619.5875
$S(g*s) f(g*a*s)$	154260.3521	1638.7472	0	0	14	6640.7878
$S(a) f(g)$	154275.7927	1654.1878	0	0	16	6652.2258
$S(a*s) f(a*g)$	154313.3811	1691.7762	0	0	10	6701.8173
$S(a*s) f(a*s)$	154908.5207	2286.9158	0	0	8	7300.9633
$S(EC* MCWC) f(EC*MCWC)$	154929.4402	2307.8353	0	0	4	7329.8823
$S(a*s*g) f(.)$	155072.4618	2450.8569	0	0	13	7454.9041
$S(s) f(s)$	155098.2902	2476.6853	0	0	4	7498.7264
$S(t) f(.)$	155122.1253	2500.5204	0	0	39	7452.5484
$S(a) f(a)$	155485.7502	2864.1453	0	0	4	7886.189
$S(EC* MCWC) f(.)$	155637.0901	3015.4852	0	0	3	8039.5252
$S(.) f(.)$	155655.4201	3033.8152	0	0	2	8059.8572

<sup>a</sup> East Coast reference area.

<sup>b</sup> Mid-continent and West Coast reference areas combined.

Survival was dependent on age, sex, and time (i.e., no area effect) while recovery estimates were dependent on age, group, and time (i.e., no sex effect). The second model which differed by 10 AIC units from the highest ranked model contained a group effect (2 groups: eastern and mid-continent/western combined) on survival and recovery estimates in addition to sex and time.

*Survival rates.*—Adults had greater survival estimates than juveniles and males had higher survival estimates than females (Table 3). Survival rates ranged from 0.58 for AHY males to 0.41 for HY females (Fig. 1). Survival rates over time varied from 0.22 for AHY females to 1.00 for AHY males, HY males, and AHY females (Fig. 2). Survival rates of 1.00 are not realistic and are an artifact of poor sample sizes in years per regions. There were no statistically significant differences among sexes in survival estimates.

Table 3. Survival rates (with standard errors) for green-winged teal banded in Canada and the U.S. 1970–2008 by time from model  $S(a*s)f(a*s)$  in MARK.

	Adults		Juveniles	
	Males	Females	Males	Females
Survival rate	0.58	0.50	0.52	0.41
Standard error	0.09	0.11	0.06	0.07

*Recovery rates.*—Recovery estimates were highest for juveniles and lowest for adults and were higher for the eastern reference area and lowest in the western reference area (Table 4 and Fig. 3). The estimates ranged from 0.052 for HY males in the eastern area to 0.028 for AHY females in the western area (Table 4). Generally, adult recovery rate estimates over time were highest in the eastern area until 1996 when either mid-continent or western reference area estimates were greater (Fig. 4). Also, juvenile western area recovery rate estimates were greater than eastern and mid-continent area estimates in 2004, 2006 and 2007 (Fig. 5). Recovery estimates were at their lowest from 1989 to 1994, which coincides with the closure of teal seasons (1988–1991) in the U.S.

Table 4. Recovery rates (with standard errors) for green-winged teal banded in Canada and the U.S. 1970–2008 by time from model  $S(a*s)f(a*s)$  in MARK.

	Adults			Juveniles		
	East Coast	Mid-continent	West Coast	East Coast	Mid-continent	West Coast
Recovery rate	0.040	0.033	0.028	0.052	0.043	0.032
Standard error	0.007	0.006	0.005	0.001	0.005	0.005

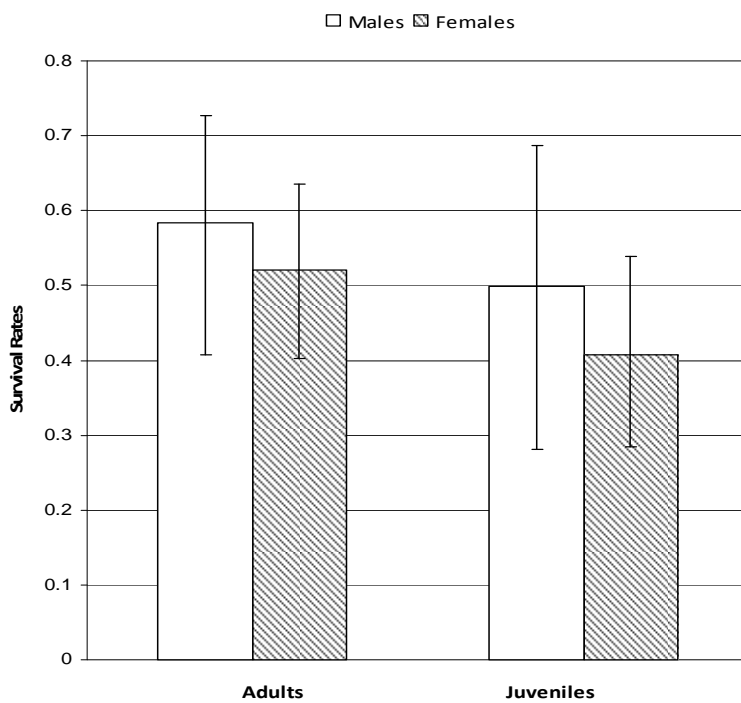


Fig. 1. Survival rates (with 95% confidence intervals) of green-winged teal banded in Canada and the U.S. 1970–2008 by age and sex from model  $S(a^*s)f(a^*s)$  in MARK.

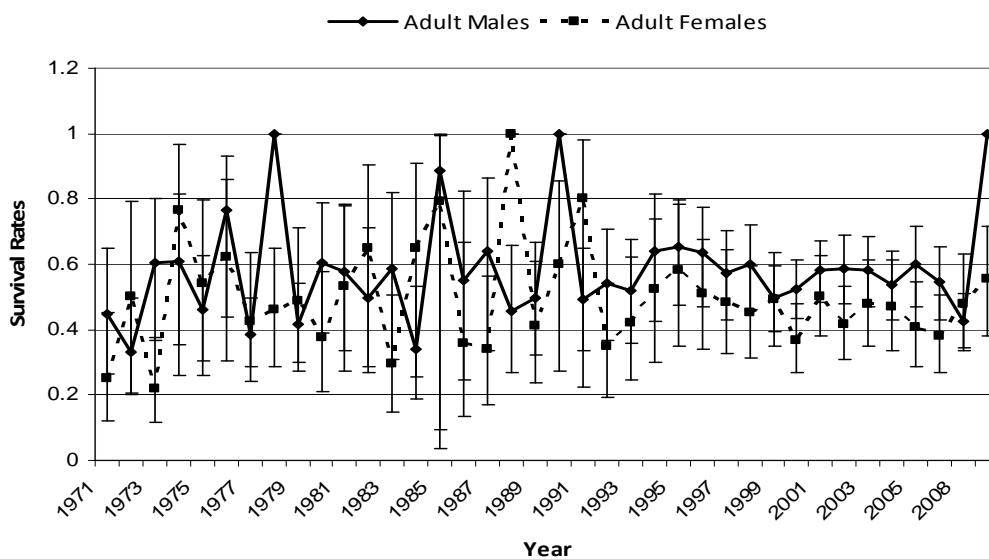


Fig. 2. Survival rates (with 95% confidence intervals) of adult male and female green-winged teal banded in Canada and the U.S. 1970–2008 by time from model  $S(a^*s^*t)f(a^*g^*t)$  in MARK.



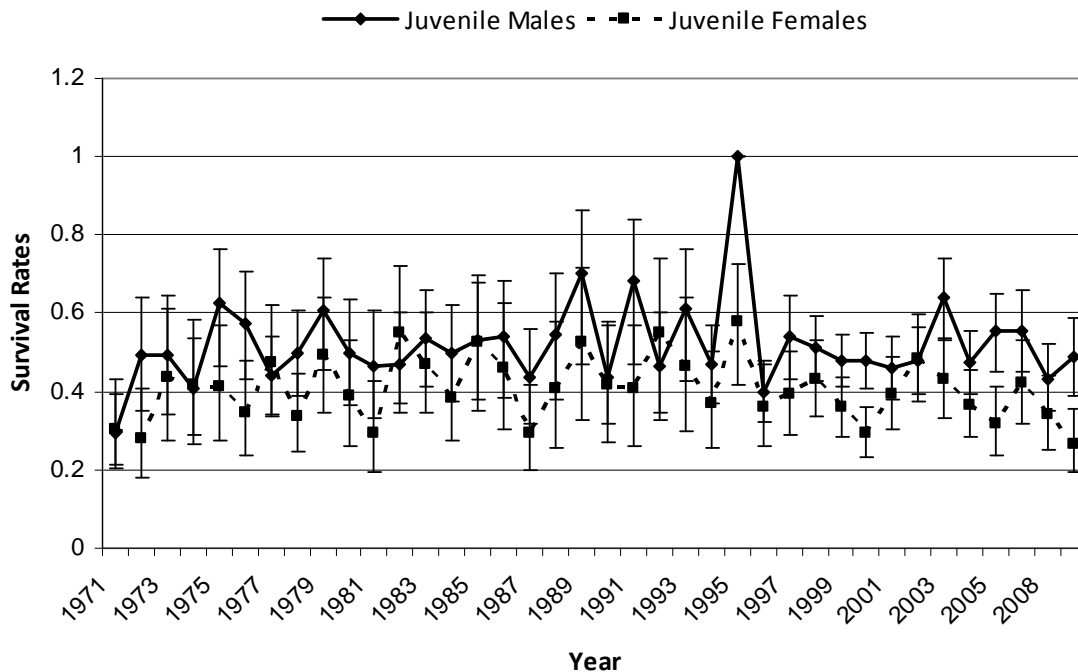


Fig. 3. Survival rates (with 95% confidence intervals) of juvenile male and female green-winged teal banded in Canada and the U.S. 1970–2008 by time from model  $S(a*s*t) f(a*g*t)$  in MARK.

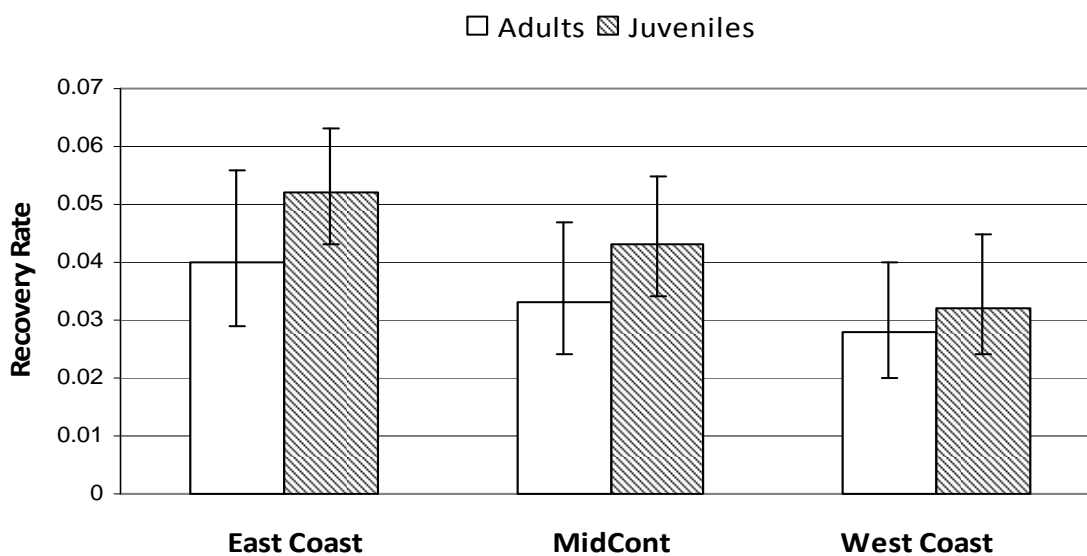


Fig. 4. Recovery rates (with 95% confidence intervals) of green-winged teal banded in Canada and the U.S. 1970–2008 by age and group from model  $S(a*s*g) f(a*s*g)$  in MARK.

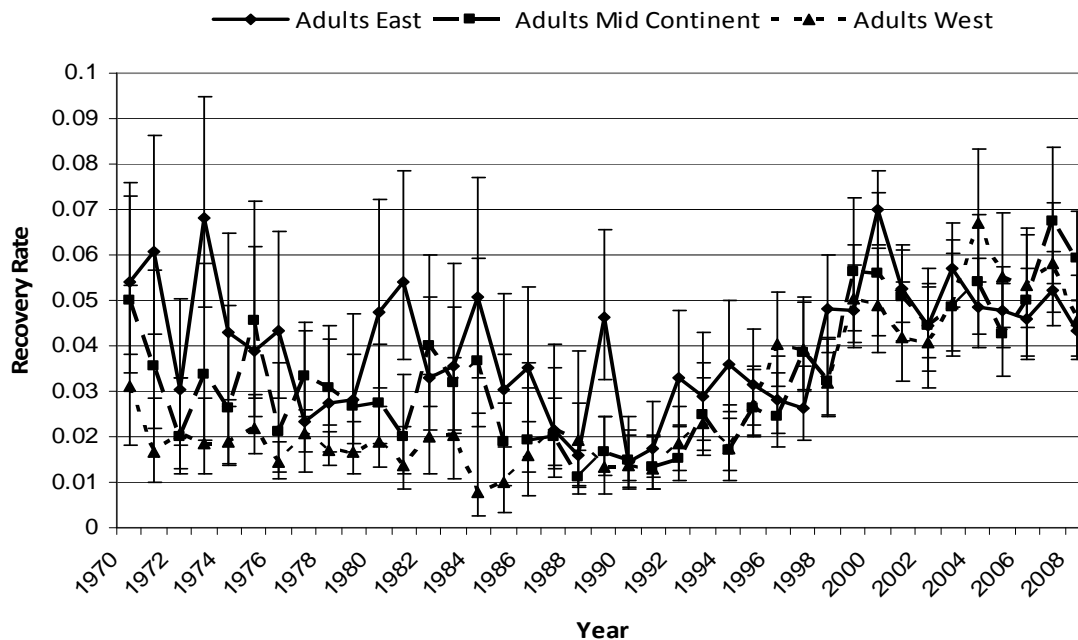


Fig. 5. Recovery rates (with 95% confidence intervals) of green-winged teal banded in Canada and the U.S. 1970–2008 by time from model  $S(a^*s^*t)f(a^*g^*t)$  in MARK.

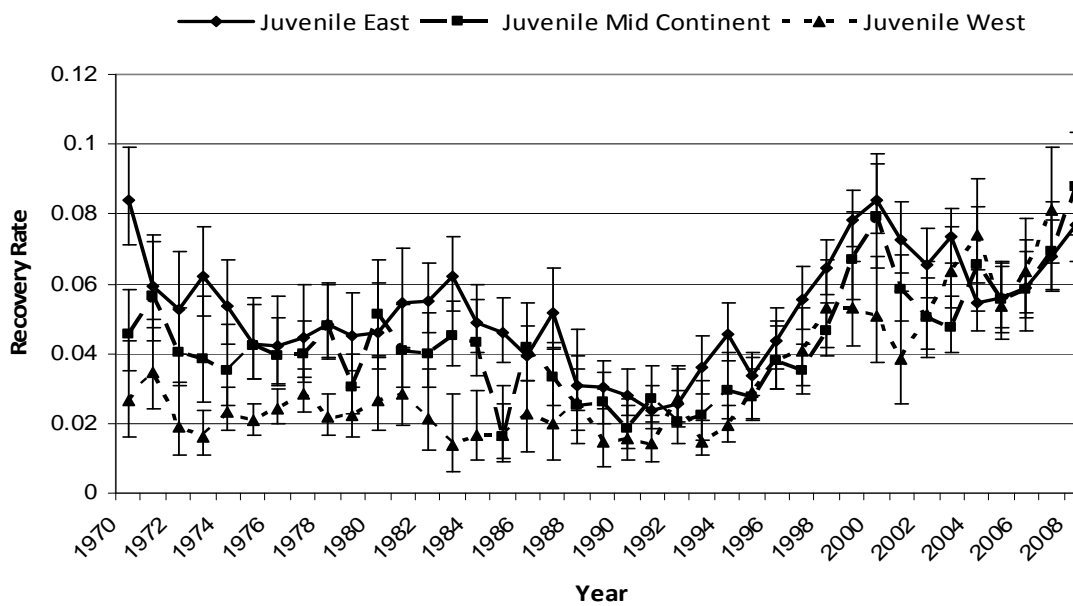


Fig. 6. Recovery rates (with 95% confidence intervals) of juvenile green-winged teal banded in Canada and the U.S. 1970–2008 by time from model  $S(a^*s^*t)f(a^*g^*t)$  in MARK.

*Survival estimates and harvest regulations packages.*—Each green-winged teal banding reference area has an average survival rate for each harvest regulation package (Table 5). The number in parentheses is the number of years over which a specific regulation package has been enacted. There were no bonus teal seasons for the western area. There was a significant difference ( $P = 0.034$ ) in survival estimates between the LIBERAL and MODERATE harvest categories. All other combinations were not significant. There were no significant differences between the areas' average survival rates and the survival rate for each harvest category.

Table 5. Green-winged teal survival estimates for each harvest regulation category for birds banded during 1970–2008 and subsequently recovered.

Average survival	Liberal	Moderate	Restrictive	Closed	Bonus-Yes	Bonus-No
East (0.445)	na	0.469 (13)	0.441 (13)	0.424 (12)	0.420 (9)	0.453 (29)
MC (0.519)	0.621 (7)	0.501 (27)	na	0.463 (4)	0.556 (20)	0.481 (17)
West (0.548)	0.553 (28)	0.534 (4)	0.531 (6)	na	na	na

### **Discussion**

Survival rates varied but were similar to those reported in the literature (Chu et al. 1995). Variability in the survival rates for green-winged teal from 1971 to 1996 was evident with extreme peaks and valleys in the graphs for all sexes except for juvenile females. Unfortunately because a fully parameterized model could not be calculated, we could not determine how well the data fit the models.

There was a consistent pattern in recovery rate estimates across banding regions and by age. Recovery rates were higher in the eastern reference area and then mid-continent and finally in the western area. A similar pattern occurred with age classes, wherein recovery rate estimates were greater for juveniles than adults. Recovery rates for both adults and juveniles over time were greater in the eastern area than those in the mid-continent and western areas from 1970 to 2003 in most years, but by 2004, rates for mid-continent and western areas were greater than those in the eastern area.

The data suggest that harvest pressure on green-winged teal varies from east to west across North America, as evidenced by significantly different average recovery rates. However, that differential harvest pressure did not translate into differential survival rates across the landscape. Thus, based only on survival rates, these results suggest data from across all banding areas could be pooled for population modeling purposes. However, the difference in harvest pressure should be taken into account when developing harvest strategies.

## **Survival Estimates and Recovery Rates (continued)**

Cinnamon Teal Survival and Recovery Analysis, 1965–2010

*Kathy Fleming, Tom Aldrich, and Shaun Oldenburger*

### ***Introduction***

Of the three North American teal species, cinnamon teal are the least widely distributed, and much less is known of their population dynamics than blue- or green-winged teal. Although cinnamon teal have been banded at moderate levels in the Pacific Flyway, difficulty in distinguishing juvenile and female cinnamon teal from blue-winged teal, and overlap in their distributions, has complicated the analysis of banding and recovery data, due to many banders identifying birds only as “unidentified teal.” We conducted an analysis of cinnamon teal (including unidentified teal) band recovery data from 1965 to 2010 in order to estimate survival and recovery rates, and determine if these varied by age, sex, species designation (either cinnamon or unidentified teal), year, or with the history of harvest regulations in the Pacific Flyway.

### ***Methods***

We used bandings and recoveries of cinnamon teal (CITE) and unidentified teal (UNTE) from the Pacific Flyway, including bandings from Alberta, British Columbia, and Colorado west of longitude -105. From these records we selected all normal, wild birds banded pre-season (July–August), and all recoveries of birds found dead or shot (Table 1, Fig. 1). We fit Brownie dead recovery models in program MARK (White and Burnham 1999) and compared a set of candidate models with survival and/or recovery rates varying by age, time, species designation (either cinnamon or unidentified teal) or, in additive models, fit to a linear time trend, or an index representing the history of the Pacific flyway harvest regulations package. This index consisted of the number of days in the regular duck season multiplied by the bag limit for each year in the Pacific Flyway from 1965 to 2010. Number of season days varied from 59 to 107 during this period, and the bag limit varied from 3 to 7 birds (K. Kruse, unpublished data); the resulting index varied from 236 to 749, but was standardized before using in the models to mean = 0 and standard deviation = 1. All additive models included interaction terms. In most cases models converged using the sine link function with simulated annealing to provide initial parameter estimates. We estimated median  $\hat{c}$  of the full model as a measure of fit, and compared candidate models using QAIC<sub>c</sub> (AIC corrected for overdispersion and small sample size; Cooch and White 2010, Burnham and Anderson 1988).

Table 1. Number of bands and recoveries by cohort and species designation used in the cinnamon teal survival and recovery analysis.

Cinnamon teal	Bands	Recoveries
Adult male	2,676	116
Juvenile male	4,865	287
Adult female	1,278	64
Juvenile female	4,131	205
Unidentified teal	Bands	Recoveries
Adult male	1,970	53
Juvenile male	10,946	282
Adult female	2,580	75
Juvenile female	9,394	204

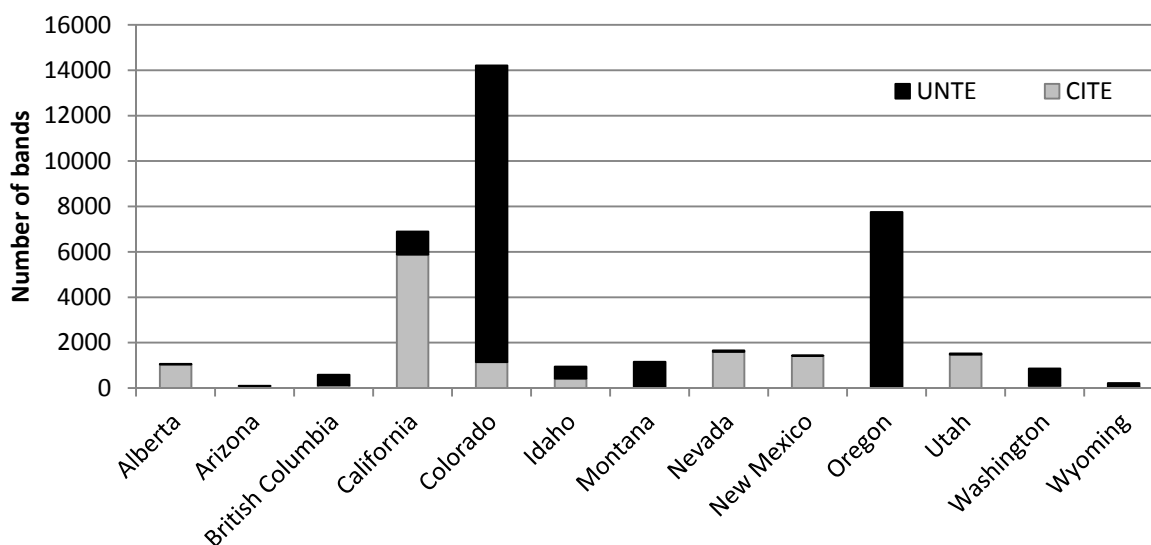


Fig. 1. Distribution of bands between cinnamon teal (gray bars) and unidentified teal (black bars) in the Pacific Flyway, Alberta, British Columbia, and Colorado west of -105 longitude.

### Results and Discussion

Although we were able to fit the full model (survival and recovery rates varying by year, sex, age, and species designation), many of the survival parameters in the model were not estimated due to the small sample of bands and recoveries in some years, and we were unable to assess goodness of fit. Therefore, we chose a reduced additive model as the “full” model:  $s(\text{age} \times \text{sex} \times \text{species} \times \text{Time}) - f(\text{age} \times \text{sex} \times \text{species} \times \text{time})$ , where survival parameters varied by age, sex, species designation, and as a linear function of time (years), and recovery parameters varied by age, sex, species, and by year (one estimate for each year; Table 2). Median  $c\text{-hat}$  for this model was 1.367, indicating this model fit the data fairly well (Cooch and White 2010). For QAIC<sub>c</sub> comparison, we limited the set of candidate models

to those that were reduced from this model (i.e., we did not consider any models with survival parameters estimated annually; Table 2). The highest ranking model was the additive model with survival rates as a function of age, sex, species designation, fit to a linear time trend (big T), and recovery rates by age, sex, and species designation, fit as a linear function of the number of regular season days\*bag (Table 2). However, the QAIC<sub>c</sub> weight for this model was only 0.5882. The second highest ranking model (with model weight 0.4118) was the additive model with both survival and recovery rates as a function of age, sex, and species designation, fit as a linear function of the number of regular season days\*bag (Table 2). Because these two models had nearly equal support, we used the model weights to calculate model-averaged parameters and their associated variances (Burnham and Anderson 1998). No other models in the candidate set had Akaike weights >0, so we did not consider other models for model averaging.

Survival rates for cinnamon teal were generally highest for juvenile males, followed by adult females, adult males, and juvenile females, although there was an interaction between cohort and the effect of the regulations package: adult female survival rates did not appear to vary with the regulations package to the same degree as the other cohorts (Table 3, Fig. 2). For unidentified teal, survival rates were also appeared to be strongly related to harvest regulations, but survival was higher for adult males than the juvenile cohorts. However, the wide confidence intervals around the estimates made it difficult to make inferences about the strength of the age, sex, species, or time effects on model parameters.

Recovery rates appeared to be related to the time series of harvest regulations, although for unidentified teal there was an interaction between sex and age for juvenile males, whose recovery rates were higher than the other cohorts during more restrictive seasons, and lower during more liberal periods (Figs. 3 and 4). In general, juvenile recovery rates were higher than adults, especially for cinnamon teal. The difference in recovery rates among cohorts was more pronounced in years with a relatively liberal regulations package (1975–1983, 1997–2010; Figs. 3 and 4). However, as with survival rates, the confidence intervals around recovery rates overlapped cohort and species differences.

In both high-ranking models, only 4 out of 32 beta coefficients were significantly different from zero: the effect of sex on survival, the effect of species designation on recovery rates, and both survival and recovery intercepts. The species designation should not be interpreted as solely a species effect (i.e. birds more likely to be blue-winged teal), because whether a bird was identified as cinnamon teal or unidentified was often due more to the banding protocol where the bird was banded than characteristics of the bird itself (Fig. 1). However, birds banded in areas where they are more often designated unidentified teal could have different recovery probabilities, due to regional differences in harvest pressure.

The small sample of bandings and recoveries in some years made it difficult to estimate annual survival and recovery rates, or even linear trends. Therefore, in addition to the model-averaged parameter estimates from the selected models, we also estimated overall survival and recovery rates using parameter estimates from the highest ranking model without a time effect:  $s(\text{sex}*\text{species})$   $f(\text{sex}*\text{species})$  (Table 2, Fig. 5). Male survival rates were higher than females, although the difference was not significant. Recovery rates were significantly higher for cinnamon teal than unidentified teal

(Fig. 5), but like survival rates, there was no difference between the sexes in recovery rates. The difference in recovery rates between cinnamon (most of which are banded in California, New Mexico, Nevada, and Utah) and unidentified teal (banded mostly in Colorado and Oregon) could be partly due to a difference in exposure to harvest between birds moving through the two regions.

Table 2. Model selection results of Brownie dead recovery models for cinnamon and unidentified teal containing age ( $a$ ), sex ( $s$ ), species designation ( $sp$ ), and time effects (both annually,  $t$ , and as a linear function of year,  $T$ ) on survival ( $s$ ) and recovery rates ( $f$ ), and additive models with the history of the regulations package in the Pacific Flyway ( $daysbag$ ).

Model	QAIC <sub>c</sub>	ΔQAIC <sub>c</sub>	AICc weights	Model likelihood	Number of Parameters	QDeviance
$s(a*s*sp*T) f(a*s*sp*daysbag)$	9107.58	0.00	0.58824	1	32	1203.46
$s(a*s*sp*daysbag) f(a*s*sp*daysbag)$	9108.29	0.71	0.41176	0.7	32	1204.17
$s(a*s*sp) f(a*t)$	9136.17	28.59	0	0	100	1095.57
$s(a*s*sp*daysbag) f(a*s*sp*daysbag)$	9142.01	34.43	0	0	28	1245.90
$s(a*s*sp*T) f(a*s*sp*T)$	9151.28	43.71	0	0	30	1251.17
$s(a*s*sp) f(a*sp*t)$	9158.03	50.45	0	0	192	931.99
$s(s*sp) f(s*sp)$	9167.98	60.41	0	0	8	1311.91
$s(a*sp) f(a*sp)$	9168.92	61.34	0	0	8	1312.85
$s(a*s*sp) f(a*s*sp)$	9169.06	61.48	0	0	16	1296.98
$s(a*s*sp*T) f(a*s*sp*t)$	9179.01	71.44	0	0	208	920.64
$s(a*s*T) f(a*s*T)$	9201.54	93.96	0	0	14	1333.46
$s(a*s*T) f(a*s*daysbag)$	9218.84	111.27	0	0	14	1350.77
$s(a*s) f(a*s)$	9238.03	130.45	0	0	8	1381.96
$s(a*s*sp) f(a*s*t)$	9242.82	135.24	0	0	192	1016.78
$s(a*s*sp) f(a*s*sp*t)$	9384.40	276.82	0	0	376	784.76

Table 3. Model-averaged parameter ranges by cohort and species designation (CITE = cinnamon teal, UNTE = unidentified teal).

Cohort	Survival rates		Recovery rates	
	CITE	UNTE	CITE	UNTE
Adult males	0.49 - 0.58	0.52 - 0.59	0.009 - 0.020	0.005 - 0.015
Adult females	0.58 - 0.59	0.46 - 0.59	0.007 - 0.021	0.007 - 0.015
Juvenile males	0.58 - 0.82	0.35 - 0.55	0.013 - 0.028	0.008 - 0.010
Juvenile females	0.30 - 0.63	0.28 - 0.38	0.010 - 0.034	0.006 - 0.013

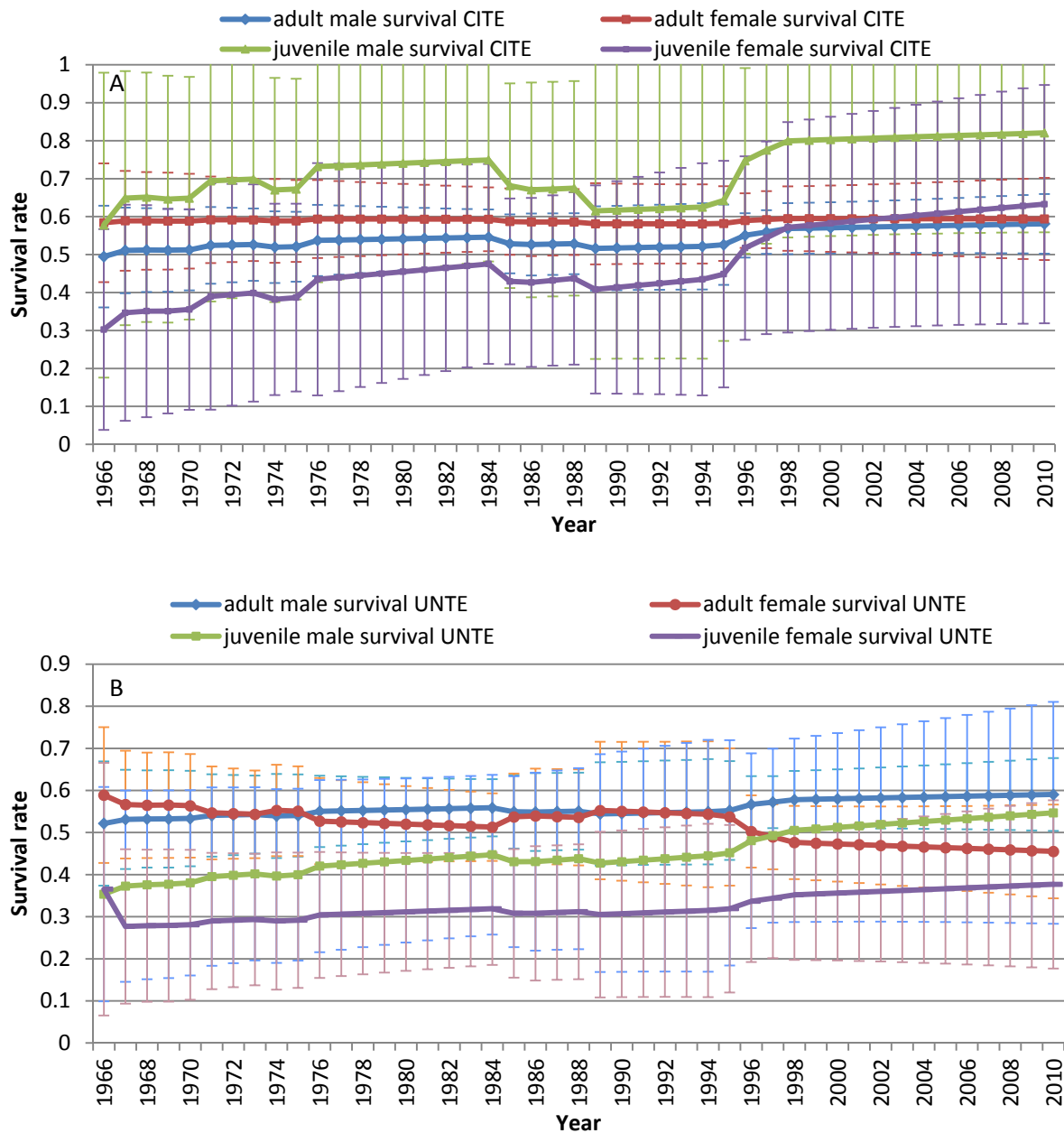


Fig. 2. Cinnamon teal (A) and unidentified teal (B) model-averaged survival rates by cohort and species designation, with 95% confidence intervals.



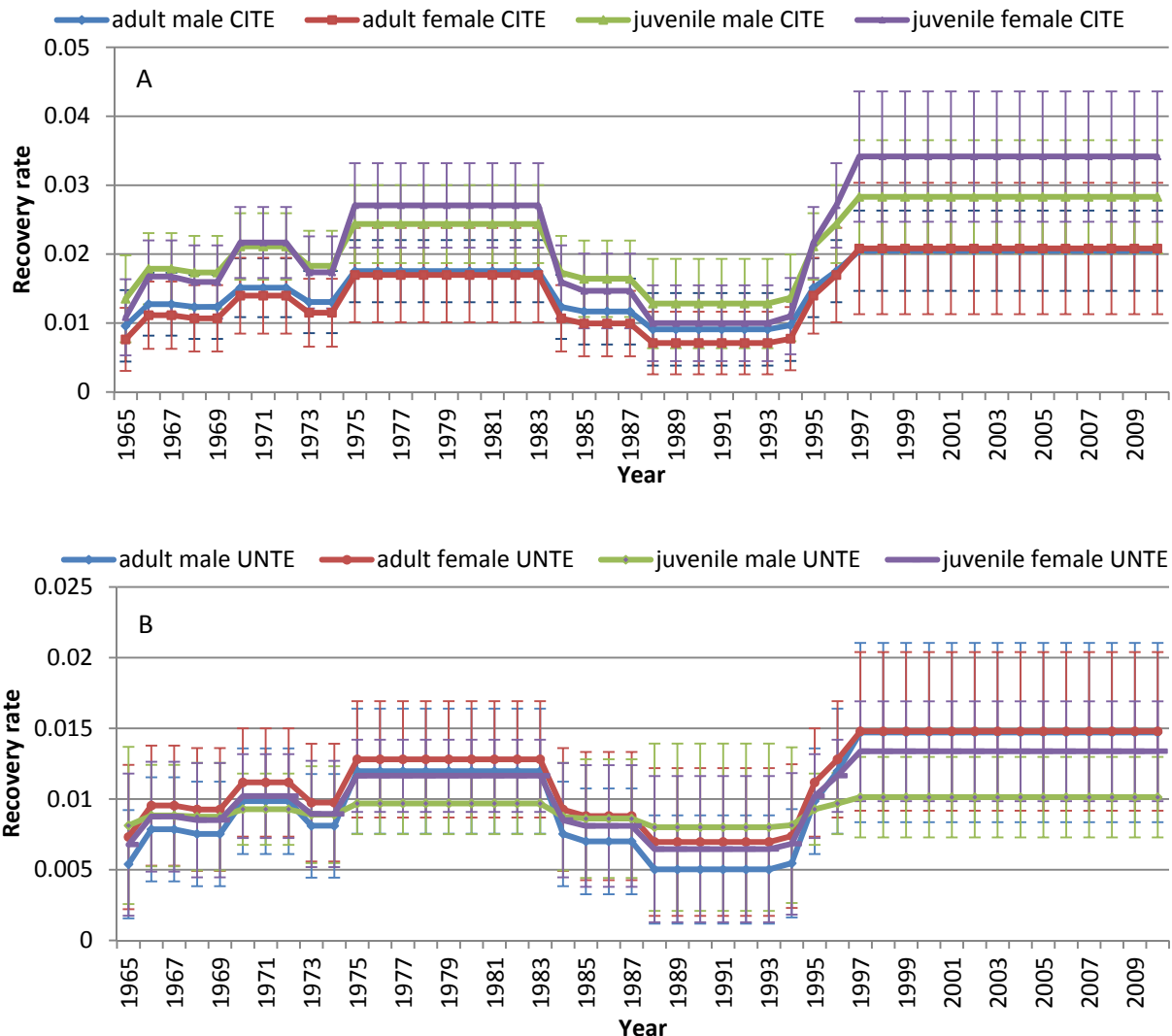


Fig. 3. Cinnamon teal (A) and unidentified teal (B) model-averaged recovery rates by cohort and species designation, with 95% confidence intervals.

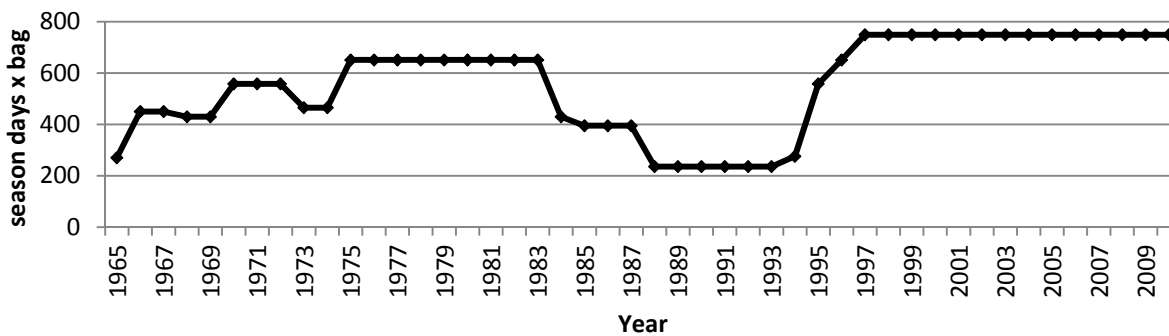


Fig. 4. Index of waterfowl harvest regulations package (number of season days x bag limit) by year in the Pacific Flyway, 1965–2010.

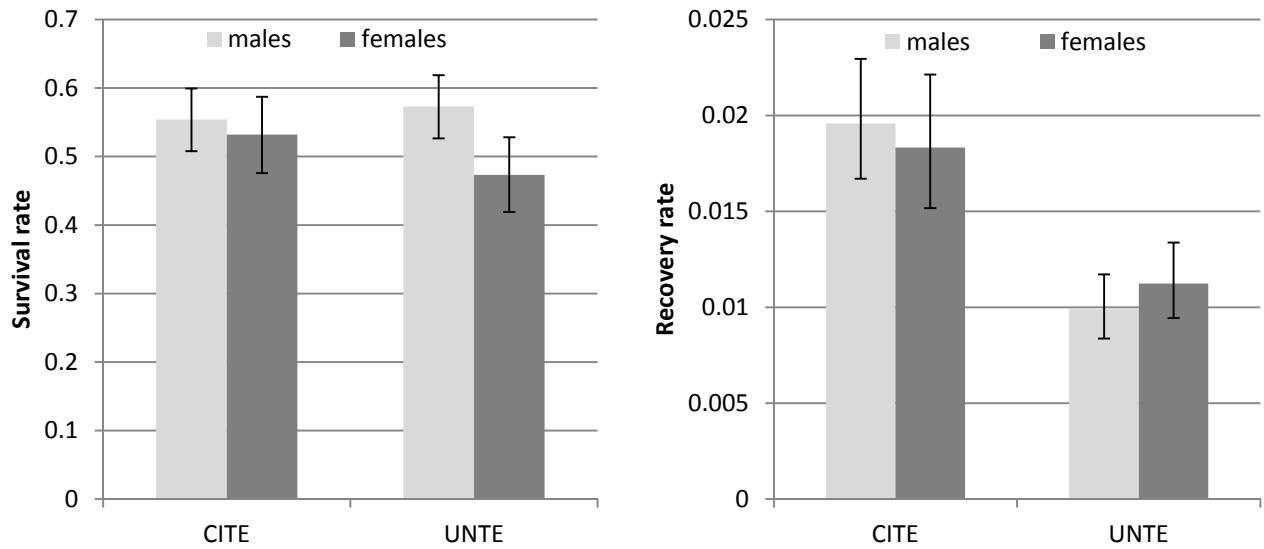


Fig. 5. Overall (all years combined) survival and recovery rates from the highest ranking model without a time effect:  $s(\text{sex}*\text{species}) f(\text{sex}*\text{species})$ . CITE = cinnamon teal, UNTE = unidentified teal. Error bars represent 95% confidence intervals.

### Conclusions

We estimated survival rates and recovery rates from 1965 to 2010 based on a sample of cinnamon and unidentified teal bands and recoveries in North America west of -105 longitude. The selected models contained additive effects of sex, age, species designation, and either a linear time trend or an effect of the Pacific Flyway harvest regulations package. However, the survival and recovery parameters estimated from these models had poor precision due to small samples of bands and recoveries in some years. Over all years, recovery rates were higher for cinnamon teal than unidentified teal, but we did not find significant differences among cohorts in either survival or recovery rates.

## Vulnerability and Recruitment

### Estimating Differential Vulnerability and Recruitment of Blue-winged and Green-winged Teal

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#### **Introduction**

We used wing data from Canadian and U.S. wing collection surveys to estimate annual harvest age ratios of blue-winged and green-winged teal from 1974 to 2008. Because results of previous work indicate that vulnerability of young-of-the-year (immature) ducks to hunting is greater than that of adult ducks, we estimated annual fall population age ratios (immature/adult) by adjusting the harvest age ratios by the differential vulnerability of young to adults (i.e., harvest age ratios divided by differential vulnerability). We used band-recovery data from normal, wild birds that were banded in Canada and the U.S. during the pre-season period (July-September) and subsequently were shot or found dead during the hunting season to estimate differential vulnerability. To the extent possible, we used the same methodologies for estimating vulnerability of young relative to adults and recruitment for blue-winged and green-winged teal. However, due to differences in migration chronology among cohorts, some additional analyses were necessary to determine whether data from early migrating cohorts (primarily adult males) could potentially bias estimates.

#### **Preliminary Analyses: Blue-winged Teal**

*Temporal considerations.*—Many adult male blue-winged teal migrate south in August and early September (Rohwer et al. 2002), well before adult females and immature birds begin fall migration (Bellrose 1980). Consequently, the proportion of the continental population's adult males that is available to hunters is greater during the special September teal season in the U.S. than during the regular seasons in Canada and the U.S., whereas adult females and immature birds are more available to hunters during regular seasons. Despite these age and sex cohort differences in availability to hunters, harvest age ratios for Canada, U.S. September seasons, and U.S. regular seasons should all produce the same estimate of fall population age ratio when corrected for differential vulnerability at the appropriate temporal and geographic scales.

To confirm that, we estimated and compared sex-specific, fall population age ratios using harvest and direct band recovery data for (1) Canada, (2) U.S. September teal seasons only, but including the September duck season in Iowa, (3) U.S. regular season only, and (4) all 3 of those combined. We analyzed data for Canada separately because much but not all of the blue-winged teal harvest in Canada occurs during September, and we did not have access to date-specific harvest estimates by age and sex cohort in Canada. Annual estimates of differential vulnerability varied widely, particularly for Canada and the U.S. September seasons, due to limited band recoveries. So, we used the average (1970-2008) vulnerability for each season (Canada, U.S. September, U.S. regular, and all seasons combined) to adjust the annual harvest age ratios for those seasons.

Although the estimates derived from Canada's harvest and the U.S. September seasons harvest were more volatile than the others, likely due to smaller sample sizes of wings, fall population age ratios estimated using data from each of the 3 seasons and all seasons combined were in general agreement for both males and females (Figs. 1 and 2). These results suggest that age ratios should be calculated using data from all seasons in Canada and the U.S. combined.

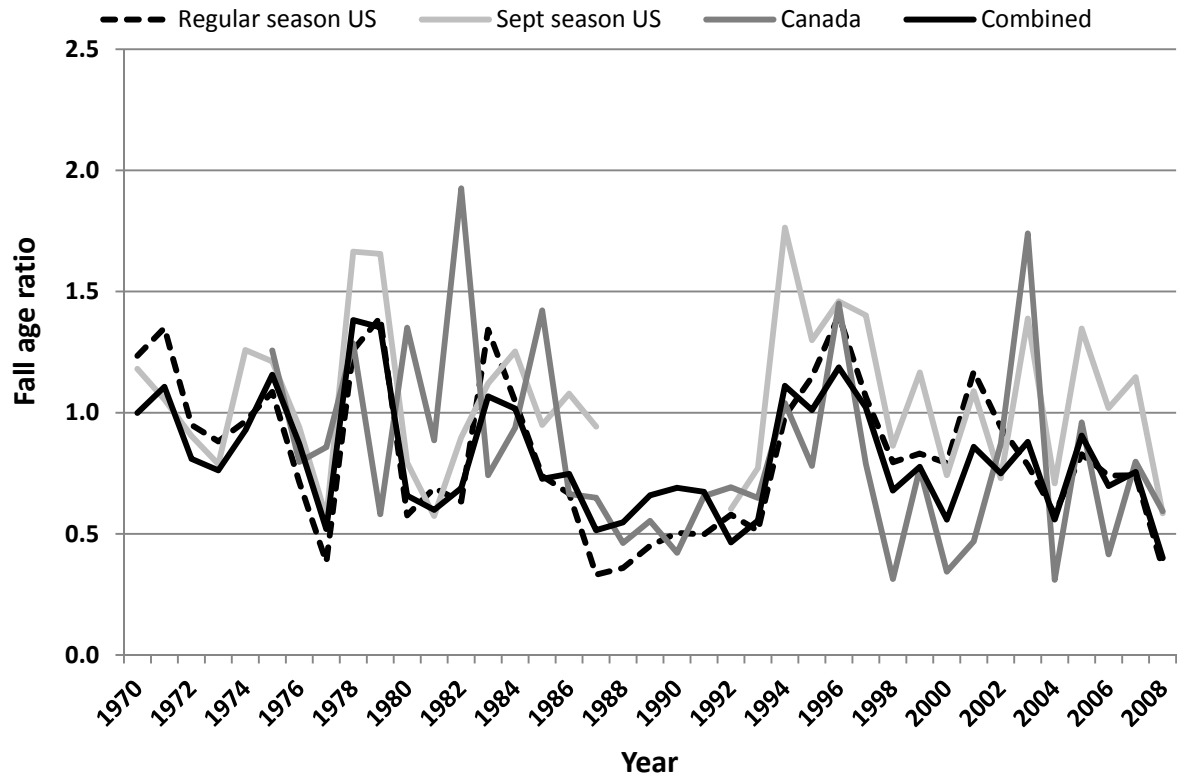


Fig. 1. Fall age ratios (immature/adult) of male blue-winged teal, as estimated from wing collection and band recovery data from (1) Canada, (2) special September duck hunting seasons in the United States, (3) regular duck hunting seasons in the United States, and (4) all sources combined.

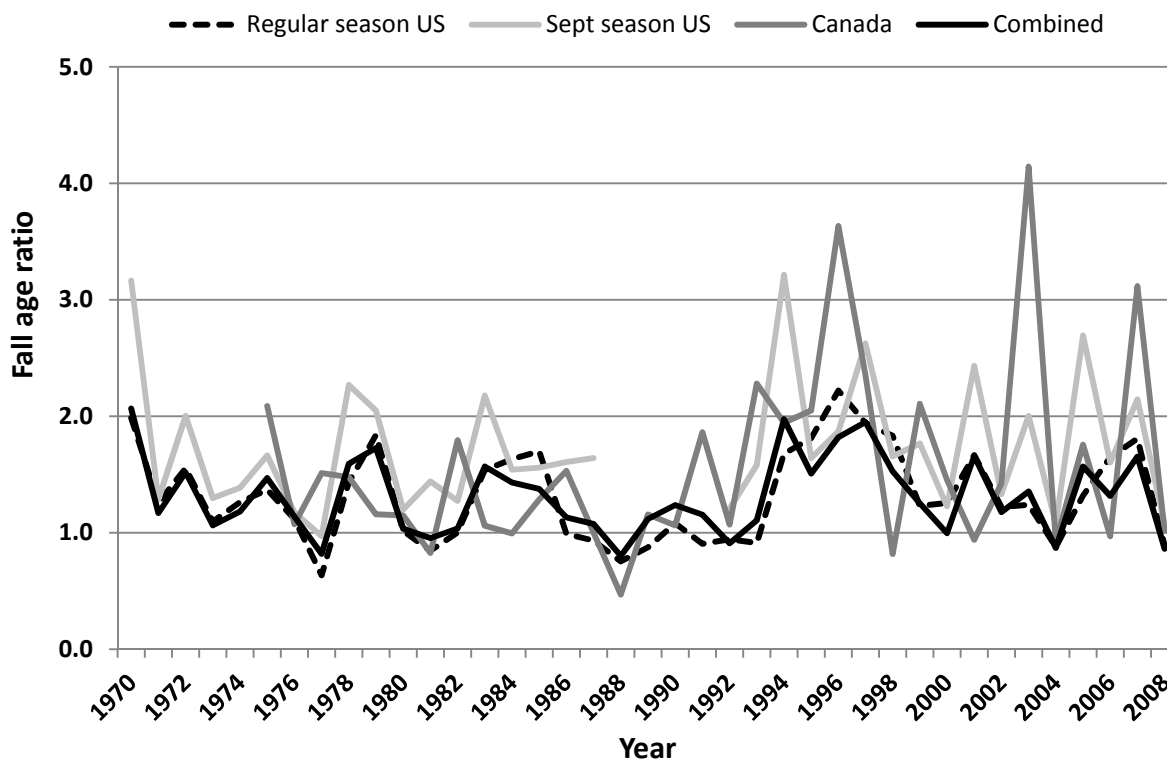


Fig. 2. Fall age ratios (immature/adult) of female blue-winged teal, as estimated from wing collection and band recovery data from (1) Canada, (2) special September duck hunting seasons in the United States, (3) regular duck hunting seasons in the United States, and (4) all sources combined.

*Spatial considerations.*— Szymanski and Dubovsky (in press) recently conducted analyses that showed the distribution and derivation of the blue-winged teal harvest. They identified breeding reference areas in North America based in part on contiguous areas with homogeneous survival rates, and harvest areas that were essentially existing harvest management jurisdictions (i.e., Canada, the U.S. portions of the Atlantic, Mississippi, Central, and Pacific Flyways, and Latin America) or subdivisions of those jurisdictions. They found that harvest rates were consistently higher for blue-winged teal banded in breeding reference areas east of  $87^{\circ}$  W longitude (eastern group) compared with birds banded west of  $87^{\circ}$  W longitude (mid-continent group). This suggested that other demographic parameters, including productivity, could also differ between the eastern and mid-continent groups. Therefore, we attempted to estimate age ratios for the eastern and mid-continent groups separately and compare them.

Blue-winged teal harvest in mid-continent harvest areas was derived almost entirely from the mid-continent group (>98% of the Mississippi and Central Flyway harvest was birds originating west of  $87^{\circ}$  W longitude [Szymanski and Dubovsky, In press]); thus, calculation of harvest age ratios for that group was straightforward. In contrast, harvest in the Atlantic Flyway was derived from both eastern and mid-continent birds. For the entire period Szymanski and Dubovsky (In press) considered (1970-2003), the proportion of the Atlantic Flyway's harvest derived from breeding reference areas east of  $87^{\circ}$  W longitude was: Atlantic Canada, 0.635; Quebec, 0.631; northern U.S. Atlantic Flyway, 0.559; central U.S.

Atlantic Flyway, 0.484; and southern U.S. Atlantic Flyway, 0.108. The remainder of the Atlantic Flyway harvest in each of those areas was derived from the mid-continent group. As a result, calculation of fall population age ratios for the eastern group was more complicated, because estimates should account for potential differences in harvest age ratios and recovery rates between the two groups.

We tried 2 different methods to compare eastern and mid-continent age ratios. Szymanski and Dubovsky's (in press) results indicated that from 1987 to 1993 a much greater proportion of the eastern harvest was derived from the eastern group (Atlantic Canada, 0.958; Quebec, 0.983; northern U.S. Atlantic Flyway, 0.856; and central U.S. Atlantic Flyway, 0.940). Except for Atlantic Canada, they found similar results for 1980-1986 (Quebec, 0.886; northern U.S. Atlantic Flyway, 0.852; and central U.S. Atlantic Flyway, 0.813). The first method we used assumed that the annual harvest age ratios were "clean enough" for those years and those harvest regions. We corrected the sex-specific harvest age ratios for differential vulnerability for all "clean" eastern harvest areas combined using direct band recoveries of birds banded east of 87° W longitude and recovered during regular seasons in those harvest areas (Tables 1 and 2). Band recoveries were few, so we assumed that differential vulnerability was constant over each of the 2 sets of years when we calculated fall population age ratios for the eastern group. To compare them to mid-continent age ratios during the same time period, we used regular season harvest age ratios from Alberta, Manitoba, Saskatchewan, and northern and central Mississippi and Central Flyway states, and corrected them for differential vulnerability as above (again assuming it was constant for each period) to obtain estimates of fall population age ratios for mid-continent birds (Tables 1 and 2).

Table 1. Annual estimates of fall age ratios (AR; immature/adult) of eastern and mid-continent female blue-winged teal, estimated from harvest age ratios corrected for differential vulnerability (DV).

Year	Eastern			Year	Mid-continent		
	Harvest AR	DV	Fall AR		Harvest AR	DV	Fall AR
1980	2.10	1.41	1.49	1980	3.35	3.44	0.97
1981	1.28	1.41	0.91	1981	1.96	3.44	0.57
1982	4.87	1.41	3.45	1982	1.91	3.44	0.55
1983	3.95	1.41	2.80	1983	3.35	3.44	0.97
1984	2.64	1.41	1.87	1984	3.24	3.44	0.94
1985	2.48	1.41	1.76	1985	3.84	3.44	1.12
1986	3.34	1.41	2.37	1986	2.23	3.44	0.65
1987	3.12	1.69	1.84	1987	2.98	1.73	1.72
1988	1.44	1.69	0.85	1988	1.36	1.73	0.79
1989	3.96	1.69	2.34	1989	2.03	1.73	1.17
1990	2.71	1.69	1.60	1990	3.06	1.73	1.77
1991	3.65	1.69	2.16	1991	2.95	1.73	1.71
1992	1.21	1.69	0.71	1992	2.66	1.73	1.54
1993	7.56	1.69	4.47	1993	2.07	1.73	1.20

Table 2. Annual estimates of fall age ratios (AR; immature/adult) of eastern and mid-continent male blue-winged teal, estimated from harvest age ratios corrected for differential vulnerability (DV).

Year	Eastern			Year	Mid-continent		
	Harvest AR	DV	Fall AR		Harvest AR	DV	Fall AR
1980	2.57	2.61	0.98	1980	6.46	6.08	1.06
1981	1.57	2.61	0.60	1981	4.47	6.08	0.74
1982	4.29	2.61	1.64	1982	4.04	6.08	0.66
1983	4.65	2.61	1.78	1983	8.60	6.08	1.41
1984	3.84	2.61	1.47	1984	7.38	6.08	1.21
1985	5.50	2.61	2.10	1985	6.43	6.08	1.06
1986	2.61	2.61	1.00	1986	3.48	6.08	0.57
1987	4.23	2.16	1.96	1987	4.64	5.23	0.89
1988	1.60	2.16	0.74	1988	3.77	5.23	0.72
1989	2.33	2.16	1.08	1989	5.68	5.23	1.08
1990	2.01	2.16	0.93	1990	7.32	5.23	1.40
1991	2.50	2.16	1.16	1991	5.70	5.23	1.09
1992	1.30	2.16	0.60	1992	6.69	5.23	1.28
1993	4.30	2.16	1.99	1993	3.19	5.23	0.61

Fall age ratios were higher in most years and on average for eastern birds for both females (mean difference = +44.8%) and males (mean difference = +24.3%). However, this method limited the time series for eastern-group age ratios to just 14 years.

The second method used data from the entire time frame examined by Szymanski and Dubovsky (in press). We subtracted age- and sex-specific harvest of the mid-continent group from the northern and central Atlantic Flyway's annual regular season harvest, leaving age- and sex-specific harvest estimates the eastern group. Szymanski and Dubovsky's (in press) results indicated the following derivation of harvest in those two harvest areas:

1970-1979: Atlantic Flyway North - 0.523 eastern, 0.477 mid-continent  
 1970-1979: Atlantic Flyway Central - 0.261 eastern, 0.739 mid-continent  
 1980-1986: Atlantic Flyway North - 0.852 eastern, 0.148 mid-continent  
 1980-1986: Atlantic Flyway Central - 0.813 eastern, 0.187 mid-continent  
 1987-1993: Atlantic Flyway North - 0.856 eastern, 0.144 mid-continent  
 1987-1993: Atlantic Flyway Central - 0.940 eastern, 0.060 mid-continent  
 1994-2003: Atlantic Flyway North - 0.445 eastern, 0.555 mid-continent  
 1994-2003: Atlantic Flyway Central - 0.506 eastern, 0.494 mid-continent

We first estimated the annual mid-continent harvest in the Atlantic Flyway North and Atlantic Flyway Central harvest areas by multiplying the estimated total annual harvest in each harvest area by the area-

and period-specific mid-continent derivation proportion. We then used regular season harvest age ratios for the north and central Mississippi and Central Flyway states to apportion Atlantic Flyway North and Atlantic Flyway Central mid-continent harvest according to age and sex. We subtracted those estimates from the total age- and sex-specific annual harvest estimates, leaving, in theory, age- and sex-specific estimates of the harvest of eastern-group blue-winged teal in the Atlantic Flyway North and Central harvest areas. For example, the 1973 harvest estimate for the Atlantic Flyway North area was 34,512 blue-winged teal, of which 47.7% or 16,462 were derived from west of 87° W longitude. The mid-continent harvest that year was 6.8% adult males, 18.1% adult females, 36.1% immature males, and 39.0% immature females. Therefore, we subtracted 1,120 adult males (6.8% of 16,462) from the estimated Atlantic Flyway North's total harvest of adult males to get the harvest of adult males derived from the eastern group, and so on. The age- and sex-cohort-specific estimates of eastern-group harvest for the two areas (Atlantic Flyway North and Central) were then combined and corrected for differential vulnerability, and the resulting fall age ratios were compared with similar estimates based on regular-season harvest age ratios for the north and central Mississippi and Central Flyway states. This method assumed no age- or sex-specific differential migration patterns by mid-continent blue-winged teal.

Problems with this approach were apparent immediately. Sample sizes of wings from birds harvested in the eastern harvest areas were small, and in 14 of the years under consideration, the estimated area-specific harvest of eastern-group birds was a negative number for at least one age and sex cohort. All of those years were during the periods 1970-1979 and 1994-2003, when large proportions of the Atlantic Flyway harvest were derived from mid-continent birds. Even after estimates for the two harvest areas were summed, the estimated harvest of eastern-group immature males in 2000 was -66 birds. Some of the resulting age ratio estimates for the eastern group were biologically unrealistic; for example, fall female age ratio estimates for 1975, 1982, 1993, and 2001, corrected for differential vulnerability, were 10.6, 10.5, 28.7, and 11.8, respectively, and estimated fall male age ratios for 1996, 1998, 2000, and 2003 were all <0.1. Further, in many years (26%) the difference was not of the same sign (positive or negative) between eastern and mid-continent estimates for males and females, and the differences were not highly correlated ( $r = 0.28$ ).

Although our first analysis suggested that blue-winged teal productivity may be greater east of 87° W longitude than it is in mid-continent breeding reference areas, the short time series available for that analysis limited its value for modeling purposes. Our attempt to use a longer time series to estimate group-specific age ratios did not provide reliable results. Consequently, we recommend that age ratios should be estimated continentally.

*Male vs. female age ratios.*—We used the full U.S. and Canada data sets to compare fall age ratios for males and females (Fig. 3), using pooled estimates of differential vulnerability (1970-2008). Female age ratios were higher and more variable than male ratios from year to year, and male age ratios appeared to be declining over time compared to female age ratios. To examine this apparent trend further, we plotted adult and immature sex ratios (male/female), corrected for differential vulnerability of females relative to males (Fig. 4).



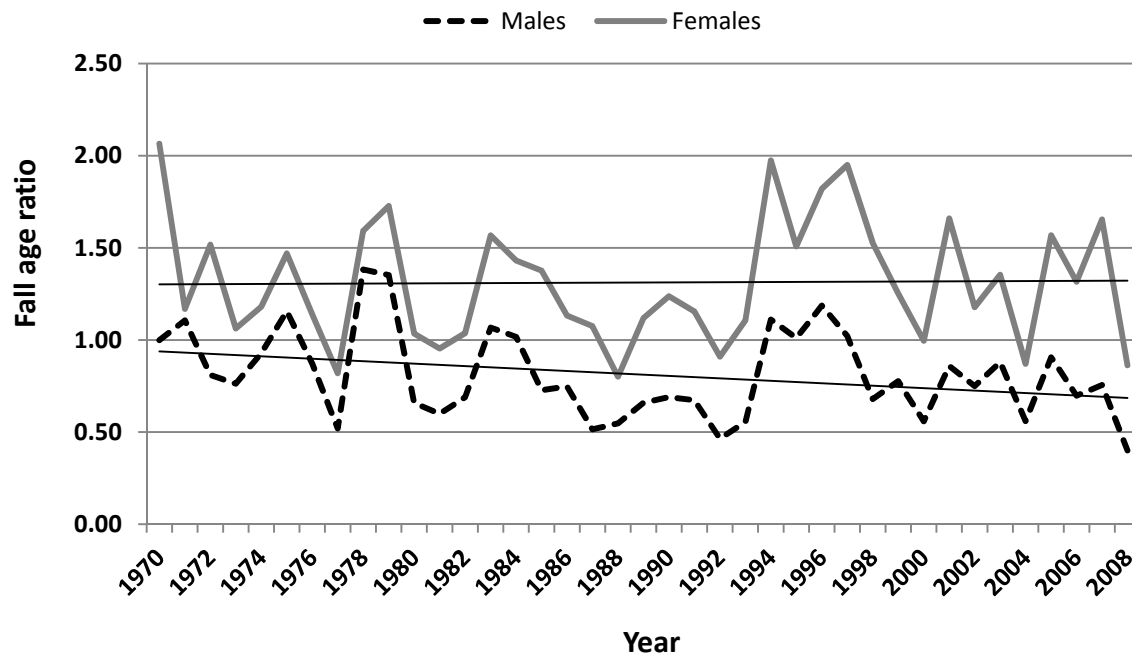


Fig. 3. Fall age ratios (immature/adult) of blue-winged teal, as estimated from wing collection and band recovery data.

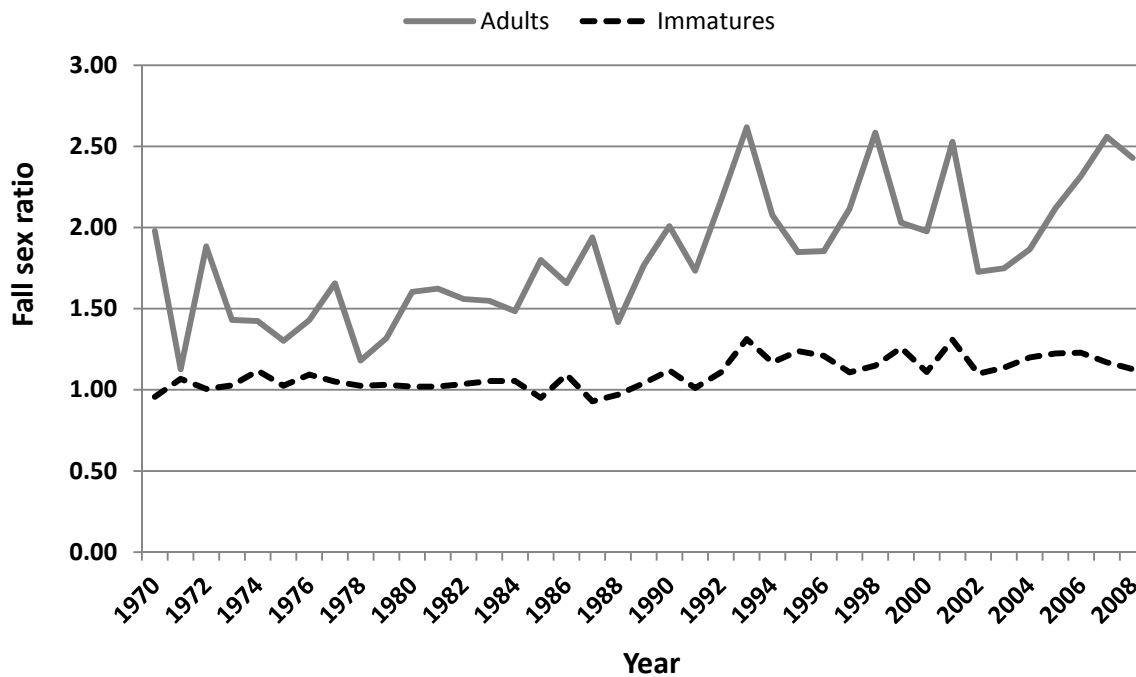


Fig. 4. Fall sex ratios (male/female) of blue-winged teal, as estimated from wing collection and band recovery data.

The fall sex ratio of adults has increased substantially over time, especially since the mid-1980s. The immature sex ratio also seems to have increased, particularly since the late 1980s when the sex ratio began to increasingly deviate from the expected 1:1. These analyses (decreasing immature males per adult male, and increasing males per female for both ages) suggest that for some reason adult males tend to be increasing relative to the other cohorts. Because of these relationships, male age ratios in population models may become increasingly biased low if these trends continue. Therefore, we recommend using females as the basis for production indices.

### ***Preliminary Analyses: Green-winged Teal***

*Temporal considerations.*—Because, like blue-winged teal, green-winged teal are harvested during both September teal seasons and regular duck seasons, we initially analyzed data to detect whether age ratio estimates might be affected by temporal differences in migration of the various cohorts. We first determined the proportion of green-winged teal harvested during the September teal seasons. No attempt was made to assess potential differences in harvest or band-recovery information due to changes in season lengths. September teal season harvests of green-winged teal on average were 2.2%, 3.8%, and 6.6% of the total-season green-winged teal harvests in the Atlantic, Mississippi, and Central Flyway harvests, respectively (the Pacific Flyway does not have September teal seasons), suggesting little to no influence of September harvests on overall results. Thus, pooling data for both September teal seasons and regular duck hunting seasons to estimate fall population age ratios is appropriate.

Within each flyway, various age ratio metrics (total immatures/total adults, male immatures/male adults, and female immatures/female adults) were highly correlated. However, across flyways these metrics were variably correlated, with Mississippi and Central Flyway metrics relatively well correlated, but low or no correlations between these two flyways and the Atlantic Flyway metrics. Also, within each flyway, total immatures/total adults for the regular season only and for the regular and September teal seasons combined were highly correlated ( $r > 0.99$ ). Finally, harvest data indicated essentially no green-winged teal harvested in Iowa during their September duck seasons. The only year in which green-winged teal were harvested during the Iowa season was in 2003 with 0.29% of the state's total 2003 green-winged teal harvest, so it had no influence on results. Due to the results of these correlation analyses, the relatively low harvest of green-winged teal during September teal seasons, and the very low numbers of green-winged teal harvested during the Iowa September duck seasons, the metric used for harvest data was total immatures for the regular and September teal seasons divided by the total adults for both seasons.

*Spatial considerations.*—Because both recruitment and differential vulnerability may vary spatially, we used a multi-response permutation procedure (MRPP; Biondini et al. 1988, Zimmerman et al. 1985) along with a clustering algorithm to separate geographic banding areas with similar band-recovery distributions (e.g., Kelley 1997, Smith 1997). We used direct recoveries from normal, wild green-winged teal banded during pre-season from 1970 to 2008 and subsequently shot or found dead during September-February in the MRPP analyses. Resulting test statistics from all pairwise comparisons of banding degree blocks were compiled into a dissimilarity matrix and clustered using Ward's method available in program CLUSTAR (Romesburg 1990). The MRPP results suggested three groups for further

analyses (Fig. 5). U.S. harvest age ratio data initially were separated into three groups to align with the MRPP analyses and band-recovery data separation. The three groups were separated largely along flyway boundaries (Pacific Flyway [western group], Central and Mississippi Flyway combined [mid-continent group], and Atlantic [eastern group]) (Fig. 5). Only band-recovery data from green-winged teal banded in the shaded areas in Fig. 5 were used in subsequent vulnerability analyses. Importantly, these groups do not represent populations, but rather were used to initially account for potential spatial heterogeneity in demographic parameters.

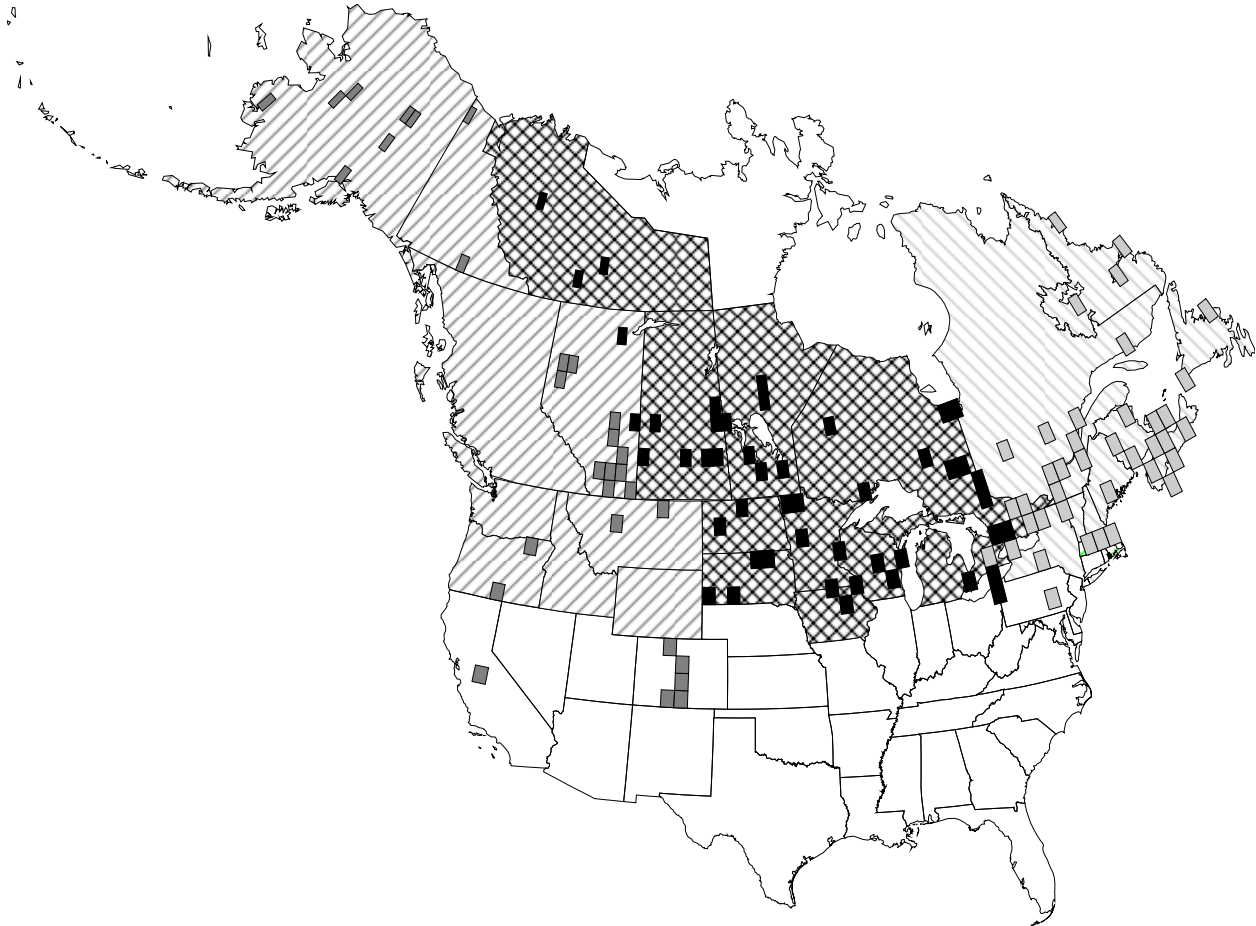


Fig. 5. Results of a multi-response permutation procedure (MRPP) to identify groupings of green-winged teal for age ratio analyses.

Annual differential vulnerability estimates varied widely (ranges: eastern group females = 0.39 to 12.29; mid-continent group females = 0.46 to 6.79; western group females = 0.39 to 3.67; eastern group males = 0.78 to 5.20; mid-continent group males = 0.35 to 3.05; western group males = 0.27 to 2.68). Previous work for other duck species (primarily mallards [Runge et al. 2002:7]) has indicated that using annual vulnerability estimates to adjust harvest age ratios provides little additional value in estimating fall age

ratios. Thus, we used the average of the vulnerability estimates for each group to calculate fall age ratios. Those values for females were 1.42, 1.28, and 1.02 for the eastern, mid-continent, and western groups, respectively, and for males were 1.51, 1.33, and 0.92. On average, the resulting fall age ratios did not appear to differ substantially for females (averages: eastern group = 2.45 immatures/adult; mid-continent group = 2.19 immatures/adult; western group = 2.43 immatures/adult) (Fig. 6). Mean values did appear to differ somewhat for males (eastern group = 1.73 immatures/adult; mid-continent group = 1.25 immatures/adult; western group = 0.96 immatures/adult) (Fig. 7). Values for eastern-group males also appeared to have declined relative to the other two groups in recent years (Fig. 7), and for about the last decade values for all 3 groups appear very similar.

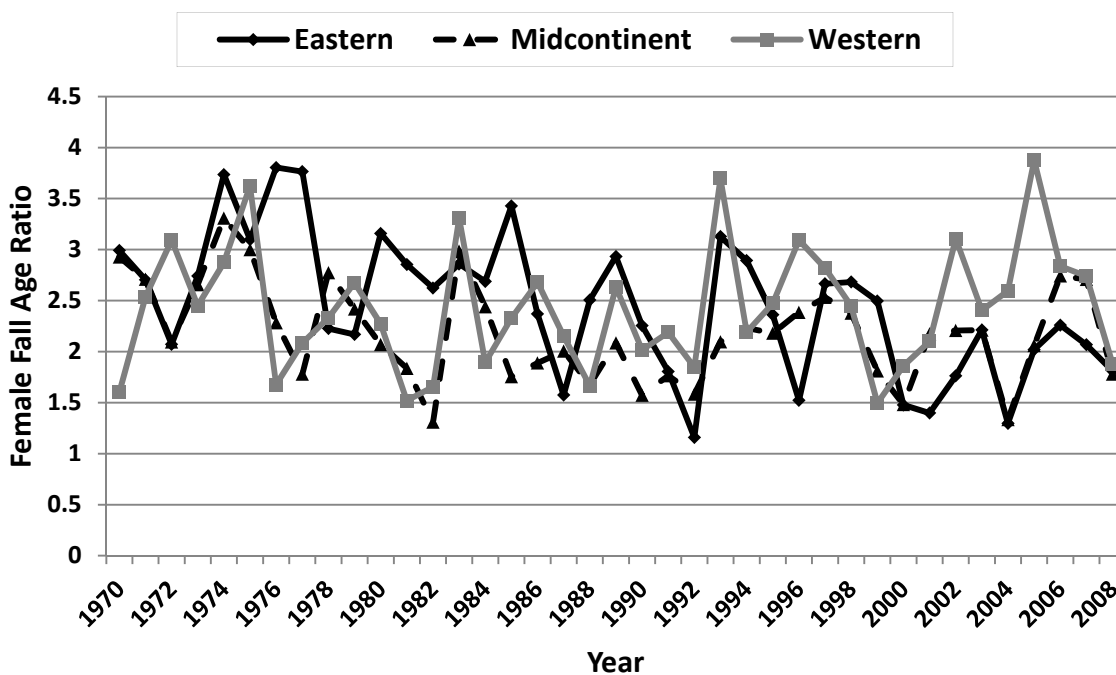


Fig. 6. Female green-winged teal fall age ratios by MRPP region using area-specific constant differential vulnerability estimates.

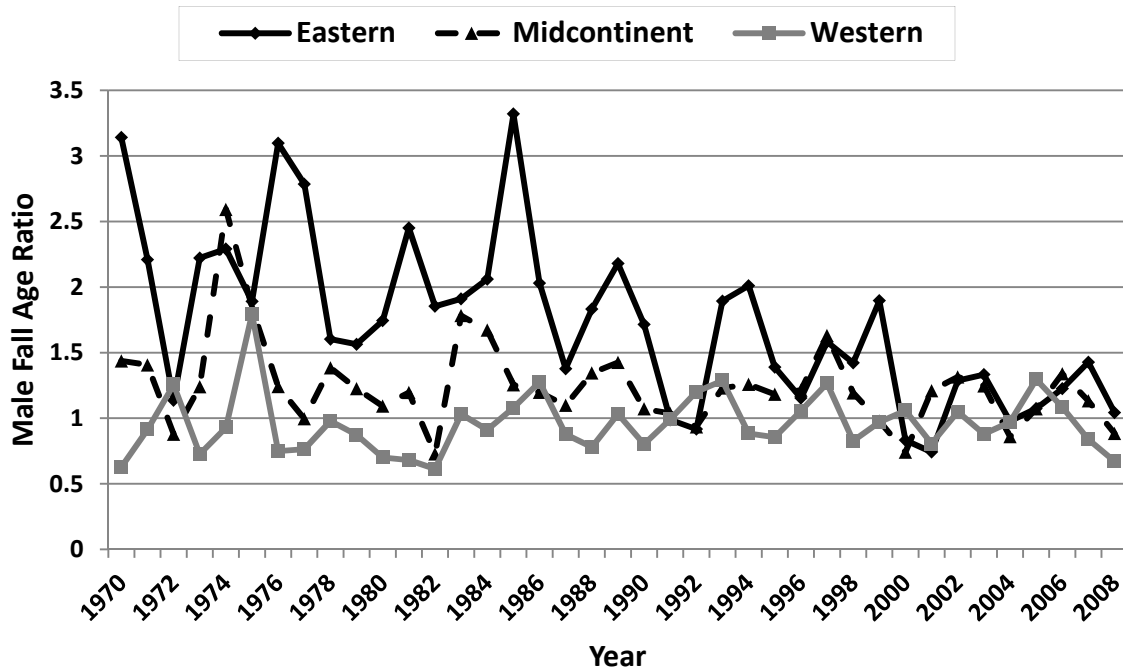


Fig. 7. Male green-winged teal fall age ratios by MRPP region using area-specific constant differential vulnerability estimates.

*Male vs. female age ratios.*—Because differences did not appear to be great among estimates for the 3 groups, particularly for females, and because sample sizes were small when data were partitioned by sex, we pooled data across the 3 areas independently for females and males. Pooled estimates suggested no trend in female age ratios (Fig. 8). For males, results suggested a slight decline over time, and estimates that were lower than those using only data for females. To investigate this latter result further, we estimated the fall sex ratios of males to females for both the adult and immature cohorts, similar to analyses that were described earlier for blue-winged teal. Like results for blue-winged teal, we also found increasing sex ratios for both cohorts (Fig. 9). For the same reasons stated above, these results suggest using pooled estimates of females only would be most appropriate in subsequent population modeling efforts.

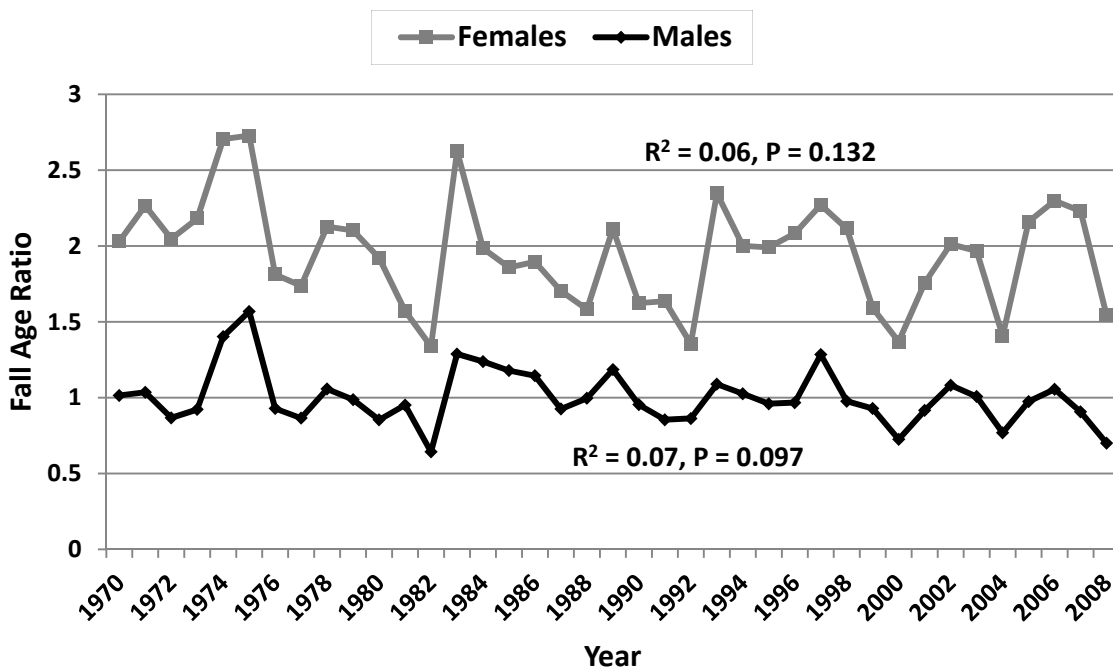


Fig. 8. Fall age ratios for male and female green-winged teal using sex-specific pooled estimates for harvest age ratios and differential vulnerability.

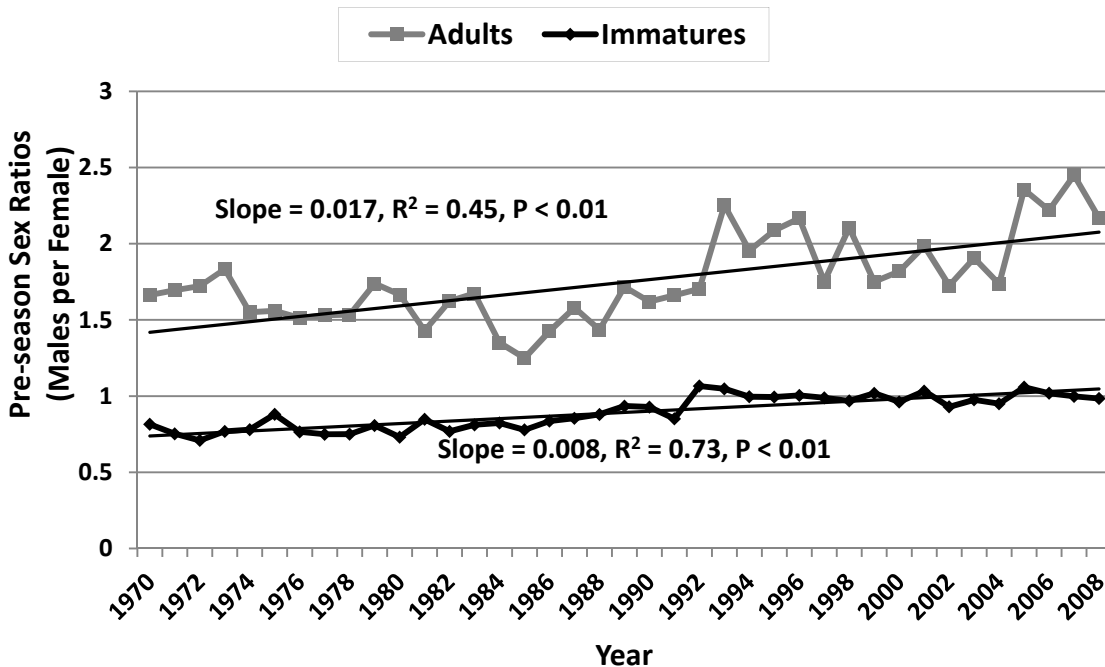


Fig. 9. Fall sex ratios of adult and immature green-winged teal using constant age-specific estimates of differential vulnerability.

### Final Analyses

All of our preliminary analyses were conducted using standard methodologies. Unfortunately, calculating variances using these methods is very involved and typically results in extremely wide confidence intervals. Therefore, we subsequently used a hierarchical modeling and Bayesian model-fitting approach developed by Zimmerman et al. (2010) to derive final estimates of blue-winged and green-winged teal fall population female age ratios. This methodology readily produces credibility intervals, which can be used for measures of precision in subsequent analyses. Comparisons of fall age ratios estimated using standard versus Bayesian methodology suggest very minor differences between the two approaches (Figs. 10 - 13). Thus, we believe the Bayesian estimates of age ratios in Table 3 represent the best available for future modeling of blue-winged and green-winged teal population dynamics.

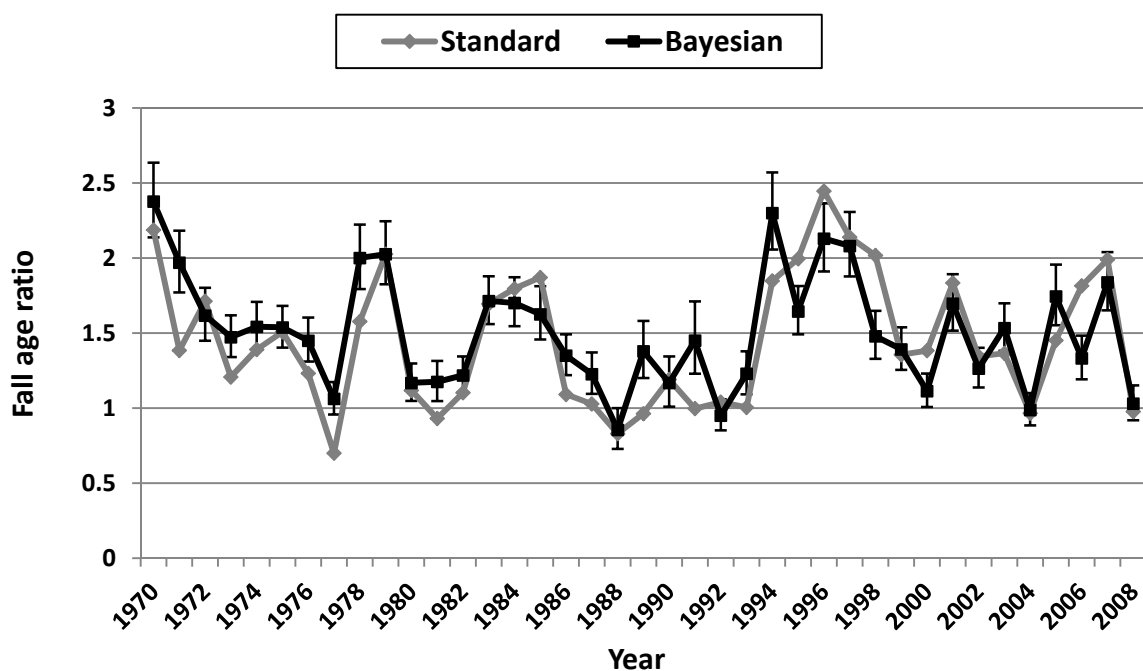


Fig. 10. Traces of standard and Bayesian (with 95% credible intervals) annual estimates of fall age ratios for female blue-winged teal, using harvest age ratios corrected with method-specific constant differential vulnerabilities.

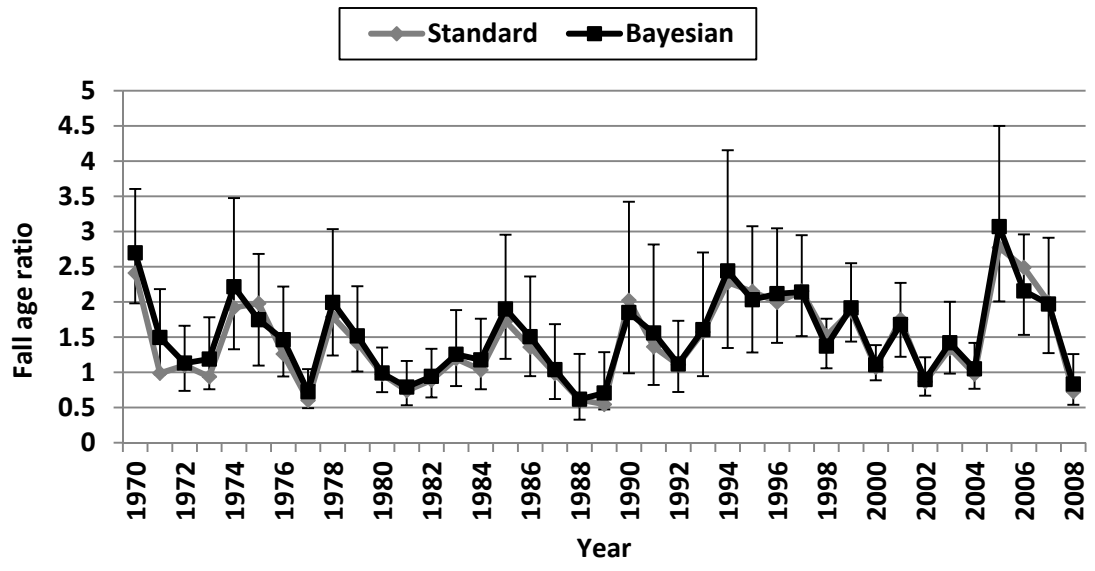


Fig. 11. Traces of standard and Bayesian (with 95% credible intervals) annual estimates of fall age ratios for female blue-winged teal, using harvest age ratios corrected with method-specific annual differential vulnerabilities.

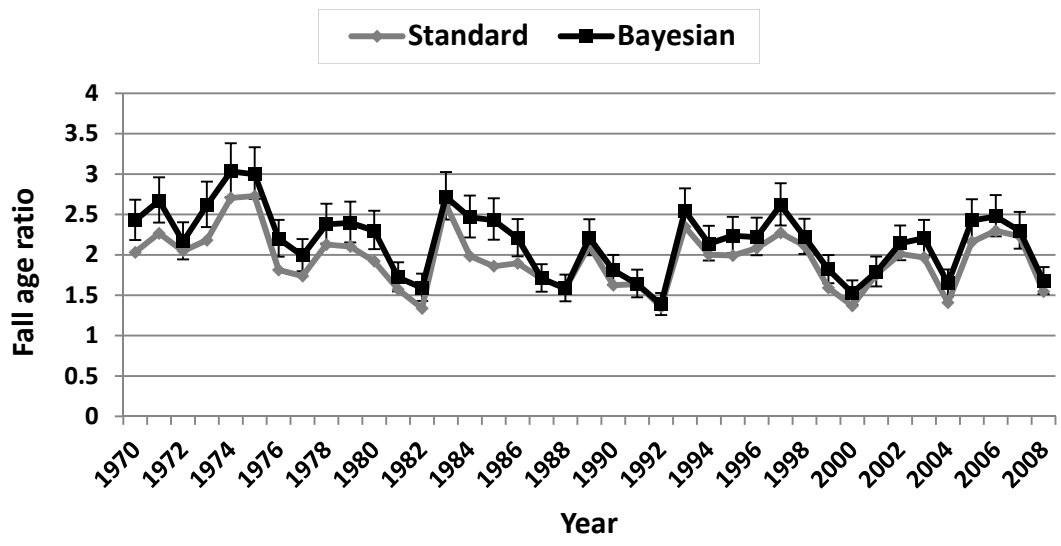


Fig. 12. Traces of standard and Bayesian (with 95% credible intervals) annual estimates of fall age ratios for female green-winged teal, using harvest age ratios corrected with method-specific constant differential vulnerabilities.



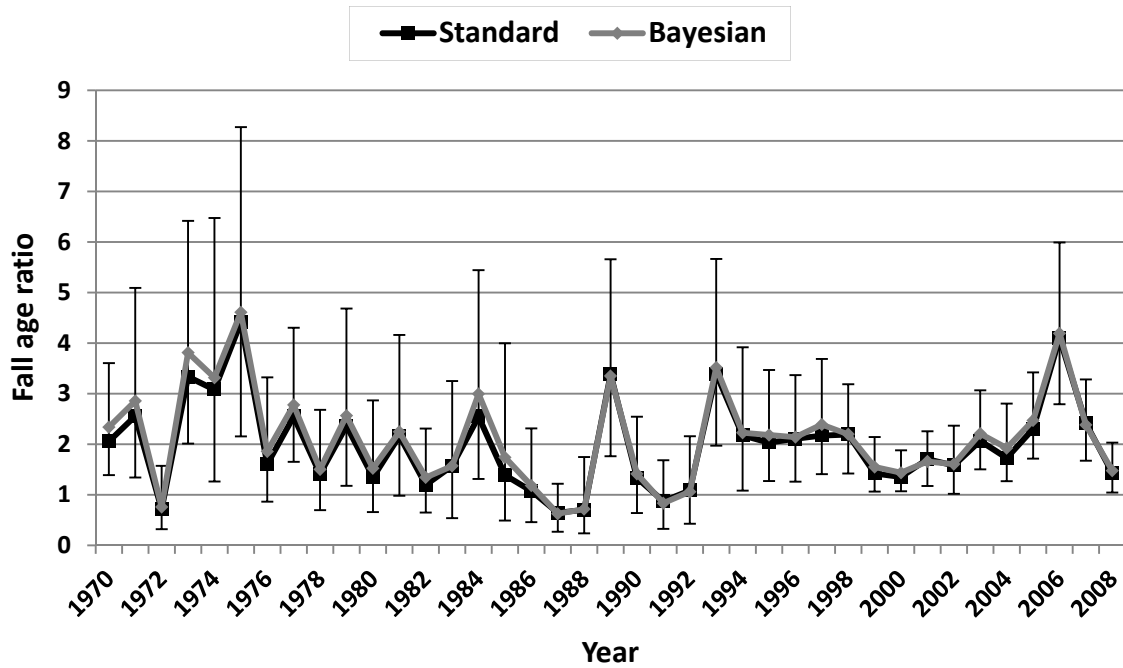


Fig. 13. Traces of standard and Bayesian (with 95% credible intervals) annual estimates of fall age ratios for female green-winged teal, using harvest age ratios corrected with method-specific annual differential vulnerabilities.

Table 3. Estimates of fall age ratios (SD) of female blue-winged and green-winged teal, derived using Bayesian methodologies and adjusted for constant differential vulnerability (DV) or annual DV, for use in population modeling efforts.

Year	Blue-winged teal		Green-winged teal	
	Constant DV	Annual DV	Constant DV	Annual DV
1970	2.38 (0.1267)	2.72 (0.4118)	2.42 (0.1274)	2.338 (0.5636)
1971	1.97 (0.1047)	1.52 (0.3096)	2.67 (0.1433)	2.856 (0.9669)
1972	1.62 (0.0900)	1.15 (0.2379)	2.16 (0.1187)	0.758 (0.3322)
1973	1.47 (0.0708)	1.21 (0.2643)	2.61 (0.1439)	3.812 (1.1360)
1974	1.54 (0.0806)	2.26 (0.5505)	3.03 (0.1717)	3.316 (1.3440)
1975	1.54 (0.0711)	1.78 (0.4034)	3.00 (0.1622)	4.609 (1.5860)
1976	1.45 (0.0745)	1.49 (0.3252)	2.20 (0.1157)	1.857 (0.6401)
1977	1.06 (0.0552)	0.74 (0.1419)	1.99 (0.1024)	2.776 (0.6810)
1978	2.00 (0.1093)	2.02 (0.4589)	2.38 (0.1250)	1.504 (0.5082)
1979	2.03 (0.1074)	1.54 (0.3077)	2.40 (0.1290)	2.566 (0.9094)
1980	1.17 (0.0636)	1.00 (0.1630)	2.30 (0.1216)	1.526 (0.5706)
1981	1.18 (0.0685)	0.81 (0.1609)	1.72 (0.0911)	2.247 (0.8339)
1982	1.22 (0.0628)	0.95 (0.1783)	1.59 (0.0867)	1.344 (0.4316)
1983	1.71 (0.0818)	1.28 (0.2765)	2.72 (0.1506)	1.571 (0.7062)
1984	1.70 (0.0826)	1.20 (0.2585)	2.46 (0.1315)	2.997 (1.0700)
1985	1.63 (0.0908)	1.95 (0.4489)	2.43 (0.1300)	1.740 (0.9151)
1986	1.35 (0.0694)	1.54 (0.3601)	2.20 (0.1175)	1.184 (0.4850)
1987	1.23 (0.0704)	1.07 (0.2724)	1.71 (0.0871)	0.626 (0.2475)
1988	0.86 (0.0702)	0.66 (0.2434)	1.58 (0.0838)	0.716 (0.4129)
1989	1.38 (0.0975)	0.75 (0.2170)	2.21 (0.1126)	3.351 (0.9964)
1990	1.17 (0.0861)	1.93 (0.6231)	1.81 (0.0952)	1.413 (0.4929)
1991	1.45 (0.1228)	1.63 (0.5143)	1.64 (0.0869)	0.836 (0.3533)
1992	0.95 (0.0530)	1.15 (0.2611)	1.38 (0.0699)	1.060 (0.4448)
1993	1.23 (0.0736)	1.66 (0.4506)	2.55 (0.1350)	3.517 (0.9474)
1994	2.30 (0.1316)	2.52 (0.7201)	2.14 (0.1096)	2.228 (0.7274)
1995	1.65 (0.0823)	2.07 (0.4633)	2.24 (0.1146)	2.184 (0.5631)
1996	2.13 (0.1157)	2.15 (0.4148)	2.22 (0.1186)	2.140 (0.5400)
1997	2.08 (0.1100)	2.16 (0.3685)	2.62 (0.1342)	2.391 (0.5831)
1998	1.48 (0.0808)	1.38 (0.1812)	2.22 (0.1113)	2.197 (0.4515)
1999	1.39 (0.0720)	1.94 (0.2838)	1.82 (0.0891)	1.551 (0.2758)
2000	1.11 (0.0571)	1.12 (0.1279)	1.53 (0.0770)	1.437 (0.2066)
2001	1.70 (0.0948)	1.70 (0.2682)	1.79 (0.0950)	1.660 (0.2787)
2002	1.26 (0.0683)	0.91 (0.1393)	2.14 (0.1101)	1.606 (0.3467)
2003	1.53 (0.0809)	1.44 (0.2612)	2.21 (0.1131)	2.211 (0.4008)
2004	0.99 (0.0550)	1.06 (0.1662)	1.65 (0.0853)	1.924 (0.3906)
2005	1.75 (0.1020)	3.11 (0.6455)	2.42 (0.1304)	2.472 (0.4388)
2006	1.33 (0.0746)	2.18 (0.3710)	2.47 (0.1297)	4.192 (0.8230)
2007	1.84 (0.0986)	2.00 (0.4189)	2.30 (0.1173)	2.382 (0.4103)
2008	1.03 (0.0597)	0.85 (0.1836)	1.67 (0.0859)	1.476 (0.2515)

### Chapter 3. Analysis of Harvest and Season Structure

#### Relationship Between Blue- and Green-winged Teal Early Harvest/Direct Harvest Rates and Early Season Structure

*Kathy Fleming, USFWS*

##### **Introduction and Methods**

An important aspect of the assessment of teal harvest potential is the determination of how teal harvest is influenced by the framework of the U.S. early teal harvest season. In the history of the early teal season there have been modifications to the number of states allowed an early season and number of season days in the Atlantic Flyway (AF), Mississippi Flyway (MF), and Central Flyway (CF). Of particular interest is the effect of the expansion of season days and states since the early season was reopened in 1992. I used the period 1992–2010 (for harvest rate) and 1992–2011 (for early harvest) to investigate the effects of changes in the total number of early season days and number of states with an early season in the AF, MF, and CF, and combined MF–CF on blue- and green-winged teal harvest during the early season (the PF does not have an early teal season). The objectives of this analysis were to (1) determine which, if any, harvest season variables were related to the early teal season harvest, and (2) identify models that might best predict early teal harvest from harvest season variables and population characteristics. I characterized early season harvest in two ways: the number of birds harvested during the early season in each flyway estimated from the Mail Survey Questionnaire (MSQ) (1992–1998) and Harvest Information Program (HIP) surveys (1999–2010), and the harvest rate based on direct recoveries of birds harvested during the early season in each flyway (Figs. 1 and 2).

I calculated an annual harvest rate by flyway based on direct recoveries during the early season (recovery month = September) in the U.S. only from 1992–2010 by taking the total number of direct recoveries of each band type and report method combination  $i$ , dividing that by the reporting rate  $\lambda_i$  for that band type and report method (using the same U.S. reporting rates as in the composite reporting rate described in Chapter 4, Model Parameters and Datasets) to get the total birds harvested during the early season of the  $i$ th band type/reporting method combination in each flyway. I summed these to get total early season harvested birds in each flyway in the U.S. in each year, and I divided these by the total number of bands of all types put out each year to get early season harvest rate in each flyway in the U.S. based on direct recoveries (Fig. 2):

$$h_{t, flyway} = \frac{\sum_i \frac{(\# \text{ direct early season recovs})_i}{\lambda_i}}{(\# \text{ total bands})_t}$$

I did not calculate harvest rates for 2011 because recovery rates could be underestimated due to late (more than 1 year after) reporting of recovered birds. I used multiple linear regression to investigate the relationship between either early harvest or harvest rate and early harvest season structure variables, and included harvest age ratio (juvenile harvest/adult harvest, uncorrected for differential vulnerability

which I assumed to be constant over the time period) and the breeding population size (*BPOP*) as additional explanatory variables.

I also compared models using pooled early season harvest or harvest rates for the MF and CF combined. The history of 9- and 16-day early teal seasons in these flyways has been nearly the same from 1992 to 2011, with the exception of Iowa in the MF, which offered a 5-day special teal and wood duck season, and Nebraska in the CF, which did not have an early season until 2000. To determine if there was a general response in early harvest or harvest rate across the two flyways, I compared models using the combined early harvest and recovery data from both with the same set of predictor variables summed over both flyways.

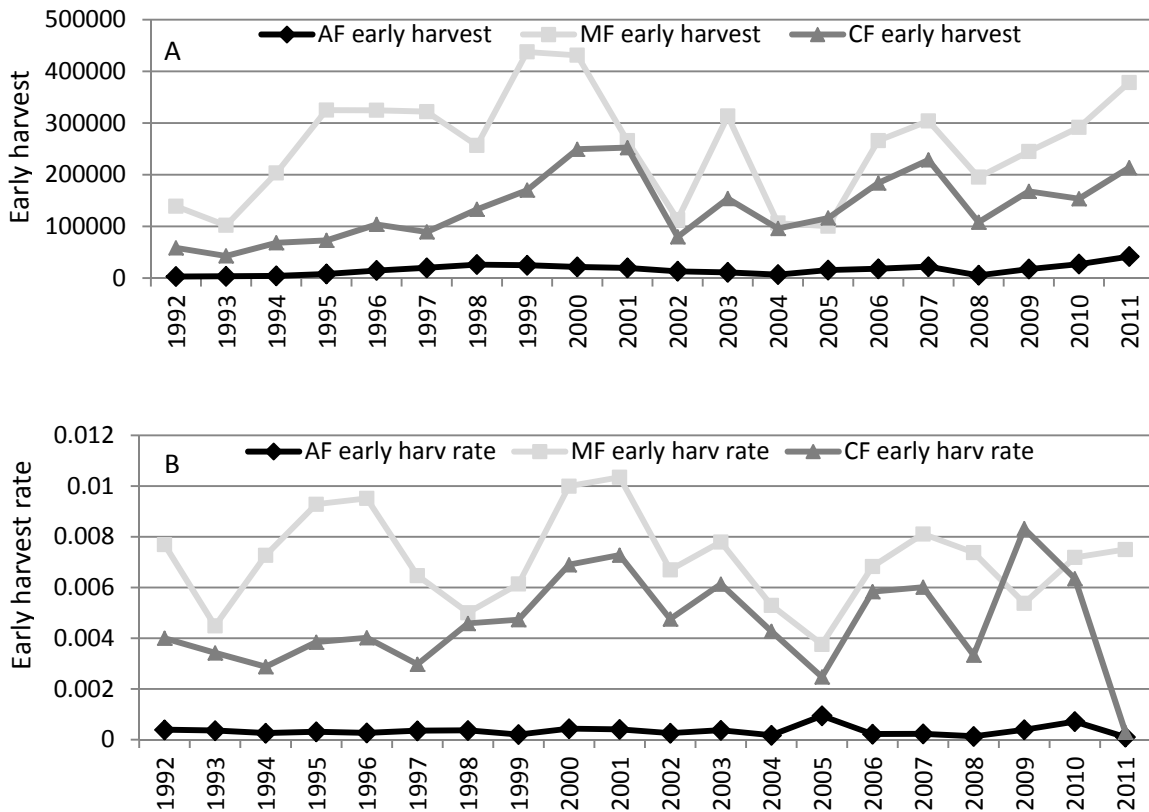


Fig. 1. Blue-winged teal early harvest 1992–2011 (A) and harvest rate 1992–2010 based on early season direct recoveries (B) by flyway.

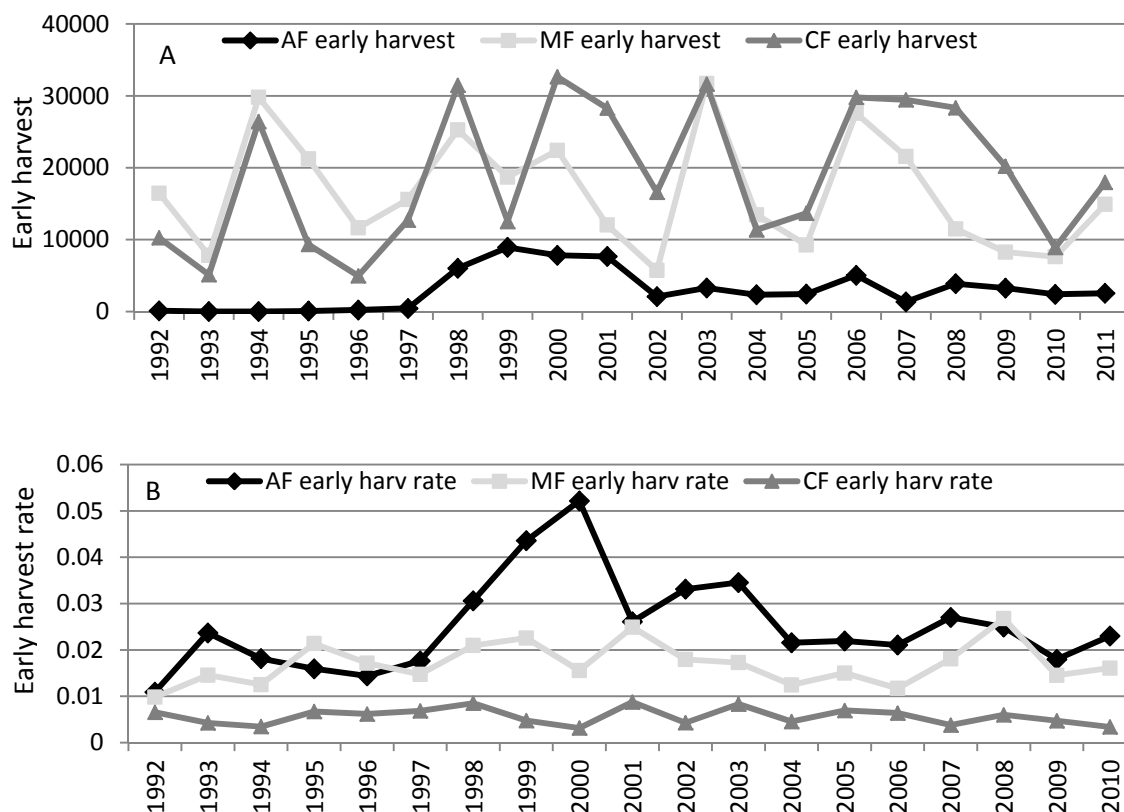


Fig. 2. Green-winged teal early harvest 1992–2011 (A) and harvest rate 1992–2010 based on early season direct recoveries (B) by flyway.

I compared the full models and sets of reduced models for each response variable and each flyway (1 full model and 14 reduced models in each set), and selected the model with the most support based on the minimum  $AIC_c$  ( $AIC$  corrected for small sample size), as well as models with  $\Delta AIC_c \leq 2$ . I evaluated fit of full models using  $R^2$ , fit of selected models using adjusted  $R^2$  (coefficient of determination adjusted for number of model parameters), and relative fit using Akaike model weights. I used the sum of Akaike weights of models containing each harvest season variable to evaluate the relative importance of each variable in the model set (Burnham and Anderson 1998).

### Results: Blue-winged Teal

**Early harvest rate:**—The fit of the full models for all flyways was relatively poor ( $R^2$  ranged from 0.13 in the MF to 0.62 in the CF). I had trouble fitting the blue-winged teal harvest rate models for the AF and the MF. In the AF, the selected model included *early season days*, but its Akaike weight was only 0.16, and the model fit was poor (Table 1). Six other models had  $\Delta AIC_c \leq 2$ , with combined weights 0.49; overall, early season days was a more important predictor than early season states (Table 2). In the MF, the selected model did not include harvest season variables, but its weight was only 0.25, also with poor

fit (Table 1). Two other models had  $\Delta AIC_c \leq 2$ , with combined weights 0.23. There was little support for either harvest season variable in the model set (Table 2). In the CF, the selected model included *early season days*, with Akaike weight 0.40; one other model had  $\Delta AIC_c \leq 2$ , containing *early season days* and *AR*, with weight 0.19 (Tables 1 and 2, Fig. 3). There was much more support for *early season days* in the model set than for *early season states* (Table 2). The best model for the combined MF–CF harvest rate contained *early season days*, with Akaike weight = 0.27 (Table 1); 2 other models in this set had  $\Delta AIC_c \leq 2$ , with combined weights 0.28. One of these models included *early season days*, although its model weight was only 0.11 (Fig. 4). *Early season days* appeared to be more important than *early season states* in predicting *early harvest rate* in these flyways (Table 2).

*Early harvest.*—All of the full models of this response variable had relatively good fit ( $R^2$  ranged from 0.7 in the MF to 0.77 in the AF). In the AF, the selected model contained *BPOP*, *AR*, and *early season states*, and fit the data fairly well (Table 1, Fig 5A). Akaike weight for this model was 0.43. One other model had  $\Delta AIC_c \leq 2$ , and contained *early season days* with weight 0.24. There was fairly equal support for both harvest season variables in the model set (Table 2). In the MF, the selected model contained *BPOP* and *age ratio*, and also fit the data well (Table 1). Akaike weight for this model was 0.43. There was 1 other model with  $\Delta AIC_c \leq 2$ , with weight 0.2, but this model contained only one variable, *BPOP*. Overall, there was little support in the model set for either harvest season variable (Table 2). The selected model for the CF contained *early season days*, and fit the data fairly well, but its weight was only 0.26 (Table 1, Fig. 5B). Two other models with  $\Delta AIC_c \leq 2$  contained *early season days* and had combined weight = 0.38. In this flyway, *early season days* had more than 3 times as much support in the model set as *early season states* (Table 2). The selected model for the combined MF–CF early harvest fit the data fairly well (model weight 0.3) but only contained one variable, *BPOP* (Table 1). Although the  $\Delta AIC_c$  values for 3 other models were  $\leq 2$  (with combined weight 0.48), none of them contained season structure variables as predictors. Overall, for the MF–CF there was more support for *early season days* than *early season states* (Table 2).

Table 1. Selected regression models (with adjusted  $R^2$ ) for each flyway and response variable. DAYS = number of early season days; STATES = number of early season states; BPOP = breeding population size; AR = harvest age ratio.

Species/flyway	Early harvest rate	Early harvest
Blue-winged teal		
AF	$0.00029 + 0.0000015 * \text{DAYS}$ (0.16)	$-21939 + 4.13 * \text{BPOP} + 5246 * \text{AR} + 1178 * \text{STATES}$ (0.73)
MF	$0.0004 + 0.000005 * \text{BPOP}$ (0.06)	$-183684 + 61.5 * \text{BPOP} + 56561 * \text{AR}$ (0.66)
CF	$0.001 + 0.000053 * \text{DAYS}$ (0.57)	$-28968 + 2280 * \text{DAYS}$ (0.69)
MF–CF combined	$0.003 + 0.000013 * \text{DAYS}$ (0.27)	$-143489 + 91.8 * \text{BPOP}$ (0.69)
Green-winged teal		
AF	$0.014 + 0.004 * \text{STATES} - 0.0002 * \text{DAYS}$ (0.35)	$-1301.7 + 719.3 * \text{STATES} + 575.5 * \text{AR}$ (0.32)
MF	$0.0099 + 0.00055 * \text{DAYS}$ (0.15)	$21172 - 8.75 * \text{BPOP} + 134.6 * \text{DAYS}$ (0.12)
CF	$0.0066 - 0.0000012 * \text{BPOP} + 0.0011 * \text{AR}$ (0.32)	$13073 - 9.56 * \text{BPOP} + 418 * \text{DAYS}$ (0.49)
MF–CF combined	$0.0080 + 0.0000165 * \text{DAYS}$ (0.08)	$30726 - 17.02 * \text{BPOP} + 236.1 * \text{DAYS}$ (0.33)

Table 2. Sum of Akaike model weights of harvest season predictor variables (over all models in each candidate set containing each predictor variable) early season states (STATES) and early season days (DAYS), in each flyway and for each response variable.

Species/flyway	Early harvest rate		Early harvest	
	DAYS	STATES	DAYS	STATES
Blue-winged teal				
AF	0.56	0.39	0.41	0.57
MF	0.33	0.31	0.21	0.21
CF	0.96	0.24	0.96	0.27
MF–CF combined	0.64	0.27	0.45	0.22
Green-winged teal				
AF	0.61	0.94	0.39	0.94
MF	0.66	0.48	0.54	0.47
CF	0.42	0.28	0.98	0.21
MF–CF combined	0.70	0.28	0.95	0.27

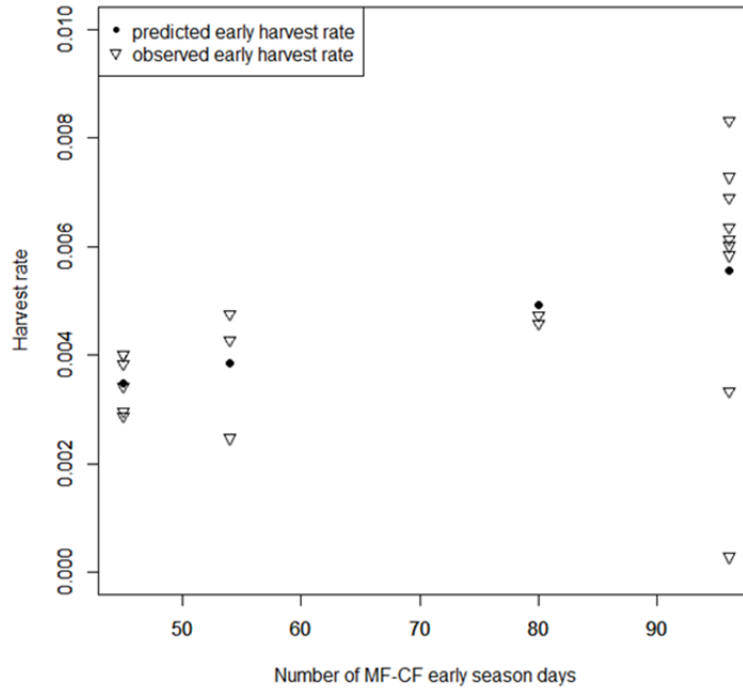


Fig. 3. Predicted and observed blue-winged teal early harvest rate from Central Flyway selected model:  $blue\text{-winged}\ teal\ early\ season\ harvest\ rate = 0.001 + 0.000053 * early\ season\ days$ .

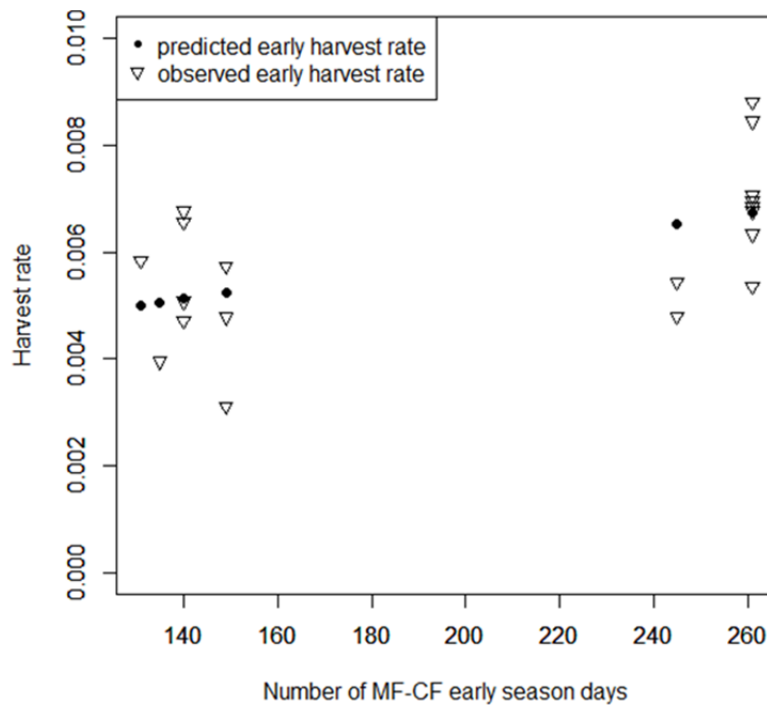


Fig. 4. Predicted and observed Mississippi-Central flyway early blue-winged teal harvest rate from selected model:  $harvest\ rate = 0.003 + 0.000013 * early\ season\ days, 1992\text{--}2010$ .



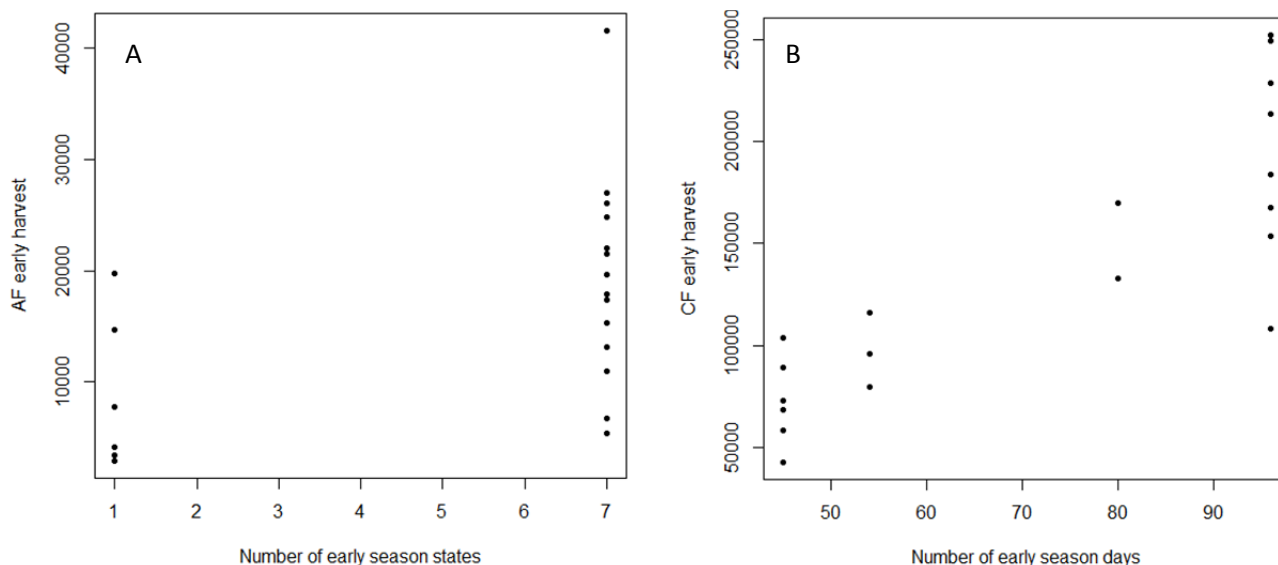


Fig. 5. Plot of (A) blue winged-teal early harvest vs. number of early season states in the Atlantic Flyway, 1992–2011; (B) blue-winged teal early harvest vs. number of early season days in the Central Flyway, 1992–2011.

### Results: Green-winged Teal

*Early harvest rate.*—The fit of the full models using this response variable ranged from  $R^2 = 0.25$  in the combined MF–CF to 0.58 in the AF. For the AF, the selected model contained both *early season states* and *early season days* (model weight 0.34, Table 1, Fig. 6A). Two other models had  $\Delta AIC_c \leq 2$  with combined weights 0.51; both of these models contained *early season states*, and one contained *early season days*. In the model set there was much more support for *early season states* than for *early season days* (Table 2). In the MF, the selected model contained *early season days* (Table 1, Fig 7). However, its Akaike weight was only 0.25, and 2 other models had  $AIC_c$  values within 2 units; both contained *early season states*, and one contained *early season days* (combined weight 0.25). Based on the summed weights, *early season days* was a more important variable in the model set than *early season states* (Table 2). In the CF, the selected model contained *BPOP* and *age ratio*, but did not contain harvest season variables (Table 1). However, the model weight was only 0.23, and 3 other models had  $AIC_c$  values within 2 units of the selected model, with combined weights 0.48. These models contained both harvest season variables. *Early season days* had more support than *early season states* in the data set (Table 2). The selected model for the combined early harvest rate in the MF and CF contained *early season days* but this model had poor fit (Akaike weight 0.23, Table 1); 3 other models had  $\Delta AIC_c$  values  $\leq 2$ , with combined weight 0.34. *Early season days* was a predictor in 2 of these models, and overall was a more important variable in the model set (Table 2, Fig. 8B).

*Early harvest.*—Fit of the full models based on this response variable ranged from  $R^2 = 0.12$  in the MF to 0.56 in the CF. In the Atlantic Flyway, the selected model contained *age ratio* and *early season states* (Table 1, Fig. 6B). The Akaike weight for this model was 0.46. One other model, containing both *early*

*season days* and *early season states*, had  $\Delta AIC_c \leq 2$ , with weight 0.29. There was marginally more support for *early season states* than *early season days* in the model set (Table 2). In the Mississippi Flyway, the selected model included *early season days* and *BPOP* (Table 1); however, this model was not well supported by the data (Akaike weight 0.13) – and 8 other models were within 2 units of the lowest  $AIC_c$ , with combined weight 0.65. One of these models had nearly the same weight as the selected model, and contained only the *age ratio* variable (weight 0.13). *Early season days* was marginally more important than *early season states* in these models (Table 2). In the Central Flyway, the selected model contained *early season days* and *BPOP* (Table 1, Fig. 9), with model weight 0.39. There was 1 other model with  $\Delta AIC_c \leq 2$ , with weight 0.18; this model contained only the *early season days* variable, which was much more important in the model set than *early season states* (Table 2). The selected model for combined early harvest in MF and CF contained *early season days* and *BPOP* (Akaike model weight 0.37, Table 1, Fig. 8A). Two other models had  $\Delta AIC_c$  values  $\leq 2$ , with combined weight 0.43. Both of these models contained *early season days*, and one contained *early season states*, but *early season days* had much more support overall in the model set (Table 2).

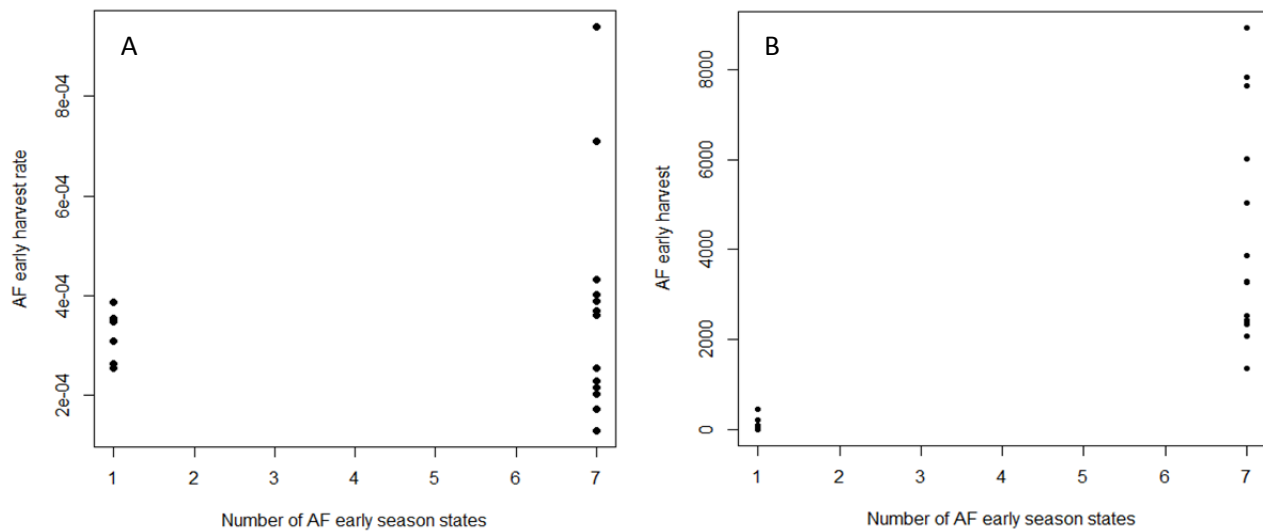


Fig. 6. Plot of green-winged teal early season harvest rate 1992–2010 (A) and early season harvest 1992–2011 (B) vs. number of early season states in the Atlantic Flyway.

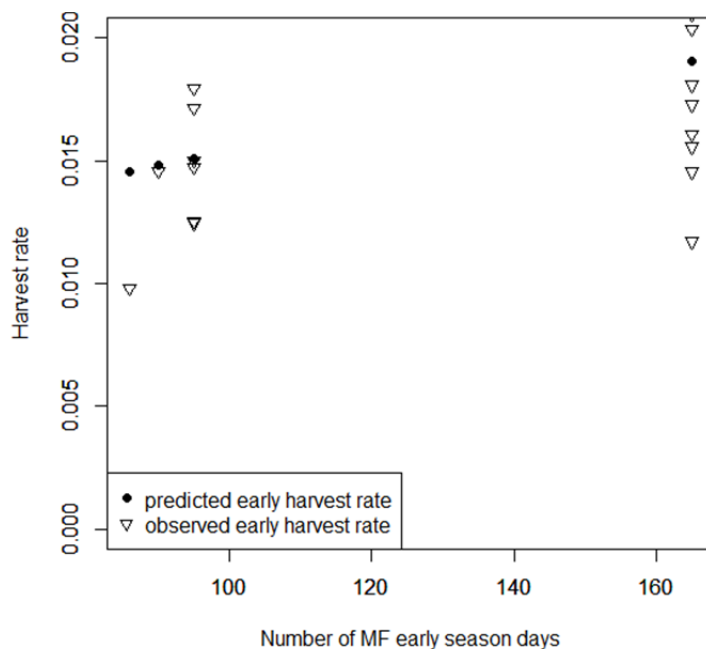


Fig. 7. Predicted and observed green-winged teal early harvest rate in the Mississippi Flyway, from the selected model:  $early\ harvest\ rate = 0.0097 + 0.00056 * early\ season\ days$ , 1992–2010.

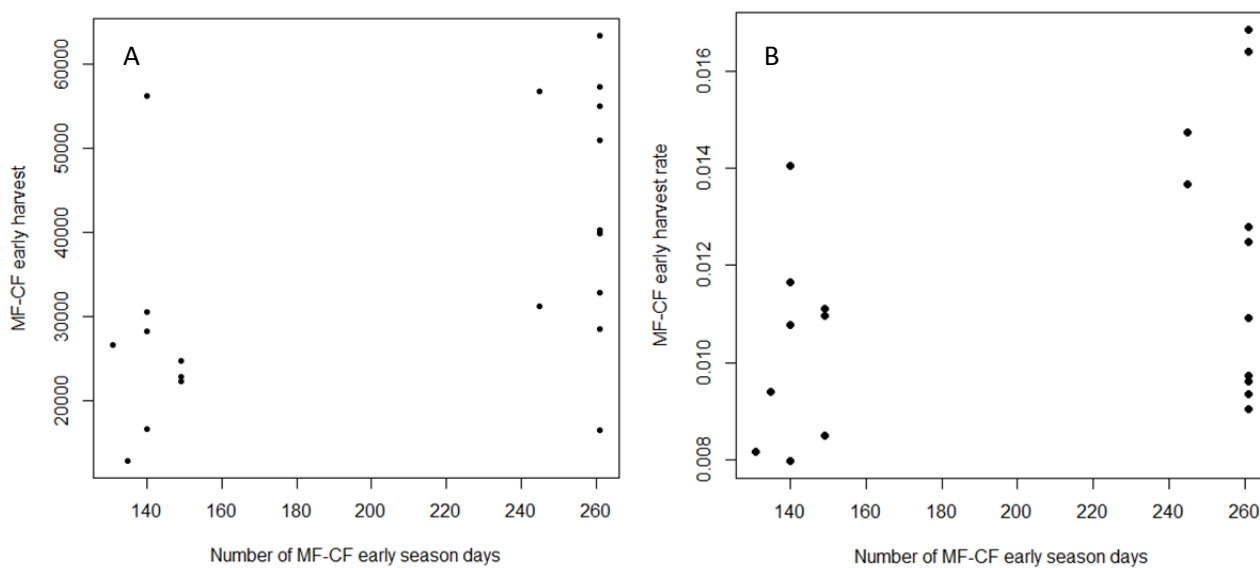


Fig. 8. Plot of (A) green-winged teal MF–CF early harvest and (B) green-winged teal MF–CF early harvest rate vs. number of early season days, 1992–2011.

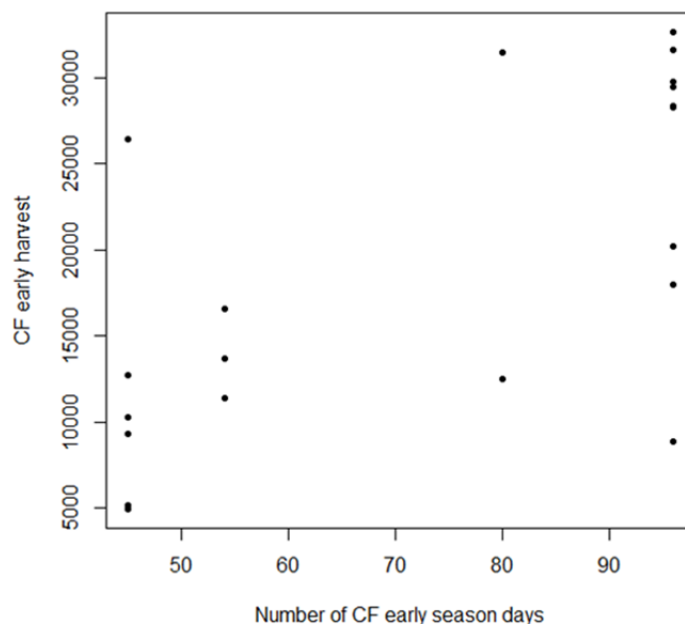


Fig. 9. Plot of green-winged teal early harvest vs. number of early season days in the Central Flyway, 1992–2011.

### Discussion

*Blue-winged teal.*—Blue-winged teal early harvest models were better fit by the data than those of green-winged teal. *Early season days* was a better predictor than *early season states*, similar to green-winged teal, and was more important in predicting harvest rate than early harvest. The AF early harvest model had the best fit, but contained a completely different set of predictor variables than the AF harvest rate model (Table 1), and did not contain *early season days*. In the Central Flyway, the number of early season days appeared to be a fairly good predictor of both the harvest rate (based on direct recoveries of banded birds during the early season) and the early season harvest. However, the number of early season days during this time period only varied between 9 (1992-1997, 2002, 2004-2005) and 16 (1998-2001, 2003, 2006-2010) in the Central and Mississippi flyways (Fig 10). Despite the similarity in early season history in the Central and Mississippi flyways, pooling the harvest and direct recoveries did not improve the predictive ability of the selected models for blue-winged teal.

*Green-winged teal.*—The selected models for green-winged teal were similar to those of blue-winged teal, although the fit of several of the models was poor. *Early season days* was more important than *early season states* in predicting both early harvest and harvest rate. The Atlantic and Central Flyway green-winged teal models were better fit by the set of covariates than the Mississippi flyway or MF–CF combined. The green-winged teal early harvest models for CF, MF, and combined CF–MF were very similar, containing only *BPOP* and *early season days*, although the harvest rate models were not. There appeared to be more variation in the two harvest time series for green-winged teal than for blue-winged teal, which may have resulted in differences in the selected models (Figs. 1 and 2). The green-winged

teal early harvest is much more annually variable than the harvest rate, perhaps due to annual changes in population size for this species.

*Model fit.*—Overall, many of the models I considered had relatively poor fit, which limited their utility in predicting relationships between early season structure and early season teal harvest. The poor fit may be due to the small number of changes in the structure of the early harvest season from 1992 to 2011, the influence of other factors not included in the models, or error in the estimates of harvest or harvest rate.

There were only two values (1 state or 7 states) for *early season states* in all the flyways during the time period covered by the data, which limits the degree to which predictions can be made about how future changes to the number of states in the early teal season will affect teal harvest. There was more variation in the number of early season days during the time period covered by the data, but even that variable was limited in most flyways to 3 or 4 values. Also, the two harvest season structure variables were correlated, both showing an increase over the time period (for all flyways combined,  $r = 0.84$ ,  $P < 0.0001$ ), making it difficult to determine which one might have the greater influence on harvest. Summed Akaike weights provided a measure of the relative importance of each variable in predicting harvest, and suggested that the number of days rather than the number of states was more important in most of the model sets. However, the underlying factors affecting harvest that both of these variables only proximately represent are the number of hunters and hunter effort, both of which are only partially controllable by the season structure. Other factors such as teal breeding population size, breeding habitat conditions, long-term trends in hunter numbers, and the status of other duck species all determine how many hunters will participate and be successful during the early teal season (Fig. 11). Timing of migration (especially in blue-winged teal) may also affect how many teal are exposed to early season hunters, especially adult males.

There are potential sources of error in both the estimate of harvest rate and early harvest during this time period that could lead to poor model fit. The time series includes both a change in the way harvest data were collected (MSQ to HIP, 1998-99) as well as a change in band reporting methods (1995-2000). Either of these could have added noise (or bias) to the time series that would be difficult to quantify. In addition, differences in the time series of harvest and harvest rates could be responsible for the inconsistencies between selected models predicting harvest rate and those predicting early harvest. These two response variables are based on two different sources of information (banding and recovery data vs. harvest surveys), and ultimately measure different aspects of harvest (Figs 1 and 2). Harvest rate, by definition, contains information on both harvest and population size, the latter represented by the sample of banded birds in that year. Breeding population size is an important predictor of early harvest: BPOP was included in 6 of 8 of the early harvest models, more than the harvest rate models. Population size is important in several respects: not only is it used (for blue-winged teal) to set the length of the early teal season (0, 7, or 16 days), but it also affects hunters' motivation to hunt. Breeding population size, along with the production of young, determines the number of ducks available during the hunting season. Harvest age ratios provide information on the year's production of juvenile birds, and were also included in several of the early harvest selected models.

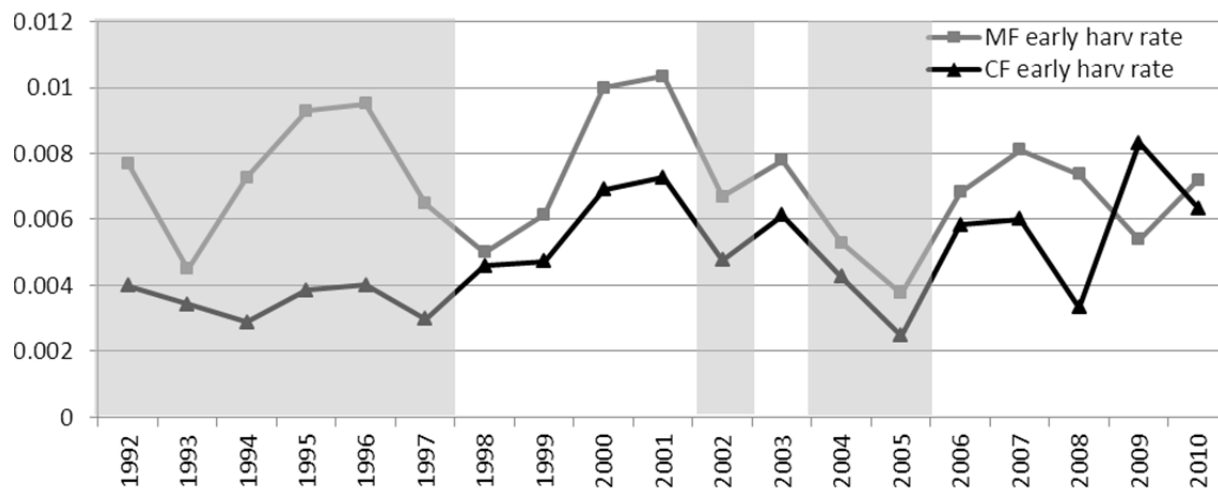


Fig. 10. Blue-winged teal early harvest rate in the Mississippi and Central flyways (9-day seasons shown in gray; all other years were 16-day seasons).

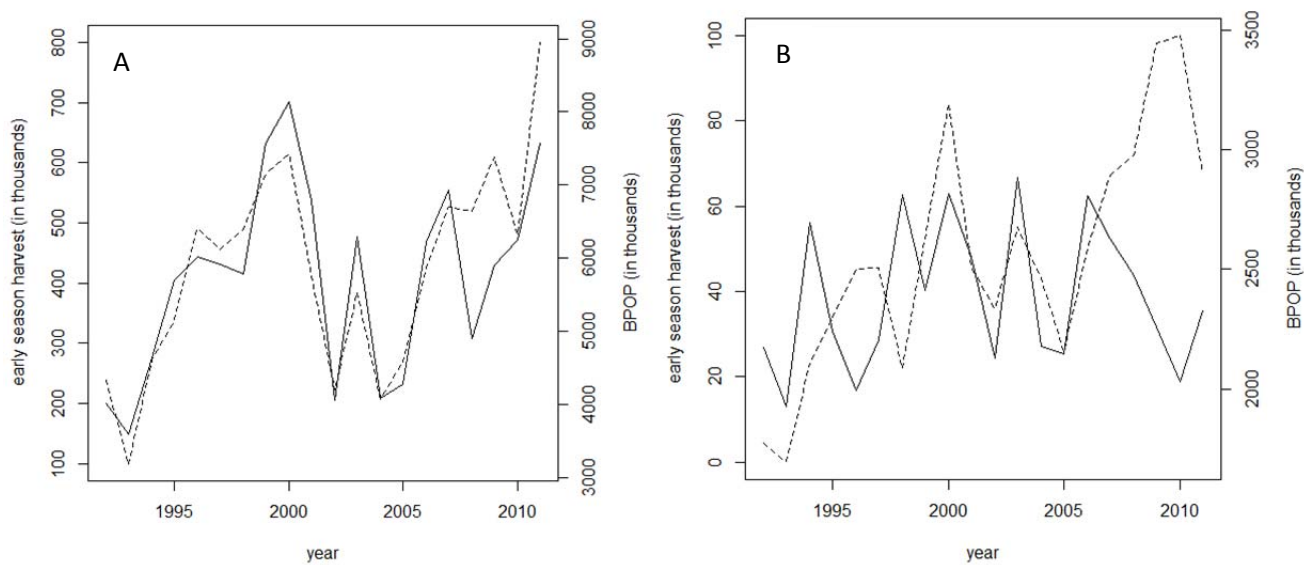


Fig. 11. Blue-winged (A) and green-winged (B) teal early harvest (in thousands; solid line, left axis) and breeding population size (in thousands; dashed line, right axis) from 1992 to 2011.

## Chapter 4. Teal Population Models and Optimal Harvest Dynamics

### Introduction

To assess the harvest potential of blue-winged and green-winged teal, we had to first develop models that described the population dynamics of each species, including recruitment dynamics and the effects of harvest. We based these models on the balance equation used in harvest management of mid-continent mallards (Runge et al. 2002). We chose this model structure because (1) sufficient banding and recovery data existed for both species to estimate survival and recovery rates, (2) information on breeding population size (BPOP) and annual production was available for both species throughout most of their range, and (3) the balance equation allowed us to incorporate alternate model structures related to hypotheses regarding the extent to which harvest may be additive or compensatory.

Using the balance equations, with sub-models to predict (1) recruitment based on pond conditions and breeding population size, and (2) survival as a function of the level of harvest, we simulated equilibrium population dynamics to estimate levels of equilibrium population size, optimal harvest rate (i.e., harvest rate resulting in the maximum sustained yield), and carrying capacity under a range of scenarios related to habitat conditions and uncertainty in each species' response to harvest.

### Balance Equation

We followed the balance equation structure developed for mid-continent mallards which predicts the May BPOP from the previous year's breeding population, annual survival, and recruitment (Runge et al. 2002):

$$\text{BPOP}_{t+1} = \text{BPOP}_t \{ m S_{t,AM} + (1 - m) [ S_{t,AF} + \text{AR}_t ( S_{t,JF} + ( S_{t,JM} * S_{fsum} / S_{msum} ) ) ] \}$$

where  $\text{BPOP}_{t+1}$  is the breeding population in year  $t+1$ ,  $\text{BPOP}_t$  is the breeding population in year  $t$ ,  $m$  is the fraction of males in the BPOP,  $\text{AR}_t$  is the female age ratio,  $S_{t,AM}$  is adult male survival in year  $t$ ,  $S_{t,AF}$  is adult female survival,  $S_{t,JM}$  is juvenile male survival,  $S_{t,JF}$  is juvenile female survival, and  $S_{fsum}/S_{msum}$  is the ratio of female-to-male summer survival.

The balance equation uses information from both May–May (BPOP) and August–August (preseason age ratios [an index to production of young], survival rates) time periods. This model is based on the following assumptions:

1. Equal sex ratio at hatching.
2. Summer survival of adults and young is the same (but can be different for males and females).
3. Survival rates for the period post-harvest to May are equal for both sexes (so that the ratio of male to female non-hunting survival can be used to estimate the ratio of male to female summer survival).
4. Ratio of male to female summer survival is constant across years.

In order to integrate information about the breeding population size (observed in May) with annual survival rates (from August to August) and preharvest age ratios (August) in a single equation, they must be synchronized to the same period of the annual life cycle. This is accomplished by translating BPOP into a preharvest population size (accounting for differences in survival between sexes from May until the preharvest period of August by multiplying by the ratio of male to female summer survival; Runge et al. 2002).

The correlation between the predicted change in the BPOP from time  $t$  to  $t+1$  (predicted  $BPOP_{t+1}/BPOP_t$ ) and the observed change ( $BPOP_{t+1}/BPOP_t$ ) was used to assess the predictive ability of the balance equation, and measured the degree of over or under-prediction based on the average (over all years) percent difference of the predicted value from the observed value. To be consistent, the same time series (1974–2009) was used for evaluations of both balance equation and recruitment model performance. Because we were developing the balance equation to simulate equilibrium dynamics, the main concern was to make the models as predictive as possible; therefore the primary criterion for choosing among datasets was the predictive ability of the resulting model.

## **Model Parameters and Datasets**

### ***BPOP***

We used the blue-winged and green-winged teal BPOP estimates from the May Waterfowl Breeding Population and Habitat Survey traditional survey area (Smith 1995) as an estimate of annual breeding population size. To determine if the balance equation could be improved by including additional breeding population estimates outside of the traditional survey area, we compared model predictions using the traditional area BPOP to those using a combined population estimate. For blue-winged teal the combined estimate comprised the traditional survey area BPOP + estimates from lake states (Wisconsin and Minnesota, 1973–2009; we did not include data from Michigan due to the limited time series of the breeding survey which began in 1992). For green-winged teal we compared the traditional survey area BPOP to estimates from the combined traditional area + eastern survey area (1990–2009). For blue-winged teal, adding in the lake states BPOP did not appreciably change the predictive ability of the model for the 26-year time series (for traditional area BPOP,  $r = 0.604$  [ $P = 0.0002$ ]; for combined BPOP,  $r = 0.601$  [ $P = 0.0002$ ]). For green-winged teal, the correlation was marginally higher (but not significant) using the combined BPOP: for the 19-year time series  $r = 0.205$  ( $P = 0.429$ ) for the traditional area BPOP vs.  $0.192$  ( $P = 0.459$ ) for the combined estimate. However, using the combined BPOP for green-winged teal would have reduced the length of the time series from 38 years to 19 years. Therefore, for both species we based the balance equations on the traditional survey area BPOP alone.

### ***Survival and Recovery Rates***

Cohort-specific survival rates were used in the balance equation to estimate the number of birds of each cohort surviving from August of year  $t$  to August of year  $t+1$ . Survival and recovery rates were also used to estimate survival in the absence of harvest (Runge 2002).



*Blue-winged teal.*— We used bandings and recoveries from 1965 to 2009 of birds banded within the three groups identified by the blue-winged teal harvest derivation analysis (Szymanski and Dubovsky in press). We selected pre-season banding records (July, August, September) of all normal, wild birds and recoveries of birds shot or found dead in all months except May, June, July, and August, and inexact dates of spring and summer (we included recoveries from March and April because blue-winged teal are shot by hunters south of the U.S. border during these months). We included both solicited (reported as part of a parts collection or mail survey, or by someone on behalf of the finder) and unsolicited (reported by finder but not at the request of another person) recoveries. We used the Brownie dead recoveries model  $s(a*s*t)f(a*s*t)$  in program MARK to estimate survival and recovery rates by year for each age and sex cohort (White and Burnham 1999). Although we used the 3-group boundaries to delineate our sample of bandings, we did not include a group effect due to the small number of recoveries in some groups and years. We used a logit link, with simulated annealing optimization to provide initial parameter estimates for the model. Fit of the full model was fairly good (median  $\hat{c}$  = 1.2; see Chapter 2, Survival and Recovery Estimates).

*Green-winged teal.*— We used green-winged teal bandings and recoveries from 1965 to 2009 for normal, wild birds found dead or shot (Table 1) within the 3-group region identified by an analysis of band-recovery distributions (see summary in Chapter 2, Vulnerability and Recruitment). We included both solicited and unsolicited bands, using the same criteria as for the blue-winged teal banding analysis except that we did not use recoveries from April, due to the small number recovered outside of the U.S. We fit the Brownie model  $s(a*s*t)f(a*s*t)$  in program MARK to generate age- and sex-specific annual survival and recovery rates, using an alternative optimization method (simulated annealing) to generate initial parameter estimates, then fit the model using maximum likelihood estimation with the sine link function (White and Burnham 1999). This model fit the data fairly well, with estimated median  $\hat{c}$  equal to 1.2. Similar to blue-winged teal, we did not include a group effect due to the small number of recoveries in some years, and because the selected model for green-winged teal survival rates did not include a group effect (see Chapter 2, Survival and Recovery Estimates).

Table 1. Number of total bandings and recoveries by cohort of green-winged teal in the 3-group region (west, mid-continent, and east) 1965–2009 (see Fig. 5 in Chapter 2, Vulnerability and Recruitment).

<b>Sex</b>	<b>Age</b>	<b>Bands</b>
Male	adult	55,827
Male	juvenile	73,403
Female	adult	29,562
Female	juvenile	57,116
<b>Sex</b>	<b>Age</b>	<b>Recoveries</b>
Male	adult	5,337
Male	juvenile	8,213
Female	adult	2,068
Female	juvenile	4,539

### Harvest Rates

Harvest rates were used to examine the relationship between survival and kill rates, to represent hypotheses of compensatory vs. additive harvest mortality, and estimate cohort-specific survival in the absence of harvest.

*Blue-winged teal.*—In order to estimate harvest rates, band recovery rates were adjusted by accounting for birds harvested but not reported. These adjustments are usually estimated using reporting rates from reward band studies (Anderson and Burnham 1976, Nichols et al. 1991, Nichols et al. 1995). A substantial proportion of blue-winged teal harvest occurs in the Caribbean and Central and South America; however, no estimates of reporting rates exist from reward bands recovered south of the U.S. border (see Model Uncertainties, below). Based on the lack of information available to estimate reporting rates south of the border, and the wide disparity in speculated reporting rates, we used only the U.S. and Canada recoveries to estimate a combined U.S. + Canada harvest rate. For this harvest rate, we used bands recovered only from September to February to represent birds killed during the U.S. and Canadian harvest seasons. We adjusted the annual U.S. + Canada recovery rates using reporting rates from mallard reward band studies (Nichols et al. 1995, Boomer et al. in press). For recoveries of abbreviated address (AVISE) bands up to 1995 we used a reporting rate of 0.32 for the U.S. and Canada (Nichols et al. 1991). During the period 1995–2009, abbreviated address bands were gradually replaced by complete address bands and later, toll free and web address bands, and new reporting methods (phone, internet) became available. From 1995-on, a substantial number of abbreviated and complete address bands were reported by other methods than by mail, with unknown (but assumed higher) reporting rates. For this period we used a composite reporting rate which was calculated as a weighted mean based on the proportions of bands in each combination of band type/reporting method/region (U.S. or Canada) recovered (P. Garrettson, unpublished data). This method is an *ad hoc* approach which, while simple to calculate, requires assumptions about how reporting rates of bands change when reported by other methods than what is inscribed on the band (e.g., abbreviated or complete address bands reported by phone or internet), and provides no estimate of precision. For abbreviated and complete address bands reported from 1995 to 2009, we adjusted reporting rates depending on the report method: for mail reports, we used 0.32 (Nichols et al. 1991); for phone and web reports we assumed the rate would be the same as for toll free bands, for which we used the average of the flyway reporting rates for toll free bands reported in Boomer et al. (in press): 0.74 for U.S., 0.54 for Canada. For “other” or “unknown” recoveries or band types we used the abbreviated address band reporting rate by mail of 0.32. If reporting method was unknown we used the reporting rate for that band type and region. For solicited bands we assumed a reporting rate of 1. These weighted recovery rates were summed over all band type/reporting method/region combinations to give a composite estimate for each year.

We calculated the annual harvest rates for each cohort according to the equation:

$$h_j = \frac{f_j}{\sum (w_i \times \lambda_i)}, \text{ where } w_i = \left(\frac{R_i}{\lambda_i}\right) / \sum \left(\frac{R_i}{\lambda_i}\right)$$

where  $h_j$  and  $f_j$  are the annual harvest rate and annual recovery rate for cohort  $j$ , respectively,  $R_i$  is the number of recoveries of region/band type/reporting method combination  $i$ , and  $\lambda_i$  is the reporting rate for region/band type/reporting method  $i$ . The denominator is the composite reporting rate, which is a weighted average of all the reporting rates for the different region/band type/reporting method combinations. Here each weight was calculated as the proportion of birds harvested by each region/band type/reporting method out of the total birds harvested in that year (not the proportion of total recoveries, because the proportion of recoveries would differ from the proportion of harvested birds if reporting rates differed among the combinations). Since the actual number of birds harvested was unknown, it was estimated by dividing the recoveries for each region/band type/reporting method combination by the reporting rate for that combination. A composite rate was calculated for each year and used to convert cohort-specific recovery rates into harvest rates (Fig. 1). Although the band recoveries from south of the U.S. border were not used to calculate U.S. + Canada harvest rates, they were used to construct an additional equilibrium dynamics model based on total harvest rates. This model was used to estimate optimal harvest levels (all countries combined) in order to place the U.S. + Canada harvest rates in the context of overall harvest potential of the species (e.g., see Fig. 12). For these recoveries we used a reporting rate of 0.1, the upper bound estimated from an analysis of blue-winged teal harvest mortality and survival (F. Johnson, unpublished data).

*Green-winged teal.*—Harvest rates for green-winged teal were calculated using all recoveries, including 175 from south of the U.S. border (Fig. 2). We calculated a composite reporting rate similarly to the method used for blue-winged teal, assigning a reporting rate of 0.1 to south of border recoveries of abbreviated and complete address bands reported by mail, and 0.23 for toll-free and web-address bands, or for abbreviated and complete address bands reported by phone or internet.

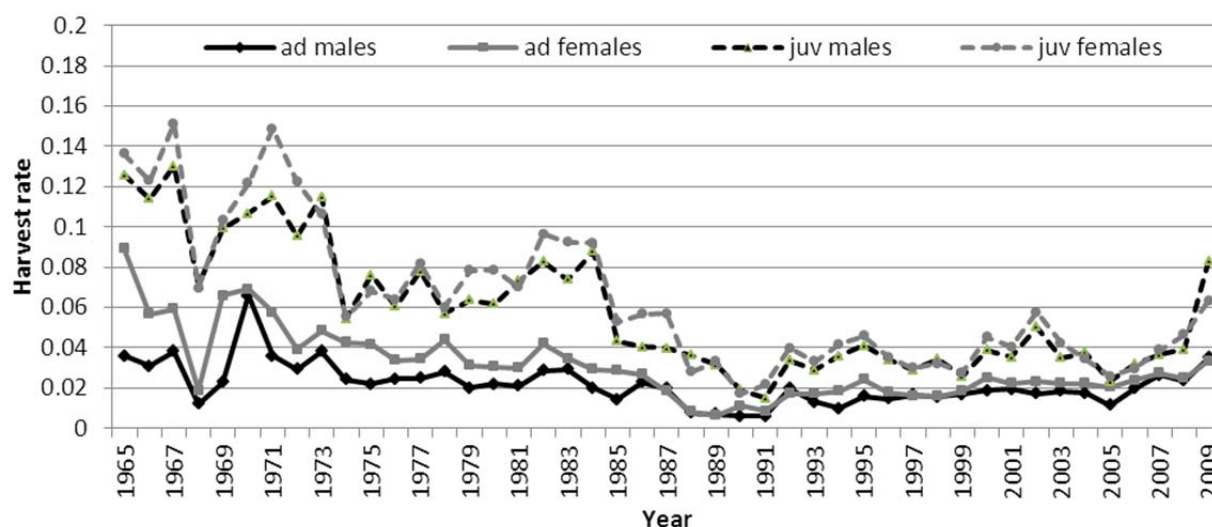


Fig. 1. Blue-winged teal U.S. + Canada annual harvest rates by cohort, 1965–2009, estimated from band recovery rates using a composite reporting rate.

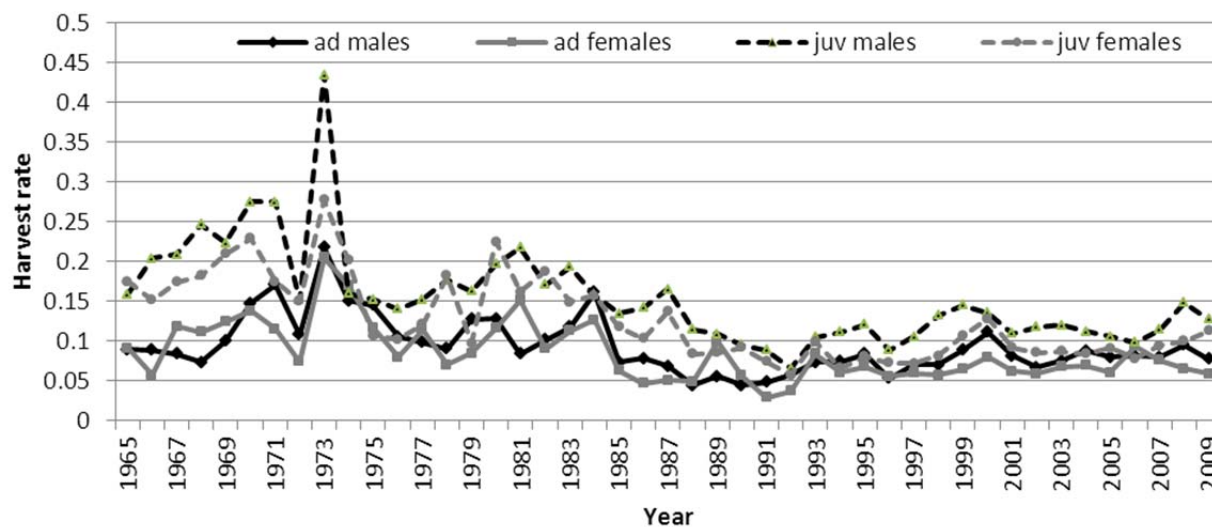


Fig. 2. Green-winged teal annual harvest rates by cohort, 1965–2009, estimated from band recovery rates using a composite reporting rate.

### Age Ratios

We used preseason age ratios from a hierarchical model fit using MCMC estimation (Chapter 2, Vulnerability and Recruitment) for the period 1970–2008 (Zimmerman et al. 2010). Evidence suggested that the male-to-female sex ratio has been increasing in both blue- and green-winged teal populations over time, possibly causing male age ratios to be biased low (Chapter 2, Vulnerability and Recruitment). Although male age ratios for blue- and green-winged teal were estimated with more precision than female age ratios, to avoid the bias from an increasing male sex ratio we used female age ratios, and compared those calculated with either constant (i.e., averaged over all years) or annual differential vulnerability based on two criteria: (1) the predictions resulting from the balance equation, measured by the correlation between the predicted and observed change in breeding population size, and (2) the fit of the recruitment model predicting age ratios as a function of the total U.S. + Canadian May pond counts and BOPs (Table 2). Based on these criteria we selected the female age ratios calculated using annual differential vulnerability. Although these age ratios exhibited wider annual fluctuations and higher variance than the age ratios calculated using a constant differential vulnerability, these fluctuations appear, at least in blue-winged teal, to be correlated with annual variation in ponds.

Table 2. Predictive performance of balance equation and fit of recruitment models for blue- and green-winged teal using female age ratios with either constant or annual differential vulnerability (DV).

	female AR, constant DV		female AR, annual DV	
	predictive correlation of balance equation	$R^2$ of recruitment model	predictive correlation of balance equation	$R^2$ of recruitment model
BWTE	0.29	0.47	0.60	0.53
AGWT	0.17	0.45	0.22	0.15

Using female age ratios in the balance equation resulted in substantial over-prediction of the observed BPOP (as estimated from the May survey) for each species (33% for BWTE and 46% for AGWT). We compensated for this over-prediction by including a bias correction factor, similar to the mid-continent mallard model (Runge et al. 2002). We chose to adjust for this bias by scaling recruitment estimates, rather than survival estimates, because (1) survival rates for blue- and green-winged teal are relatively low, and (2) the female age ratios we used were, on average, higher than the male age ratios. The recruitment bias correction factor was included as a multiplier to the age ratio in the balance equation:

$$\text{BPOP}_{t+1} = \text{BPOP}_t \{mS_{t,AM} + (1 - m)[S_{t,AF} + (\text{bias correction factor} \times AR_t(S_{t,JF} + (S_{t,JM} \times S_{fsum}/S_{msum})))]\}$$

We fit the bias correction factor by minimizing the average over-prediction over the time series of the balance equation (1970–2009). We minimized this value, rather than the sum of the squared differences between the predicted and observed BPOP, because minimizing the sum of squared differences resulted in average model under-prediction. For BWTE, the age-ratio bias correction factor was 0.59, for AGWT, it was 0.51.

### ***Ratio of Summer Survival***

We estimated the ratio of summer survival ( $\psi$ , males/females) as the ratio of non-hunting survival of combined adult and juvenile males to that of combined adult and juvenile females. It was assumed that male and female survival was equal during the post-harvest period until May, such that differences in summer survival were equal to differences in annual survival in the absence of harvest.

### ***Male Fraction in the BPOP***

We calculated the male fraction by first breaking down the balance equation into separate cohorts of the population, representing the change in each cohort from time  $t$  to  $t+1$  using the transition matrix of the balance equation:

$$\begin{bmatrix} N_{t+1,AM} \\ N_{t+1,AF} \end{bmatrix} = \begin{bmatrix} S_{AM} & RS_{JM}/\psi \\ 0 & S_{AF} + RS_{JF} \end{bmatrix} \begin{bmatrix} N_{t,AM} \\ N_{t,AF} \end{bmatrix}$$

Assuming the population is at equilibrium with stable male and female proportions, we used the eigenvector of the right eigenvalue of the transition matrix above to calculate the stable (equilibrium) male fraction (Runge et al. 2002).

### **Predictions from Balance Equations**

Although the final blue-winged teal model was a better predictor of BPOP ( $r = 0.6$ ,  $P = 0.002$ ) than the final green-winged teal model ( $r = 0.2$ ,  $P = 0.22$ ), neither model performed very well. A substantial amount of variability in the BPOP was not explained by the survival rates or age ratios. In the case of blue-winged teal, much of this variability was related to the May pond count in the prediction year: a simple linear regression to predict blue-winged teal BPOP in year  $t$  as a function of total ponds in year  $t$  and the previous year's BPOP explained 72% of the total variability in BPOP from 1974–2011 ( $\text{BPOP}(t+1) = -188.1 + (0.7 \times \text{BPOP}(t)) + (0.35 \times \text{total ponds})$  ( $F_{2,33} = 44.25$ ,  $P < 0.0001$ ). However, a regression model

of BPOP that requires data collected in the forthcoming year is not very useful as a predictive model in the current year. Further investigation of the factors that affect the BPOP of both teal species is warranted, not only to better understand their population dynamics, but also to improve the performance of predictive models used in decision making.

### Equilibrium Population Model and Optimal Harvest Levels

To assess the harvest potential of teal, we predicted the impact of various levels of harvest on population dynamics under average annual breeding habitat conditions. We adapted the balance equation to accommodate sub-models that would (1) predict annual survival rates under a specified level of harvest, given assumptions of either additive or compensatory harvest; and (2) predict recruitment under specified habitat conditions (number of May ponds) and population abundance (BPOP).

#### Survival Sub-models

Survival sub-models were developed similarly to those in the mid-continent mallard model to incorporate the effect of harvest in the balance equation. In the absence of information on the effect of harvest on survival, we considered two hypotheses: first, that harvest was additive (i.e., in addition to other sources of mortality):

$$S_{t,sex,age} = S_{0,sex}^a (1 - K_{t,sex,age})$$

where  $S_{t,sex,age}$  is annual survival of each cohort,  $S_{0,sex}^a$  is sex-specific survival in the absence of harvest, estimated under the additive model, and  $K_{t,sex,age}$  is cohort-specific kill rate. Kill rate, rather than harvest rate, is used to account for crippling loss during the hunting season, which is assumed to be an additional 20% mortality (Anderson and Burnham 1976). The second hypothesis was that of compensatory harvest (i.e., compensating for other sources of mortality, up to a point called the compensation threshold, Anderson and Burnham 1976):

$$S_{t,sex,age} = \begin{cases} S_{0,sex}^c & \text{if } K_{t,sex,age} \leq 1 - S_{0,sex}^c \\ 1 - K_{t,sex,age} & \text{if } K_{t,sex,age} \geq 1 - S_{0,sex}^c \end{cases}$$

where  $S_{0,sex}^c$  is sex-specific survival in the absence of harvest under the compensatory model. We fit the additive model as a linear regression line constrained with x-intercept = 0 (survival = 0 when harvest rate = 1) and y-intercept equal to non-hunting survival (survival when harvest rate = 0). We fit the compensatory model using an optimization procedure (nlminb) in the stats package in R that minimized the sum of squares for both parts of the compensatory curve, below and above the compensation threshold (R Development Core Team 2011). Non-hunting survival was estimated as the y-intercept of the curve for each cohort separately, and for combined (adults and juveniles) males and combined females (Table 3, Fig. 3). Overall, the ranges of harvest rates for teal were not sufficient to determine if there was more support for either the additive or compensatory models. The fit (measured by  $R^2$ ) of the compensatory model in all cases was equal to zero because the set of observed harvest rates fell far below the compensation threshold, where the regression was fit as a horizontal line with y-intercept equal to  $(1 - \text{mean harvest rate})$ . Fit of the additive model was poor for all cohorts ( $R^2 < 0.1$ , except for

green-winged teal juvenile males , where  $R^2 = 0.18$ ). Estimates of non-hunting survival differed among cohorts: for blue-winged teal, they were highest for adult males, followed by adult females, juvenile males and juvenile females. In general they were lower for green-winged teal, and followed the same trend among cohorts except that non-hunting survival was higher for juvenile males than adult females (Table 3). Estimates of non-hunting survival also differed depending upon which model, compensatory or additive, was fit to the survival and kill rate data. Although this seems counterintuitive, given that survival in the absence of harvest should be the same regardless of whether harvest is compensatory or additive, these different estimates represent the underlying uncertainty in the relationship between harvest and survival, given that we have never observed survival rates in the absence of hunting (Runge 2002).

### ***Recruitment Sub-models***

We developed models using relationships between female age ratios (using annual estimates of differential vulnerability), BPOP, and May ponds to predict annual recruitment. Blue- and green-winged teal age ratios both showed a strong positive relationship to the total number of May ponds counted each year, and a non-significant positive relationship to BPOP. When both total ponds and BPOP were included in the recruitment model, the slope coefficient for BPOP was negative (but still not significant) for both species (Figs.4, 5 and Table 4). However, the fit of both the BWTE and AGWT recruitment models improved with the addition of BPOP, so it was retained in order to induce density-dependent behavior in the equilibrium balance equation. The recruitment model for blue-winged teal was: female AR (annual DV) =  $0.4462 + (0.0002855 * \text{total ponds}) - (0.00007031 * \text{BPOP})$  (Table 4, Fig. 6). For green-winged teal, the recruitment model was: female AR (annual DV) =  $1.471 + (0.000222 * \text{total ponds}) - (0.000268 * \text{BPOP})$  (Table 4, Fig. 6).

Table 3. Survival in the absence of harvest, estimated under hypotheses of additive or compensatory harvest.

	Adult males	Adult females	Juvenile males	Juvenile females	Combined males	Combined females
<u>BWTE</u>						
S <sub>0</sub> compensatory	0.6249	0.5431	0.4988	0.4448	0.5573	0.4940
S <sub>0</sub> additive	0.6418	0.5644	0.5374	0.4822	0.5875	0.5251
<u>AGWT</u>						
S <sub>0</sub> compensatory	0.5933	0.4856	0.5018	0.4356	0.5481	0.4954
S <sub>0</sub> additive	0.6692	0.5391	0.6180	0.5154	0.6458	0.5274

Table 4. Coefficients of blue-winged and green-winged teal recruitment models predicting female age ratios (using annual estimates of differential vulnerability) from total (U.S. + Canada) May ponds and BPOP.

Coefficient	Estimate	Std. Error	t- value	P	Model R <sup>2</sup>
<u>BWTE</u>					0.53
Intercept	0.4462	0.2931	1.522	0.138	
Total ponds	0.0002855	0.00005076	5.624	<0.0001	
BPOP	-0.00007031	0.00006591	-1.067	0.294	
<u>AGWT</u>					0.15
Intercept	1.471	0.7350	2.001	0.0539	
Total ponds	0.0002222	0.00009419	2.359	0.0246	
BPOP	-0.0002679	0.0003185	-0.841	0.4065	



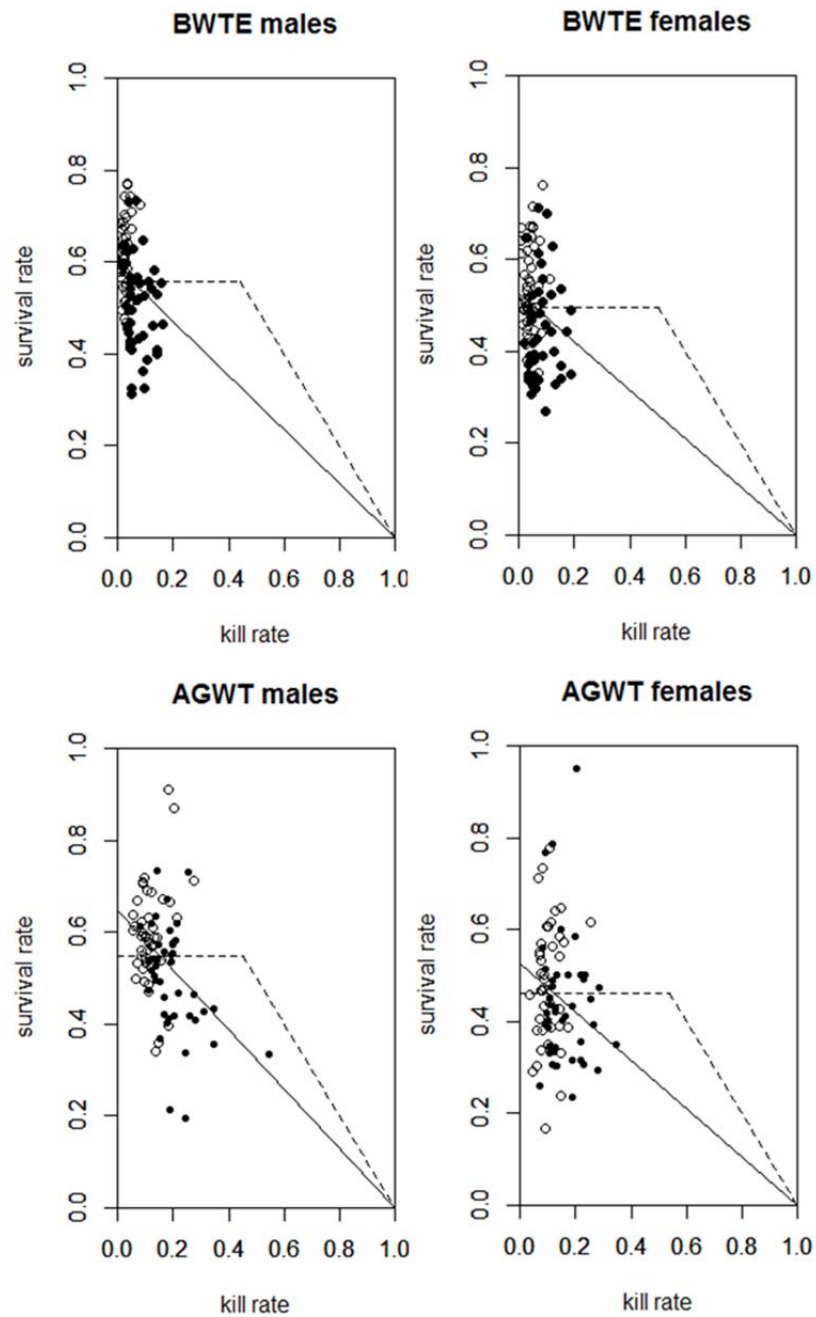


Fig. 3. Annual survival (using all recoveries) vs. kill rates (using only U.S. and Canadian recoveries) for combined males and females, and corresponding models of additive and compensatory harvest fit using the combined datasets. Y-intercepts represent survival in the absence of harvest. Open circles, adults; solid circles, juveniles; solid line, additive model; dashed line, compensatory model.

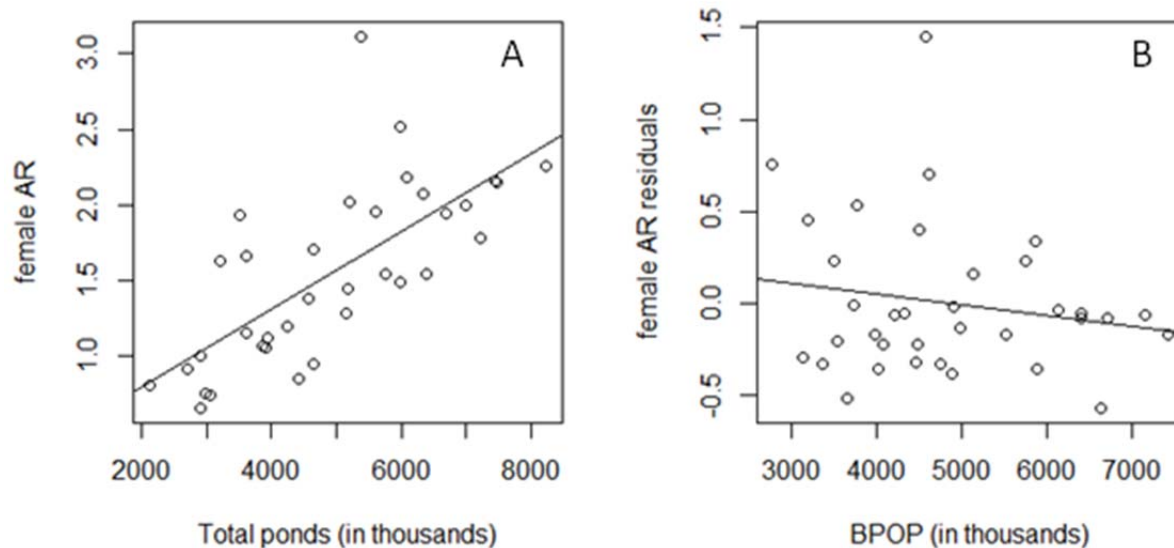


Fig. 4. Relationship between (A) blue-winged teal female age ratio (calculated using annual estimates of differential vulnerability) and total (U.S. + Canadian) May ponds; and (B) residuals from the regression of blue-winged teal female age ratio (calculated using annual estimates of differential vulnerability) on total May ponds vs. BPOP.

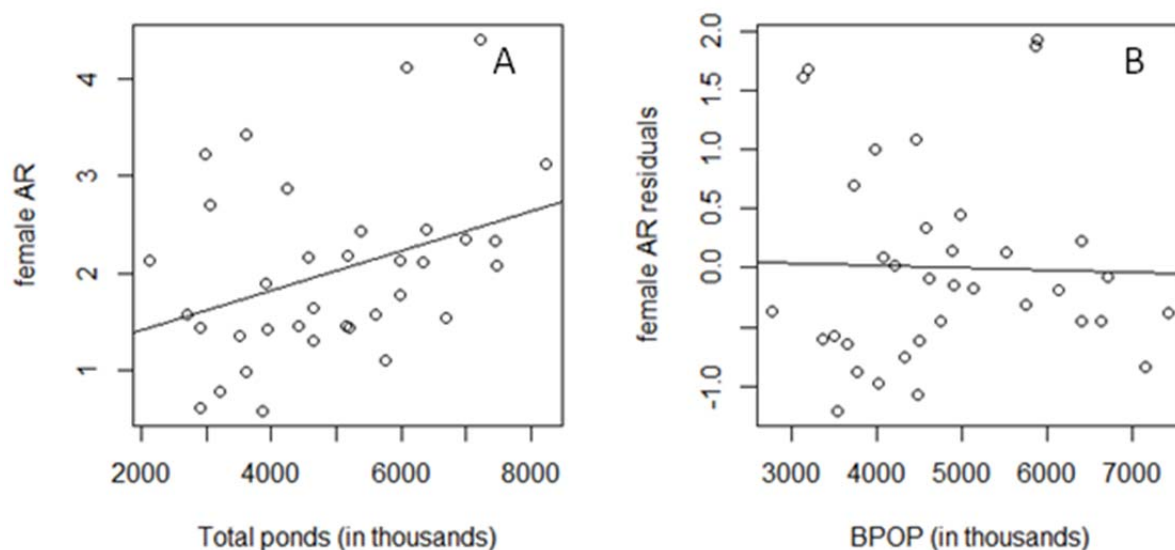


Fig. 5. Relationship between green-winged teal female age ratio (calculated using annual estimates of differential vulnerability) and total (U.S. + Canadian) May ponds (A), and (B) residuals from the regression of green-winged teal female age ratio (calculated using annual estimates of differential vulnerability) on total May ponds vs. BPOP.

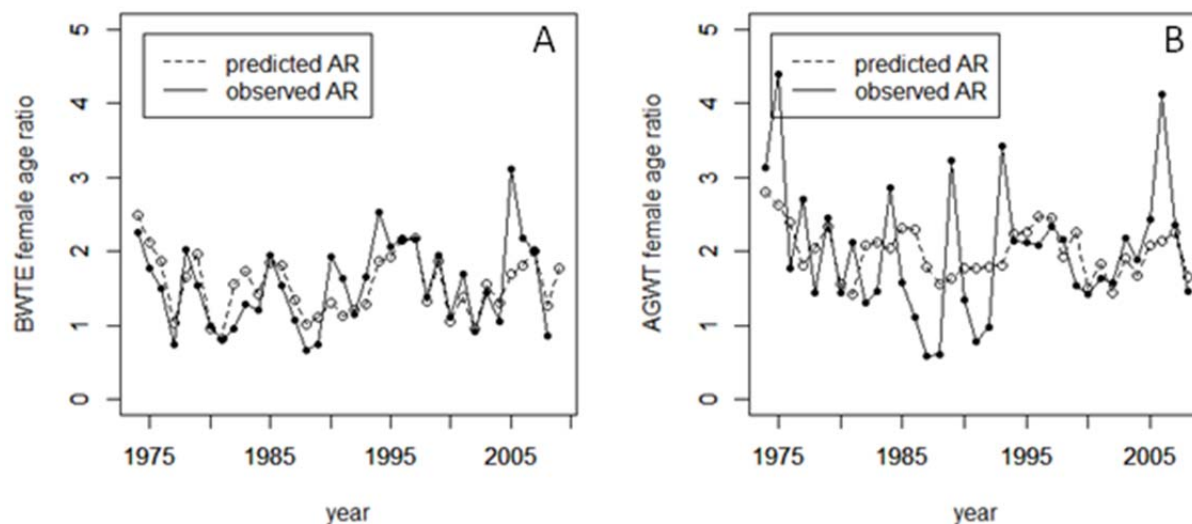


Fig. 6. Predicted female age ratio calculated using annual estimates of differential vulnerability (from recruitment model) vs. observed age ratio for blue-winged teal (A) and green-winged teal (B).

### Simulating Equilibrium Population Dynamics

We simulated equilibrium dynamics for each species under 3 scenarios of environmental conditions: 5.088 million ponds, which is the mean total prairie May pond count from 1955 to 2011, and the upper and lower 95% confidence intervals about this mean (5.614 and 4.562 million ponds, respectively; Fig. 7). Since 1974, when U.S. ponds were first comprehensively counted, the total May pond count has varied widely, from 8.231 million ponds (1974) to 2.126 million ponds (1981). Although the number of teal produced, and therefore, harvested in any given year may be affected by variability in the pond count, a measure with more utility in harvest management is the long-term harvest potential or sustainable harvest rate of the species. We characterized teal harvest potential as that harvest rate which resulted in the highest sustainable harvest achievable under average pond conditions. Because we estimated “average pond conditions” based on the 1974–2011 mean pond count, we also estimated harvest potential at the 95% confidence limits of the mean, representing our confidence in an interval within which we would expect future mean pond counts to fall (assuming no temporal trend in wetness in the prairies). We used recruitment and survival sub-models to generate predictions of annual survival (given the specified harvest rate) and age ratios (given the pond count and predicted BPOP) that were input in the balance equation in each year. For each pond count (average ponds  $\pm$  95% CI), we ran the balance equation through 1000 sets of iterations of 100 years each, with each set corresponding to a specified harvest rate within the range 0.001–0.5. One hundred years allowed the equilibrium population size corresponding to that level of harvest to be reached. The 1955–2009 average BPOP (4,762,000) was used to generate age ratio estimates for the first year of each iteration. Each specified harvest rate was translated into cohort-specific kill rates by accounting for crippling loss (assumed to be 20%) and multiplying by the mean differential vulnerability (DV) of each cohort expressed as a ratio to

adult males. For blue-winged teal, the cohort DV estimates were: adult females, 1.251; juvenile males, 2.012; juvenile females, 2.221. For green-winged teal, the DV estimates were: adult females, 0.77; juvenile males, 1.389; juvenile females, 1.087. For each set of kill rates, 2 sets of survival rates were generated, one for the additive harvest model, and one for compensatory harvest model, and two sets of equilibrium dynamics were run. For each 1000 iterations we selected the optimal harvest rate that resulted in the highest equilibrium harvest. We converted this into cohort-specific optimal harvest rates using the DV of each cohort relative to adult males.

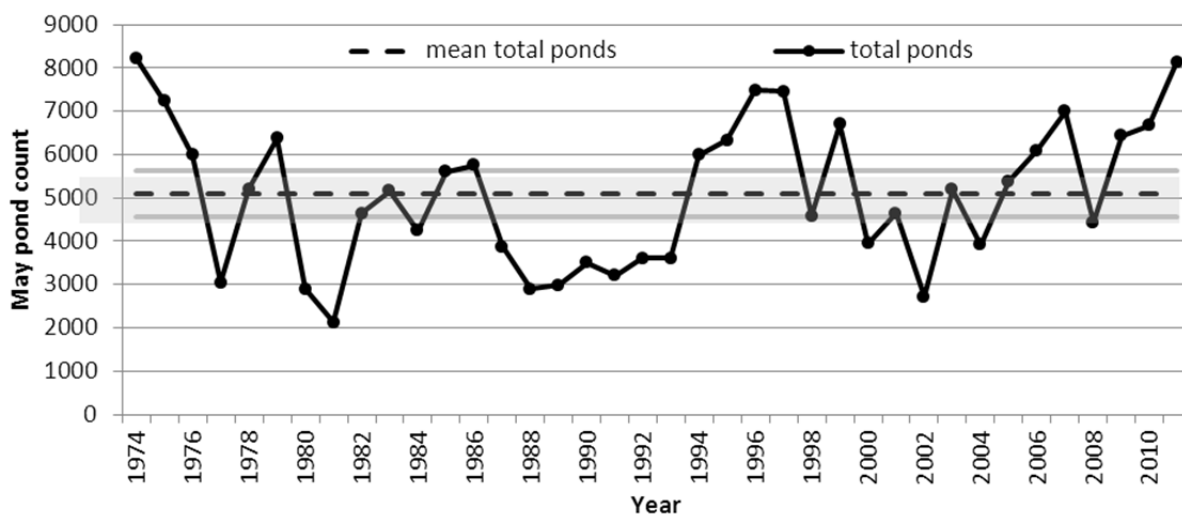


Fig. 7. Total (U.S. + Canadian) May ponds 1974–2011 (solid black line), with mean (5,088 million ponds, dashed line) and 95% confidence intervals (shaded region).

### ***Optimal Harvest Rates***

*Blue-winged teal.*—For the additive model, simulated optimal harvest rates for blue-winged teal under average pond conditions ranged from 0.047 for adult males to 0.105 for juvenile females (Table 5, Fig. 8), and increased slightly with increasing pond counts across the 95% confidence interval. Harvest rates were substantially higher for the compensatory models than the additive models, and only varied slightly within the pond confidence intervals (Table 5, Fig. 8). In general, the optimal harvest rates predicted for the additive model were about 2–2.5 times higher than average observed harvest rates on blue-winged teal (estimated from banding recovery rates 1974–2009), while those predicted for the compensatory model were about 7–9 times higher than observed harvest rates (Fig. 8).

*Green-winged teal.*—Simulated optimal harvest rates for green-winged teal under average pond conditions ranged from 0.098 for adult females to 0.177 for juvenile males for the additive model (Table 6, Fig. 8). Optimal harvest rates for this species showed similar trends to blue-winged teal, with higher harvest rates under the compensatory models, and increasing rates from the lower to upper 95% CI under the additive model (Table 6, Fig. 6). Overall, green-winged teal optimal harvest rates were higher than blue-winged teal. Optimal rates by cohort for the additive model were 1.3 to 1.5 times higher than average observed harvest rates by cohort (estimated from banding recovery rates 1974–2009) on green-

winged teal, while optimal compensatory rates were 2.6 to 3 times higher than average observed harvest rates (Fig. 8).

Table 5. Equilibrium optimal harvest rates by cohort for blue-winged teal.

Total ponds	Optimal harvest rate, additive model			
	Adult males	Adult females	Juvenile males	Juvenile females
5614	0.057	0.072	0.115	0.127
5088	0.047	0.059	0.095	0.105
4562	0.037	0.047	0.075	0.083
Total ponds	Optimal harvest rate, compensatory model			
	Adult males	Adult females	Juvenile males	Juvenile females
5614	0.182	0.228	0.366	0.404
5088	0.174	0.218	0.351	0.387
4562	0.174	0.218	0.351	0.387

Table 6. Equilibrium optimal harvest rates by cohort for green-winged teal.

Total ponds	Optimal harvest rate, additive model			
	Adult males	Adult females	Juvenile males	Juvenile females
5614	0.137	0.106	0.191	0.149
5088	0.128	0.098	0.177	0.139
4562	0.119	0.092	0.165	0.130
Total ponds	Optimal harvest rate, compensatory model			
	Adult males	Adult females	Juvenile males	Juvenile females
5614	0.284	0.219	0.395	0.309
5088	0.269	0.207	0.374	0.293
4562	0.260	0.200	0.362	0.283

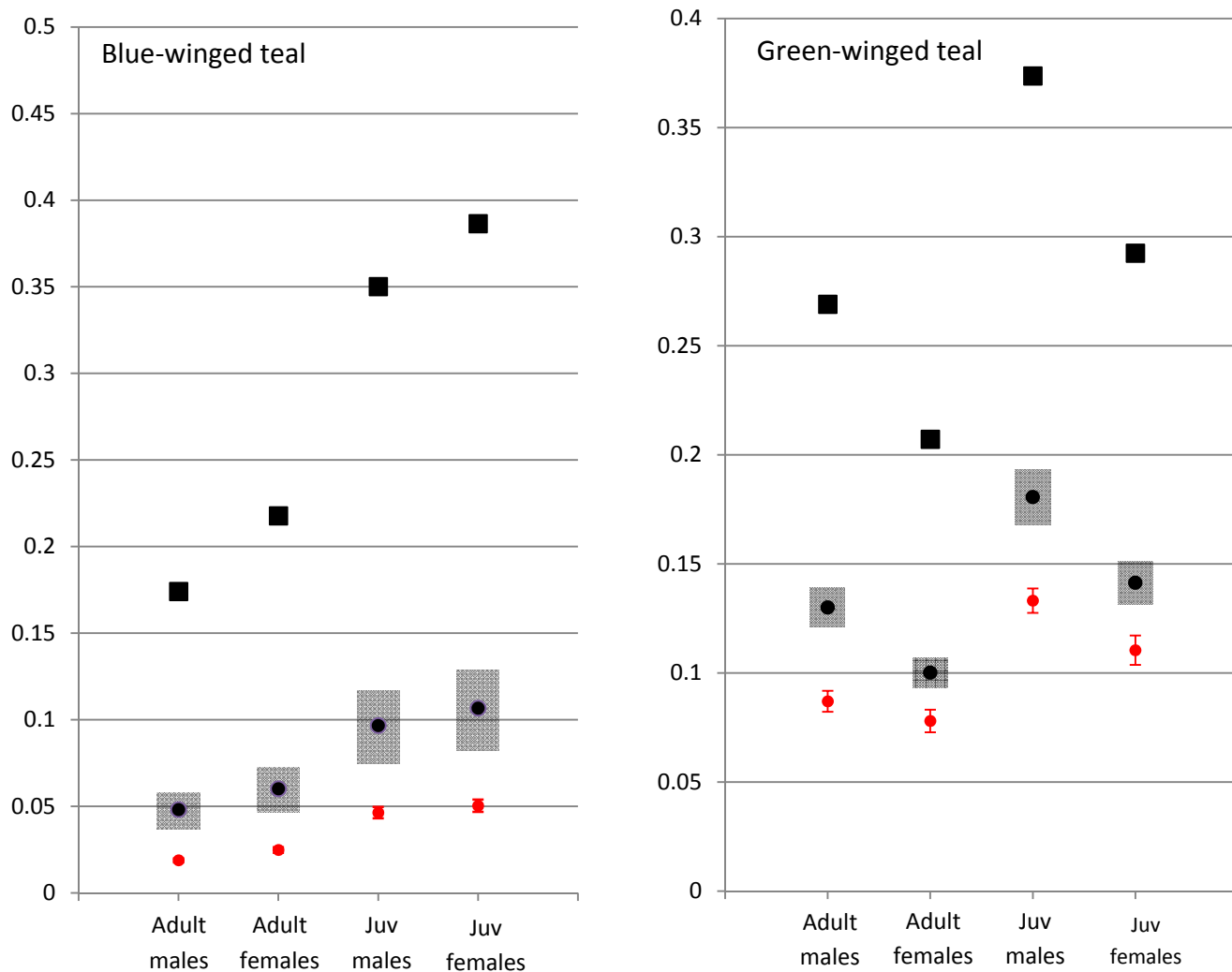


Fig. 8. Blue-winged and green-winged teal optimal and average harvest rates by cohort. Black squares: optimal equilibrium harvest rates for the compensatory model under average pond conditions; black circles with gray boxes: optimal harvest rates for the additive model under average pond conditions and  $\pm 95\%$  CI; orange circles and error bars: 1974–2009 average cohort harvest rate from band recoveries,  $\pm SE$ .

### Interpreting Optimal Harvest Estimates

Blue-winged and green-winged teal populations undergo significant annual fluctuations due to their high reproductive potential and dependence on annual pond conditions (especially blue-winged teal). Simulating the equilibrium dynamics of teal allowed us to predict how populations might respond to changing levels of harvest under equilibrium conditions, and to provide an estimate of harvest potential to inform long-term decision making in harvest management.

Based on these simulations, we believe that additional harvest opportunity exists for both blue-winged and green-winged teal. However, our uncertainty about how both species' abundance might respond to harvest at higher levels (and our inability to estimate that uncertainty) makes it difficult to quantify what that additional harvest opportunity might be (see Model Uncertainties, below). The most conservative estimate of optimal harvest rates is based on the additive hypothesis, that any amount of harvest reduces survival rates. The most liberal approach would be to follow the compensatory hypothesis, although this assumes harvest mortality has no effect on population demography up to the compensation threshold and only then impacts abundance, which is unrealistic. More likely, teal populations respond to harvest in some manner intermediate to the two hypotheses. Additional work is needed to provide a formal context for evaluating the performance of additive vs. compensatory models, to allow for a more realistic simulation of teal population dynamics and sustainable harvest.

### ***Optimal Harvest***

The equilibrium simulations allow us to estimate the optimal harvest rate that results in the highest sustainable harvest under equilibrium conditions. Because our input harvest rates were derived from band recovery data, the optimal harvest rate output from the model is in the same currency (i.e., it can be compared to the annual harvest rates from the Brownie band recovery model; Figs 1, 2). In the same way, the equilibrium population size (equilibrium BPOP) output from the model is comparable to our annual BPOP estimates, which are also input in the model. However, in order to calculate the harvest that would be achieved under the optimal harvest rate, we must first convert the equilibrium BPOP to a fall flight which requires assumptions about 2 unknown parameters – summer survival and recruitment – to estimate population size in August. For this reason, the optimal harvest estimates from the simulations are not comparable to the harvest estimated by the Harvest Information Program (HIP) survey in any given year. However, the optimal harvest rates can be compared to actual harvest rates derived from banding recoveries to compare actual harvest rates to harvest potential, and could be converted into an estimate of harvest in any year when information about production and summer survival is available.

### ***Equilibrium Population Size and Harvest Rate***

We plotted the results of the equilibrium simulation for blue- and green-winged teal to show the relationship between harvest rate and equilibrium breeding population size under additive and compensatory harvest models (Figs. 9 and 10). Under the additive model, equilibrium BPOP decreases with any increase in harvest rate, with optimal harvest rate occurring at approximately half the carrying capacity (indicated by the y-intercept of each curve). Under the compensatory model, harvest rates below the compensation threshold do not result in a decrease in the equilibrium BPOP. The optimal harvest rate is that which occurs just before the threshold is reached; however, any further increase in the harvest rate results in a rapidly declining harvest rate and equilibrium population size.

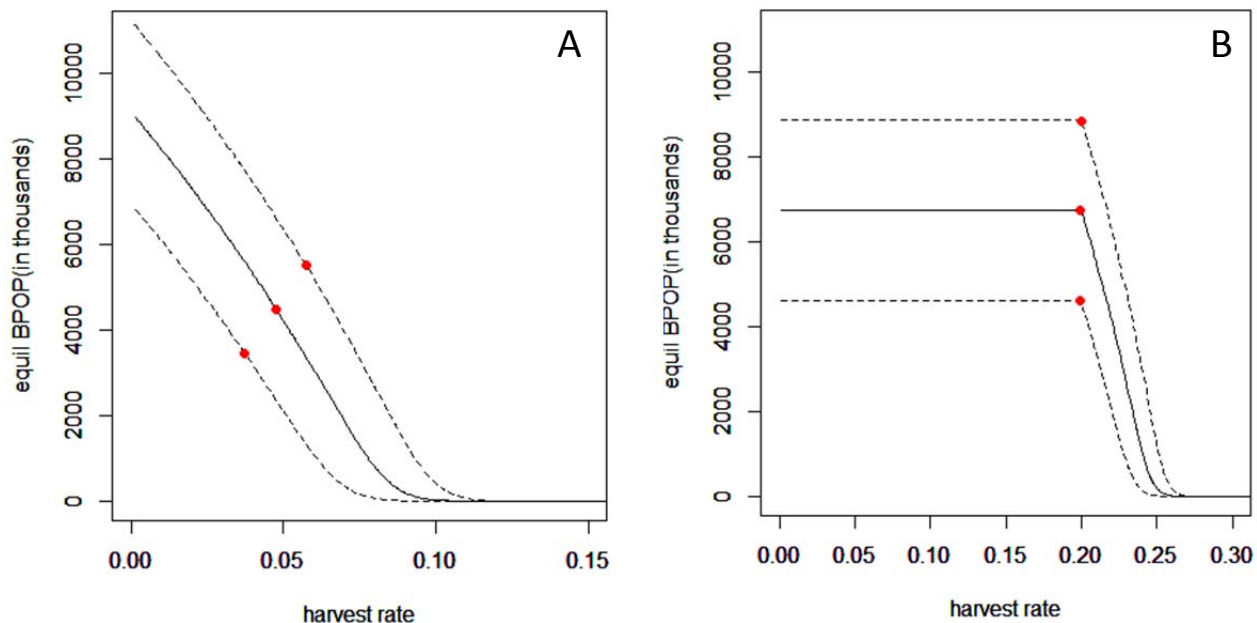


Fig. 9. Plot of equilibrium BPOP vs. harvest rate (adult males) for blue-winged teal based on additive (A) and compensatory (B) models. Solid lines indicate equilibrium breeding population size under average pond conditions; dashed lines represent  $\pm 95\%$  confidence intervals around the average May pond count. Red points indicate the optimal harvest rate on adult males.

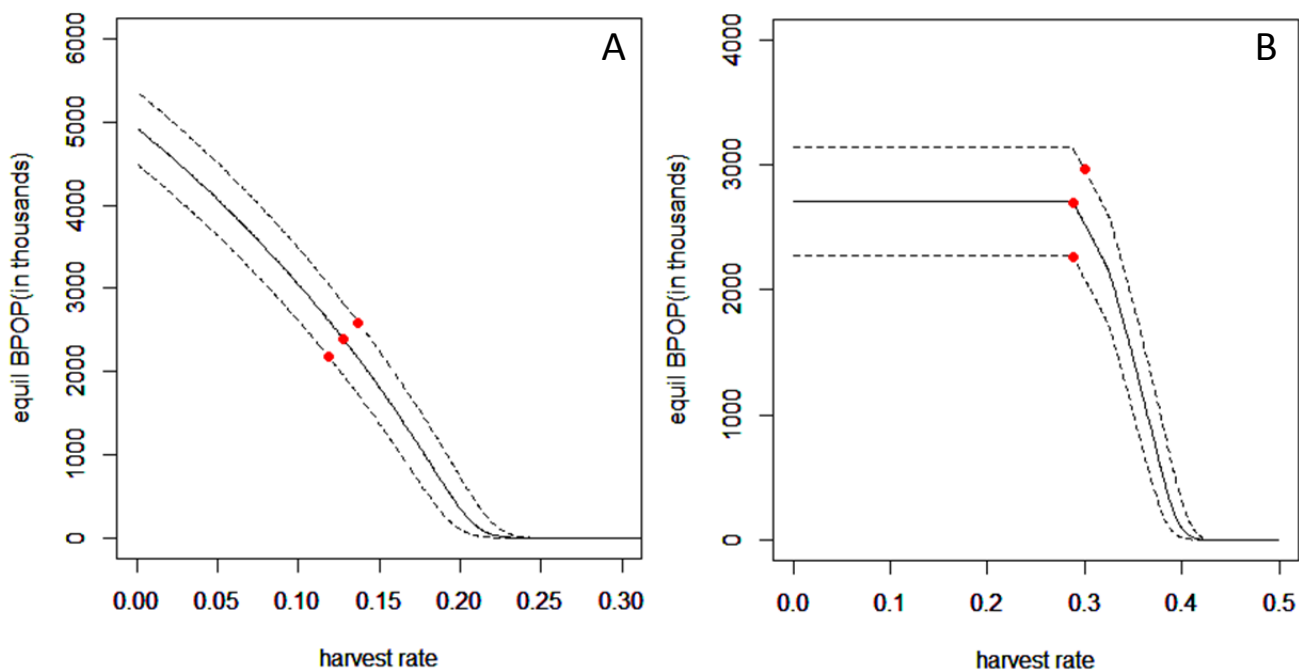


Fig. 10. Plot of equilibrium BPOP vs. harvest rate (adult males) for green-winged teal based on additive (A) and compensatory (B) models. Solid lines indicate equilibrium breeding population size under average pond conditions; dashed lines represent  $\pm 95\%$  confidence intervals around the average pond count. Red points indicate the optimal adult male harvest rate.



## Comparison of Equilibrium Dynamics of U.S. + Canada Harvest to Overall Harvest of Blue-winged Teal

Although we used the equilibrium dynamics model based on U.S. + Canada recoveries to generate estimates of harvest potential for blue-winged teal, these estimates depend on the assumption that the proportion of the harvest rate to the total harvest rate (all countries) remains constant. However, over time this proportion may change. We can track this change by estimating the proportion of U.S. + Canada harvest rate to the total harvest rate (i.e., all recoveries) each year (Fig. 11). To estimate harvest rates for all recoveries, we needed to select a reporting rate for south of the border (SB) recoveries. But because we are interested only in the change in the proportion of U.S. + Canada harvest rates to the total, and not the absolute value, we felt the choice of reporting rate was not important as long as the true reporting rate does not change over time. We used the upper bound estimated by F. Johnson (unpublished data) as the SB reporting rate: for abbreviated and complete address bands reported by mail, 0.1; for toll-free and web-address bands, or for abbreviated and complete address bands reported by phone or internet, we multiplied this range of rates by the ratio of U.S. reporting rate toll-free/U.S. reporting rate abbreviated address =  $0.74/0.32 = 2.31$ , which resulted in a reporting rate of 0.23. We estimated composite reporting rates in the same manner as described previously, and used these to calculate annual U.S. + Canada + SB harvest rates. We estimated the proportions of U.S. + Canada harvest rates to the total harvest rate by cohort and the trend in the proportions by cohort over time (Fig. 11). Based on our choice of reporting rate, on average the U.S. + Canada harvest rates constituted about 68% of the total blue-winged teal harvest rate. Although this proportion has varied from 0.55 to  $>1$  since 1965 (due to sampling error in some early years the estimates of U.S. + Canada harvest rates were higher than the total harvest rates), since the reinstatement of the early teal season in 1991 both harvest rates and their proportion appear to have become much more consistent (Fig. 11). The yield curves for the two harvest rates (U.S. +Canada vs. U.S. + Canada + SB) reflect this proportion (Fig. 12).

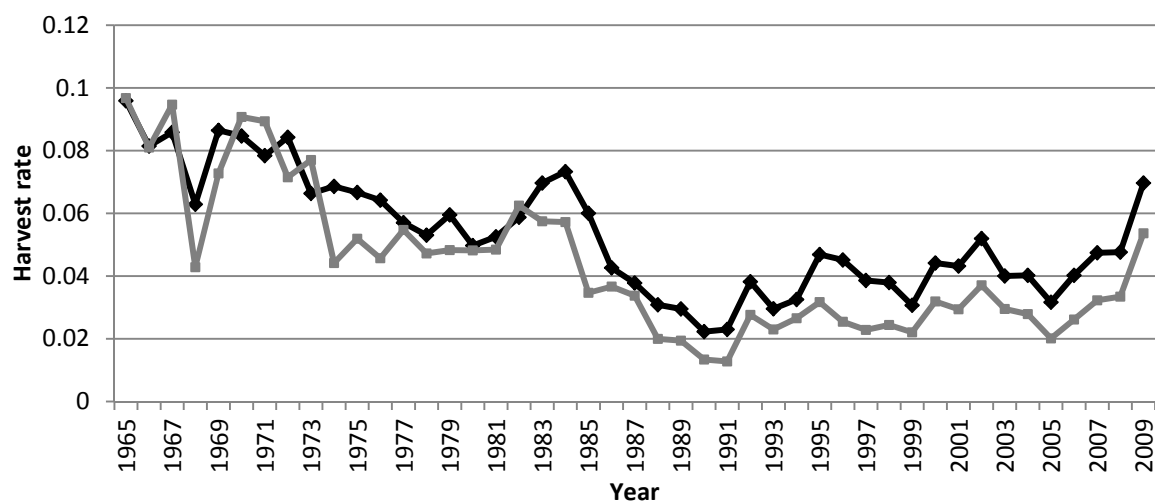


Fig. 11. Average (of all cohorts) blue-winged teal U.S. + Canada harvest rates (gray line) and total harvest rates (all recoveries, black line) by year, 1965–2009, estimated from band recoveries.

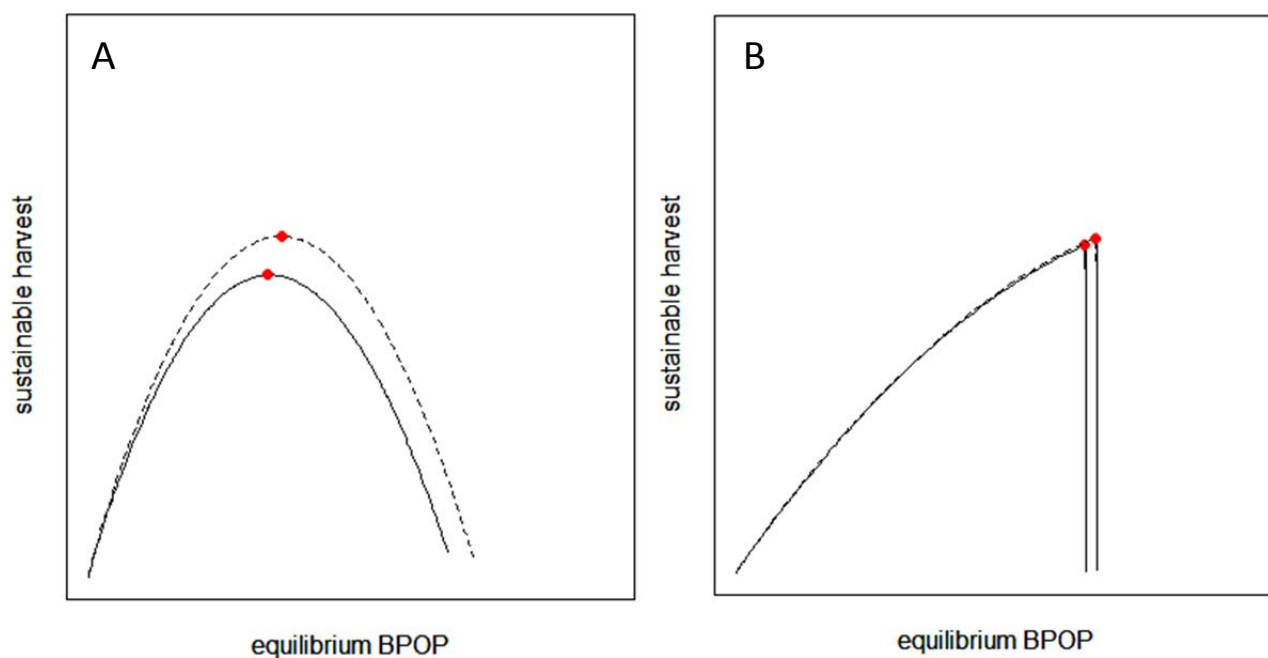


Fig. 12. Blue-winged teal yield curves based on the additive (A) and compensatory models (B). Solid lines represent sustainable harvest and equilibrium population size (U.S.+CA) under average pond conditions; dashed lines represent total harvest and equilibrium population size (U.S. + Canada + south of the U.S. border) under average pond conditions (assuming a reporting rate of 0.1 for abbreviated and complete address bands and 0.231 for toll-free bands and bands reported by phone or internet).

## **Model Uncertainties**

Challenges exist in understanding and quantifying teal harvest potential, due to (1) a lack of information about blue-winged teal (and to some extent, green-winged teal) distribution, harvest, and reporting rates south of the U.S. border, (2) the degree to which harvest is additive or compensatory, especially given the long distance migration of blue-winged teal and substantial harvest south of the U.S. border, and (3) uncertainty about the functional form of density dependence.

### ***Incorporating Uncertainty in the Models***

All of the parameter estimates we used in the population models have associated variances and covariances representing both process and sampling error. For the most part, we were unable to incorporate this uncertainty formally in our model structure, and therefore cannot provide estimates of precision for our model predictions. However, most of the modeling presented here could be integrated in a Bayesian estimation framework, which would provide estimates of parameter variance and covariance, and allow competing models to be evaluated based on their relative support from the data. Future modifications to these models, especially if they are being used in a formal decision-making context, will need to incorporate parameter and model uncertainty explicitly in the estimation process.

### ***Reporting Rates South of the U.S. Border***

A substantial proportion of blue-winged teal harvest occurs in the Caribbean and Central and South America; however, no estimates of reporting rates exist from reward bands recovered south of the U.S. border. Blue winged-teal bands have been recovered in 6 countries/territories in the Caribbean, 8 countries in Central America (including Mexico), and 7 countries in South America. Reporting rates likely differ among countries, between rural areas and urban centers, and depending on who harvested the bird (e.g., a hunt club or subsistence hunter), due to differences in education, language barriers, and other demographic characteristics. In a single visit to several small villages in the Cienaga Grande region of Colombia, Botero and Rusch (1988) reported that they collected a number of blue-winged teal bands (103) equal to 3% of the entire bands recovered in South America; they surmised that many bands in rural areas are kept as souvenirs but not reported (Botero and Rusch 1988). Botero and Rusch (1994) stated that a conservative band reporting rate for the Neotropics would be 1/5 of the U.S. reporting rate. Johnson (unpublished data) used blue-winged teal survival rates and assumptions about the proportion of mortality due to harvest to estimate upper and lower bounds on reporting rates south of the border. Assuming that harvest accounts for no more than 40% of total annual mortality (the level reported for mallards), he estimated reporting rates within the range of 2-10%. However, if this lower reporting rate were correct, the number of estimated harvested birds south of the border would be as much as 4 times as high as the number harvested in the U.S. and Canada combined. Although few estimates of blue-winged teal harvest are available for countries south of the U.S. border, there is limited information on Mexican harvest. Based on data collected in 7 regions of Mexico, Kramer et al. (1995) estimated the Mexican annual total waterfowl harvest from 1987 to 1993 (all species) to be 89,456 birds, which was less than 1% of the annual estimated U.S. harvest during the 10-year period of 1983-1992. In Kramer et al.'s study (1995), blue-winged teal accounted for 8.9% of the Mexican harvest,

while green-winged teal accounted for 25%. However, the number of blue-winged teal bands reported from Mexico from 1987 to 1993 (219) was about 1/6 the number of bands reported from the U.S. during the same period (1337). If we assume that the ratio of blue-winged teal harvest in Mexico during the period estimated by Kramer et al. (1995) to that in the U.S. measured by the Mail Survey Questionnaire program (7,962/505,023, or about 1/60) is similar to the ratio of harvest rates between the two countries, this would suggest that reporting rates in Mexico are 10 times higher than those in the U.S! Based on the lack of information available to estimate reporting rates south of the border, and the wide disparity in speculated reporting rates, in this assessment of teal harvest potential we used only the U.S. and Canada recoveries to estimate a combined U.S. + Canada harvest rate. However, this assumes an unknown, but constant proportion of additional harvest potential realized south of the U.S. border. Efforts to better quantify the amount of subsistence harvest in Mexico and other countries in Central and South America, as well as band reporting rates in these regions, could provide valuable information for monitoring how future U.S. blue-winged teal harvest rates compare to the overall harvest potential of the species.

### ***Effect of Harvest on Survival***

Determining the amount of harvest that can be sustained by a population requires knowledge of how harvest affects the population; that is, to what degree it is additive (any amount of harvest is in addition to natural mortality) or compensatory (harvest up to a certain level is compensated by natural mortality). Because teal have been harvested at relatively low rates, with little variation in historical harvest levels, not much is known about how populations respond to harvest at higher rates. Although a number of studies have supported the hypothesis that hunting mortality is compensatory (e.g., Anderson and Burnham 1976, Burnham and Anderson 1984, Trost 1987, Nichols et al. 1991), there is evidence suggesting that for some waterfowl species, such as mallards and northern pintails, harvest may be additive, at least in some years (Smith and Reynolds 1992). Further, there is more support for population models containing additive harvest effects than those with compensatory harvest (U.S. Fish and Wildlife Service 2010, 2012a). However, no hypotheses have been proposed or tested to explain the ecological relationship between harvest and survival in teal. Devineau et al. (2010) compared survival and harvest rates in the 1950s–1960s between European and American green-winged teal, and found that, although harvest rates on European teal were about 3 times as high as those on American teal, survival rates were similar. Although this suggests some degree of compensation for harvest, differences between subspecies (and continents) hinder any direct extrapolation to American green-winged teal. For this assessment, we lacked the information necessary to develop ecologically based models about compensatory and additive mortality in teal; as an alternative we fit survival and harvest rates to the phenomenological models presented in Anderson and Burnham (1976). Future modeling efforts for teal would benefit from expanded efforts to incorporate meaningful ecological hypotheses related to the effects of harvest on teal populations.

### ***Density Dependence***

The manner in which density dependence is incorporated in the balance equation can have a dramatic impact on its resulting equilibrium dynamics (Runge and Johnson 2002). We incorporated density

dependence in the recruitment sub-model of the equilibrium balance equation, through the negative relationship between fall age ratio and the BPOP. However, this relationship was weak for both species. Removing the effect of annual ponds (using the residuals of the regression of age ratio on ponds) does not improve this relationship, suggesting that production is not strongly affected by population size (at least over the range of historical BPOP estimates). Rohwer et al. (2002) compared blue-winged teal fall population size (constructed from annual survival rates, age ratios, and BPOP) to population size the following spring (BPOP), and found that the proportion of the fall population lost during the winter was correlated ( $r = 0.71$ ,  $P < 0.0001$ ) with the size of the fall population. This suggests that winter mortality, rather than production, may be density dependent, similar to the hypothesized relationship in northern pintails (U.S. Fish and Wildlife Service 2010). Without an independent estimate of fall teal abundance, we cannot directly test this possibility, and acknowledge that our results could be very different, given a different functional form of density dependence included in the balance equation.

## Summary

To assess teal harvest potential, we used balance equations to represent blue- and green-winged teal populations in a simulation of equilibrium dynamics. Survival and harvest rates were estimated from Brownie band recovery models, and used to develop relationships relating survival to harvest under alternative hypotheses of additive and compensatory harvest mortality. We used female fall age ratios estimated with annual differential vulnerability to develop recruitment models to predict production as a function of breeding population size and habitat conditions. We ran the balance equations under equilibrium habitat conditions (average pond count  $\pm 95\%$  CI) and estimated optimal harvest rates by cohort for each hypothesis of additive and compensatory harvest. Simulated optimal harvest rates for blue-winged teal under the additive model were approximately twice as high as average blue-winged teal harvest rates by cohort from 1965 to 2009, while optimal rates under the compensatory model were up to 10 times higher than average harvest rates. For green-winged teal, optimal harvest rates under the additive model were up to 1.5 times higher than average harvest rates by cohort, and compensatory optimal harvest rates were approximately 3 times as high. Based on these simulations, teal harvest potential may be higher than our current levels of harvest, but due to the lack of information on important aspects of their population dynamics (e.g., relationship to ponds, density dependence, etc.) it is difficult to quantify how much additional harvest potential exists. Further work to quantify uncertainty in model parameters and better understand the response of teal populations to harvest will improve our ability to predict harvest potential for these species.

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